Effect of Prescribed Burning on Forest Tree Diversity and Species Composition of Understory Woody Regeneration.

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Abstract
Fire plays a key role in shaping the forests of the Southeastern United States. Humans have altered the prevalence of fire, thereby changing the composition of woody species in forested landscapes. Three forest management units under different prescribed burn regimes were sampled at the Oakland Road Hunting Area to determine the composition of woody species. Species diversity (Shannon diversity index) was estimated for both the overstory and understory for each management unit. Sorenson's similarity index was calculated to determine differences in composition of the overstory and understory species. Unit 3 had significantly lower Shannon diversity index values than either unit 1 or unit 2 for both understory and overstory species. There was no significant difference in Sorenson's similarity index values among the management units. Increased fire frequency found in unit 3 lowered the species diversity, favoring more fire tolerant species. The differences in prescribed burning regimes influenced species diversity but did not have a significant impact on the differences between community composition in the understory versus the overstory of the forests in this study.

Introduction
Fire has played a significant role in shaping the composition of Southeastern United States forests for thousands of years. The composition of these forest has been under continuous change since their establishment in the region after the end of last glacial period approximately 12,000 years ago (Engstrom et al., 2001). Pine *(Pinus)* and Oak (*Quercus)*-Hickory (*Carya)* forest have alternated dominance over the region throughout this time period as a result of change occurring in the fire regime ("NatureServe Explorer: An online encyclopedia of life", 2017). Fire intensity and frequency directly influence species diversity, composition, and the regeneration of woody understory species in Southeastern forests.

Dating back to the end of the last glacial maximum, deciduous oak–hickory hardwood forest established dominance over the southeast with their tall, fast growing broadleaf structure, which provided a sufficient means for establishing dominance in the canopy. Their dominance over the region was the result of a disturbance regime consisting of naturally occurring fires which were low-intermediate in frequency and intensity ("NatureServe Explorer: An online encyclopedia of life", 2017). This disturbance regime was highly beneficial to oak—hickory seedling regeneration as it inhibited the understory from becoming heavily occupied by an array of shade-tolerant tree species such as red maple (*Acer rubrum),* American beech (*Fagus grandfolia*), flowering dogwood *(Cornus florida),* and mountain laurel (*Kalmia latifolia).* These shade-tolerant species inhibit light penetration to the floor, where the shade-intolerant oak and pine saplings require sunlight to grow effectively (Keyser et al., 2017).

The dominance of the oak-hickory forest in the southeast began to decline around 8,000 years ago upon the establishment of the longleaf pine (*Pinus palustris*)-wiregrass ecosystems which originated in Mexico and spread across the coastal plain up into the piedmont. These ecosystems began to dominate the coastal plain from East Texas to North Carolina. (Engstrom et al., 2001).

The dominance of longleaf pine-wiregrass ecosystems was a result of frequent and intense fires created through the accumulation of its resinous needles on the forest floor. The frequency of fires within these ecosystems can be attributed to the occurrence of drought seasons with lightning storms which are moderately frequent in the southeast. The resin found within longleaf pine needles becomes very flammable during dry seasons. Occasionally, lightning strikes ignite this cocktail of volatile leaf-litter, causing intense fires to spread throughout the wiregrass, producing too great a disturbance for the survival of most other tree species native to the area (Rubertus et al., 1989).

This highly adapted species of pine then began to infiltrate the dense hardwood forest over the course of several thousand years. These dry seasons low in relative humidity easily produced reoccurring fires that stunted regeneration in the oak-Hickory forest. Left unable to compete with such disturbance, eventually their geographic range experienced a northward shift into the southern Appalachian Mountains where they retained their dominance high in canopy. Along the borders of the longleaf pine's fundamental niche in the mountainous region, a co-existing mixture of xeric pine/ hardwood forest became established (Elliot et al., 1999).

The natural occurrence of fire and its effect on ecosystem management became apparent to Southeastern Native Americans that called this region home before European settlement. The Native Americans were the first to artificially influence fire and its positive effect upon the southeast forest ecosystems. Their use of prescribed fire provided a benefit for humans and promoted the longleaf pine ecosystem. By burning the forest, Native Americans improved habitat of game species, promoted the regeneration and diversity of desired woody tree species, and controlled the abundance of insects and disease known to plague many trees in this area (Elliot et al., 2004).

Since the establishment of the Europeans in the 15th century, this mutualistic relationship quickly became exploitative as the pine forest became a target for deforestation. The tall, dense trunks of longleaf pine provided an excellent lumber source for a rapidly growing civilization. Deforestation of the longleaf pine provided a means for agriculture, construction, and land development. The geographic range of the longleaf has now been reduced to a remnant 3% of the original acreage (Engstrom et al., 2001).

Replanting of the faster growing loblolly pine (*Pinus taeda*), shortleaf pine (*Pinus echinata*), and slash pine (*Pinus elliottii*) in areas once used for agriculture has gradually shifted longleaf populations into that of a depressed state. These types of pines do not tolerate fire to any comparable measure with the longleaf, thus, with the decline of longleaf populations came suppression of fire within the region. During the early 1900s, an anti-wildfire movement also contributed to suppression of fire. The hardwood forest became able to regain much of their geographical range in response, resulting in mixed pine and hardwood forest that now extend down into the coastal plain region. Lack of fire regimes has since allowed for the understory to become heavily occupied by an array of shade-tolerant tree species, inhibiting light penetration to the floor, where the shade-intolerant oak and pine saplings require sunlight (Keyser et al., 2017).

Introduction of exotic invasive species like Chinese privet and kudzu into the area has also negatively affected species regeneration and diversity. These exotic species can become dominant in forests of the southeast, as they are able to thrive in the area with little competition from native species. This competitive exclusion is due to similarities in environmental conditions to that of their origin. Native species of the Southeast U.S. are not equipped with adequate adaptations for competition against these species. Without fire the presence of these highly competitive shade tolerant and exotic invasive species is likely to restructure the species composition of the southeastern forests the same way the longleaf pine did thousands of years ago. Often prescribed fire is used as a management tool to reduce exotic invasive plant species in the understory of forest ecosystems (Emery and Gross, 2005). Prescribed fire ecosystem management has been on the rise over recent decades in order to combat the spreading of these types of species and to restore diversity to forests within the region (Keyser et al., 2012, Keyser et al., 2017).

This study serves to investigate the role of fire in promoting species diversity, regeneration, and composition in pine-oak-hickory forests. Diversity of the understory and overstory species is compared between three separate units. Similarities in species composition between understory and overstory within each studied unit is also compared across the units. It was predicted differences in burn regimes will have an impact on the diversity of species and the composition of the woody understory species found in a forested area. These predictions were made based on nearly a 45-year history of management plants for Oakland Road Hunting Area, such as timber thinning, prescribed burning, and wildlife management which also contributes to a flourishing forest ecosystem. The null hypothesis is that there would be no significant difference observed in similarities between overstory and understory woody species composition between each unit.

Materials and Methods

Study Area:

The area under study was a U.S. Army Corps of Engineer's wildlife and timber management area known as Oakland Road Hunting Area located on West Point Lake in Chambers County, Alabama (Fig. 1). The area has been managed for approximately 45 years, though for this study, only the burn regimes and timber thinning for the last ten to fifteen years were considered (Table 1). Three separate burn units within Oakland Road Hunting Area were selected to represent forests under different burn regimes. Unit 1 is predominantly oak-hickory and is located on the south side of an old asphalt road. The burn regime for this unit is every 3 years and was last burned in 2015, though, at the time of data collection, it had not been burned in 2018. Unit 2 is predominantly xeric pine-oak-hickory and was located on the north side of the road. Unit 2 is also on a 3-year burn regime and was successfully burned in 2018. Unit 3 was a smaller area located near the center of unit 1 and has been a highly managed loblolly/shortleaf pine stand since being thinned in 2004. Unit 3 has also been undergoing longleaf pine restoration efforts since 2014. The burn regime of the unit has changed from every 3 years to that of a 1 to 2-year rotation, and was burned in 2014, 2015, and 2017.

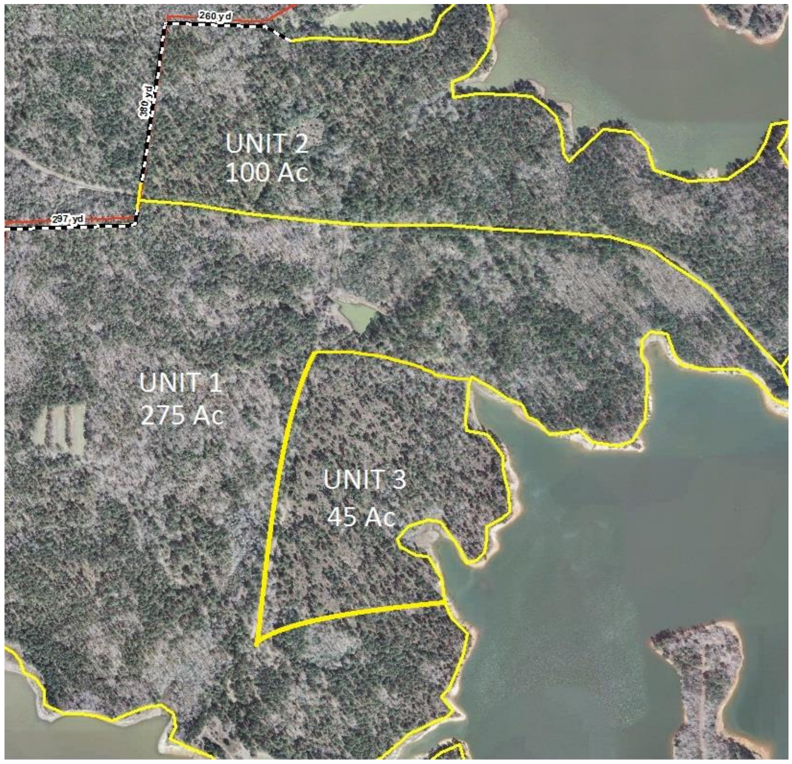

Figure 1. Location of forest management units at Oakland Road Hunting Area adjacent to West Point Lake in Chambers Co., Alabama.

			Year Burned													Year Thinned
AREA	UNIT	ACRES	18	17	16	15	14	13	12	11	10	9	8	7	6	
Oakland	1	275	X			X		X			X			X		2004
Oakland	2	100				X			X			X			X	2004
Oakland	3	45		X		X	X	X			X			X		2004

Table 1. Years during which prescribed fire was conducted in each forest management unit at Oakland Road Hunting Area adjacent to West Point Lake in Chambers Co., Alabama.

Data Collection:

Each management unit was sampled with 10 plots. Data was collected from a total of 30 fixed area circular plots, each with a radius of 10m. The initial sample point location in each unit was selected by generating a random distance (m) and azimuth from forest edge. The additional plots were placed

21m from previous sample point center in a random azimuth to ensure no overlap existed between plots within the forest management unit.

The diameter of all woody tree species greater than 2m in height within 10m radius plot were identified and DBH measured to characterize the forest overstory. Trees located along the edge of the plot were measured if over half the tree base was inside the diameter. Trees with over half of the base outside the plot edge were not measured and no data was collected. Dead trees were not measured. Trees were measured for diameter at breast height (DBH, 1.3m). Standard DBH practices were following during data collection. Four 2m radius subplots were established to sample understory species diversity and composition at each sample point. The subplots were established by measuring 5m out from the center point of the plot in each cardinal direction. At each subplot's center point, a 2m radius was measured and all tree saplings under 2m in height were identified to genus and counted.

Data analysis:

Species diversity of the understory and overstory for each unit was calculated using the Shannon diversity index (H'). The mean Shannon diversity index for both overstory and understory was calculated for each management unit. The overstory woody species diversity was compared among forest management units to determine if differences in overstory diversity existed. The understory woody species diversity was compared among forest management units to determine if differences in understory diversity existed. Similarities between woody species composition in the overstory and understory for each plot was calculated using a Sorenson's similarity index (S_s). The mean Sorenson's similarity index between overstory and understory composition for each management unit was calculated. The Sorenson's similarity index was compared among management units to determine if a significant difference existed. A one-way analysis of variance (ANOVA) (p=0.05) with a post-hoc Tukey's test (p=0.05) was used to determine any if significant effects from prescribed burning frequency was observed amongst comparisons.

Results

The mean Shannon diversity index for the overstory diversity for unit 1 was H'=1.118 (sd=0.5252). The mean Shannon diversity index for the overstory in unit 2 was H'=1.228 (sd=0.1384). For unit 3, the mean Shannon diversity index was H'=0.338 (sd=0.3647). The one-way ANOVA determined a significant difference between one or more treatment groups (p=0.00002). The Tukey's post-hoc test determined no significant difference between unit 1 and unit 2 (p>0.01), but there was a significant difference between unit 1 and unit 3 (p<0.01), as well as between unit 2 and unit 3 (p<0.01) (Fig. 2).

The mean Shannon diversity index for understory species in unit 1 was H'=1.389 (sd=0.2137). For unit 2 the understory diversity index was calculated to be H'=1.541 (sd=0.2764). The mean Shannon diversity index of Unit 3 understory diversity was H'=0.907 (sd=0.3604). The one-way ANOVA determined a significant difference between one or more treatment groups (p=0.0001). The Tukey's post-hoc test determined no significant difference between unit 1 and unit 2 (p>0.01), but there was a significant difference between unit 1 and unit 3 (p<0.01), as well as between unit 2 and unit 3 (p<0.01) (Fig. 3).

In comparing understory woody species to overstory woody species composition, the mean Sorenson's similarity index in unit 1 was S_s=0.522 (sd=0.1436). The mean Sorenson's similarity index in unit 2 was Ss=0.585 (sd=0.1833). In unit 3, the mean Sorenson's similarity index was S_s=0.623 (sd=0.2909). Differences of Sorenson's similarity in species composition in overstory and understory between treatment groups was not considered significant b the ANOVA (F=0.5640, p=0.5755). No Tukey's post-hoc analysis was performed. (Fig. 4)

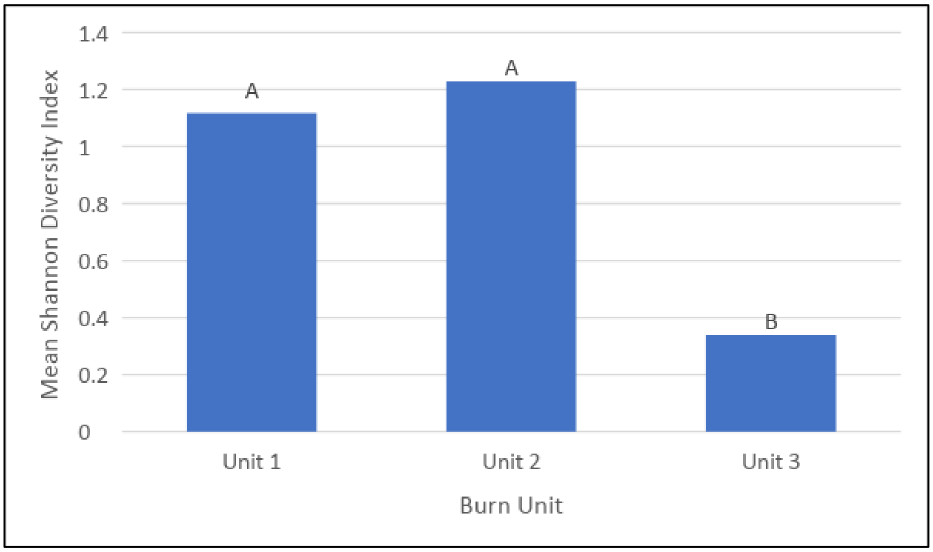

Figure 2. The average diversity index for woody tree species in the overstory of 3 separate burn units. Common letters above the columns indicate no significant difference in species diversity. Different letters indicate that a significant difference was observed between units.

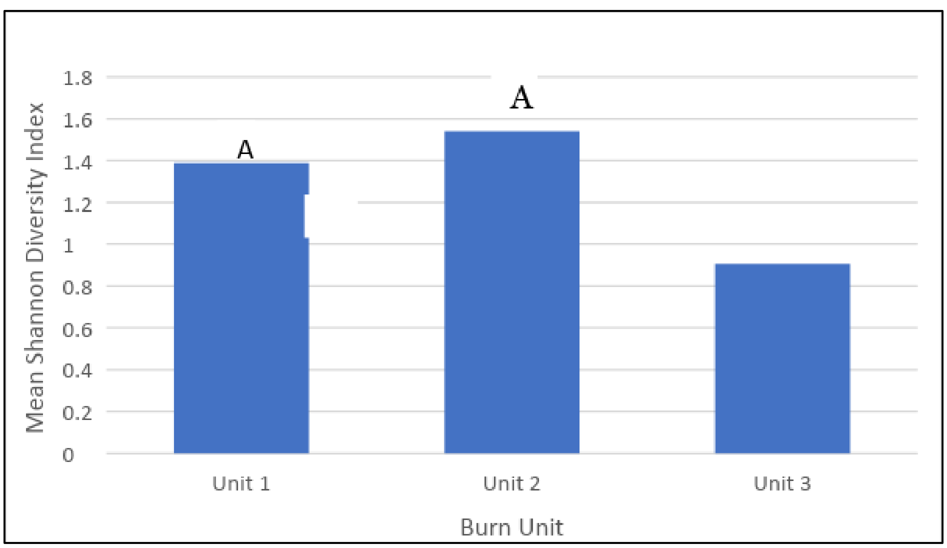

Figure 3. The mean Shannon diversity index for woody tree species in the understory of burn units. Greater values indicate higher levels of species diversity. Different letters indicate a significant difference while similar letters indicate no significant difference exists (Tukey's, p=0.05).

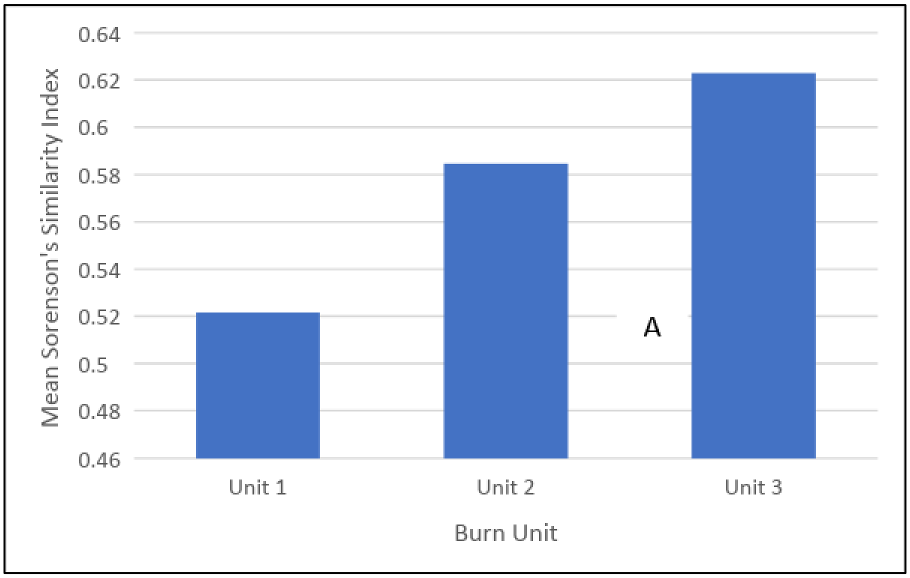

Figure 4. The mean Sorenson's similarity index between composition of overstory woody species and understory woody species within a burn unit. Index values range from 0-1, with higher values indicating greater similarity and lower values indicating fewer similarities in species composition. Common letters above the columns indicate that no significant difference was found (Tukey's p=0.05).

Discussion

The more frequent prescribed burning in unit 3 had a significant impact on the diversity of both the overstory trees and the woody understory stems. This increase in fire frequency decreased the reduced the number of species with low tolerance to fire. The reduced fire frequency in unit 1 and unit 2 allowed species not as highly adapted to fire to survive and reproduce in the understory. In addition, the reduced fire frequency in unit 1 and unit 2 allowed a wider variety of understory woody species to survive. While no significant difference in Sorenson's similarity index values was found, unit 1 showed the least similarity between understory species composition and overstory species composition.

The measures of species diversity and community similarity between understory and overstory may be due to the time of year sampling occurred. Trees and saplings were identified during the middle of winter, making the procedure extremely difficult due to lack of leaves on many of the woody species. The lack of leaves likely contributed to faults in the identification process, which may have lowered the diversity values recorded.

There was little presence of exotic invasive species within the study area, suggesting that the prescribed burns are making an impact on their suppression. The quantitative data regarding shade intolerant species was also low compared to that of the shade intolerant hardwoods and pines that dominate the canopy in the area, showing the effectiveness of the management practices being carried out upon the units under study. The predominate hardwoods observed during the study were oak-hickory, and sweet gum (*Liquidambar styraciflua*) which was expected, along with a mixture of loblolly and shortleaf pines.

During the collection of data in unit 3, many longleaf pine saplings planting during the 2014 restoration were observed outside of the sampled plots. Only 1 of these saplings was included in the raw data collected, however, the longleaf saplings have responded well to the increased frequency of prescribed burns. There were numerous oak, sweetgum, and hickory trees ranging from small saplings to trees that were up to 15cm in diameter killed entirely by the increased burn regime.

Many observations were made that suggest that the prescribed fire is managing the ecosystem as intended. Additional studies need to be conducted, preferably during the early to late spring when many of the woody species are in bloom.

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