LONG-TERM FIRE EXCLUSION WEAKENS THE RESISTANCE OF FIRE-ADAPTED SOUTHERN APPALACHIAN FORESTS TO WILDFIRE

by

DANA O. CARPENTER

(Under the Direction of Nina Wurzburger)

ABSTRACT

The long-term exclusion of fire may weaken forest resiliency to the return of fire. Tree traits for fire adaption often co-occur with traits for nutrient conservation, including the ectomycorrhizal (ECM) association. In the absence of fire, the ECM strategy may facilitate the accumulation of organic matter, which becomes colonized by fine roots that are vulnerable to consumption. Therefore, stands of fire-adapted trees may become less resistant to wildfire than stands of fire-intolerant trees. We tested this idea following the 2016 Rock Mountain wildfire. We found increasing depth and stocks of the organic horizon and greater fine root abundance within this horizon with increasing ECM dominance, and that the wildfire consumed an equal proportion of organic matter and fine roots across plots. The probability of tree stress and above-ground mortality increased with ECM dominance post fire, indicating that stands of fire-adapted, ECM species had a weakened forest resistance to wildfire.

INDEX WORDS: wildfire, disturbance, reintroduction, ecosystem resilience, biogeochemistry, mycorrhizal fungi, plant functional traits

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B.S., Southern Illinois University Carbondale, 2010

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2019

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December 2019

DEDICATION

To the women in my life who have inspired resilience, perseverance, and determination; even if some are no longer on this earth.

ACKNOWLEDGEMENTS

My sincere thanks goes to my advisor, Nina Wurzburger, who has been an invaluable source of support, perspective, and encouragement. Her feedback and guidance has allowed me to grow as both a critical thinker and a professional. I wish to show my appreciation for my co-advisor, Joe O'Brien, and committee members, Louise Loudermilk, Mac Callaham, and Kevin Hiers. Thank you all for this opportunity, and for your feedback and advice during my time here. I am grateful to the Wharton Conservancy for their assistance with logistics and for their continued enthusiasm for this project. I would also like to express my gratitude to everyone in the Wurzburger Lab (Andrés Barón-Lopez, Carly Phillips, Jessie Motes, Sarah Ottinger, Rose Parham, and Annabelle Barr), the U.S. Forest Service Center for Forest Disturbance Science (Gregg Chapman, Christie Hawley, Ream Thomas, and Nathan Miller), and Tall Timbers (Derek Wallace, Steve Flanagan, and Saunders Drukker) for their collaboration, technical support, field support, and friendship during this project. I greatly appreciate the supportive critiques of the Chung lab. Thank you Roberto Carrera-Martínez for the friendship, stats advice, and coffee no matter the time of day. Jules NeSmith deserves a huge thank you for her unflagging encouragement and numerous pep talks. Melanie Taylor, Bryan Wohlford, Apollo, Dingo, and Kara all deserve more gratitude than I know how to give. I am deeply grateful to Ellie Fowler, without whom I could not have completed this work. A long distance thanks to all of the friends I have made through Windmill Ranch over the years. Finally, a wholehearted and eternal thank you to Sara Baer and Kim Elsenbroek for the decade-plus friendship, support, and memories; beyond a doubt, you two gave me the most inspiration to pursue this degree.

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CHAPTER 1

INTRODUCTION

Anthropogenic activities are inducing novel changes to the structure and function of terrestrial ecosystems (Williams and Jackson 2007, Williams et al. 2007, Hobbs et al. 2014). One human-induced driver is the alteration of natural disturbance regimes, which can weaken the resiliency of ecosystems to future disturbance (Varner et al. 2005, O'Brien et al. 2010, Johnstone et al. 2016, Dudney et al. 2018). The exclusion of fire from fire-adapted forests is one example of this problem, as it selects for fire-intolerant species (Abrams 1992, Frost 1998, Scott et al. 2012) that further suppress fire (Nowacki and Abrams 2008), and eventually cause the ecosystem to transition to a fire-intolerant state (O'Brien et al. 2008, Scott et al. 2012, Kreye et al. 2013). However, state changes in forest ecosystems may take decades to centuries to fully manifest, making it unclear how contemporary forests undergoing this transition might respond to the return of fire (Bond et al. 2004, Johnstone et al. 2016). This leads to a critical question for ecologists and land-managers alike: How do fire-adapted ecosystems respond to fire after long-term exclusion?

A consideration of how fire has shaped the evolution of plant traits is central to this question. Throughout evolutionary history, plants evolved traits to tolerate, recover from and even promote fire (Bond et al. 2004, Kane et al. 2008, Lamont and He 2017). However, fire-dependent ecosystems also tend to be nutrient poor (Boerner 1982), as fires consume organic matter and trigger nutrient losses (Boring et al. 2004, Lavoie et al. 2010). As a result, functional traits relating to fire tolerance tend to co-occur with those that facilitate nutrient conservation. In the absence of fire, however, traits for nutrient conservation may supersede those relating to fire, resulting in ecosystem properties that are novel relative to the conditions under which the traits evolved.

One possible outcome of long-term fire exclusion is that it leads to abiotic and biotic properties that weaken ecosystem resistance to fire. When leaf litter is long unburned, it can accumulate in organic soil horizons (Varner et al. 2005) that become colonized by fine roots (Schenk and Jackson 2002), which can be vulnerable to consumption if fire returns (O'Brien et al. 2010). In contrast, under a frequent fire regime and little organic matter accumulation, fine roots predominantly colonize mineral soil horizons that are thermally protected from fire (McLean 1969, Brown and Smith 2000). Although fire-adapted tree species have specialized traits that facilitate their direct resistance to fire (*i.e.*, bark thickness) (Abrams 1992, Varner et al. 2016) all trees are likely to experience increasing physiological stress as fire consumes an increasing proportion of their fine root biomass (Varner et al. 2005, O'Brien et al. 2010). In some cases, fine root consumption leads to delayed tree mortality (*i.e.*, 3 + years post fire) when the fine root system is inadequate to support nutrient and water acquisition (Swezy and Agee 1991, Varner et al. 2007).

In the absence of fire, fire-adapted tree species may increase forest vulnerability to fine root consumption because of the co-occurrence of fire adaptive and nutrient conserving traits. Fire adapted species tend to have leaf litter that is more flammable (Pausas et al. 2017, Dell et al. 2017) and holds less moisture (Kreye et al. 2013, 2018), but is also more nutrient-poor and resistant to decay (Alexander and Arthur 2014) compared to litter from fire-intolerant species. Further, fire-adapted tree species tend to associate with ectomycorrhizal (ECM) fungi, which independently evolved from arbuscular mycorrhizal (AM) ancestors over multiple plant lineages (*e.g.* Pinaceae, Fagaeae and Eucalypteae; (Brundrett and Tedersoo 2018)). In contrast to AM fungi, ECM fungi are capable of extracting nutrients from organic matter (Read and Perez-Moreno 2003), which can further suppress decomposer activity (Averill 2016, Taylor et al. 2016) and lead to the formation of deep organic horizons (Phillips et al. 2013). This interaction may result in the surprising possibility that long-term fire exclusion makes fire-adapted forests less fire resistant than fire-intolerant forests, because fine roots in the organic horizon are vulnerable to consumption, increasing the probability of canopy decline and tree mortality (O'Brien et al. 2010).

Here, we evaluate how the return of fire after a century of exclusion affects the response of southern Appalachian forests undergoing transition from a fire-adapted to a fire-intolerant state. Prior to European settlement, this region was dominated by fire-adapted tree species, including *Castanea dentata*, *Pinus* spp. and *Quercus* spp. and burned frequently (*e.g.*, every 2-14 years), due to lighting-ignited wildfire and management fires set by indigenous peoples (Delcourt and Delcourt 1997, 1998; Nowacki and Abrams 2008). Fire exclusion since the turn of the 20^{th} century, and a suite of other potential factors (*e.g.*, climate, loss of *C. dentata*, nitrogen deposition (Elliott and Swank 2008, Pederson et al. 2015, Jo et al. 2019), have led to a mosaic of fire-adapted and fire-intolerant stands in southern Appalachia, where the encroachment of fire-intolerant species is widespread, but also dependent on topographic position (Elliott and Swank 2008).

Numerous wildfires burned across the southern Appalachians following a severe drought in the fall of 2016, providing an opportunity to evaluate the mechanisms of how fire exclusion affects forest vulnerability to wildfire. The Rock Mountain wildfire was ignited in northern Georgia and moved north into western North Carolina, burning over 9,000 ha before being extinguished. The fire was slow-moving with persistent smoldering that consumed much of the organic horizon down to the mineral soil surface. We tested the idea that long-term fire exclusion would lead to the counter-intuitive result that stands composed of fire-adapted species would prove less resistant to wildfire than those with fire-intolerant species. Such a response could manifest from differences in the accumulation of organic matter and resulting fine root distributions due to the coordination of fire-adaptive traits with nutrient conservative traits, including the mycorrhizal association. Specifically, we hypothesized that: 1) the organic soil horizon depth and stock would increase with increasing dominance of fire-adapted, ECM trees; 2) fine root biomass and length in the organic soil horizon would increase with increasing dominance of fire-adapted, ECM trees, such that 3) wildfire would consume the largest amount of organic matter and fine root biomass and length in stands dominated by fire-adapted, ECM tree species; and 4) canopy decline and stem mortality would increase after fire in stands with increasing dominance of fire-adapted, ECM tree species.

CHAPTER 2

METHODS

The Rock Mountain wildfire offered an excellent opportunity to investigate how southern Appalachian forests, which are undergoing transition due to long-term fire exclusion, respond to wildfire. This fire (centroid -83.52, 34.987) was ignited by an arsonist in November 2016 and burned 9824 ha in the Chattahoochee and Nantahala National Forests of northeast Georgia and southwest North Carolina over 25 days. The wildfire ignited during a severe drought, allowing the organic soil horizon and downed woody materials to be available to fire and be completely consumed, which is rare in the southern Appalachian region. Most of the fire consumed only surface fuels leaving most of the standing vegetation intact. Fire behavior was highly variable due to the rugged terrain, variation in vegetation and because it burned upslope and downslope both day and night.

The vegetation in the area of the Rock Mountain wildfire is a mixed hardwood forest, dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) in xeric areas transitioning to maple (*Acer* spp.) and tulip poplar (*Liriodendron tulipifera)* dominance in mesic areas. The hemlock wooly adelgid (*Adelges tsugae*) created areas of standing dead hemlocks (*Tsuga canadensis*) in riparian areas. The annual precipitation for this region is approximately 190 cm and the mean monthly temperatures for this study site range between 20°C in June through August and 5°C in December and January (Knoepp et al. 2008). The soils across area are Inceptisols or Ultisols weathered from igneous or metamorphic parent material. Most soils of the area are Typic or Umbric Dystrudepts, Typic Humudepts, Typic Hapludults or Typic Kanhapludults with soil textures characterized variously as loamy, fine-loamy, coarse-loamy, clayey and loamy-skeletal (Soil Survey Staff "Web Soil Survey").

In the summer of 2017, we established four spatial blocks distributed across the fire perimeter. Block locations were identified with GIS and stratified across the burned area, and to capture differences in elevation and fire age. Each block contained eight plots, where four were inside and four were outside the burned area (i.e., burned or unburned condition) and plots within each block were separated by a maximum distance of 2 km. Each set of four plots (within each block and burned/unburned condition) were distributed along a topographic gradient to capture four positions: low elevation, two mid-slopes (one north-facing and one south-facing), and ridge. As a result, our 32 plots captured a range of elevations (low elevation: 762-895 m, midslopes 805-927 m, and ridgetops: 957-1035 m). This design allowed us to sample and partition the spatial variability of the burn, topographic variation in tree species composition, soils, and capture variation in the mycorrhizal dominance across plots.

Each plot was 12 m in radius (452.4 m^2) and we established plot centers with a galvanized metal spike and used a Haglof hypsometer to mark trees within 12 m of plot center. All living trees or shrubs with a stem diameter at breast height greater than 10 cm were tagged and identified in 2017 and monitored for the following two growing seasons. At this point, none of the trees in our plots appeared to be dead as a result of the fire. Trees were categorized by mycorrhizal host type and their fire tolerance to calculate plot-level basal area by ECM and fire-adapted trees, hereafter referred to as ECM abundance and fire tolerance abundance. Trees with ericoid mycorrhizal (ERM) associations were grouped with ECM trees due their traits being more similar to ECM fungi than AM fungi.

To understand the how fire and ECM abundance affected O horizon depth and stocks, we conducted a series of measurements in the summer of 2017. We sampled the depth of the O_{ea} horizon using a steel probe (2 cm diameter), where we collected five samples in each cardinal directions at 2 m increments (2, 4, 6, 8, and 10 m) away from plot center for a total of 20 samples per plot. We removed fresh litter (O_i horizon) and measured the depth of the O_{ea} to the nearest 0.25 cm. We then sampled the entire mass of the O horizon from four locations in each plot. First, we determined sampling location by haphazardly tossing a 0.04 m^2 quadrat from plot center towards each cardinal direction. We collected the entire O horizon within the quadrat using a serrated knife, and the material was dried at 60 °C for >48 hours. We sorted the dried organic horizon matter into seven categories – O_i (leaf litter), O_{ea} (humus), charcoal, three classes of fine fuels (defined as 1 hour (0-60 mm), 10 hour (61-25 mm), 100 hour (>26 mm)) (Lutes et al. 2006) and miscellaneous (i.e., pine cones, acorns, samaras). To separate the O horizon from roots and adhering mineral soil, we used a 2 mm sieve, but in some cases it was necessary to submerge samples in DI water over night to allow mineral soil to sink. The following day we decanted the floating organic matter into pre-weighed Whatman 41 filter paper placed inside funnels and drained completely. The filter paper and organic matter was subsequently dried at 60 °C for at least 48 hours. Total organic matter mass was calculated for each quadrat on a g m^{-2} basis. From each quadrat, O_i and O_{ea} samples were homogenized individually before grinding to a fine powder, weighing into tin capsules, then analyzed for total carbon (C) and nitrogen (N) by Micro-Dumas combustion. Total C and N where then expressed on a g m^{-2} basis.

To understand the how fire and ECM abundance affected fine root biomass and length in the organic horizon we collected four, randomly located soil cores from each of the 32 plots during the summer of 2017 using a 4 cm diameter, PVC cylinder with a beveled edge and a rubber mallet. We separated the soil core into depth increments – O horizon, 0-10 cm mineral soil and 10-20 cm mineral soil. All cores were frozen until processed. At the time of processing, we randomly selected three of the four cores to be fully processed, and we only processed the O horizon depth of the fourth core. We increased the sampling of O horizon depth because of the greater variability in root mass and length among cores from the same plot. Cores were thawed for 48 hours before roots were hand separated from soil as best as possible using forceps for no longer than 10 minutes per sample. Fine roots from the organic horizon were often entangled in organic matter at this stage. Roots with organic matter were transferred to a large plexiglass tray with 1 x 1 cm grids, illuminated on a light board and were submerged with tap water. Using digital calipers, roots were placed into one of three diameter categories: <1 mm, 1-2 mm and >2 mm. For each category, we quantified root length using the line-intersect technique modified from Hendrick and Pregitzer (1993) and Wurzburger and Hendrick (2007). Roots in the >2 mm and 1-2 mm size classes were then cleaned with a paintbrush, dried and weighed. Because roots in the <1 mm class were often entangled in organic matter and fungal hyphae, we collected a representative subsample of cleaned root length to quantify specific root length (SRL; cm g^{-1}), which was applied to root length data to estimate biomass. All cleaned root samples were placed in a drying oven at 60 °C for >48 hours before being weighing. For each depth and size class, root data were expressed as cm $m^{-2}$and g m^{-2}.

To understand the how fire and ECM abundance affected tree response post fire we surveyed all trees during the summers of 2018 and 2019 for signs of tree stress or mortality. For each tree, we recorded basal sprouts and epicormic sprouts as a count per tree, and the crown coverage was categorized as either 0 (no crown), 1 (1-25% crown), 2 (26-50% crown), 3 (51-

75% crown), or 4 (76-100% crown). We identified two classes of mortality: "complete" where there were no leaves in the canopy or sprouts of any kind, and "aboveground" where canopy had no leaves or epicormics sprouts, but basal sprouts could be present. We also noted whether trees had been windthrown or damaged by other fallen trees.

Statistical Analyses

We sought to test whether the species composition of stands affected its resistance to wildfire after long-term exclusion. Our hypothesis was based on the idea that most fire-adapted tree species in temperate forests associate with ECM fungi, and ECM-dominated forests tend to have more organic matter accumulation and slower decomposition and nutrient cycling relative to AM-dominated stands (Phillips et al. 2013). Thus, the co-occurring trait of mycorrhizal identity and its effect on biogeochemical cycles, not fire-tolerance *per se*, was the hypothesized driver of organic matter accumulation and fine root consumption following the return of fire. To test this assumption about the co-occurrence of traits, we categorized the 35 tree species found in our 32 study plots by mycorrhizal association type and fire tolerance, where we considered bark thickness and flammable foliage as traits associated with fire adaptation (Brose and Van Lear 1999, Varner et al. 2016). We found a strong correlation between the relative abundance of ECM tree species vs. fire-adapted tree species at the plot level (r^2=0.92, p<0.0001, Figure 1) where the relative abundance was calculated as the percent of total basal area per plot. Underscoring this result, all AM tree species documented in this study were considered fire intolerant, while only a fraction of ECM tree species were not considered fire-adapted, including *Betula alleghaniensis, B. lenta*, *Fagus grandifolia*, *Tilia americana*, and *Tsuga canadensis* (see Appendix Table 1). These non-fire tolerant ECM species accounted for ~14% of the ECM species, but less than 6%

of the stems in our study. Thus, fire-adaptation was correlated with the ECM association across our study plots, and all of our statistical analyses (see below) test the importance ECM abundance as a potential driver of organic matter accumulation, fine root consumption and tree stress following fire. We conducted the same this analyses using the fire tolerance abundance to verify that they generated the same results (see Appendix).

Organic horizon

To determine the probability of O_{ea} presence across the gradient of ECM abundance and presence or absence of fire, we constructed a generalized linear mixed model with a binomial distribution, where fire, ECM basal area and their interaction were fixed effects and topographic position and block were random effects, using glmer (R package: *lme4*; (Bates et al. 2015)). If random effects accounted for no variance in the model, we ran a logistic regression model with no random effects. We then analyzed O_{ea} depth, C and N stocks and the C:N with a linear mixed effects model using lmer (R package *lme4*; (Bates et al. 2015)) where fire, ECM basal area and their interaction were fixed effects and topographic position and block were random effects. We conducted F tests using Kenward-Roger approximated degrees of freedom using afex (R package *afex*; (Singmann et al. 2019))

Root biomass and length

To determine how ECM dominance, fire, and their interaction affected root biomass and length in the different horizons, we fit linear mixed-effect models (as above) where fire, ECM basal area, soil depth and all possible interactions were fixed effects while topographic position and block were random effects. We excluded non-significant interactions from the final models. We constructed these models for each of the three root diameter size classes. We used emmeans (R package *emmeans*; (Lenth et al. 2019)) to evaluate significant differences between the root biomass or length in a specific depth of the burned or unburned plots, and to assess differences in biomass or length at different depths.

Tree stress

We used an ordinal logistic regression approach to calculate how the probability of tree stress (basal sprouts and crown class) changed with ECM abundance, fire, the mycorrhizal association type of the tree and all possible interactions. We first used cumulative link mixed models (R package: *ordinal;*(Christensen 2019)) where ECM basal area, mycorrhizal type, fire and their interactions were fixed effects and topographic position, block and species were random effects. We then applied the final model as an ordinal logistic regression approach using polr (R package: *MASS*; (Venables and Ripley 2002)), where all model terms were fixed effects and to graph predictions, we assigned levels of topographic position and block that generated the smallest random effects. We separately analyzed variables from 2018 and 2019.

To determine how the probability of tree mortality and aboveground biomass mortality varied with ECM abundance, fire, the mycorrhizal association type of the tree and their interactions, we utilized a generalized linear mixed model with a binomial distribution (as above) where ECM abundance, fire, the mycorrhizal association type of the tree and all possible interactions were fixed effects. If random effects accounted for no variance in the model, we ran a logistic regression model with no random effects. For all analyses, when necessary we square-root or ln-transformed (after adding 1 to each value if there were 0 values in the dataset) to resolve issues with non-normal error distributions. All analyses were conducted in R (version 3.6.1, (R Core Team 2014)).

CHAPTER 3

RESULTS

Organic horizon

We first assessed the presence and depth of the O_{ea} horizon (*i.e.*, the duff or humus layer), which accumulates slowly over time, but provides an environment for fine root colonization (Schenk and Jackson 2002) that is vulnerable to fire consumption (Varner et al. 2005, Varner et al. 2009). We found that the probability of a plot containing an O_{ea} horizon increased with increasing ECM abundance (z=2.57, p=0.01) (Figure 2a) and declined following fire (z=2.05, p=0.04) (Figure 2b). Similarly, the depth of the O_{ea} horizon increased with increasing ECM abundance ($F_{1,15}$=7.96, p=0.01) (Figure 3a) and declined with fire ($F_{1,23}$=35.6, p<0.0001) (Figure 3b). For neither the presence nor depth of the O_{ea} horizon did we detect a significant interaction between ECM abundance and fire, suggesting that a similar proportion of O horizon was lost to fire regardless of ECM tree abundance. Based on the difference between burned and unburned plots, we estimate that the wildfire consumed an average of 1.31 cm of the O_{ea} horizon. To better understand the effect of ECM abundance on O_{ea} depth prior to the wildfire, we calculated a difference of 1.64 cm from 0% to 100% ECM abundance in the unburned plots.

We next assessed the standing stocks of mass, total C and total N in the O horizon. The mass of the O_i (litter) and O_{ea} (humus) horizons increased with increasing ECM abundance ($F_{1,15}$=6.2, p=0.02) (Fig 4a) and declined after the fire ($F_{1,55}$=45.4, p<0.0001) (Fig. 4b). The stocks of C and N were consistently lower in the burned *versus* unburned plots, but the C:N of O horizon stocks were not statistically different (Table 1 and 2). These results suggest that the wildfire removed a relatively consistent amount of C and N from organic matter across the plots in our study. Unlike O horizon depth and mass, we did not detect a significant effect of ECM abundance on C and N stocks, possibly due to lower sampling intensity and high fine scale heterogeneity within plots. Within the O horizon, the O_{ea} horizon contained more mass than did the O_i horizon ($F_{1,54}$=104, p<0.0001) (Figure 4a). The same was true for total C and N (Table 1 and 2).

Fine root biomass and length

We found that the biomass of fine roots (<1 mm diameter) increased with increasing ECM abundance in the O horizon, but not in the mineral soil depths (depth by ECM abundance interaction; $F_{2,81}$=8.85, p=0.0003) (Figure 5a; Table 3 and 4). Fine root biomass in the O horizon was lower in burned *versus* unburned plots, but not in the other soil depths (soil depth by fire interaction; $F_{2,81}$=9.91, p=0.0001) (Figure 5b; Table 3 and 4). The difference between burned and unburned plots suggests that on average 100 g m^{-2}, or ~ 83%, of fine root biomass in the O horizon was consumed by fire. The medium (1-2 mm diameter) and coarse (>2 mm) root size classes were consistently affected by depth, but of these only the medium roots were affected by ECM abundance. Both the medium and coarse roots were significantly affected by the interaction of depth and fire ($F_{2,81}$=6.56, p=0.002 and $F_{2,81}$=4.60, p=0.01, respectively) (Table 3 and 4).

Fine root length followed a similar pattern to that of biomass and increased with increasing ECM abundance in the O horizon, but not in the mineral soil depths (depth by ECM abundance interaction $F_{2,81}$=8.27, p=0.0005) (Fig. 6a, Table 5 and 6). Fine root length in the O horizon was lower in burned *versus* unburned plots, but in the 0-10 cm depth biomass was higher in burned *versus* unburned plots (depth by fire interaction; $F_{2,81}$=12.27, p<0.0001) (Fig. 6b, Table 5 and 6). Both the medium and coarse root size classes were affected by the interaction of depth and fire ($F_{2,81}$=5.07, p=0.008 and $F_{2,81}$=4.40, p=0.02, respectively) (Table 5 and 6). The difference between burned and unburned plots suggests that on average 1632 m m^{-2}, or ~ 73%, of fine root length in the O horizon was consumed by fire.

Tree stress

In the third growing season post fire, we surveyed live and dead trees and documented a two-fold increase in the probability of post-fire tree mortality (z=2.11, p=0.03) (Figure 7), where 4.2% and 1.7% of trees had died in the burned vs. unburned plots, respectively. We found that wind and other tree damage were not related to fire, ECM abundance, nor their interaction (p > 0.1). As a result, we excluded wind killed or damaged trees from the analysis in order to examine metrics of tree health (*i.e.*, crown cover and basal sprouting) as a function of ECM abundance and in response to wildfire.

In 2018, the second growing season post fire, the probability of crown decline increased with ECM dominance (z =-2.477, p=0.01), and was modestly related to fire (z= 1.676, p=0.09) (Figure 8a). In 2019, the probability of tree crown decline depended on the interaction of ECM dominance and fire (z=4.32, p<0.0001), where the probability of a tree having a full crown declined with increasing ECM basal area in burned stands (Figure 8b). This finding supports the idea that increasing fine root consumption with increasing ECM abundance led to compensatory reduction in crown area over the three years post-fire independent of tree mortality.

When analyzing the abundance of basal sprouts as an indicator or tree stress, both 2018 and 2019 data showed an interaction of ECM dominance and fire, where the probability of trees having basal sprouts increased with ECM dominance in the burned plots. This interaction, however, weakened between year 1 and year 2 of the study (2018: z=-3.17, p=0.002; 2019: z=-2.27, p=0.02) (Figure 9ab).

Because most southern Appalachian trees have the capacity to sprout from the base following top-kill, we categorized trees by those that retained or lost their pre-burn aboveground biomass (*i.e*., no crown, no epicormic sprouts, but may possess basal sprouts). We found an increasing probability of aboveground mortality with increasing ECM abundance in the burned plots (fire by ECM abundance interaction; (z=-2.90, p= 0.004) (Figure 10), where ~16% of trees lost aboveground biomass in stands dominated by ECM trees following fire compared to ~1% in stands dominated by AM associating trees.

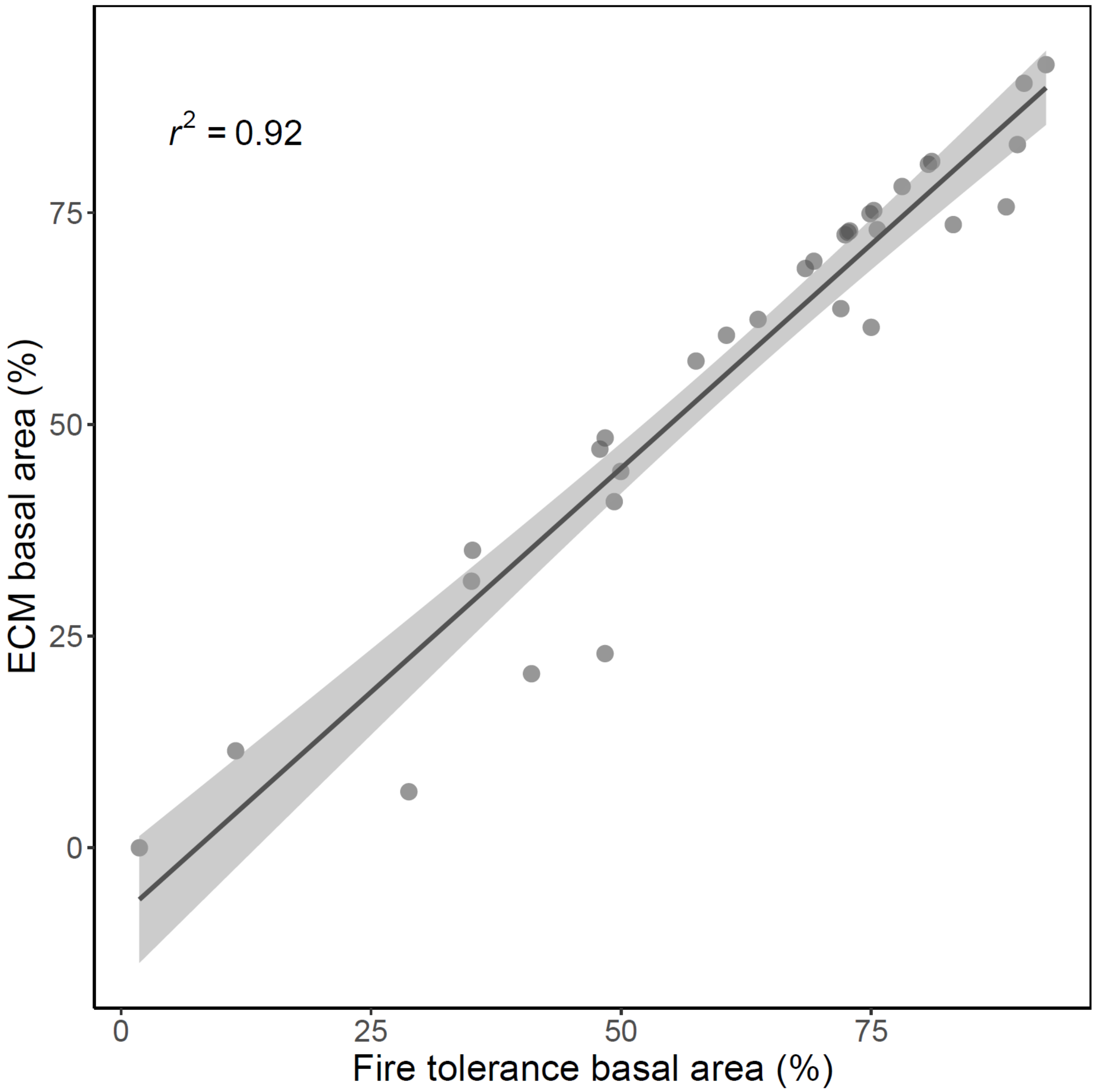

Figure 1. The relative abundance (% basal area) of fire-adapted trees and ECM trees were closely correlated at the plot level (p<0.0001) across all plots inside and outside the burn scar of the 2016 Rock Mountain wildfire.

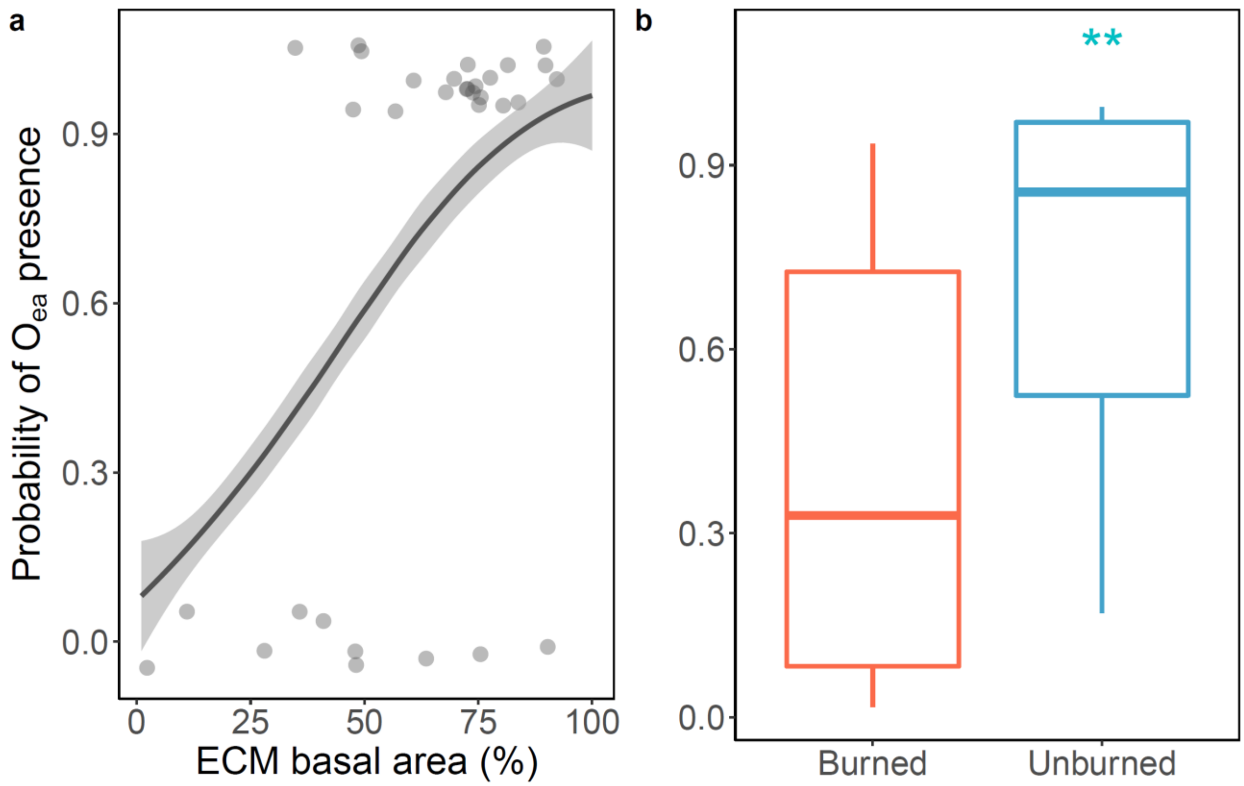

Figure 2. Probability of O_{ea} horizon presence (a) increases with increasing dominance of ECM trees (z=2.57, p=0.01) and (b) is lower in burned *versus* unburned plots (z=2.05, p=0.04). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences (p<0.05) between burned and unburned plots denoted with **.

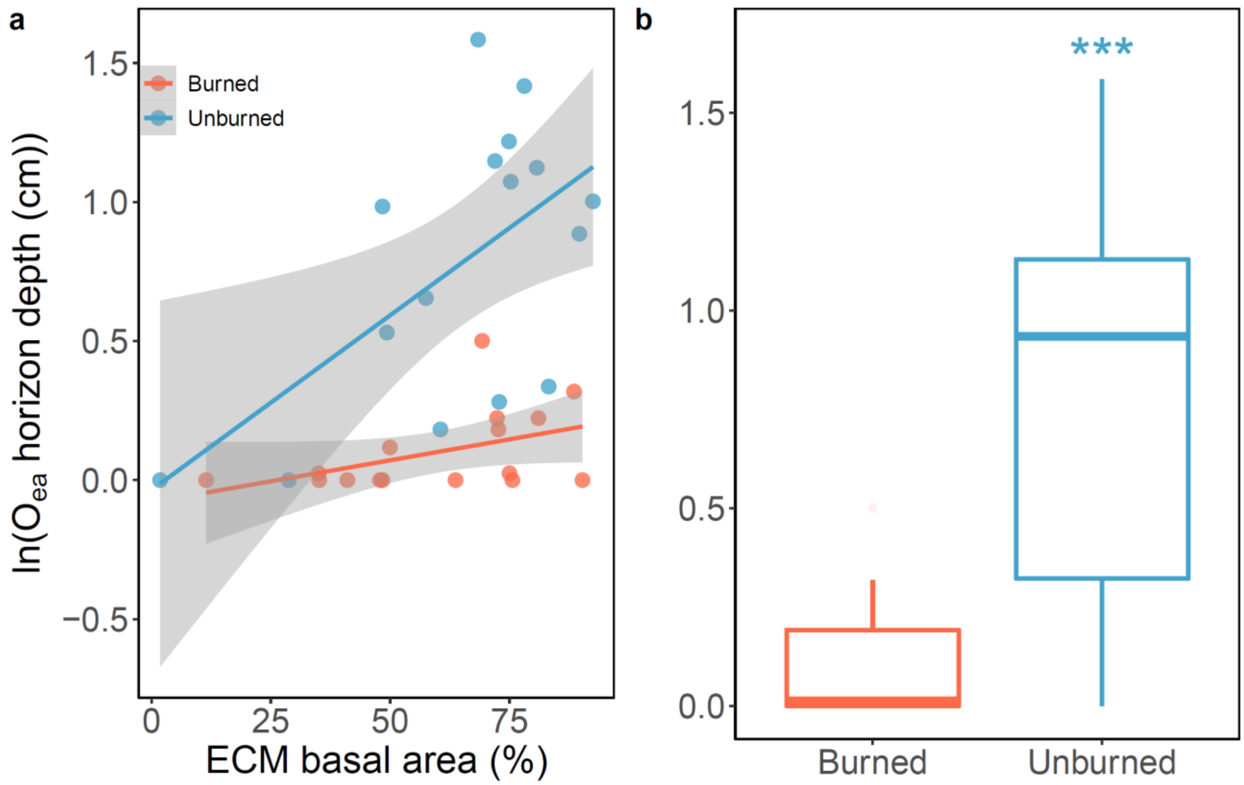

Figure 3. Depth of O_{ea} horizon (a) increases with increasing dominance of ECM trees ($F_{1, 15}=7.96$, $p=0.01$) and (b) is lower in burned *versus* unburned plots ($F_{1, 23}=35.59$, $p<0.0001$). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences ($p<0.001$) between burned and unburned plots denoted with ***.

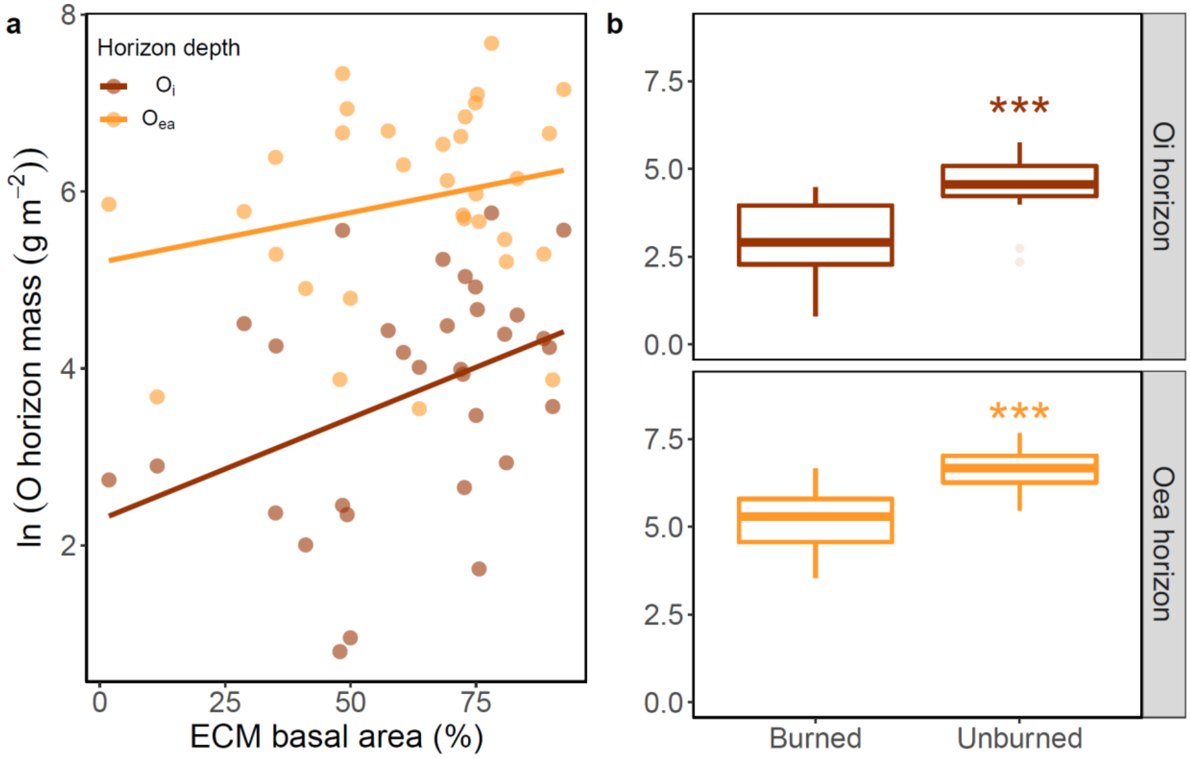

Figure 4. Organic horizon stocks (a) increase with increasing ECM basal area ($F_{1, 15}$=6.20, p=0.02) and (b) are lower in burned plots versus unburned plots for both soil horizons ($F_{1, 55}$=45.43, p<0.0001). Values are presented in g m^{-2}. Brown represents the O_i horizon while orange represents the O_{ea} horizon in both panels. Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences (p<0.001) between burned and unburned plots denoted with ***.

Table 1. O horizon total carbon and nitrogen stocks g m^{-2}, and C:N ratios; all values are back transformed and means (and standard errors). Significant differences between burned and unburned plots denoted with a different letter ($\alpha<0.05$).

	Burned	Unburned
O_i total C	9.21 (+3.12, -2.33) b	45.43 (+12.32, -9.69) a
O_{ea} total C	72.96 (+21.24, -16.45) b	327.35 (+55.00, -47.09) a
O_i total N	0.23 (+0.07, - 0.05) b	1.00 (+0.25, - 0.20) a
O_{ea} total N	3.01 (+0.89, -0.68) b	12.04 (+1.87, -1.62) a
O_i total C:N	40.27 (+3.44, -3.17) a	45.42 (+2.51, - 2.38) a
O_{ea} total C:N	24.23 (+0.38, -0.38) a	27.18 (+0.73, -0.70) a

Table 2. Model results of O horizon total carbon and nitrogen stocks (g m^{-2}), and C:N ratios using dominance of ECM species as a continuous variable.

	Burn		**ECM**	
	F	*p*	F	*p*
ln(O_i total C)	$F_{1,23}$=26.31	< 0.0001	$F_{1,26}$=3.21	= 0.08
ln(O_{ea} total C)	$F_{1,23}$=27.09	< 0.0001	$F_{1,14}$=1.19	= 0.29
ln(O_i total N)	$F_{1,23}$=24.02	< 0.0001	$F_{1,22}$=3.51	= 0.07
O_{ea} total N	$F_{1,23}$=30.29	< 0.0001	$F_{1,14}$=1.40	= 0.26
ln(O_i C:N)	$F_{1,23}$=1.96	= .18	$F_{1,27}$=0.64	= 0.43
ln(O_{ea} C:N)	$F_{1,23}$=16.18	= 0.0006	$F_{1,24}$=0.51	= 0.48

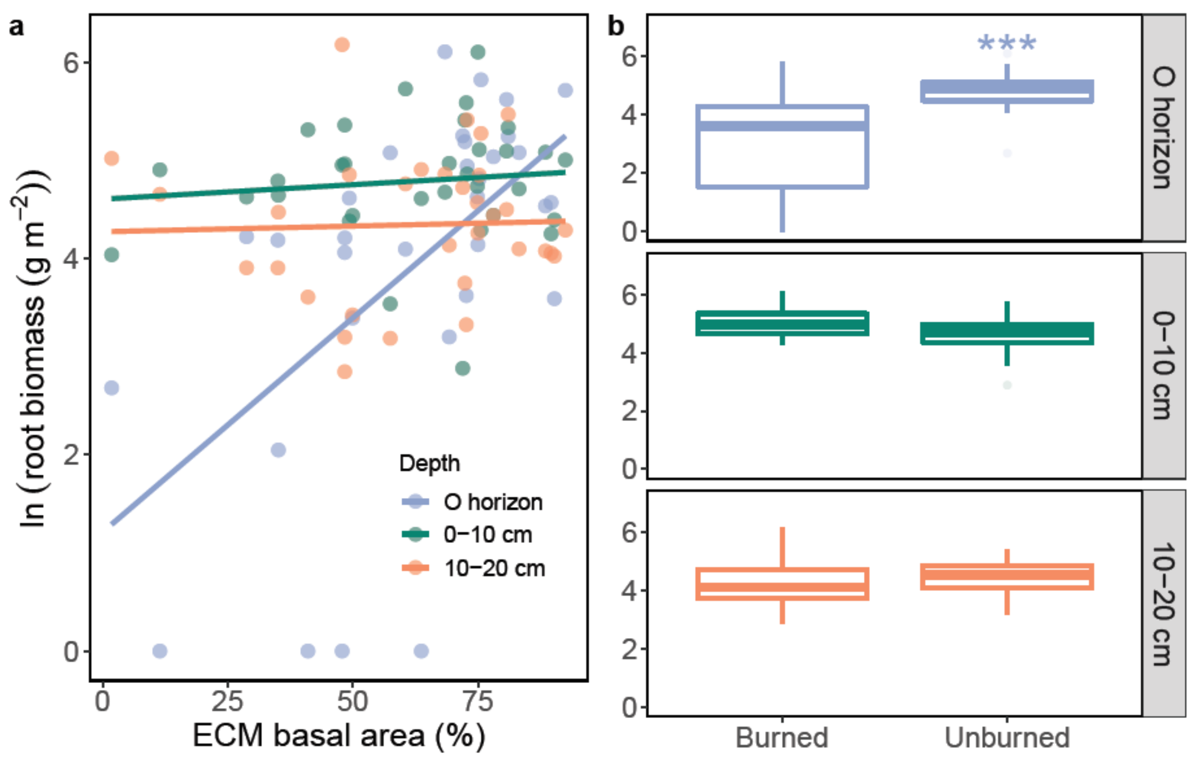

Figure 5. Fine root (<1 mm) biomass was influenced by an interaction of ECM tree abundance and depth, and fire and depth, but not the interaction of all three. (a) Biomass increased with ECM abundance in the O_{ea} horizon, but not in the other soil depths ($F_{2,81}$=8.85, p=0.0003). (b) Biomass in the O_{ea} horizon is lower in burned *versus* unburned plots, but is not different in the other two depths ($F_{2,81}$=9.91, p=0.0001). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences (p < 0.01) between burned and unburned plots denoted with ***.

Table 3. Soil depth was a significant predictor of root biomass (g m^{-2}) across all root diameter classes. Interactions between depth and ECM dominance, and depth and fire occurred only in the fine (<1 mm) diameter root class. In the 1-2 mm and >2 mm classes the only significant interaction occurred between depth and fire.

	Depth		**ECM**		**Fire**		**Depth x ECM**		**Depth x Fire**	
	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
ln(<1mm biomass)	$F_{2,81}$=7.05	=0.002	$F_{1,16}$=8.78	=0.009	$F_{1,82}$=4.62	=0.03	$F_{2,81}$=8.85	=0.0003	$F_{2,81}$=9.91	=0.0001
ln(1-2mm biomass)	$F_{2,81}$=39.74	<0.0001	$F_{1,18}$=5.84	=0.03	$F_{1,82}$=3.65	=0.06	$F_{2,81}$=2.82	=0.07	$F_{2,81}$=6.56	=0.002
ln(>2mm biomass)	$F_{2,81}$=21.66	<0.0001	$F_{1,16}$=1.06	=0.32	$F_{1,82}$=11.91	=0.0009	$F_{2,81}$=2.65	=0.08	$F_{2,81}$=4.60	=0.01

Table 4. Significantly greater root mass ($g \cdot m^{-2}$) was found in the O horizon of the unburned plots for both the fine (<1mm) and the coarse (>2 mm) roots. Root mass was significantly different in the lower 10 cm of soil of the unburned plots for the coarse roots, but not for any other diameter class. Significant differences between burned and unburned plots within each size class is denoted by a different lowercase letter ($\alpha < 0.05$). Values are back-transformed means (and standard errors).

	<1 mm diameter		**1-2 mm diameter**		**>2 mm diameter**	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
Organic Horizon	20.46 (+14.18, -8.54) b	120.75 (+26.49, -21.72) a	2.05 (+1.29, -0.91) a	11.37 (+5.42, -3.67)a	2.16 (+1.78, -1.14)b	18.31 (+9.18, -6.12) a
0-10 cm	149.47(+19.60, -17.34) a	96.27 (+17.59, -14.87) a	66.10 (+22.19, -16.68) a	37.38 (+8.58, -6.98)a	90.62 (+55.26, -34.47) a	77.25 (+32.32, -22.79) a
10-20 cm	70.61 (+17.34,-13.96) a	83.24 (+13.85, -11.88) a	24.14 (+5.35, -4.41) a	49.75 (+5.97, -5.33)a	25.80 (+18.58, -10.97)b	209.97(+70.86, -52.97) a

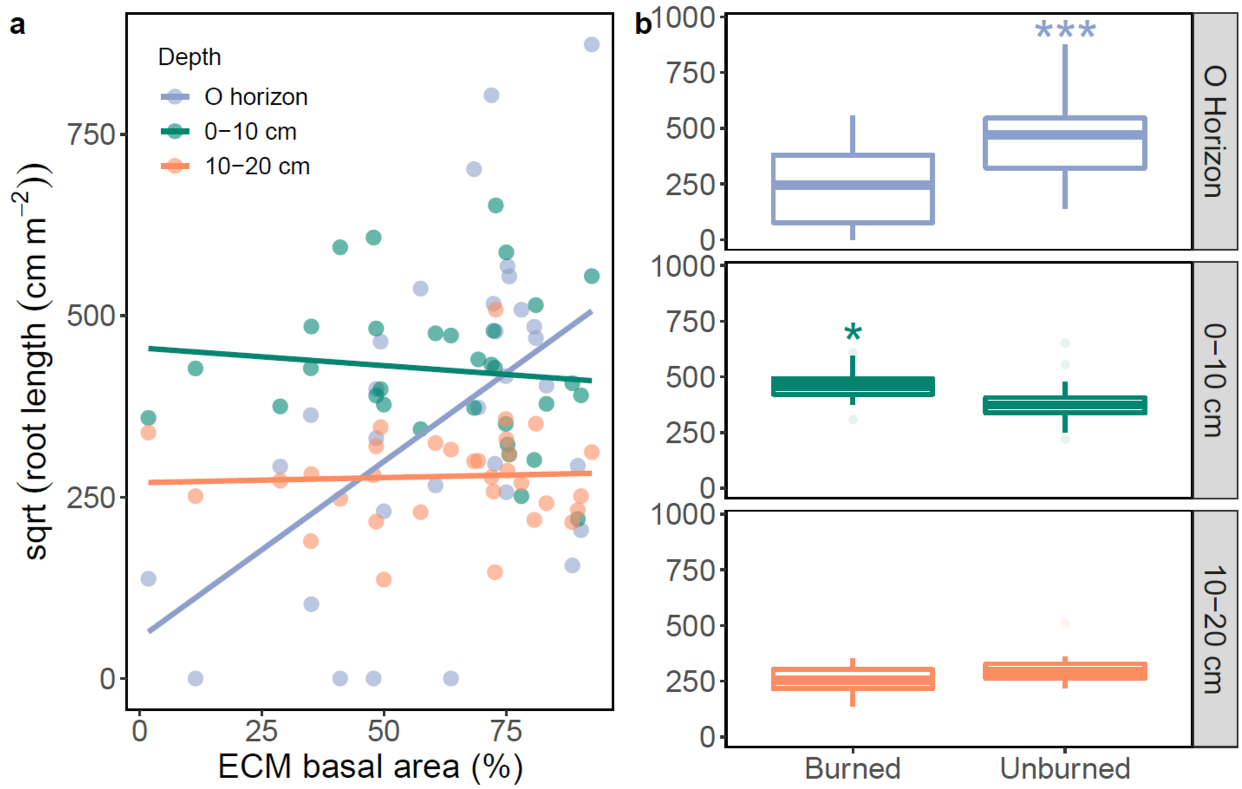

Figure 6. Fine root (< 1 mm) length depends on the interaction of ECM basal area and depth, and fire and depth, where (a) length increases with ECM abundance in the O_{ea} horizon, but not in the other soil depths ($F_{2,81}$=8.27, p=0.0005), and (b) length in the O_{ea} horizon is lower in burned *versus* unburned plots, but in the 0-10 cm depth is higher in burned *versus* unburned plots ($F_{2,81}$=12.27, p<0.0001). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p<0.001 = ***; p<0.05 = **).

Table 5. Soil depth and fire were significant predictors of root length (m m^{-2}) across all diameter classes. Interactions between depth and ECM dominance, and depth and fire occurred in the fine (<1 mm) and 1-2 mm diameter root classes, while the coarse (>2 mm) root class only had a depth by fire interaction.

	Depth		**ECM**		**Fire**		**Depth x ECM**		**Depth x Fire**	
	F	*p*	F	*p*	F	*p*	F	*p*	F	*p*
sqrt(<1mm length)	$F_{2,81}$=13.28	<0.0001	$F_{1,42}$=3.01	=0.09	$F_{1,82}$=6.51	=0.01	$F_{2,81}$=8.27	=0.0005	$F_{2,81}$=12.27	<0.0001
ln(1-2mm length)	$F_{2,81}$=40.52	<0.0001	$F_{1,16}$=4.09	=0.06	$F_{1,82}$=5.23	=0.02	$F_{2,81}$=6.68	=0.002	$F_{2,81}$=5.07	=0.008
sqrt(>2mm length)	$F_{2,81}$=21.33	<0.0001	$F_{1,16}$=0.04	=0.84	$F_{1,82}$=5.71	=0.02	$F_{2,81}$=2.44	=0.09	$F_{2,81}$=4.40	=0.02

Table 6. Root length (m m^{-2}) was significantly higher in the O horizon of the unburned plots *versus* burned plots for both the fine (<1mm) and the medium (1-2mm) root size class. In the 0-10 cm depth, root length was significantly higher in burned *versus* unburned plots for the fine roots, but not for any other diameter class. The only significant difference of length in 10-20 cm of mineral soil was found in the >2mm roots of the unburned plots. Significant differences between burned and unburned plots within each size class is denoted by a different lowercase letter ($\alpha < 0.05$) or an asterisk ($\alpha < 0.1$). Values are back-transformed means (and standard errors).

	<1 mm diameter		**1-2 mm diameter**		**>2 mm diameter**	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
Organic Horizon	600.4(+256.6, -211.1) b	2232.8 (+491.2, -442.4)a	0.27 (+0.48,-0.18)b	5.37 (+6.69, -2.98)a	2.33 (+1.91, -1.34) a	9.82 (+3.60, -3.04) a
0-10 cm	2155.5 (+195.0, -186.6) *	1490.6 (+213, 198.8)	76.9 (+9.80, -8.69)a	48.5 (+9.11, -7.67)a	38.34 (+10.0, -8.84) a	30.00 (+6.51, -5.88) a
10-20 cm	649.9 (+81.8, -77.0) a	912.8 (+108.8, -102.7) a	37.1 (+9.60, -7.63)a	66.5 (+10.9, -9.34)a	17.25 (+6.32, -5.34) b	44.62 (+6.20, -5.80) a

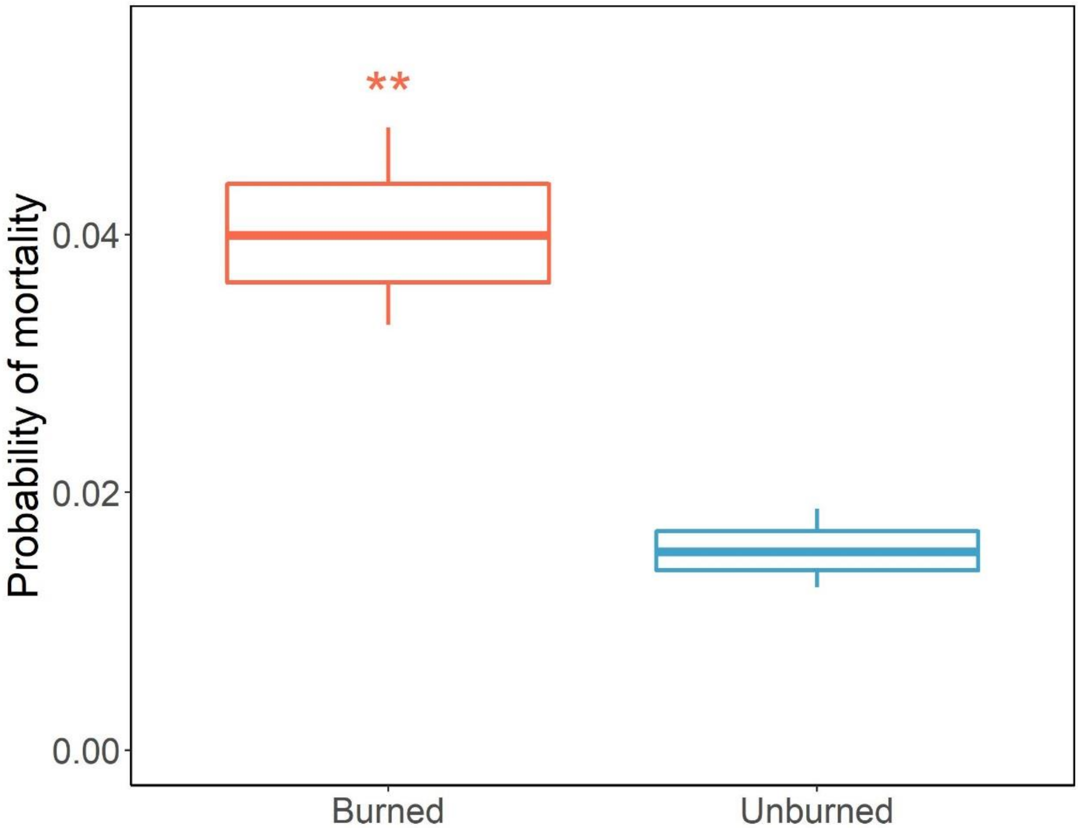

Figure 7. Tree mortality by the end of the study only depended on fire (z=2.11, p=0.03), where the probability of a tree dying was higher if it was in a burned vs. unburned plot.

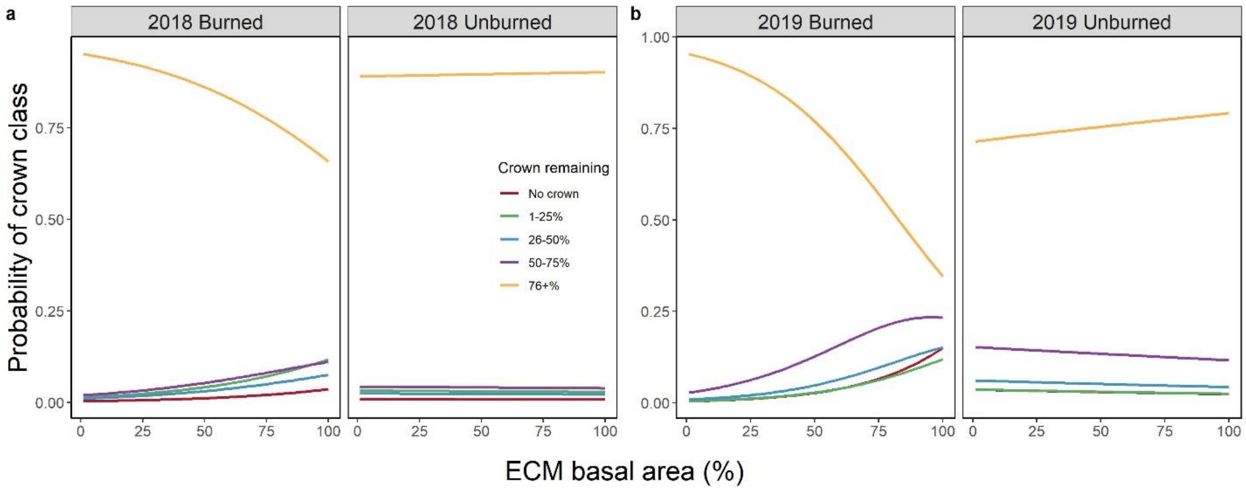

Figure 8. The probability of crown decline depended on year of the study, where a) in 2018, probability of crown decline increased with ECM dominance (*z*=-2.477, *p*=0.01), and was modestly related to fire (z= 1.676, *p*=0.09); and b) in 2019, the probability of tree crown decline depended on the interaction of ECM dominance and fire (*z*=4.32, *p*<0.0001) the probability of a tree having a full crown declined with increasing ECM basal area in burned stands.

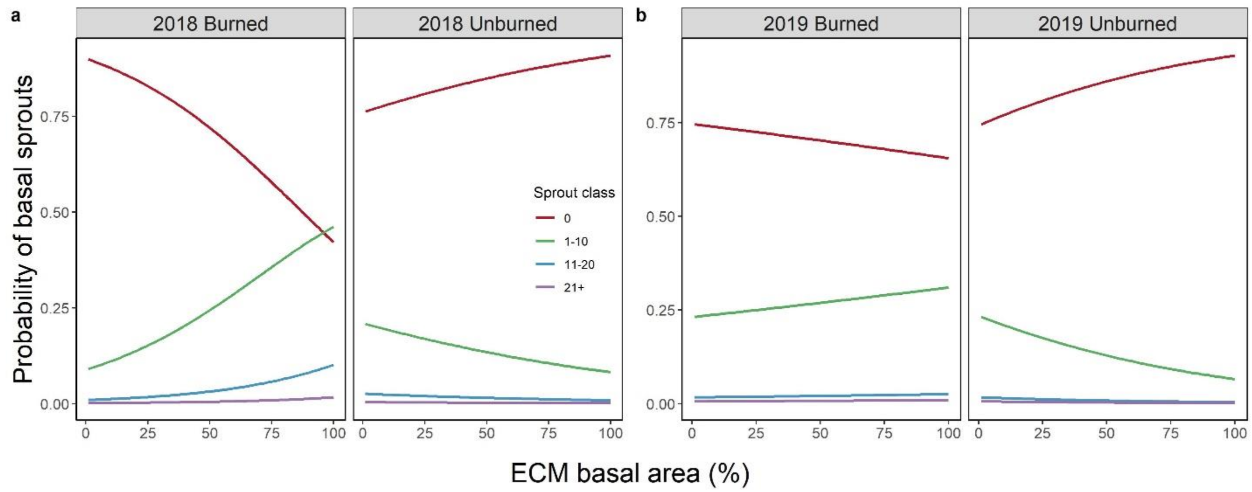

Figure 9. The probability of basal sprouts depended on the interaction of ECM dominance and fire, where the probability of trees having basal sprouts increased with ECM dominance in the burned plots, but this interaction weakened between a) year 1 and b) year 2 of the study (2018: z=-3.17, p=0.002; 2019: z=-2.27, p=0.02).

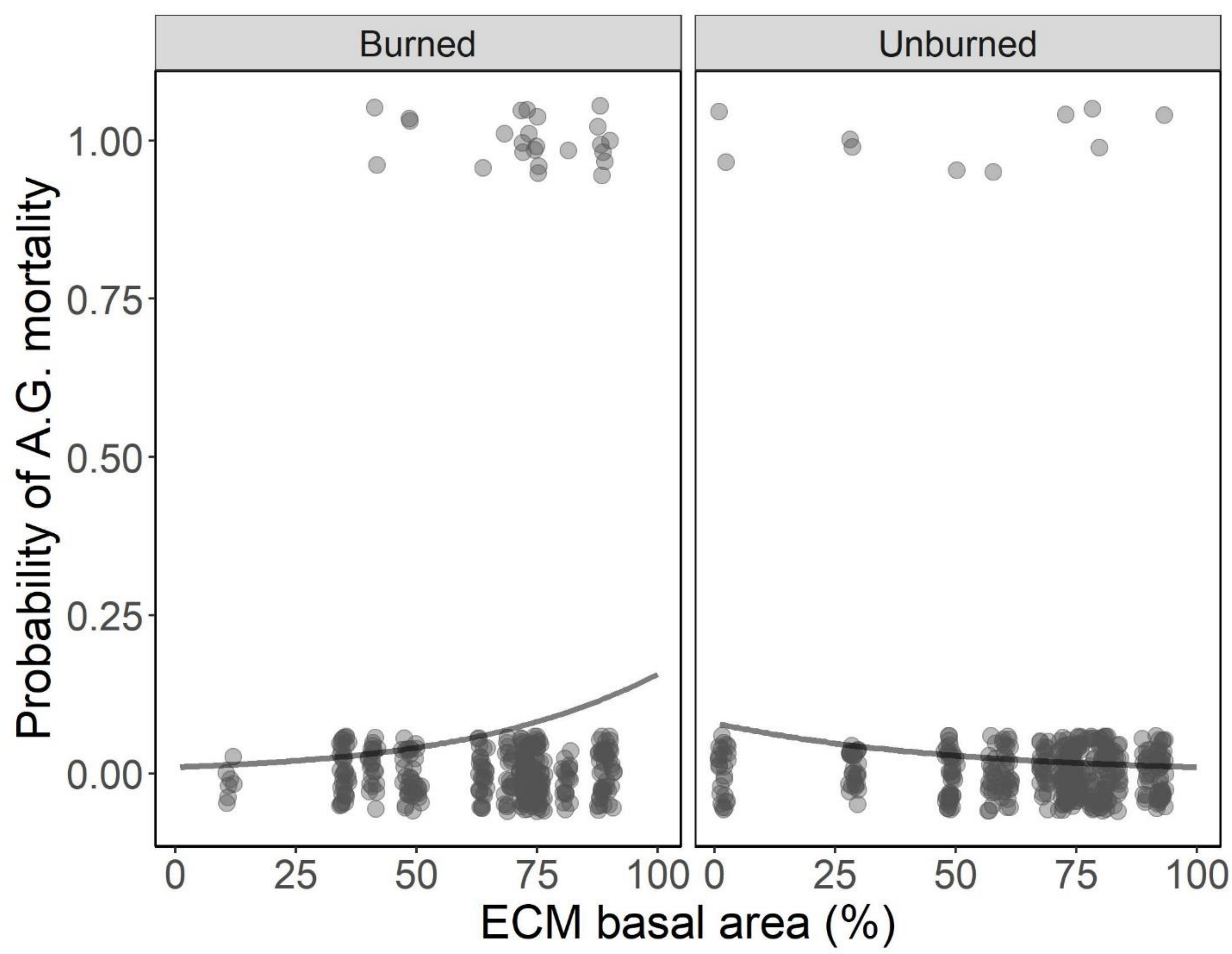

Figure 10. The mortality of the aboveground biomass by the end of the study increased with increasing ECM dominance in burned plots (*z*=-2.90, *p*= 0.004).

CHAPTER 4

DISCUSSION

The long-term exclusion of fire from fire-adapted forests may weaken their resistance to future fire (Larson et al. 2013). This problem is often examined in the context of high-intensity crown fires that result in direct tree mortality, but surface fires can also result in tree mortality that is often delayed (O'Brien et al. 2010) and for many ecosystems, the mechanisms behind this phenomenon remain untested (Hood et al. 2018). We investigated how a wildfire that occurred after nearly 100 years of fire exclusion affected southern Appalachian forests. These forests evolved with frequent fire (Abrams 1992, Frost 1998, Lafon et al. 2017), but due to long-term fire exclusion now contain a mosaic of fire-adapted and fire-intolerant stands. Because of the co-occurrence of fire adaptation and nutrient conserving traits such as the ECM association, we hypothesized that fire-adapted, ECM-dominated stands would be less resistant to wildfire than fire-intolerant, AM-dominated stands, because they would contain atypical fuels in the form of a deep O horizon. We found increasing presence of the O horizon and fine root biomass and length within the O horizon with increasing ECM dominance. Further, we observed a higher probability of canopy decline, basal sprouting and aboveground biomass mortality following fire in stands with increasing ECM dominance. Our findings point to the consumption of the O horizon and fine roots as a mechanism behind tree stress (O'Brien et al. 2010), suggesting that long-term fire exclusion has a negative effect on the ability of a fire-adapted ecosystem to withstand fires that consume the organic horizon.

Organic horizon

We found that the probability of O horizon presence (Figure 2) and the depth of the O horizon (Figure 3) increased with the increasing dominance of ECM trees, regardless of whether the plot had burned during the Rock Mountain wildfire. The increasing presence and depth of the O_{ea} horizon with increasing ECM dominance likely results from the recalcitrant litter produced by ECM-associating trees, which has a slower decomposition rate relative to litter of AM-associated trees (Phillips et al. 2013, Taylor et al. 2016). Despite the recalcitrant nature of ECM litter, ECM fungi can excrete extracellular enzymes to obtain nutrients directly from this organic matter (Read and Perez-Moreno 2003), effectively suppressing microbial activity (Taylor et al. 2016, Wurzburger and Brookshire 2017), and further slowing decomposition rates in ECM-dominated stands (Averill 2016). Under conditions of frequent fire, the ability of ECM trees to retain and recycle nutrients in organic matter may have suppressed the invasion of fire-intolerant, nutrient-acquisitive species and helped maintain the ecosystem in its fire-dependent state (Wurzburger et al. 2017). Interestingly, these same traits appear to weaken fire resistance following long-term fire exclusion by promoting the accumulation of an organic horizon that is colonized by fine roots.

Roots

We quantified fine root biomass and length in the presence and absence of fire, to determine if increasing ECM dominance predisposes fine root consumption by fire. We found that ECM dominance increased both the length and the biomass of the fine roots contained in the O horizon (Figure 5 and 6). In unburned plots, the O horizon accounted for nearly 40% of the biomass and 50% of the length of fine roots (< 1 mm) we observed in the top 20 cm of soil (Table 4 and 6), indicating potential for physiological stress following O horizon consumption by fire. The consumption of fine roots has been linked to physiological stress and delayed mortality of trees in other fire-adapted ecosystems that have been long-unburned (Varner et al. 2009, O'Brien et al. 2010), and our work offers a new framework – the dominant mycorrhizal association type of the forest – to help predict which forest stands may be more susceptible to decline or delayed mortality when fire is reintroduced. Although we did not identify the species or mycorrhizal association of the roots colonizing the O horizon, it is likely that both AM and ECM roots colonized this layer to access the nutrients found in the decomposing litter. This is further supported by the lack of a difference in tree stress and mortality between AM and ECM trees (see *Tree stress* below). Surprisingly, we observed more fine root length in the 0-10 cm soil depth in burned vs. unburned plots (Figure 6), suggesting there was new fine root production in the mineral soil post-fire, which occurred as a response to the losses of fine roots in the organic horizon. This idea is supported by evidence that fine root production can occur from spring to summer in southern Appalachian forests (Davis et al. 2004). A downward migration of fine roots into mineral soil suggests that over the long term, ECM-dominated stands may become more resistant to future fire events.

Tree stress

We found that nearly three years post wildfire, the probability of tree stress and aboveground stem mortality increased with increasing dominance of fire-adapted, ECM associated species. Specifically, we observed a decline in the crown class of trees, and an increase in basal sprouting and the mortality of aboveground biomass with increasing ECM dominance, likely due to the increased consumption of roots and organic horizon by the fire. We found that the mycorrhizal association of an individual tree did not help predict tree stress or aboveground mortality, suggesting that in ECM-dominated stands, both AM and ECM associated species are vulnerable to fine root consumption and delayed decline.

We found that tree crown decline increased with increasing ECM dominance following fire (Figure 8), suggesting that a reduction in crown cover resulted from the consumption of the O_{ea} horizon and loss of fine roots. When trees lose a significant portion of their fine root biomass or length, they may lack the ability to acquire nutrients and water to maintain their full canopy (O'Brien et al. 2010). In our study, after nearly three years post fire, only ~30% of trees possessed a full canopy in ECM-dominated stands, while ~75% maintained a full canopy in our unburned plots (Figure 8). When under stress, many tree species produce basal sprouts (Meier et al. 2012), and when stresses are severe, basal sprouts can replace aboveground biomass that was lost to fire, drought or disease, functioning as an important trait for disturbance recovery (Clarke et al. 2013). We found that the probability of basal sprouting increased with increasing ECM dominance following fire (Figure 9), but this relationship dampened between the first and second growing season of our study, suggesting that some basal sprouts are shed over time.

Unlike previous studies documenting high levels of fine root consumption (e.g. O'Brien et al. 2010), tree mortality up to 3 years post-fire was relatively low in our study (Figure 7), and was not affected by the dominance of ECM trees. Tree species of southern Appalachian forests might be more tolerant of fine root consumption relative to pines due to their ability reallocate resources to basal sprouting while shutting down the flow of carbon to stem growth and leaf production and maintenance (Clarke et al. 2013). However, when we excluded wind-damaged trees from our analysis, we found an increasing probability of aboveground biomass mortality with increasing ECM dominance following fire (Figure 10), where 16% of trees lost their aboveground biomass in ECM-dominated stands compared to a maximum of 8% in unburned stands. While many of these individuals have the potential to basally-sprout, it raises the possibility that crown decline (Figure 8) and aboveground biomass mortality (Figure 10) will create light gaps that facilitate a further shift towards fire-intolerant species (Nowacki and Abrams 2008).

Fire effects

Our study provides the opportunity to assess the effect of the Rock Mountain wildfire on organic matter consumption after a century of fire exclusion. By assessing the differences between the depth and the stocks of O_{ea} in burned *versus* unburned plots we were able to estimate losses of organic matter, total C and total N. When scaled up, we estimate that 6,537 kg ha^{-1} of O horizon mass, 2,906 kg ha^{-1} of C, and 98 kg ha^{-1} of N were consumed in the fire. On top of this, we estimate that 1,258 kg ha^{-1} of root biomass was consumed. While we did not directly quantify how much lost organic matter volatilized *versus* deposited as ash elsewhere, our measurements capture the net effect of fire on these stocks of elements. In the context of N, this fire-induced N loss accounts for about 17 years of ammonium and nitrate wet deposition (average of 5.5 kg N ha^{-1} at the nearby Coweeta Hydrologic Lab), which has been elevated since at least the late 1970s (National Atmospheric Deposition Program). Elevated atmospheric N deposition rates have been linked to changes in species composition (Bobbink et al. 2010, McDonnell et al. 2018, Jo et al. 2019) and nutrient cycling (Knoepp et al. 2008). Therefore, wildfire or prescribed fire may represent a way to release excess N, as has been demonstrated in longleaf pine ecosystems (Tierney et al. 2019).

Methodological considerations

We note two key challenges in capturing the effect of fire in a heterogeneous ecosystem, including sampling of heterogeneous variables such as organic matter and fine roots and inferring fire effects *post hoc* by comparing burned and unburned stands. Variables such as O horizon mass and fine root mass are highly variable at small spatial scales, and this spatial heterogeneity could be accentuated by fire. For example, the O horizon mass remaining post fire depends on the starting mass and its flammability, but is also affected by small-scale differences in moisture, wind, and combustion. Our ability to detect a relationship between ECM tree dominance and O horizon presence and depth, but not O horizon mass, is likely due to the lower intensity of our sampling within plots for mass *versus* depth. Further, there is additional uncertainty introduced by using burned and unburned plots to infer fire effects, as we lack information on the pre-fire condition of each of our sampling plots.

Conclusions:

Anthropogenic activities are changing disturbance regimes that are critical for maintaining ecosystem structure and function (Johnstone et al. 2016). An increasingly important question for ecosystem change is how long-term fire exclusion affects the resistance of an ecosystem to the reintroduction of fire. In southern Appalachian forests, long-term fire exclusion has resulted in a mosaic of stands with varying levels of fire-adapted and fire-intolerant species. Intuitively, we might expect the encroachment of fire-intolerant species to weaken the resistance of these forests to their historical fire regime. Our study demonstrates the opposite phenomenon – that stands dominated by fire-adapted, ECM trees were less resistant to the reintroduction of wildfire than stands dominated by fire-intolerant, AM trees. Our findings suggest that the co-occurrence of fire adaptation and nutrient conserving traits among tree species can result in new biotic and abiotic ecosystem properties that weaken wildfire resistance in the ecosystem. In the long term, it is unclear whether fire reintroduction will further reinforce the dominance of fire-intolerant species in these forests by creating light gaps that favor fire-intolerant species over fire-adapted species. Such effects might be minimized by reintroducing fire under conditions that limit O horizon consumption at regular intervals to suppress recruitment of fire-intolerance species. Furthermore, our work provides a cautionary tale to forest and fire managers, that the reintroduction of fire can have surprising effects due to the novel fuels caused by a century of fire exclusion.

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APPENDICES

Appendix table 1. Complete list of tree species within the plots of the Rock Mountain study site, where mycorrhizal associations include arbuscular (AM), ectomycorrhizal (ECM) and ericoid mycorrhizal (ERM).

Plot	Scientific name	Common name	DBH (cm)	Mycorrhizal association	Pyro-affinity
1B1	*Acer rubrum*	Red Maple	11.9	AM	Intolerant
1B1	*Acer rubrum*	Red Maple	11.9	AM	Intolerant
1B1	*Acer rubrum*	Red Maple	10.5	AM	Intolerant
1B1	*Acer rubrum*	Red Maple	19	AM	Intolerant
1B1	*Acer saccharum*	Sugar Maple	30.1	AM	Intolerant
1B1	*Acer saccharum*	Sugar Maple	20.3	AM	Intolerant
1B1	*Betula lenta*	Sweet Birch	12.3	ECM	Intolerant
1B1	*Carya glabra*	Pignut Hickory	10.9	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	19	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	16.3	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	20.2	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	12	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	14.2	ECM	Tolerant
1B1	*Carya ovalis*	Red Hickory	18.7	ECM	Tolerant

1B1	*Carya ovalis*	Red Hickory	35.3	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	20.3	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	12.3	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	12.9	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	13	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	17.6	ECM	Tolerant
1B1	*Carya tomentosa*	Mockernut Hickory	10.9	ECM	Tolerant
1B1	*Liriodendron tulipifera*	Yellow Poplar	33.1	AM	Intolerant
1B1	*Liriodendron tulipifera*	Yellow Poplar	19.7	AM	Intolerant
1B1	*Liriodendron tulipifera*	Yellow Poplar	26.8	AM	Intolerant
1B1	*Oxydendrum arboreum*	Sourwood	20.2	ERM	Tolerant
1B1	*Oxydendrum arboreum*	Sourwood	24.4	ERM	Tolerant
1B1	*Quercus alba*	White Oak	20.5	ECM	Tolerant
1B1	*Quercus montana*	Chestnut Oak	16.2	ECM	Tolerant
1B1	*Quercus montana*	Chestnut Oak	29.8	ECM	Tolerant
1B1	*Quercus rubra*	Northern Red Oak	18.7	ECM	Tolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	13.2	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	23.7	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	23.1	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	29	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	26.5	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	29.8	AM	Intolerant

1B2	*Liriodendron tulipifera*	Yellow Poplar	28.5	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	29.3	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	28.6	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	28.8	AM	Intolerant
1B2	*Liriodendron tulipifera*	Yellow Poplar	28.6	AM	Intolerant
1B2	*Pinus strobus*	Eastern White Pine	39.2	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	26.2	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	26.7	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	23.6	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	39.6	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	64.1	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	48	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	34	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	38.5	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	30.3	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	53.7	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	47.7	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	32.4	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	37.6	ECM	Tolerant
1B2	*Pinus strobus*	Eastern White Pine	36.5	ECM	Tolerant
1B2	*Platanus occidentalis*	American Sycamore	23.2	AM	Intolerant
1B2	*Platanus occidentalis*	American Sycamore	25.3	AM	Intolerant

1B3	*Acer rubrum*	Red Maple	10.5	AM	Intolerant
1B3	*Acer rubrum*	Red Maple	30.1	AM	Intolerant
1B3	*Acer rubrum*	Red Maple	18.7	AM	Intolerant
1B3	*Acer rubrum*	Red Maple	37	AM	Intolerant
1B3	*Acer rubrum*	Red Maple	52.3	AM	Intolerant
1B3	*Carpinus caroliniana*	Hornbeam	10.6	ECM	Intolerant
1B3	*Cornus florida*	Flowering Dogwood	16.4	AM	Intolerant
1B3	*Cornus florida*	Flowering Dogwood	13	AM	Intolerant
1B3	*Nyssa sylvatica*	Blackgum	15	AM	Intolerant
1B3	*Nyssa sylvatica*	Blackgum	35.5	AM	Intolerant
1B3	*Oxydendrum arboreum*	Sourwood	42.4	ERM	Tolerant
1B3	*Oxydendrum arboreum*	Sourwood	37.9	ERM	Tolerant
1B3	*Quercus alba*	White Oak	57.7	ECM	Tolerant
1B3	*Quercus montana*	Chestnut Oak	10.7	ECM	Tolerant
1B4	*Acer rubrum*	Red Maple	10	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	12.2	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	13.7	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	19.6	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	18.8	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	26.2	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	24.5	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	14.8	AM	Intolerant

1B4	*Acer rubrum*	Red Maple	11.1	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	31.5	AM	Intolerant
1B4	*Acer rubrum*	Red Maple	12.4	AM	Intolerant
1B4	*Betula lenta*	Sweet Birch	26	ECM	Intolerant
1B4	*Betula lenta*	Sweet Birch	22.1	ECM	Intolerant
1B4	*Betula lenta*	Sweet Birch	27.2	ECM	Intolerant
1B4	*Carya glabra*	Pignut Hickory	22.5	ECM	Tolerant
1B4	*Carya ovalis*	Red Hickory	15.6	ECM	Tolerant
1B4	*Magnolia acuminata*	Cucumber Magnolia	38.5	AM	Intolerant
1B4	*Ostraya virginiana*	Hophornbeam	19.4	ECM	Intolerant
1B4	*Oxydendrum arboreum*	Sourwood	10.9	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	12.8	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	15.6	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	21.8	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	13.2	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	16.4	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	11.7	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	20.3	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	14.7	ERM	Tolerant
1B4	*Oxydendrum arboreum*	Sourwood	19.3	ERM	Tolerant
1B4	*Pinus rigida*	Pitch Pine	46.7	ECM	Tolerant
1B4	*Pinus rigida*	Pitch Pine	41.6	ECM	Tolerant

1B4	*Quercus coccinea*	Scarlet Oak	52.8	ECM	Tolerant
1B4	*Quercus coccinea*	Scarlet Oak	13	ECM	Tolerant
1B4	*Quercus coccinea*	Scarlet Oak	26.7	ECM	Tolerant
1B4	*Quercus coccinea*	Scarlet Oak	24.1	ECM	Tolerant
1B4	*Quercus montana*	Chestnut Oak	23.9	ECM	Tolerant
1B4	*Quercus montana*	Chestnut Oak	44	ECM	Tolerant
1B4	*Quercus montana*	Chestnut Oak	13.4	ECM	Tolerant
1B4	*Quercus montana*	Chestnut Oak	13.4	ECM	Tolerant
1B4	*Robinia pseudoacacia*	Black Locust	20.2	AM	Intolerant
1B4	*Tsuga canadensis*	Eastern Hemlock	29.7	ECM	Intolerant
1U5	*Acer pensylvanicum*	Striped Maple	17.7	AM	Intolerant
1U5	*Acer rubrum*	Red Maple	17.9	AM	Intolerant
1U5	*Acer rubrum*	Red Maple	12.3	AM	Intolerant
1U5	*Amelanchier arborea*	Downy Serviceberry	19.9	AM	Intolerant
1U5	*Betula lenta*	Sweet Birch	20.5	ECM	Intolerant
1U5	*Betula lenta*	Sweet Birch	27.1	ECM	Intolerant
1U5	*Carya glabra*	Pignut Hickory	60.6	ECM	Tolerant
1U5	*Carya tomentosa*	Mockernut Hickory	15.7	ECM	Tolerant
1U5	*Carya tomentosa*	Mockernut Hickory	14.8	ECM	Tolerant
1U5	*Carya tomentosa*	Mockernut Hickory	10.7	ECM	Tolerant
1U5	*Carya tomentosa*	Mockernut Hickory	16.6	ECM	Tolerant
1U5	*Magnolia macrophylla*	Bigleaf Magnolia	25.3	AM	Intolerant

1U5	*Oxydendrum arboreum*	Sourwood	12.7	ERM	Tolerant
1U5	*Oxydendrum arboreum*	Sourwood	15.7	ERM	Tolerant
1U5	*Oxydendrum arboreum*	Sourwood	17.9	ERM	Tolerant
1U5	*Oxydendrum arboreum*	Sourwood	18.4	ERM	Tolerant
1U5	*Pinus strobus*	Eastern White Pine	60.5	ECM	Tolerant
1U5	*Quercus alba*	White Oak	64.2	ECM	Tolerant
1U5	*Quercus rubra*	Northern Red Oak	34.7	ECM	Tolerant
1U6	*Acer rubrum*	Red Maple	20	AM	Intolerant
1U6	*Acer rubrum*	Red Maple	12.9	AM	Intolerant
1U6	*Acer rubrum*	Red Maple	16.1	AM	Intolerant
1U6	*Carpinus caroliniana*	Hornbeam	14.6	ECM	Intolerant
1U6	*Carpinus caroliniana*	Hornbeam	10.9	ECM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	16.4	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	20.3	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	34.1	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	31.8	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	29.2	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	28.7	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	26.2	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	17.8	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	20.8	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	47.9	AM	Intolerant

1U6	*Liriodendron tulipifera*	Yellow Poplar	21.4	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	16.7	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	25.7	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	34.6	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	10.8	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	14.4	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	14	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	25.6	AM	Intolerant
1U6	*Liriodendron tulipifera*	Yellow Poplar	29.9	AM	Intolerant
1U6	*Platanus occidentalis*	American Sycamore	23.7	AM	Intolerant
1U6	*Platanus occidentalis*	American Sycamore	28.2	AM	Intolerant
1U6	*Platanus occidentalis*	American Sycamore	51.4	AM	Intolerant
1U6	*Platanus occidentalis*	American Sycamore	12.5	AM	Intolerant
1U7	*Acer rubrum*	Red Maple	44.9	AM	Intolerant
1U7	*Betula lenta*	Sweet Birch	26.5	ECM	Intolerant
1U7	*Carya tomentosa*	Mockernut Hickory	18.4	ECM	Tolerant
1U7	*Carya tomentosa*	Mockernut Hickory	21.9	ECM	Tolerant
1U7	*Carya tomentosa*	Mockernut Hickory	13.8	ECM	Tolerant
1U7	*Liriodendron tulipifera*	Yellow Poplar	35.6	AM	Intolerant
1U7	*Oxydendrum arboreum*	Sourwood	13.7	ERM	Tolerant
1U7	*Oxydendrum arboreum*	Sourwood	42.3	ERM	Tolerant
1U7	*Oxydendrum arboreum*	Sourwood	13.8	ERM	Tolerant

1U7	*Oxydendrum arboreum*	Sourwood	32.6	ERM	Tolerant
1U7	*Quercus alba*	White Oak	30.8	ECM	Tolerant
1U7	*Quercus coccinea*	Scarlet Oak	52.7	ECM	Tolerant
1U7	*Quercus coccinea*	Scarlet Oak	61.3	ECM	Tolerant
1U7	*Quercus montana*	Chestnut Oak	23.2	ECM	Tolerant
1U7	*Quercus montana*	Chestnut Oak	42.8	ECM	Tolerant
1U7	*Quercus montana*	Chestnut Oak	17.4	ECM	Tolerant
1U7	*Tsuga canadensis*	Eastern Hemlock	10.5	ECM	Intolerant
1U7	*Tsuga canadensis*	Eastern Hemlock	15.9	ECM	Intolerant
1U7	*Tsuga canadensis*	Eastern Hemlock	10.4	ECM	Intolerant
1U7	*Tsuga canadensis*	Eastern Hemlock	26.6	ECM	Intolerant
1U8	*Acer rubrum*	Red Maple	15.8	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	13.3	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	20.7	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	13.8	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	17.2	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	16.8	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	12.7	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	24.9	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	10.2	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	12.8	AM	Intolerant
1U8	*Acer rubrum*	Red Maple	11.3	AM	Intolerant

1U8	*Acer rubrum*	Red Maple	11	AM	Intolerant
1U8	*Carya tomentosa*	Mockernut Hickory	14.5	ECM	Tolerant
1U8	*Carya tomentosa*	Mockernut Hickory	14.3	ECM	Tolerant
1U8	*Cornus florida*	Flowering Dogwood	10.2	AM	Intolerant
1U8	*Kalmia latifolia*	Mountain Laurel	11.3	ERM	Tolerant
1U8	*Nyssa sylvatica*	Blackgum	11	AM	Intolerant
1U8	*Nyssa sylvatica*	Blackgum	12.1	AM	Intolerant
1U8	*Nyssa sylvatica*	Blackgum	21.3	AM	Intolerant
1U8	*Oxydendrum arboreum*	Sourwood	12.3	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	10.8	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	16.2	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	17.2	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	10.9	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	18.9	ERM	Tolerant
1U8	*Oxydendrum arboreum*	Sourwood	18.1	ERM	Tolerant
1U8	*Pinus strobus*	Eastern White Pine	10.8	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	31.4	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	42.2	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	21.3	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	32.1	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	22.7	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	38.7	ECM	Tolerant

1U8	*Quercus coccinea*	Scarlet Oak	12.5	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	16.3	ECM	Tolerant
1U8	*Quercus coccinea*	Scarlet Oak	31.5	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	12.4	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	25.2	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	23.5	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	30.4	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	45.6	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	14.7	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	14.9	ECM	Tolerant
1U8	*Quercus montana*	Chestnut Oak	22.2	ECM	Tolerant
1U8	*Quercus velutina*	Black Oak	21.2	ECM	Tolerant
2B1	*Acer rubrum*	Red Maple	32.7	AM	Intolerant
2B1	*Acer rubrum*	Red Maple	49.9	AM	Intolerant
2B1	*Acer rubrum*	Red Maple	20.7	AM	Intolerant
2B1	*Acer saccharum*	Sugar Maple	12.6	AM	Intolerant
2B1	*Carya ovalis*	Red Hickory	12.9	ECM	Tolerant
2B1	*Carya tomentosa*	Mockernut Hickory	22.2	ECM	Tolerant
2B1	*Carya tomentosa*	Mockernut Hickory	27.3	ECM	Tolerant
2B1	*Halesia carolina*	Carolina Silverbell	16.3	AM	Intolerant
2B1	*Liriodendron tulipifera*	Yellow Poplar	25.6	AM	Intolerant
2B1	*Liriodendron tulipifera*	Yellow Poplar	45	AM	Intolerant

2B1	*Liriodendron tulipifera*	Yellow Poplar	61.4	AM	Intolerant
2B2	*Acer rubrum*	Red Maple	24.3	AM	Intolerant
2B2	*Acer rubrum*	Red Maple	14	AM	Intolerant
2B2	*Acer rubrum*	Red Maple	41.2	AM	Intolerant
2B2	*Acer saccharum*	Sugar Maple	10.2	AM	Intolerant
2B2	*Acer saccharum*	Sugar Maple	25.9	AM	Intolerant
2B2	*Acer saccharum*	Sugar Maple	17.2	AM	Intolerant
2B2	*Betula lenta*	Sweet Birch	28.9	ECM	Intolerant
2B2	*Betula lenta*	Sweet Birch	43.5	ECM	Intolerant
2B2	*Betula lenta*	Sweet Birch	11.6	ECM	Intolerant
2B2	*Betula lenta*	Sweet Birch	23.5	ECM	Intolerant
2B2	*Betula lenta*	Sweet Birch	19.5	ECM	Intolerant
2B2	*Carya tomentosa*	Mockernut Hickory	16.9	ECM	Tolerant
2B2	*Carya tomentosa*	Mockernut Hickory	17.1	ECM	Tolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	40.6	AM	Intolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	20.8	AM	Intolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	54.5	AM	Intolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	51.1	AM	Intolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	47.4	AM	Intolerant
2B2	*Liriodendron tulipifera*	Yellow Poplar	51.8	AM	Intolerant
2B2	*Quercus alba*	White Oak	70.2	ECM	Tolerant

	Rhododendron	Rosebay			
2B2	*maximum*	Rhododendron	11.1	ERM	Tolerant
2B2	*Tilia americana*	American Basswood	28.5	AM	Intolerant
2B2	*Tilia americana*	American Basswood	19.4	AM	Intolerant
2B2	*Tilia americana*	American Basswood	25	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	13.4	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	10	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	10.7	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	22.6	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	12.1	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	17.1	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	22.1	AM	Intolerant
2B3	*Acer rubrum*	Red Maple	12.4	AM	Intolerant
2B3	*Magnolia fraseri*	Frasier Magnolia	18.9	AM	Intolerant
2B3	*Magnolia fraseri*	Frasier Magnolia	17.1	AM	Intolerant
2B3	*Oxydendrum arboreum*	Sourwood	16.5	ERM	Tolerant
2B3	*Oxydendrum arboreum*	Sourwood	22.9	ERM	Tolerant
2B3	*Oxydendrum arboreum*	Sourwood	21.9	ERM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	22.5	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	24.1	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	31.6	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	46.1	ECM	Tolerant

2B3	*Quercus coccinea*	Scarlet Oak	33.4	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	38.2	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	36	ECM	Tolerant
2B3	*Quercus coccinea*	Scarlet Oak	32.7	ECM	Tolerant
2B3	*Quercus velutina*	Black Oak	29.7	ECM	Tolerant
2B3	*Robinia pseudoacacia*	Black Locust	48.8	AM	Intolerant
2B4	*Acer rubrum*	Red Maple	33.2	AM	Intolerant
2B4	*Acer rubrum*	Red Maple	30.5	AM	Intolerant
2B4	*Acer rubrum*	Red Maple	49.2	AM	Intolerant
2B4	*Acer rubrum*	Red Maple	26.9	AM	Intolerant
2B4	*Carya ovalis*	Red Hickory	22.4	ECM	Tolerant
2B4	*Carya tomentosa*	Mockernut Hickory	15.7	ECM	Tolerant
2B4	*Carya tomentosa*	Mockernut Hickory	14.7	ECM	Tolerant
2B4	*Carya tomentosa*	Mockernut Hickory	17.3	ECM	Tolerant
2B4	*Carya tomentosa*	Mockernut Hickory	19.3	ECM	Tolerant
2B4	*Halesia carolina*	Carolina Silverbell	19	AM	Intolerant
2B4	*Magnolia macrophylla*	Bigleaf Magnolia	12.7	AM	Intolerant
2B4	*Oxydendrum arboreum*	Sourwood	18.2	ERM	Tolerant
2B4	*Oxydendrum arboreum*	Sourwood	21.5	ERM	Tolerant
2B4	*Oxydendrum arboreum*	Sourwood	17.5	ERM	Tolerant
2B4	*Oxydendrum arboreum*	Sourwood	18.3	ECM	Tolerant
2B4	*Pinus rigida*	Pitch Pine	46.4	ECM	Tolerant

2B4	*Pinus strobus*	Eastern White Pine	36.5	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	15.3	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	22.5	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	14.8	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	10.8	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	21.4	ECM	Tolerant
2B4	*Pinus strobus*	Eastern White Pine	20.3	ECM	Tolerant
2B4	*Quercus coccinea*	Scarlet Oak	15	ECM	Tolerant
2B4	*Quercus coccinea*	Scarlet Oak	52.9	ECM	Tolerant
2B4	*Quercus coccinea*	Scarlet Oak	53.5	ECM	Tolerant
2B4	*Quercus montana*	Chestnut Oak	28.4	ECM	Tolerant
2B4	*Quercus montana*	Chestnut Oak	21.4	ECM	Tolerant
2B4	*Quercus montana*	Chestnut Oak	21.4	ECM	Tolerant
2B4	*Quercus montana*	Chestnut Oak	13.6	ECM	Tolerant
2B4	*Robinia pseudoacacia*	Black Locust	22.7	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	29.9	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	17.9	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	19.5	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	16.2	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	27.1	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	14	AM	Intolerant
2U5	*Acer rubrum*	Red Maple	16.3	AM	Intolerant

2U5	*Acer saccharum*	Sugar Maple	29	AM	Intolerant
2U5	*Carya tomentosa*	Mockernut Hickory	16.5	ECM	Tolerant
2U5	*Carya tomentosa*	Mockernut Hickory	15	ECM	Tolerant
2U5	*Carya tomentosa*	Mockernut Hickory	11.4	ECM	Tolerant
2U5	*Carya tomentosa*	Mockernut Hickory	12.2	ECM	Tolerant
2U5	*Cornus florida*	Flowering Dogwood	11.7	AM	Intolerant
2U5	*Liriodendron tulipifera*	Yellow Poplar	36	AM	Intolerant
2U5	*Nyssa sylvatica*	Blackgum	13.4	AM	Intolerant
2U5	*Pinus strobus*	Eastern White Pine	11.7	ECM	Tolerant
2U5	*Pinus strobus*	Eastern White Pine	13.9	ECM	Tolerant
2U5	*Pinus strobus*	Eastern White Pine	11.6	ECM	Tolerant
2U5	*Pinus strobus*	Eastern White Pine	20	ECM	Tolerant
2U5	*Quercus coccinea*	Scarlet Oak	27.5	ECM	Tolerant
2U5	*Quercus coccinea*	Scarlet Oak	29	ECM	Tolerant
2U5	*Quercus coccinea*	Scarlet Oak	23.9	ECM	Tolerant
2U5	*Quercus coccinea*	Scarlet Oak	15.3	ECM	Tolerant
2U5	*Quercus coccinea*	Scarlet Oak	33.5	ECM	Tolerant
2U6	*Acer rubrum*	Red Maple	20.8	AM	Intolerant
2U6	*Acer rubrum*	Red Maple	10.3	AM	Intolerant
2U6	*Acer rubrum*	Red Maple	11.9	AM	Intolerant
2U6	*Acer rubrum*	Red Maple	22.1	AM	Intolerant
2U6	*Carya tomentosa*	Mockernut Hickory	13	ECM	Tolerant

2U6	*Carya tomentosa*	Mockernut Hickory	21.5	ECM	Tolerant
2U6	*Carya tomentosa*	Mockernut Hickory	14.6	ECM	Tolerant
2U6	*Carya tomentosa*	Mockernut Hickory	10.1	ECM	Tolerant
2U6	*Cornus florida*	Flowering Dogwood	12.1	AM	Intolerant
2U6	*Cornus florida*	Flowering Dogwood	11.2	AM	Intolerant
2U6	*Liriodendron tulipifera*	Yellow Poplar	36.3	AM	Intolerant
2U6	*Liriodendron tulipifera*	Yellow Poplar	43.2	AM	Intolerant
2U6	*Magnolia fraseri*	Frasier Magnolia	15.9	AM	Intolerant
2U6	*Quercus alba*	White Oak	20.2	ECM	Tolerant
2U6	*Quercus alba*	White Oak	22	ECM	Tolerant
2U6	*Quercus alba*	White Oak	16.9	ECM	Tolerant
2U6	*Quercus alba*	White Oak	20	ECM	Tolerant
2U6	*Quercus alba*	White Oak	19.9	ECM	Tolerant
2U6	*Quercus coccinea*	Scarlet Oak	37.5	ECM	Tolerant
2U6	*Quercus coccinea*	Scarlet Oak	35.5	ECM	Tolerant
2U6	*Quercus velutina*	Black Oak	22.3	ECM	Tolerant
2U6	*Quercus velutina*	Black Oak	22.6	ECM	Tolerant
2U7	*Acer rubrum*	Red Maple	18.9	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	14.7	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	14.4	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	11	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	16.2	AM	Intolerant

2U7	*Acer rubrum*	Red Maple	21.6	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	33.9	AM	Intolerant
2U7	*Acer rubrum*	Red Maple	23.7	AM	Intolerant
2U7	*Acer saccharum*	Sugar Maple	24.2	AM	Intolerant
2U7	*Acer saccharum*	Sugar Maple	35.1	AM	Intolerant
2U7	*Kalmia latifolia*	Mountain Laurel	10.5	ERM	Tolerant
2U7	*Kalmia latifolia*	Mountain Laurel	11.3	ERM	Tolerant
2U7	*Kalmia latifolia*	Mountain Laurel	11.6	ERM	Tolerant
2U7	*Nyssa sylvatica*	Blackgum	15.9	AM	Intolerant
2U7	*Nyssa sylvatica*	Blackgum	17.2	AM	Intolerant
2U7	*Oxydendrum arboreum*	Sourwood	27.3	ERM	Tolerant
2U7	*Oxydendrum arboreum*	Sourwood	20.5	ERM	Tolerant
2U7	*Oxydendrum arboreum*	Sourwood	18.3	ERM	Tolerant
2U7	*Oxydendrum arboreum*	Sourwood	14.7	ERM	Tolerant
2U7	*Oxydendrum arboreum*	Sourwood	30.7	ERM	Tolerant
2U7	*Quercus coccinea*	Scarlet Oak	46.2	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	32.5	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	48	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	33.5	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	12.3	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	49.1	ECM	Tolerant
2U7	*Quercus montana*	Chestnut Oak	12.4	ECM	Tolerant

2U8	*Acer rubrum*	Red Maple	15.7	AM	Intolerant
2U8	*Acer rubrum*	Red Maple	21.3	AM	Intolerant
2U8	*Acer rubrum*	Red Maple	19.2	AM	Intolerant
2U8	*Acer rubrum*	Red Maple	12.7	AM	Intolerant
2U8	*Carya glabra*	Pignut Hickory	12.5	ECM	Tolerant
2U8	*Carya glabra*	Pignut Hickory	21.4	ECM	Tolerant
2U8	*Carya tomentosa*	Mockernut Hickory	11	ECM	Tolerant
2U8	*Carya tomentosa*	Mockernut Hickory	10.6	ECM	Tolerant
2U8	*Cornus florida*	Flowering Dogwood	18	AM	Intolerant
2U8	*Liriodendron tulipifera*	Yellow Poplar	12.5	AM	Intolerant
2U8	*Oxydendrum arboreum*	Sourwood	13.1	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	24.9	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	20.1	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	17.3	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	17.3	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	14.9	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	14.2	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	17.5	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	18.8	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	13.2	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	12.7	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	24.9	ERM	Tolerant

2U8	*Oxydendrum arboreum*	Sourwood	12.2	ERM	Tolerant
2U8	*Oxydendrum arboreum*	Sourwood	14.9	ERM	Tolerant
2U8	*Pinus rigida*	Pitch Pine	36.1	ECM	Tolerant
2U8	*Pinus rigida*	Pitch Pine	42.7	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	11.7	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	11.1	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	17.2	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	17.1	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	11.3	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	16	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	12.1	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	29.5	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	11.2	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	53.2	ECM	Tolerant
2U8	*Pinus strobus*	Eastern White Pine	12.3	ECM	Tolerant
2U8	*Quercus coccinea*	Scarlet Oak	31.4	ECM	Tolerant
2U8	*Quercus coccinea*	Scarlet Oak	68.8	ECM	Tolerant
2U8	*Quercus coccinea*	Scarlet Oak	39.9	ECM	Tolerant
2U8	*Quercus montana*	Chestnut Oak	14.6	ECM	Tolerant
3B1	*Acer rubrum*	Red Maple	37	AM	Intolerant
3B1	*Acer rubrum*	Red Maple	18.5	AM	Intolerant
3B1	*Acer rubrum*	Red Maple	26.5	AM	Intolerant

3B1	*Carya glabra*	Pignut Hickory	11.1	ECM	Tolerant
3B1	*Carya glabra*	Pignut Hickory	12.5	ECM	Tolerant
3B1	*Carya glabra*	Pignut Hickory	13.6	ECM	Tolerant
3B1	*Carya tomentosa*	Mockernut Hickory	10.3	ECM	Tolerant
3B1	*Carya tomentosa*	Mockernut Hickory	10	ECM	Tolerant
3B1	*Carya tomentosa*	Mockernut Hickory	10	ECM	Tolerant
3B1	*Carya tomentosa*	Mockernut Hickory	17.7	ECM	Tolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	44.2	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	30.7	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	42.9	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	35.7	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	27.7	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	42	AM	Intolerant
3B1	*Liriodendron tulipifera*	Yellow Poplar	36.9	AM	Intolerant
3B1	*Quercus rubra*	Northern Red Oak	55.3	ECM	Tolerant
3B1	*Quercus rubra*	Northern Red Oak	50.3	ECM	Tolerant
3B2	*Acer rubrum*	Red Maple	15.4	AM	Intolerant
3B2	*Acer rubrum*	Red Maple	25.6	AM	Intolerant
3B2	*Acer rubrum*	Red Maple	12.3	AM	Intolerant
3B2	*Acer saccharum*	Sugar Maple	12.6	AM	Intolerant
3B2	*Acer saccharum*	Sugar Maple	26.2	AM	Intolerant
3B2	*Betula lenta*	Sweet Birch	33.4	ECM	Intolerant

3B2	*Carya tomentosa*	Mockernut Hickory	19	ECM	Tolerant
3B2	*Liriodendron tulipifera*	Yellow Poplar	40.8	AM	Intolerant
3B2	*Liriodendron tulipifera*	Yellow Poplar	58.5	AM	Intolerant
3B2	*Liriodendron tulipifera*	Yellow Poplar	15.4	AM	Intolerant
3B2	*Liriodendron tulipifera*	Yellow Poplar	47.4	AM	Intolerant
3B2	*Liriodendron tulipifera*	Yellow Poplar	25.9	AM	Intolerant
3B2	*Quercus alba*	White Oak	50.6	ECM	Tolerant
3B2	*Quercus alba*	White Oak	44.5	ECM	Tolerant
3B2	*Quercus alba*	White Oak	53.9	ECM	Tolerant
3B2	*Quercus alba*	White Oak	34.5	ECM	Tolerant
3B3	*Acer rubrum*	Red Maple	14	AM	Intolerant
3B3	*Acer rubrum*	Red Maple	12.5	AM	Intolerant
3B3	*Acer saccharum*	Sugar Maple	53.2	AM	Intolerant
3B3	*Acer saccharum*	Sugar Maple	18.9	AM	Intolerant
3B3	*Carya glabra*	Pignut Hickory	44.7	ECM	Tolerant
3B3	*Carya glabra*	Pignut Hickory	50.5	ECM	Tolerant
3B3	*Carya tomentosa*	Mockernut Hickory	37.1	ECM	Tolerant
3B3	*Carya tomentosa*	Mockernut Hickory	18.6	ECM	Tolerant
3B3	*Carya tomentosa*	Mockernut Hickory	46.4	ECM	Tolerant
3B3	*Halesia carolina*	Carolina Silverbell	10.6	AM	Intolerant
3B3	*Nyssa sylvatica*	Blackgum	12.9	AM	Intolerant
3B3	*Nyssa sylvatica*	Blackgum	13.4	AM	Intolerant

3B3	*Nyssa sylvatica*	Blackgum	11.4	AM	Intolerant
3B3	*Quercus montana*	Chestnut Oak	44	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	58.6	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	33.5	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	29.8	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	16.5	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	24.5	ECM	Tolerant
3B3	*Quercus montana*	Chestnut Oak	31.4	ECM	Tolerant
3B4	*Acer rubrum*	Red Maple	14.5	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	12.4	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	13.3	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	16.6	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	30.1	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	13.2	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	12.1	AM	Intolerant
3B4	*Acer rubrum*	Red Maple	11.7	AM	Intolerant
3B4	*Betula lenta*	Sweet Birch	27.3	ECM	Intolerant
3B4	*Betula lenta*	Sweet Birch	32.8	ECM	Intolerant
3B4	*Carya glabra*	Pignut Hickory	13.2	ECM	Tolerant
3B4	*Carya glabra*	Pignut Hickory	20.8	ECM	Tolerant
3B4	*Carya glabra*	Pignut Hickory	24.2	ECM	Tolerant
3B4	*Kalmia latifolia*	Mountain Laurel	10.5	ERM	Tolerant

3B4	*Kalmia latifolia*	Mountain Laurel	10.2	ERM	Tolerant
3B4	*Ostraya virginiana*	Hophornbeam	24.7	ECM	Intolerant
3B4	*Oxydendrum arboreum*	Sourwood	10.1	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	18.2	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	12.2	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	17.1	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	13.9	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	12.1	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	23.2	ERM	Tolerant
3B4	*Oxydendrum arboreum*	Sourwood	17.5	ERM	Tolerant
3B4	*Quercus coccinea*	Scarlet Oak	32.9	ECM	Tolerant
3B4	*Quercus coccinea*	Scarlet Oak	21.1	ECM	Tolerant
3B4	*Quercus coccinea*	Scarlet Oak	43.6	ECM	Tolerant
3B4	*Quercus coccinea*	Scarlet Oak	34.9	ECM	Tolerant
3B4	*Quercus coccinea*	Scarlet Oak	46.8	ECM	Tolerant
3B4	*Quercus montana*	Chestnut Oak	15.7	ECM	Tolerant
3B4	*Quercus rubra*	Northern Red Oak	23.8	ECM	Tolerant
3B4	*Quercus rubra*	Northern Red Oak	54.9	ECM	Tolerant
3B4	*Quercus rubra*	Northern Red Oak	15.2	ECM	Tolerant
3U5	*Acer rubrum*	Red Maple	20.6	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	10	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	14.7	AM	Intolerant

3U5	*Acer rubrum*	Red Maple	19.2	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	17.4	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	12.6	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	19.8	AM	Intolerant
3U5	*Acer rubrum*	Red Maple	18.5	AM	Intolerant
3U5	*Carya glabra*	Pignut Hickory	19.3	ECM	Tolerant
3U5	*Carya tomentosa*	Mockernut Hickory	19.7	ECM	Tolerant
3U5	*Liriodendron tulipifera*	Yellow Poplar	12.1	AM	Intolerant
3U5	*Liriodendron tulipifera*	Yellow Poplar	27	AM	Intolerant
3U5	*Liriodendron tulipifera*	Yellow Poplar	23.8	AM	Intolerant
3U5	*Liriodendron tulipifera*	Yellow Poplar	38.9	AM	Intolerant
3U5	*Liriodendron tulipifera*	Yellow Poplar	15.9	AM	Intolerant
3U5	*Magnolia fraseri*	Frasier Magnolia	29.1	AM	Intolerant
3U5	*Magnolia fraseri*	Frasier Magnolia	11.2	AM	Intolerant
3U5	*Oxydendrum arboreum*	Sourwood	17.1	ERM	Tolerant
3U5	*Oxydendrum arboreum*	Sourwood	23.7	ERM	Tolerant
3U5	*Oxydendrum arboreum*	Sourwood	19.1	ERM	Tolerant
3U5	*Oxydendrum arboreum*	Sourwood	24.2	ERM	Tolerant
3U5	*Quercus alba*	White Oak	11.6	ECM	Tolerant
3U5	*Quercus alba*	White Oak	22.4	ECM	Tolerant
3U5	*Quercus alba*	White Oak	43.1	ECM	Tolerant
3U5	*Quercus coccinea*	Scarlet Oak	40.5	ECM	Tolerant

3U5	*Quercus coccinea*	Scarlet Oak	32.2	ECM	Tolerant
3U5	*Quercus coccinea*	Scarlet Oak	47	ECM	Tolerant
3U6	*Acer rubrum*	Red Maple	15.3	AM	Intolerant
3U6	*Acer rubrum*	Red Maple	24.2	AM	Intolerant
3U6	*Betula lenta*	Sweet Birch	14.5	ECM	Intolerant
3U6	*Betula lenta*	Sweet Birch	37.5	ECM	Intolerant
3U6	*Betula lenta*	Sweet Birch	12.4	ECM	Intolerant
3U6	*Carpinus caroliniana*	Hornbeam	10.7	ECM	Intolerant
3U6	*Carpinus caroliniana*	Hornbeam	15	ECM	Intolerant
3U6	*Carpinus caroliniana*	Hornbeam	15	ECM	Intolerant
3U6	*Carpinus caroliniana*	Hornbeam	10	ECM	Intolerant
3U6	*Carpinus caroliniana*	Hornbeam	12.1	ECM	Intolerant
3U6	*Carya tomentosa*	Mockernut Hickory	24.7	ECM	Tolerant
3U6	*Carya tomentosa*	Mockernut Hickory	12.7	ECM	Tolerant
3U6	*Cornus florida*	Flowering Dogwood	10.8	AM	Intolerant
3U6	*Fraxinus pennsylvanica*	Green Ash	10.6	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	10	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	20.6	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	22.1	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	21.5	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	13.1	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	10.5	AM	Intolerant

3U6	*Liriodendron tulipifera*	Yellow Poplar	21.9	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	13.4	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	25.5	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	21.3	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	28.2	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	24.9	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	18.2	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	11.1	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	23.1	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	31.4	AM	Intolerant
3U6	*Liriodendron tulipifera*	Yellow Poplar	18.5	AM	Intolerant
3U7	*Acer rubrum*	Red Maple	23.3	AM	Intolerant
3U7	*Acer rubrum*	Red Maple	18.9	AM	Intolerant
3U7	*Acer rubrum*	Red Maple	12.8	AM	Intolerant
3U7	*Acer rubrum*	Red Maple	15.3	AM	Intolerant
3U7	*Acer rubrum*	Red Maple	16.9	AM	Intolerant
3U7	*Betula lenta*	Sweet Birch	12.2	ECM	Intolerant
3U7	*Betula lenta*	Sweet Birch	24.4	ECM	Intolerant
3U7	*Betula lenta*	Sweet Birch	18.3	ECM	Intolerant
3U7	*Carya glabra*	Pignut Hickory	30.3	ECM	Tolerant
3U7	*Carya glabra*	Pignut Hickory	11.7	ECM	Tolerant
3U7	*Carya tomentosa*	Mockernut Hickory	19.4	ECM	Tolerant

3U7	*Carya tomentosa*	Mockernut Hickory	21.4	ECM	Tolerant
3U7	*Carya tomentosa*	Mockernut Hickory	33.6	ECM	Tolerant
3U7	*Carya tomentosa*	Mockernut Hickory	23.8	ECM	Tolerant
3U7	*Nyssa sylvatica*	Blackgum	32.7	AM	Intolerant
3U7	*Nyssa sylvatica*	Blackgum	31.5	AM	Intolerant
3U7	*Oxydendrum arboreum*	Sourwood	12.7	ERM	Tolerant
3U7	*Oxydendrum arboreum*	Sourwood	15.2	ERM	Tolerant
3U7	*Oxydendrum arboreum*	Sourwood	14.1	ERM	Tolerant
3U7	*Quercus montana*	Chestnut Oak	23	ECM	Tolerant
3U7	*Quercus montana*	Chestnut Oak	49.4	ECM	Tolerant
3U7	*Quercus montana*	Chestnut Oak	18.3	ECM	Tolerant
3U7	*Quercus velutina*	Black Oak	28.3	ECM	Tolerant
3U8	*Acer rubrum*	Red Maple	12.2	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	18.7	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	16	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	12.9	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	20.7	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	18.6	AM	Intolerant
3U8	*Acer rubrum*	Red Maple	14.5	AM	Intolerant
3U8	*Amelanchier arborea*	Downy Serviceberry	23.3	AM	Intolerant
3U8	*Amelanchier arborea*	Downy Serviceberry	13.6	AM	Intolerant
3U8	*Carya tomentosa*	Mockernut Hickory	12.4	ECM	Tolerant

3U8	*Carya tomentosa*	Mockernut Hickory	37.5	ECM	Tolerant
3U8	*Carya tomentosa*	Mockernut Hickory	25.6	ECM	Tolerant
3U8	*Liriodendron tulipifera*	Yellow Poplar	20.4	AM	Intolerant
3U8	*Liriodendron tulipifera*	Yellow Poplar	23.9	AM	Intolerant
3U8	*Oxydendrum arboreum*	Sourwood	26.5	ERM	Tolerant
3U8	*Oxydendrum arboreum*	Sourwood	14.8	ERM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	15.3	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	19.7	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	17.7	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	27.6	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	18.3	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	27.1	ECM	Tolerant
3U8	*Quercus coccinea*	Scarlet Oak	34.1	ECM	Tolerant
3U8	*Quercus montana*	Chestnut Oak	32.6	ECM	Tolerant
3U8	*Quercus montana*	Chestnut Oak	25.6	ECM	Tolerant
3U8	*Quercus rubra*	Northern Red Oak	23.1	ECM	Tolerant
3U8	*Quercus rubra*	Northern Red Oak	20	ECM	Tolerant
4B1	*Acer rubrum*	Red Maple	10.6	AM	Intolerant
4B1	*Acer rubrum*	Red Maple	12.8	AM	Intolerant
4B1	*Acer rubrum*	Red Maple	27.3	AM	Intolerant
4B1	*Acer saccharum*	Sugar Maple	14.6	AM	Intolerant
4B1	*Acer saccharum*	Sugar Maple	12.6	AM	Intolerant

4B1	*Acer saccharum*	Sugar Maple	30.6	AM	Intolerant
4B1	*Carya tomentosa*	Mockernut Hickory	27.8	ECM	Tolerant
4B1	*Fagus grandifolia*	American Beech	14.9	ECM	Intolerant
4B1	*Fagus grandifolia*	American Beech	12.5	ECM	Intolerant
4B1	*Halesia carolina*	Carolina Silverbell	18	AM	Intolerant
4B1	*Halesia carolina*	Carolina Silverbell	10.6	AM	Intolerant
4B1	*Nyssa sylvatica*	Blackgum	24.3	AM	Intolerant
4B1	*Nyssa sylvatica*	Blackgum	13.1	AM	Intolerant
4B1	*Oxydendrum arboreum*	Sourwood	26.1	ERM	Tolerant
4B1	*Oxydendrum arboreum*	Sourwood	23.9	ERM	Tolerant
4B1	*Oxydendrum arboreum*	Sourwood	18.5	ERM	Tolerant
4B1	*Quercus coccinea*	Scarlet Oak	30.5	ECM	Tolerant
4B1	*Quercus coccinea*	Scarlet Oak	45.6	ECM	Tolerant
4B1	*Quercus montana*	Chestnut Oak	51.9	ECM	Tolerant
4B1	*Quercus rubra*	Northern Red Oak	49.9	ECM	Tolerant
4B2	*Acer rubrum*	Red Maple	22.4	AM	Intolerant
4B2	*Carya tomentosa*	Mockernut Hickory	20.3	ECM	Tolerant
4B2	*Carya tomentosa*	Mockernut Hickory	37.8	ECM	Tolerant
4B2	*Carya tomentosa*	Mockernut Hickory	13.5	ECM	Tolerant
4B2	*Carya tomentosa*	Mockernut Hickory	44	ECM	Tolerant
4B2	*Carya tomentosa*	Mockernut Hickory	0.3	ECM	Tolerant
4B2	*Liriodendron tulipifera*	Yellow Poplar	37.2	AM	Intolerant

4B2	*Liriodendron tulipifera*	Yellow Poplar	64.4	AM	Intolerant
4B2	*Liriodendron tulipifera*	Yellow Poplar	47.2	AM	Intolerant
4B2	*Nyssa sylvatica*	Blackgum	25.5	AM	Intolerant
4B2	*Tilia americana*	American Basswood	66.3	ECM	Intolerant
4B3	*Betula lenta*	Sweet Birch	30.2	ECM	Intolerant
4B3	*Betula lenta*	Sweet Birch	13.1	ECM	Intolerant
4B3	*Carya tomentosa*	Mockernut Hickory	19.4	ECM	Tolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	19.9	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	37.4	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	36	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	64.8	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	57.4	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	53.5	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	62.4	AM	Intolerant
4B3	*Liriodendron tulipifera*	Yellow Poplar	50.1	AM	Intolerant
4B3	*Oxydendrum arboreum*	Sourwood	14	ERM	Tolerant
4B3	*Quercus montana*	Chestnut Oak	30.3	ECM	Tolerant
4B3	*Quercus montana*	Chestnut Oak	27.6	ECM	Tolerant
4B3	*Quercus rubra*	Northern Red Oak	39.9	ECM	Tolerant
4B3	*Quercus velutina*	Black Oak	76	ECM	Tolerant
4B4	*Acer rubrum*	Red Maple	14.8	AM	Intolerant
4B4	*Acer rubrum*	Red Maple	26.1	AM	Intolerant

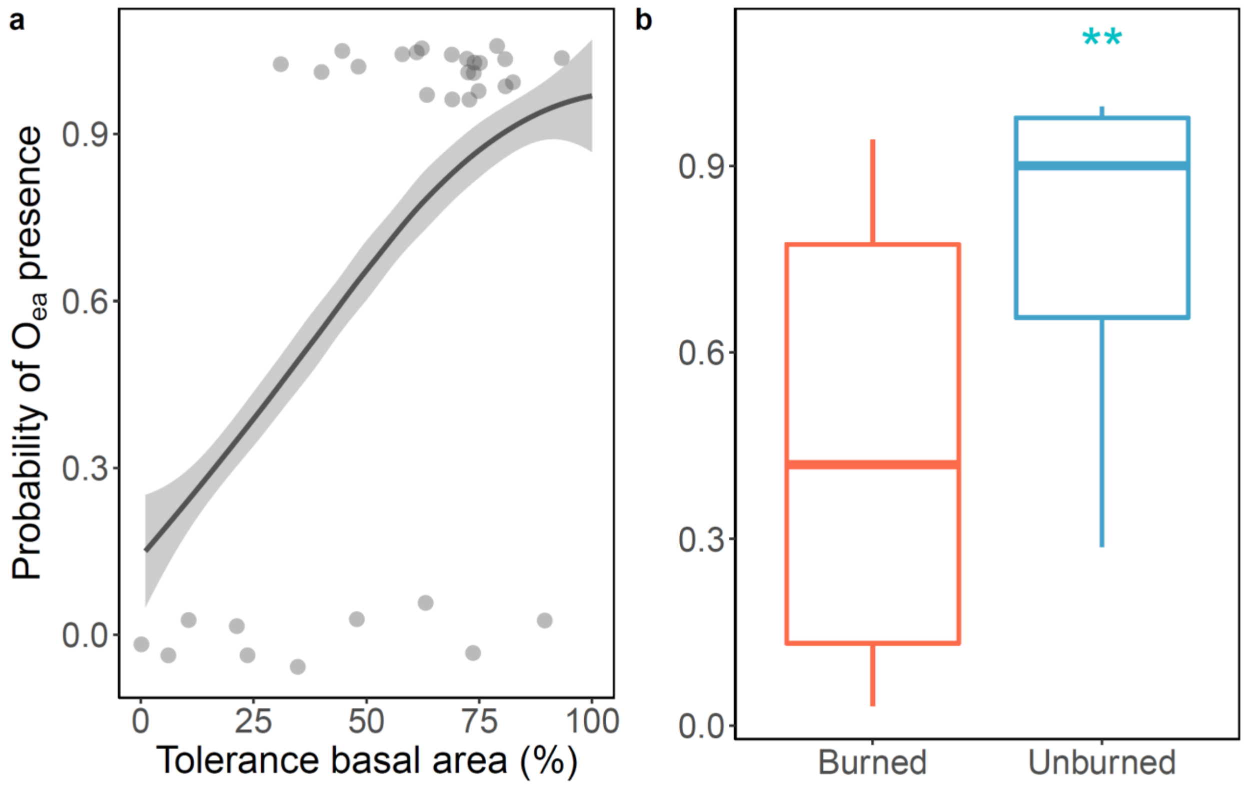
4B4	*Acer rubrum*	Red Maple	18.5	AM	Intolerant
4B4	*Acer saccharum*	Sugar Maple	12.3	AM	Intolerant
4B4	*Carya glabra*	Pignut Hickory	11.7	ECM	Tolerant
4B4	*Carya glabra*	Pignut Hickory	12.9	ECM	Tolerant
4B4	*Carya tomentosa*	Mockernut Hickory	14.3	ECM	Tolerant
4B4	*Carya tomentosa*	Mockernut Hickory	47.8	ECM	Tolerant
4B4	*Oxydendrum arboreum*	Sourwood	38.2	ERM	Tolerant
4B4	*Quercus coccinea*	Scarlet Oak	47.9	ECM	Tolerant
4B4	*Quercus coccinea*	Scarlet Oak	28.7	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	44.1	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	28.3	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	40.5	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	15.8	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	23.5	ECM	Tolerant
4B4	*Quercus montana*	Chestnut Oak	12.3	ECM	Tolerant
4B4	*Quercus velutina*	Black Oak	36.8	ECM	Tolerant
4B4	*Symplocos tinctoria*	Sweetleaf	10.9	AM	Intolerant
4U5	*Acer rubrum*	Red Maple	10	AM	Intolerant
4U5	*Acer rubrum*	Red Maple	12.8	AM	Intolerant
4U5	*Magnolia fraseri*	Frasier Magnolia	17.1	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	20.7	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	13.3	AM	Intolerant

4U5	*Nyssa sylvatica*	Blackgum	17.9	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	19.1	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	15.5	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	34.5	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	19.3	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	14	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	21.1	AM	Intolerant
4U5	*Nyssa sylvatica*	Blackgum	13.4	AM	Intolerant
4U5	*Oxydendrum arboreum*	Sourwood	18.6	ERM	Tolerant
4U5	*Oxydendrum arboreum*	Sourwood	12.3	ERM	Tolerant
4U5	*Oxydendrum arboreum*	Sourwood	13.7	ERM	Tolerant
4U5	*Oxydendrum arboreum*	Sourwood	14	ERM	Tolerant
4U5	*Oxydendrum arboreum*	Sourwood	21.1	ERM	Tolerant
4U5	*Pinus rigida*	Pitch Pine	35.3	ECM	Tolerant
4U5	*Pinus rigida*	Pitch Pine	33.7	ECM	Tolerant
4U5	*Pinus rigida*	Pitch Pine	46.5	ECM	Tolerant
4U5	*Pinus rigida*	Pitch Pine	35.4	ECM	Tolerant
4U5	*Quercus coccinea*	Scarlet Oak	55.6	ECM	Tolerant
4U5	*Quercus coccinea*	Scarlet Oak	47.7	ECM	Tolerant
4U5	*Quercus coccinea*	Scarlet Oak	46.2	ECM	Tolerant
4U5	*Quercus coccinea*	Scarlet Oak	27	ECM	Tolerant
4U5	*Quercus rubra*	Northern Red Oak	12.6	ECM	Tolerant

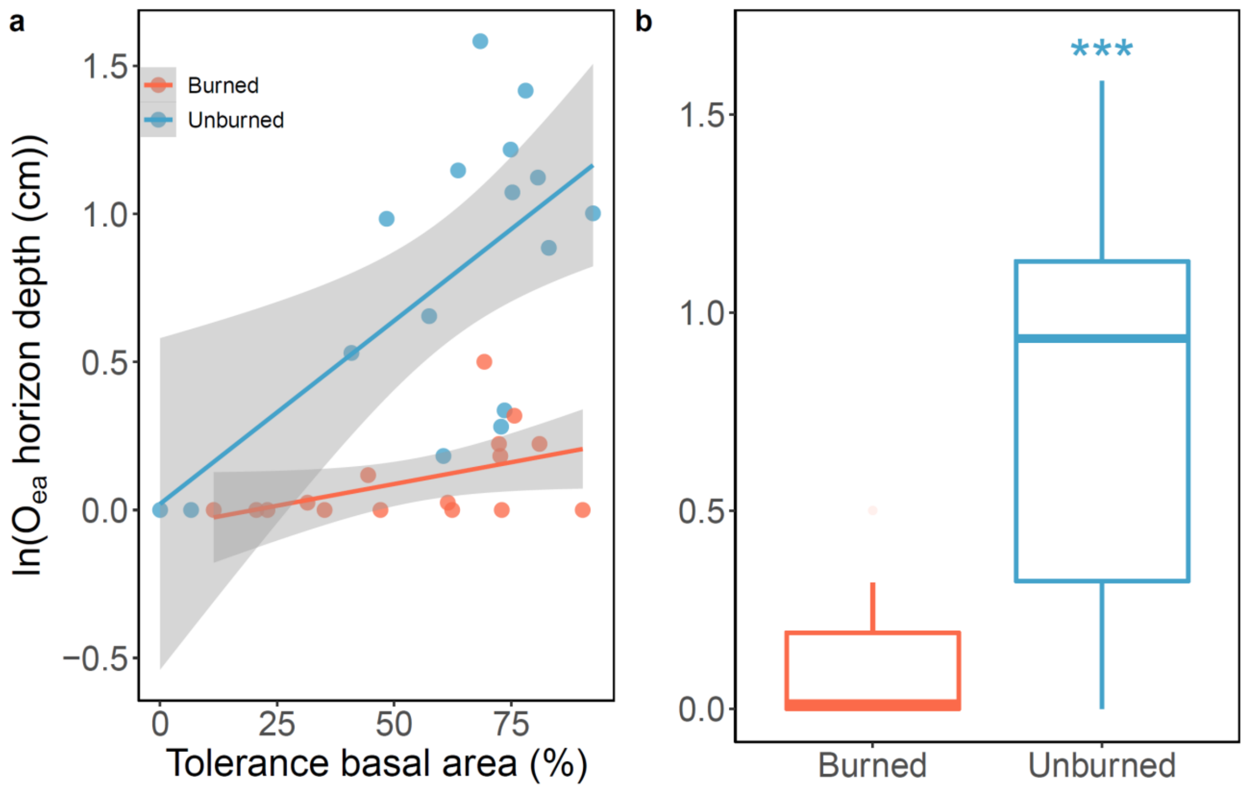
4U5	*Quercus velutina*	Black Oak	20.7	ECM	Tolerant
4U6	*Acer rubrum*	Red Maple	10.1	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	21.5	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	19.4	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	35.9	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	16.2	AM	Tolerant
4U6	*Acer rubrum*	Red Maple	14.8	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	27.9	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	15.9	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	10.4	AM	Intolerant
4U6	*Acer rubrum*	Red Maple	14.4	AM	Intolerant
4U6	*Betula lenta*	Sweet Birch	13.8	ECM	Intolerant
4U6	*Betula lenta*	Sweet Birch	18	ECM	Intolerant
4U6	*Betula lenta*	Sweet Birch	17	ECM	Intolerant
4U6	*Betula lenta*	Sweet Birch	15.2	ECM	Intolerant
4U6	*Ilex opaca*	American Holly	12.8	AM	Intolerant
4U6	*Nyssa sylvatica*	Blackgum	20.5	AM	Intolerant
4U6	*Oxydendrum arboreum*	Sourwood	30.3	ERM	Tolerant
4U6	*Oxydendrum arboreum*	Sourwood	11.5	ERM	Tolerant
4U6	*Oxydendrum arboreum*	Sourwood	29.5	ERM	Tolerant
4U6	*Pinus strobus*	Eastern White Pine	39.5	ECM	Tolerant
4U7	*Acer rubrum*	Red Maple	16.7	AM	Intolerant

4U7	*Acer rubrum*	Red Maple	31.7	AM	Intolerant
4U7	*Acer rubrum*	Red Maple	12.4	AM	Intolerant
4U7	*Acer rubrum*	Red Maple	19.5	AM	Intolerant
4U7	*Acer rubrum*	Red Maple	15.8	AM	Intolerant
4U7	*Acer saccharum*	Sugar Maple	45	AM	Intolerant
4U7	*Oxydendrum arboreum*	Sourwood	24.8	ERM	Tolerant
4U7	*Oxydendrum arboreum*	Sourwood	10.5	ERM	Tolerant
4U7	*Oxydendrum arboreum*	Sourwood	17.9	ERM	Tolerant
4U7	*Quercus montana*	Chestnut Oak	45	ECM	Tolerant
4U7	*Quercus montana*	Chestnut Oak	16	ECM	Tolerant
4U7	*Quercus montana*	Chestnut Oak	59.3	ECM	Tolerant
4U7	*Quercus rubra*	Northern Red Oak	33.1	ECM	Tolerant
4U7	*Quercus rubra*	Northern Red Oak	47.4	ECM	Tolerant
4U7	*Quercus rubra*	Northern Red Oak	25	ECM	Tolerant
4U7	*Quercus rubra*	Northern Red Oak	40.5	ECM	Tolerant
4U8	*Acer rubrum*	Red Maple	26.6	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	12.7	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	18.8	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	11.1	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	12.8	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	18.5	AM	Intolerant
4U8	*Acer rubrum*	Red Maple	15.6	AM	Intolerant

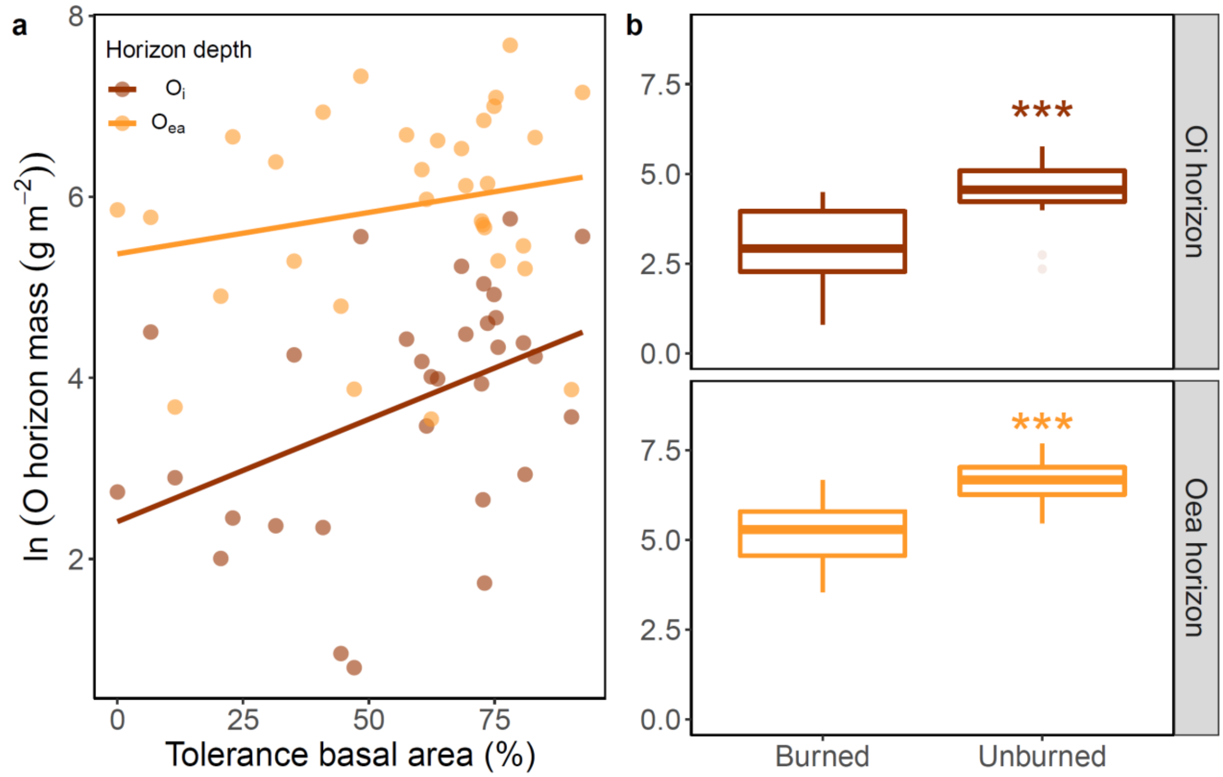
4U8	*Acer rubrum*	Red Maple	16.4	AM	Intolerant
4U8	*Carya tomentosa*	Mockernut Hickory	23	ECM	Tolerant
4U8	*Nyssa sylvatica*	Blackgum	10.8	AM	Intolerant
4U8	*Nyssa sylvatica*	Blackgum	15.1	AM	Intolerant
4U8	*Nyssa sylvatica*	Blackgum	22.7	AM	Intolerant
4U8	*Nyssa sylvatica*	Blackgum	14.9	AM	Intolerant
4U8	*Oxydendrum arboreum*	Sourwood	20.6	ERM	Tolerant
4U8	*Pinus rigida*	Pitch Pine	20	ECM	Tolerant
4U8	*Pinus rigida*	Pitch Pine	34.9	ECM	Tolerant
4U8	*Pinus strobus*	Eastern White Pine	13.4	ECM	Tolerant
4U8	*Pinus strobus*	Eastern White Pine	11.3	ECM	Tolerant
4U8	*Pinus strobus*	Eastern White Pine	13.6	ECM	Tolerant
4U8	*Pinus strobus*	Eastern White Pine	12.9	ECM	Tolerant
4U8	*Quercus coccinea*	Scarlet Oak	31.1	ECM	Tolerant
4U8	*Quercus coccinea*	Scarlet Oak	53.9	ECM	Tolerant
4U8	*Quercus coccinea*	Scarlet Oak	43.3	ECM	Tolerant
4U8	*Quercus montana*	Chestnut Oak	14.4	ECM	Tolerant
4U8	*Quercus montana*	Chestnut Oak	37.2	ECM	Tolerant
4U8	*Quercus montana*	Chestnut Oak	11.1	ECM	Tolerant
4U8	*Quercus rubra*	Northern Red Oak	49.1	ECM	Tolerant
4U8	*Quercus velutina*	Black Oak	21	ECM	Tolerant
4U8	*Robinia pseudoacacia*	Black Locust	33.1	AM	Intolerant



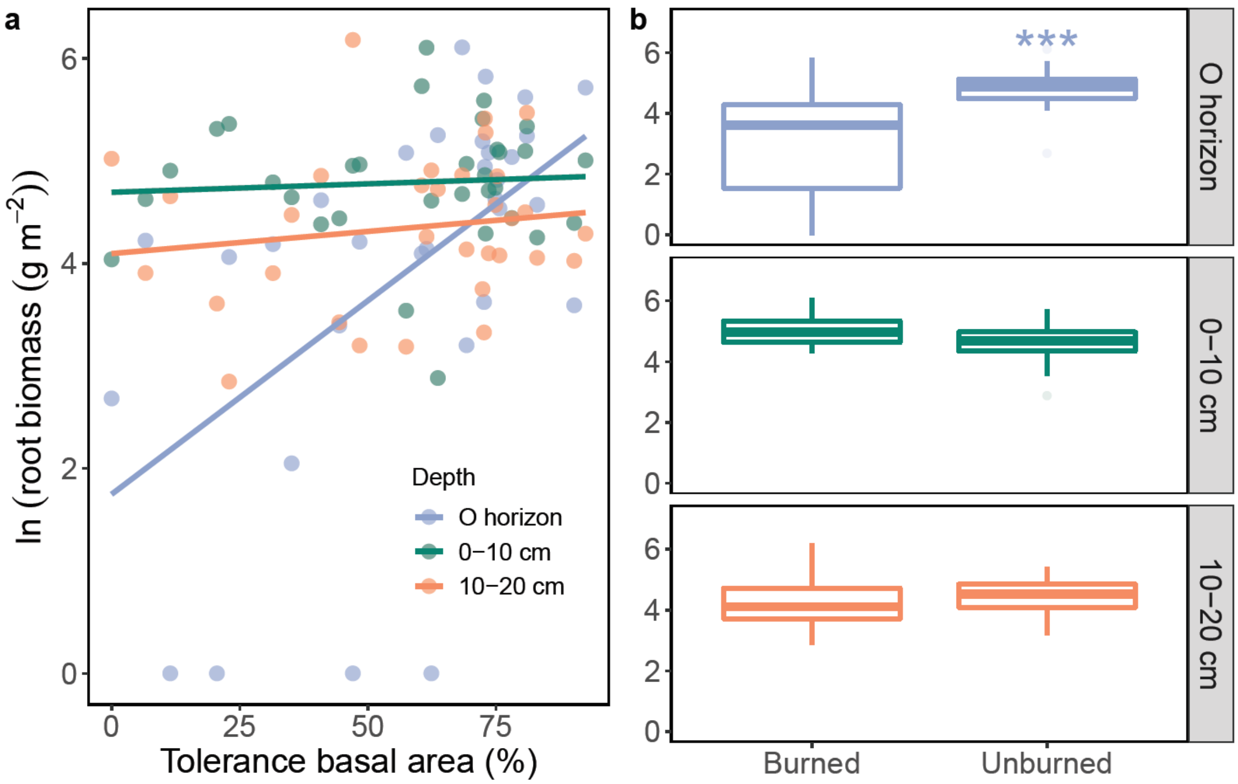
Appendix Figure 1. Probability of O_{ea} horizon presence (a) increases with increasing dominance of fire tolerant trees (*z*= 2.72, *p*=0.007) and (b) is lower in burned *versus* unburned plots (*z*=1.979, *p*=0.017). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p < 0.05 = **).



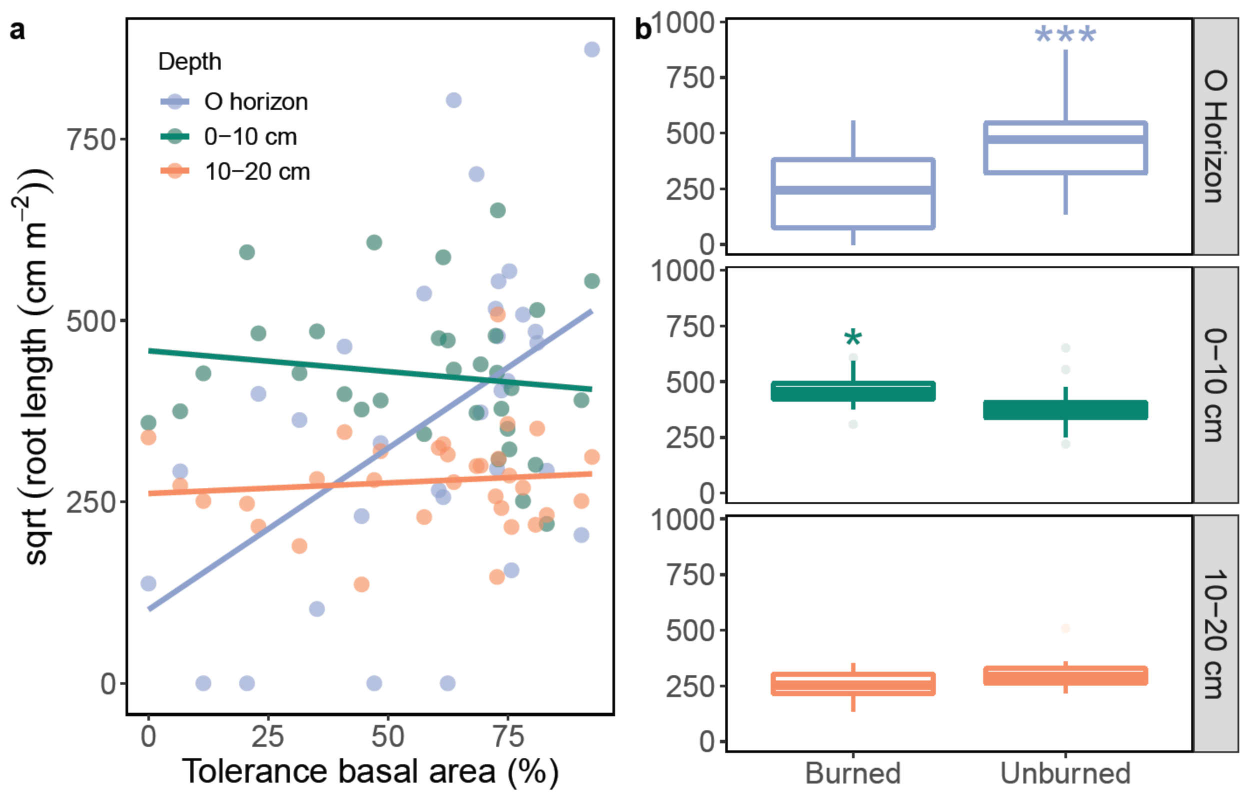
Appendix Figure 2 Depth of O_{ea} horizon (a) increases with increasing dominance of fire tolerant trees ($F_{1,\ 10.65}$=9.28, *p*=0.01) and (b) is lower in burned *versus* unburned plots (F=$_{1,\ 22.57}$=37.19, *p*<.0001). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p < 0.001 = ***).



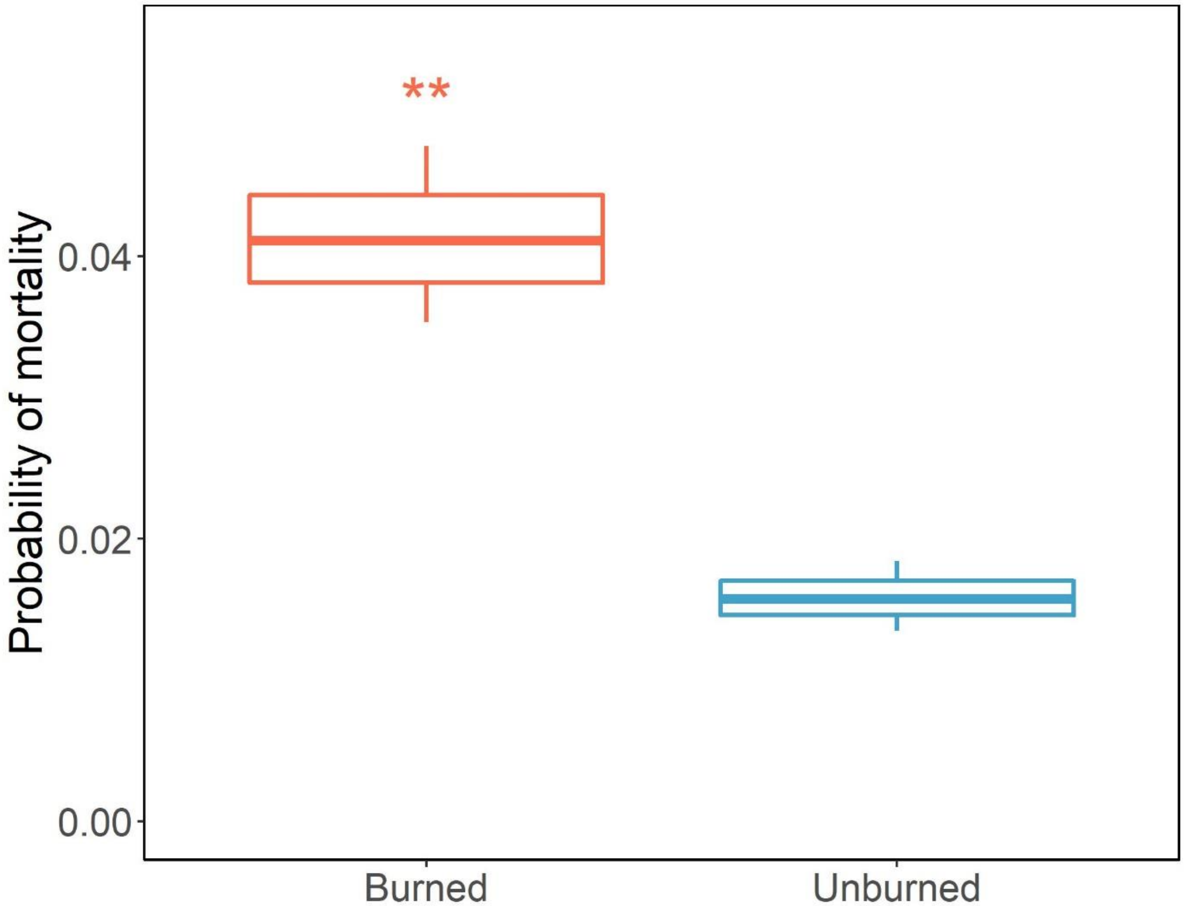
Appendix Figure 3. Organic matter stocks (a) increase with increasing fire tolerant basal area ($F=_{1,\ 11.36}=5.35$, $p=0.04$), and (b) are lower in burned plots *versus* unburned plots for both horizons ($F=_{1,\ 55.07}=43.37$, $p<0.0001$) (b). Brown represents the O_i horizon while orange represent the O_{ea} horizon in both panels. Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p < 0.001 = ***).



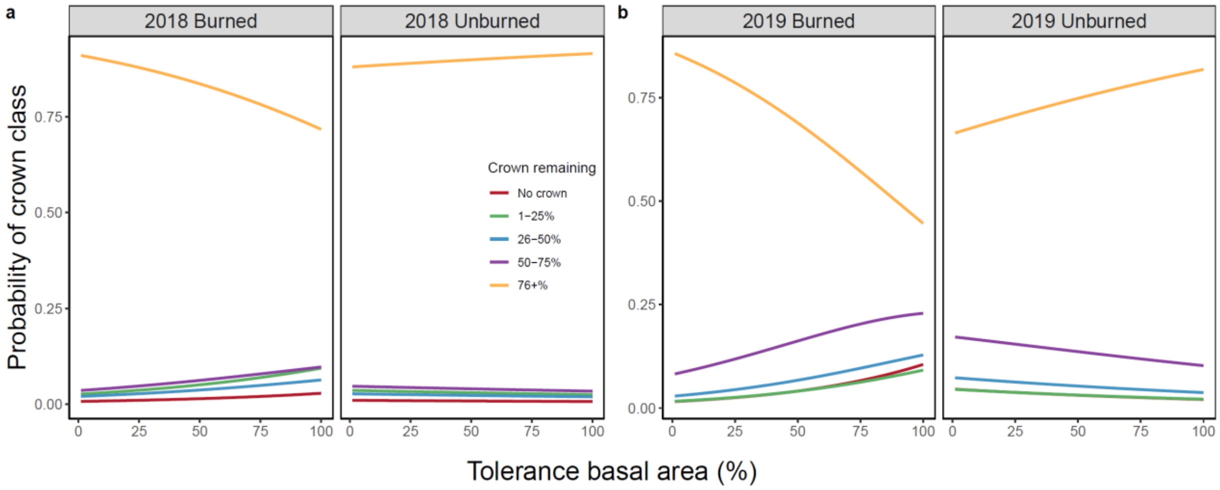
Appendix Figure 4. Fine root biomass depends on the interaction of fire tolerance basal area and depth, and fire and depth, but not an interaction between all three. (a) Biomass increases with tolerance basal area in the O_{ea} horizon, but not in the other soil depths ($F=_{2,81.18}=6.57$, $p=0.002$). (b) Root biomass in the O_{ea} horizon is lower in burned *versus* unburned plots, but in the 0-10 cm depth is higher in burned *versus* unburned plots ($F=_{2,81.18}=9.91$, $p=0.0003$). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p < 0.001 = ***; p < 0.05 = **).



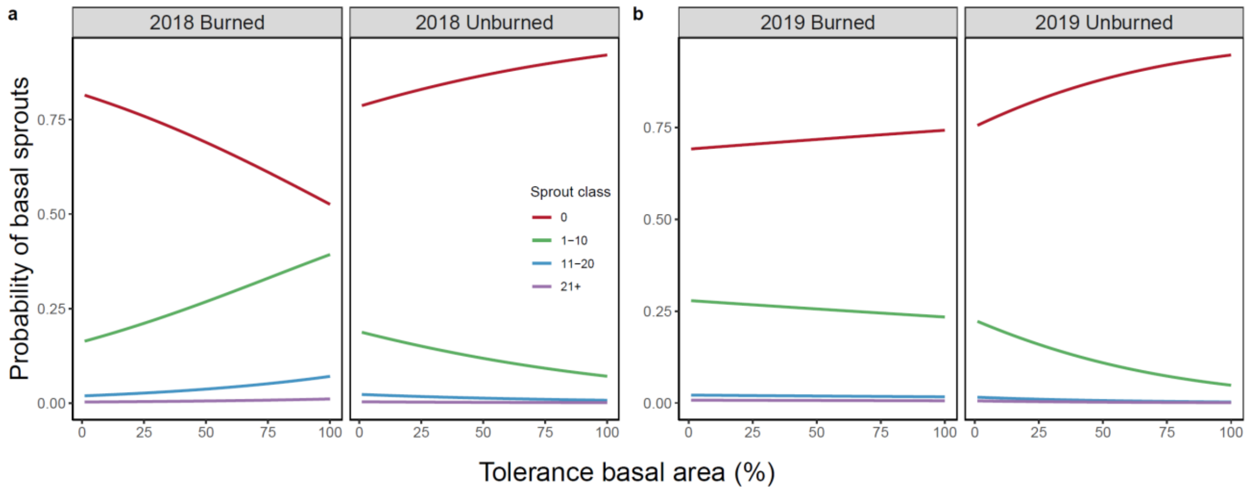
Appendix Figure 5. Fine root (< 1 mm) length depends on the interaction of fire tolerance basal area and depth, and fire and depth, but not an interaction between all three. (a) Length increases with increasing fire tolerance basal area in the O_{ea} horizon, but not in the other soil depths ($F=_{2,81.05}=7.85$, $p=0.0008$), (b) Root length in the O_{ea} horizon is lower in burned *versus* unburned plots, but in the 0-10 cm depth is higher in burned *versus* unburned plots ($F=_{2,81.05}=11.60$, $p<0.0001$). Values in panel b are presented as boxplots with the median value and upper and lower quartiles. Significant differences denoted by the following criteria: (p < 0.001 = ***; p < 0.05 = **).



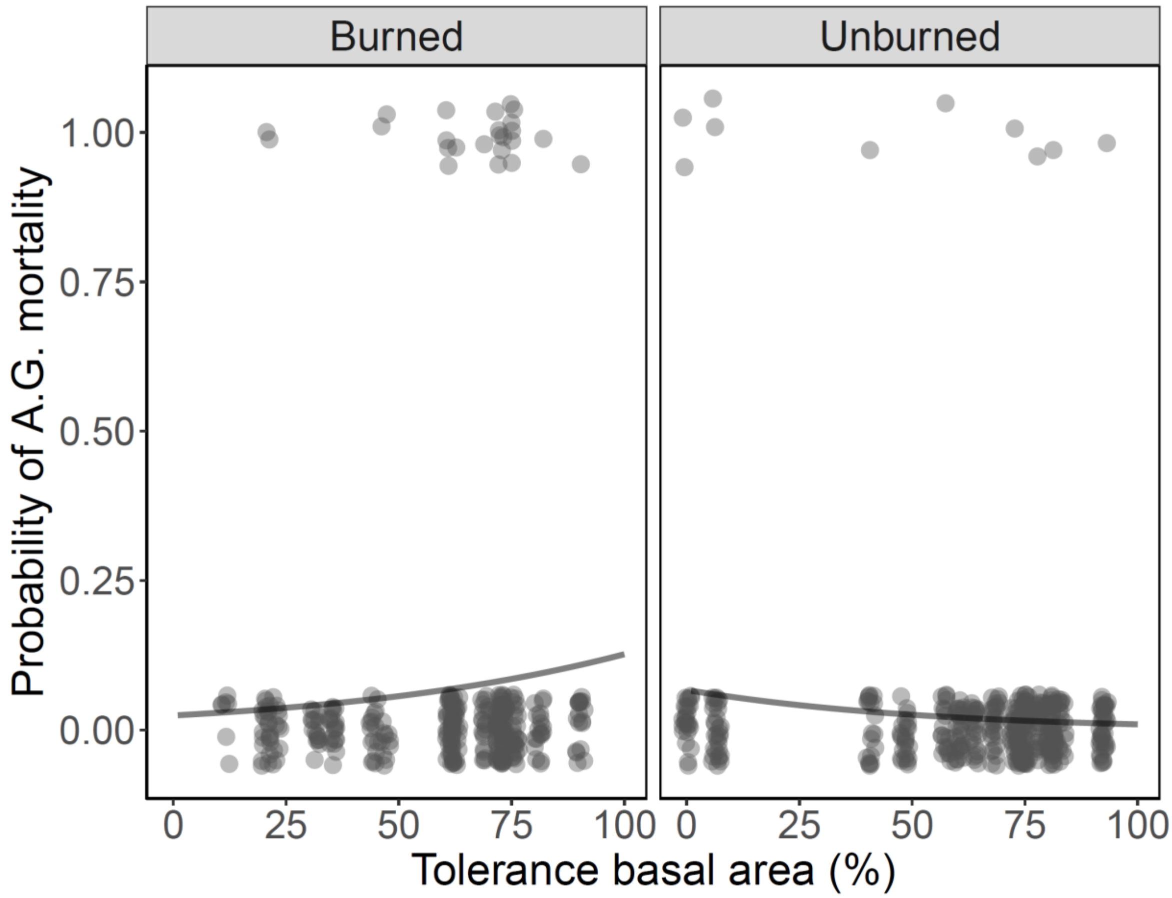
Appendix Figure 6. Tree mortality by the end of the study was higher in burned vs. unburned plots (z=-2.12, p=0.03).



Appendix Figure 7. The probability of crown decline depended on year of the study Where a) in 2018, probability of crown decline increased with increasing dominance of fire tolerant trees (z=-1.93, p=0.05); and b) in 2019, the probability of tree crown decline depended on the interaction of fire tolerance dominance and fire (z=3.53, p=0.0004), where the probability of a tree having a full crown declined with increasing dominance of fire tolerant trees in burned stands.



Appendix Figure 8. The probability of basal sprouts depended on the interaction of fire tolerance dominance and fire, where the probability of trees having basal sprouts increased with fire tolerance dominance in the burned plots, but this interaction weakened between a) year 1 and b) year 2 of the study (2018: z=-2.46, p=0.01; 2019: z=-2.02, p=0.04).



Appendix Figure 9. The mortality of the aboveground biomass by the end of the study increased with increasing ECM dominance in burned plots (z=-2.46, p= 0.01).