THE EFFECTS OF OVERSTORY RETENTION ON SPECIES COMPOSITION AND HEIGHT GROWTH FOLLOWING CLEARCUT AND GROUP SELECTION REGENERATION HARVESTS IN THE MISSOURI OZARK HIGHLANDS

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

THE EFFECTS OF OVERSTORY RETENTION ON SPECIES COMPOSITION AND HEIGHT GROWTH FOLLOWING CLEARCUT AND GROUP SELECTION REGENERATION HARVESTS IN THE MISSOURI OZARK HIGHLANDS

presented by Guerric T. Good, a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

The objectives of this study focus on whether treatment and aspect significantly influence tree regeneration. This study utilizes data from 16-year-old clearcuts and group openings within the Missouri Ozarks to assess the height and quantity of regenerating tree species. Additionally, a qualitative review of the efficacy of height reference charts developed by Vickers et al. (2017) was completed.

Analysis of the sampled population revealed that trees had significantly greater mean heights within group openings compared to clearcuts, and the mean height of trees regenerating on protected slopes was significantly greater than trees on exposed slopes. The white oak group had significantly greater mean heights on protected slopes compared to exposed slopes and in group openings compared to clearcuts. Red and white oaks had significantly more individuals within clearcuts compared to group openings. When only trees within the tallest ten percent (90^{th} percentile of height) of all sampled individuals were analyzed, there were significant differences in mean height and trees per hectare for regenerating oaks between the two treatments and aspects. Specifically, there were significantly more oaks above the 90^{th} percentile within clearcuts, but oaks were significantly taller within group openings compared to clearcuts.

Review of the height reference charts developed by Vickers et al. (2017) show that the charts can be effectively used to assess the 90^{th} percentile of 16-year-old trees within clearcuts. Trees growing within group openings analyzed with the reference charts show that there were consistent differences from the data collected and the charts developed for clearcuts. For example, the red oak species group measured within group openings was consistently below the 90^{th} percentile threshold shown for clearcuts, and white oaks within group openings on exposed slopes were taller than the expected 90^{th} percentile line. Therefore, reference charts should be developed specifically for trees within group openings.

CHAPTER 1

INTRODUCTION

Many studies evaluate short-term forest dynamics after a regeneration treatment, but few studies quantify long-term outcomes of regeneration treatments to evaluate success. The Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term, landscape-scale project developed and managed by the Missouri Department of Conservation to assess effects of forest management practices on a wide array of ecosystem types and forest functions (Shifley & Brookshire, 2000). Three southeastern Missouri counties, Shannon, Carter, and Reynolds, host 1,133 hectares managed using even-aged management, 1,494 hectares of uneven-aged management, and 1,167 hectares of no active management (to serve as a study control).

MOFEP has been utilized to better understand forest stand dynamics of oaks and their competitors following disturbance or various types of forest management. The even-aged management used in MOFEP includes clearcuts for regeneration harvest, and the uneven-aged management follows the predominate use of single-tree selection interspersed with group selection. MOFEP provides the opportunity to analyze long-term effects of regeneration treatments on tree growth, stand composition, and regeneration success. Previous studies have improved the understanding of oak regeneration through sprouting (Dey & Jensen, 2002), evaluated regeneration success of different species following alternative silvicultural treatments (Kabrick et al., 2008), and developed reference charts for forest managers to assess the height of trees regenerating in clearcuts (Vickers et al., 2017). By developing a deeper understanding of stand dynamics under these management conditions, predictive models can guide management elsewhere in the Central Hardwoods and throughout the eastern US.

This study was developed to further investigate the effects of even-aged and uneven-aged forest management on regeneration outcomes at MOFEP. Specifically, this work compares the demographics of regeneration within clearcuts (an even-aged method) and group openings (an uneven-aged method) to assess if the size of the canopy opening effectively alters regeneration success for oak species. Although past studies suggest that oaks can regenerate with uneven-aged management in this region (Loewenstein, 1996), it is unclear if meaningful differences develop between clearcutting and group selection. Further, two aspect classes (exposed or protected) were included to determine interactions of silvicultural treatment and site. A greater understanding of regeneration patterns will provide forest managers with the knowledge to choose regeneration treatments that best suit their objectives.

OBJECTIVES

The overall objective of this study was to evaluate the effects of regeneration treatments (group harvests and clearcuts) and aspect (protected and exposed) on sapling density and species composition in the Missouri Ozarks. Specifically, effects of treatment and aspect will be determined for the entire regeneration cohort and by species group for 1) the number of saplings (trees per hectare) and 2) the height of the regenerating saplings. Because not all individuals in the regeneration cohort are expected to live through stem exclusion, the dominant population will be determined using height percentiles to focus on the trees most likely to recruit to the canopy. Finally, data for this study were applied to reference charts developed for the Missouri Ozarks in order to assess charts' effectiveness.

HYPOTHESES

This study tests the following hypotheses:

1. The retention of overstory surrounding a group opening will reduce the number of regenerating individuals for all species present compared to a clearcut.
2. Regenerating saplings in clearcuts will be taller at 16 years of growth than trees growing in a group opening with the surrounding overstory retained.
3. Regeneration harvest on exposed aspects will regenerate a greater amount of oak individuals than regeneration harvest on protected aspects.
4. Clearcuts result in a greater amount of trees per hectare than group openings when only the most competitive (top ten percent) of trees are considered.

CHAPTER 2

LITERATURE REVIEW

OAK PHYSIOLOGY AND REGENERATION CHARACTERISTICS

Quercus spp. are an important group of tree species within the United States (Hanberry & Nowacki, 2016) and around the world (Johnson, Shifley, & Rogers, 2009). Throughout history, oaks have been key in providing humans, wildlife, and the environment a variety of ecosystem services, such as wood material for fuel and timber and acorns for food supply (Johnson et al., 2009). Oaks have had strong impacts in a variety of habitats, especially within the Central Hardwood Region of the eastern half of the United States (Whitney, 1994). Native Americans influenced the regeneration of oak species through anthropogenic fires for thousands of years (Pyne, 1982; Whitney, 1994). It was the arrival of Europeans, however, that caused an even greater change to oak species composition and regeneration throughout the Central Hardwoods Region (Hicks, 1997; Pallardy, Nigh, & Garrett, 1998; Nowacki & Abrams, 2008). The prevalence of oaks was seen as a signal of potentially fertile agricultural land for newly arrived groups of people, which caused some oak populations to decrease as land was needed for agriculture (Johnson et al., 2009). However, settlement practices of open grazing and annual burning likely contributed to the dominance of oaks today despite also contributing to potential avenues for invasive and competitive species to colonize (Dey et al., 2018). The advent of industrialization escalated the negative effect on oak populations through logging practices (Johnson et al., 2009; Hicks, 1997).

Understanding the regeneration ecology of oaks is important for considering silvicultural approaches for successfully regenerating oak. Oaks are monoecious and therefore capable of producing seeds (acorns) with only a single parent tree (Johnson et al., 2009). Environmental factors have been found to play a role in acorn production (Sharp & Sprague, 1967; Sork & Bramble, 1993). For example, late frost events have been found to reduce acorn production (Cecich & Sullivan, 1999; Wolgast & Trout, 1979). Edaphic and topographic features, however, appear to have limited influence (Tryon and Carvell, 1962; Wolgast 1972).

Oaks are capable of regenerating vegetatively through seedling, stump, and stool sprouts (Burns & Honkala, 1990). These instances of sprouting are a function of dormant adventitious buds under the bark receiving a stimulus resulting from a disturbance (Kramer & Kozlowski, 1979). Such disturbances may include the tree being cut during a tending or harvest treatment or as recurring sprout-dieback cycles of seedlings and saplings in the understory. The quantity and quality of the sprouts resulting from a disturbed oak tree is influenced by both the diameter and age of the tree (Kharitonovich, 1937; Dey & Jensen, 2002). The probability of sprouting has been found to be inversely proportional to the diameter of the cut tree (Dey & Jensen, 2002).

Successful oak regeneration often relies upon existing and competitive oak regeneration prior to a regeneration treatment (Loftis, 2004). Advanced regeneration commonly develops if there is too little light for seedlings to sustain continued growth and recruit but enough light for the seedling to establish and persist (Larsen & Johnson, 1998). The seedling may experience a process of growth and dieback until a disturbance event allows enough light for recruitment. Thus, light availability is important for the development of oak advance regeneration and the recruitment of oak saplings. Oaks within the Missouri Ozarks are generally shade-intolerant, and previous research has recommended 33% sunlight for successful oak regeneration (Roach and Gingrich, 1968). With sufficient light levels, advance regeneration develop and persist for a long duration, and the existence or absence of advanced oak regeneration can help define what management practices will be needed to promote oaks (Larsen & Johnson, 1998).

For oak populations to sustainably regenerate there must disturbance events to create growing space. Within oak stands these events help stimulate the regeneration patterns of the trees present by supporting seed production and establishment (Vickers et. al., 2014). There are a variety of natural disturbances that can occur, such as extreme weather, insect migration, changes in the atmosphere, and fire (Smith et al., 1997). The disturbance events, as previously mentioned, have the potential to provide the cornerstone for tree regeneration by developing a better growing site through increased growing space, light, or nutrients.

SILVICULTURE FOR OAK REGENERATION

Silvicultural practices can be used to promote oak species within a target stand (Smith, 1986). While different techniques have been used historically by landowners and forest managers to support oak regeneration on small scales, the intentional management for oaks focused on the use of even-aged management (Roach & Gingrich, 1968). Even-aged management results in a stand of trees that is relatively close in age, generally no more than two decades apart (Smith, 1986). Clearcuts and shelterwoods are two common even-aged prescriptions for oak regeneration (Johnson et al., 2009). Clearcutting as a regeneration method where there is nearly the complete removal of all the existing overstory (Roach & Gingrich, 1968), and it has been shown to be effective at regenerating oaks in the Central Hardwoods if there is sufficient oak advanced reproduction present (Roach & Gingrich, 1968; Sander, 1977; Johnson, 1993). Clearcutting with reserves is a modified clearcut treatment that leaves a select few overstory trees scattered or clumped within the stand to increase aesthetic value (Helms, 1998). Shelterwoods are typically completed through a three-step process: preparatory cut for existing crown growth, establishment cut to promote seedlings, and a removal cut to help recruit regeneration (Johnson et al., 2009, Helms, 1998). However, Loftis (1990) indicates that the preparatory and establishment cuts are actually just removal cuts to provide success to existing advanced reproduction. In this method, midstory herbicide treatment is used to reduce basal area to encourage development of existing advance reproduction, followed by a removal cut to release the advance reproduction once competitive (Loftis 1990).

While it is clear oaks can be regenerated successfully through even-aged silvicultural systems, management objectives may make this type of management less desirable. Aesthetics, wildlife habitat, a focus on sustained harvesting, and a variety of other stakeholders' objectives can support the implementation of overstory retention methods (Guldin, 1996). The retention of canopy trees within a stand can support a wide array of wildlife needs as well as support human derived values (Mitchell & Beese, 2002). In cases throughout the eastern hardwoods, forest managers have pursued uneven-aged management for myriad needs, such as public desires and biodiversity (Larsen & Johnson, 1998; Leak & Filip, 1977; Weigel & Parker, 1997).

Uneven-aged management is defined by the presence of at least three distinct age cohorts growing within close proximity (Smith, 1986). The most extensive and least intensive regeneration treatment is single-tree selection. Aptly named, single-tree selection is used when the management objectives match that of single tree mortality in a stand. Uneven-aged management of oaks has been met with successes. Single-tree selection has lower utility on mesic sites (Schweitzer & Dey, 2011), but evidence from the Pioneer forest in southeastern Missouri has indicated this treatment's efficacy to regenerate oaks over long time periods (Loewenstein, 1996). Forest managers have found single-tree selection to be more effective on xeric sites compared to more mesic sites (Loewenstein, 1996).

Group selection is an uneven-aged treatment that removes all woody stems within a designated treatment area, but the scale of the disturbance caused by a group selection harvest is limited to the growing space of a few mature trees (one to two tree heights of the tallest trees around the regeneration area) (Law & Lorimer, 1989). Group selection provides more sunlight to the regeneration than single-tree selection, but the residual canopy surrounding the group opening reduces sunlight in the opening compared to fully exposed conditions of a clearcut. At the stand-level, group selection spreads out the affected area and results in a mosaic of regenerating tree cohorts, with small even-aged pockets that contribute to an uneven-aged structure at a broader scale. The group openings could provide more suitable growing conditions for less shade tolerant species than single-tree selection. Jenkins and Parker (1998) found that group openings out-performed single-tree selection in the regeneration of seedlings and subsequent recruitment for saplings of white oaks.

Modeling the dynamics of forests combines complex data resulting from the process of stand dynamics, the species present, and environmental and edaphic features. Two primary methods for measuring trees include an assessment of the diameter and height. Diameter at breast height (DBH) refers to the traditional diameter metric taken from a tree at 4.5 feet above ground. Diameter is an important descriptor of the influence of tree density on a particular species' growth (Oliver & Larson, 1990). Tree height is predominately density-independent, and the height of each tree is the expression of site-specific characteristics such as soil quality and light availability combined with species competitiveness (Oliver & Larson, 1990).

Effective models can be indispensable to forest managers in deciding how best to meet their objectives. Factors for individual species regeneration can be detailed through stocking charts that consider basal area, quadratic mean diameter, and trees per unit area (Roach & Gingrich, 1968). Determining the vigor and responsiveness of oak sprouting to a treatment can be better understood by a study completed through MOFEP by Dey and Jensen (2002). The evaluation of stump sprouting determined that as a given tree diameter increases, the quantity and vigor of the resulting sprouts decreases. These two studies provide tools to examine the existing tree cohort and inform what prescription to apply to a stand. The development of a model to assess regeneration post-treatment could determine how effective a treatment was without extending beyond a forest managers career and provide the details necessary for continued management in the landscape.

Modeling the growth pattern of regenerating tree species after a treatment is valuable in determining the success of the treatment as well as assessing the competitiveness of individual trees against the stand population. Vickers et al. (2017) utilized data from the long-term MOFEP study to develop reference charts to assess the height percentile of 8 species groups over 16 years. These reference charts were developed for clearcuts in the Missouri Ozarks, and it will be important to test these charts to determine their effectiveness at different sites.

CHAPTER 3

METHODS

STUDY SITE

The data utilized in this study were gathered from the Missouri Ozark Forest Ecosystem Project (MOFEP). Initiated in 1989, MOFEP provides opportunities to evaluate ecosystem characteristics as influenced by forest management (Shifley & Brookshire, 2000). MOFEP is a long-term, landscape-scale experiment comprised of greater than 3700 hectares in Carter, Reynolds, and Shannon counties of southeastern Missouri's Current River watershed (Brookshire & Dey 2000; Kabrick et al., 2000). Organized as a randomized complete block design, MOFEP is comprised of three blocks. Each block contains three sites, and each site was randomly assigned one management treatment including even-aged management, uneven-aged management, or control without management (Figure 1).

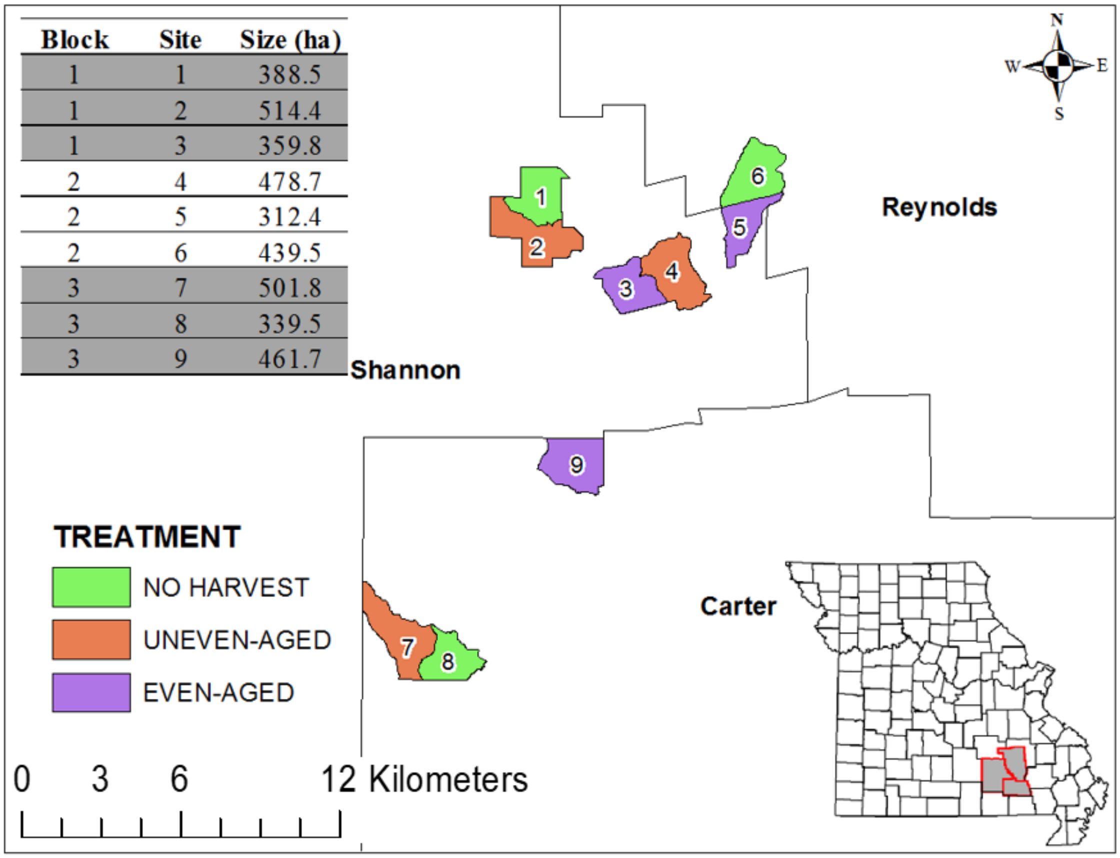

Figure 1. Missouri Ozark Forest Ecosystem Project location and site management classifications.

EXPERIMENTAL DESIGN OF MOFEP

This study explores data from both the even-aged management (EAM) and uneven-aged management (UAM) sites of MOFEP. The EAM implemented prior to this study took place in sites three, five, and nine, and UAM within MOFEP was expressed on the landscape as group selection within sites two, four, and seven, and single-tree selection was implemented in the forest matrix surrounding group openings (Figure 1). The sites defined as EAM followed the MDC Forest Land Management Guidelines (2013), which derive stand prescriptions from Roach and Gingrich (1968). Stand prescriptions identified by Roach and Gingrich (1968) focus on high quantity wood production through even-aged management that includes clearcutting and intermediate thinning.

UAM throughout MOFEP takes the form of single-tree selection and group selection, and the specific stand prescriptions follow the guidelines developed by Law and Lorimer (1989). Group openings designed as regeneration harvests for oak rely on existing oak advanced regeneration and the assurance of at least 33% sunlight for the regenerating oak cohort (Law & Lorimer, 1989). The stocking level of MOFEP sites was assessed by area managers with Gingrich stocking charts, and the residual basal area (RBA) of UAM sites was designed to provide optimal sunlight for oak regeneration (Roach & Gingrich, 1968). Regeneration treatments are scheduled to occur every 10 years and influence around 10 percent of the total site each entry (Brookshire & Dey, 2000).

The group openings were implemented in a circular shape with harvest diameters of one standard tree height (21.3 meters) on exposed aspects and two standard tree heights (42.6 meters) on protected aspects (Figure 2). The size of group openings reflects the optimal sunlight for oak regeneration at the center of the circular group openings (Roach & Gingrich, 1968). An additional harvest treatment in the form of single-tree selection was implemented in the forest matrix between the circular group openings (Brookshire & Dey, 2000).

Figure 2. Aerial photograph of group openings implemented in MOFEP study courtesy of Dr. John Kabrick

SAMPLING AND DATA COLLECTION FOR MOFEP

EAM and UAM sites were sampled after the regeneration harvests. Circular permanent plots were placed following a randomized stratification process throughout the sites to collect information about the regeneration following each treatment type (Shifley et al., 2000) (Figure 3). The propensity of the original randomized plots to directly sample the group openings was low; therefore, additional plots were supplemented in UAM sites to directly measure the group openings. In total, this study utilizes information gathered from 18 0.2 ha plots in EAM sites and 74 0.2 ha plots in UAM sites.

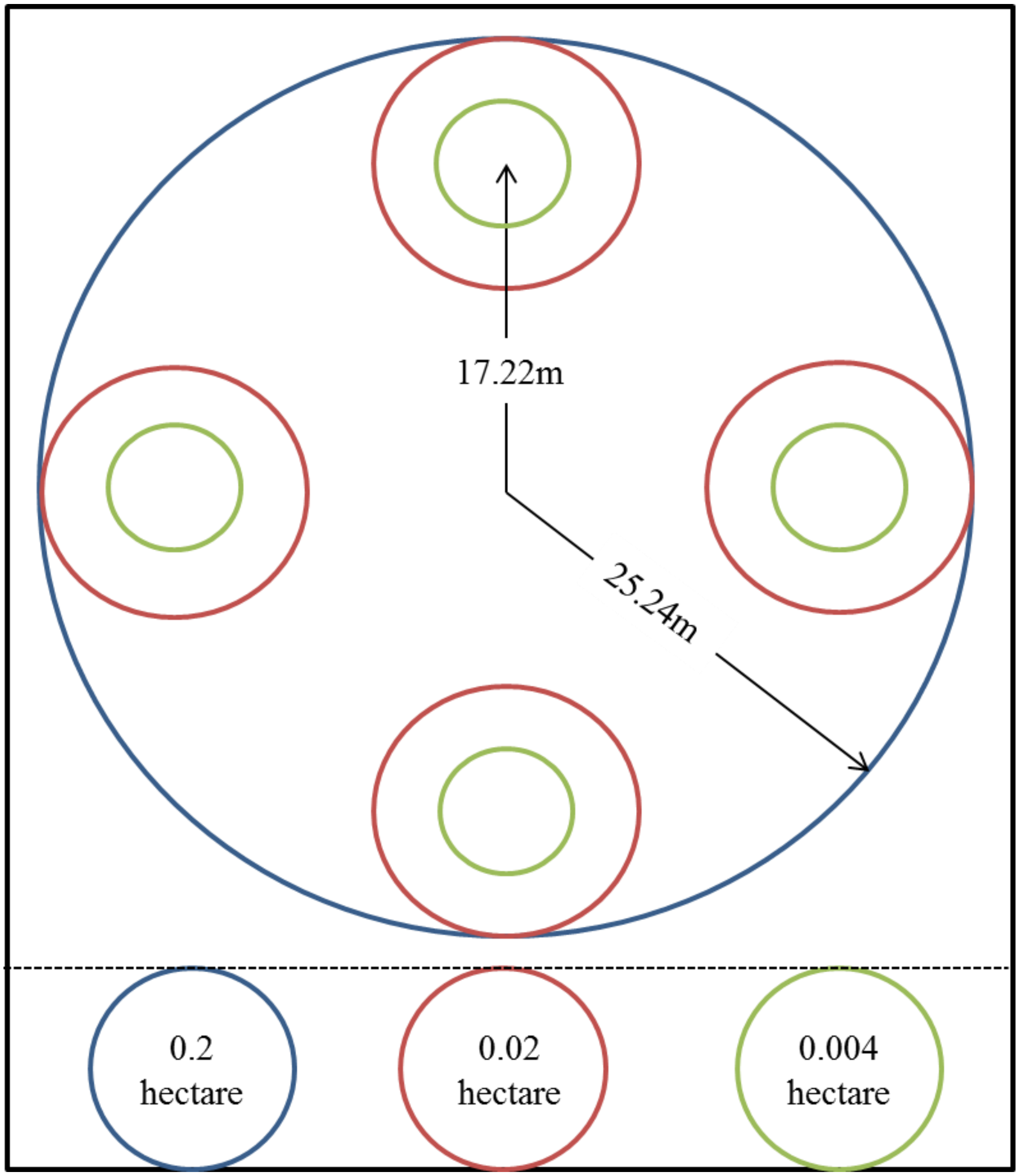

Figure 3. MOFEP plot design and spatial orientation.

The clearcuts were sampled in 1999, 2004, and 2012, and the group openings were sampled during the winter of 2012-2013. Only the data collected in 2012 from clearcuts were used in the direct comparison between the even-aged and uneven-aged management after 16 years of regeneration. The information gathered from these plots include: treatment, site, aspect, and plot identifier, as well as more detailed information such as the tree species, diameter at breast height (DBH), and overall height. In each 0.02

hectare plot live woody vegetation with a DBH between 3.81-11.43 centimeters were tagged and the DBH and height were recorded (Shifley & Brookshire, 2000).

DESIGN FOR RESEARCH AND DATA ANALYSIS

The experimental design of this study uses a factorial analysis with treatment (clearcut and group selection) and aspect (exposed and protected). Exposed aspects ranging from 135 degrees to 314 degrees and protected aspects ranging from 315 degrees to 134 degrees functions as a summary review of many factors including soil type, soil moisture, temperature, and sunlight (Kabrick et al., 2000). Individual tree data including species, height, and diameter were collected from the 0.02 hectare subplots 16 years after the regeneration treatments took place. These data classifications form the backbone for the subsequent analyses of height and diameter.

Species groupings in this analysis played a fundamental role in comparing the 47 species within clearcuts and 36 species within group openings. Earlier MOFEP analyses (Shifley et al., 2000) structured species groups to eight species subsets: other spp., maple spp., pine, hickory spp., scarlet oak, black oak, post/chinkapin oak, and white oak. For this analysis eight species groups were created for a broader comparison, most notably through the combination of oaks into the two categories of red oaks and white oaks. The species groupings use for this study include: hickories (*Carya tomentosa, Carya glabra,* etc.), maples (*Acer rubrum* and *Acer saccharum*), mixed hardwoods (*Juglans nigra, Prunus serotina, Ulmus rubra,* etc.), red oaks (*Quercus coccinea, Quercus rubra, Quercus velutina,* etc.), white oaks (*Quercus alba, Quercus muehlenbergii, Quercus* *stellata,* etc.*),* shortleaf pine (*Pinus echinata),* others (*Rhus copallina, Vaccinium arboreum,* etc.), and an additional category for total species present (see appendix).

Forest managers can utilize descriptive analyses to inform appropriate silvicultural treatments. Three descriptions of information collected for this study were number of species and percent composition, diameter distribution, and height distribution. The distribution of species throughout exposed and protected backslopes of the EAM and UAM sites was first reviewed through a compositional analysis. The percent composition of each species group was calculated for the trees regenerating within each aspect of each treatment by adding up a count of trees within each species group divided by the total count of all individuals sampled. This review of composition was carried out for clearcuts and group openings on both exposed and protected aspects.

The DBH distribution of each species group was first calculated at the plot level, and then the plot level mean was compared for each treatment and aspect. The DBH of all trees measured in this study's plots was compiled into two-centimeter size classes for each species group for the regeneration treatment and aspect these treatments occurred on. Tree diameter classes ranged from one centimeter to greater than 22 centimeters.

Mean tree height was determined by species group for each plot. The height distribution for each plot was determined using 1 m height classes. Plot-level values were averaged across site (exposed/protected) and management (EAM/UAM) for analyses.

Analysis of variance (ANOVA) was utilized as an analysis tool in this study due to its inherent ability to test multiple sample means and their interactions (Zar, 1999). Mixed model Analysis of Variance was used to test effects of site, management, and their interaction on diameter, height, and number of trees. The model included a random block effect following the MOFEP experimental design. There were a total of 27 plots within group openings for block 1, 28 for block 2, and 28 for block 3. There were also 6 plots within clearcuts for each of the three blocks. Tests were conducted separately for each species group. Levene's test was chosen over Bartlett's test due to Levene's capability to operate with non-normal data. For instances of non-normality, data was transformed to be analyzed with a normal distribution. These data were examined and configured using Microsoft Excel (Microsoft 2010), and statistical significance was determined with $\alpha = 0.05$ and conducted analyses using SAS 9.3 (SAS Institute, Cary NC).

The second tier of data analysis implemented in this study is based off the assumption that the total number of trees present at 16 years after regeneration will not all recruit to the canopy (Oliver & Larson, 1990). The analysis of a specific subset of the total data attempts to reduce the "noise" of all the species that will not eventually recruit to the canopy in order to assist land managers with a focus group for treatment applications. This approach was indirectly inspired by Vickers et al. (2017), in which the development of reference charts could be used to assess tree development by height and age up to 16 years of growth providing a percentile estimate for the individual. Because this study was interested in understanding which trees were most likely to recruit to the canopy, the idea of using a percentile threshold was instituted. Therefore, a review of those individuals most likely to recruit to the overstory can be condensed to individuals greater than the 90^{th} percentile in height.

The second-tier analysis performed for this study provides three windows into the regeneration present after the clearcuts and group selections:

1) Clearcut^{CC90} – average number of trees per hectare in the clearcuts that met the 90th percentile height threshold calculated from clearcut plots.

2) Group opening^{CC90} – average number of trees per hectare in group selections that met the 90th percentile height threshold calculated from clearcut plots.

3) Group opening^{GP90} – average number of trees per hectare in group selections that met the 90th percentile height threshold calculated from the group selection plots.

Each of these analysis subsets are derived from thresholds identifying the 90th percentile of tree heights regenerating within sampled plots of EAM and UAM sites. The thresholds were calculated independently for each treatment and each aspect for the two treatments through the percentile function within Microsoft Excel (2010). The thresholds for Clearcut^{CC90} were determined to 7.62 meters on both exposed and protected aspects, and Group^{GP90} thresholds were 9.35 meters on exposed aspects and 9.36 meters on protected aspects. The individual trees that had heights equal to or greater than the 90th percentile were included in the second-tier analysis. A third hybrid "treatment" pairs Clearcut^{CC90} height thresholds and trees sampled within group openings. This comparative analysis of trees from both regeneration treatments in a single variable depicts trees that regenerated within the group openings as if they had grown within clearcuts.

The statistical analysis of the trees most likely to recruit to the canopy, those above the 90th percentile, is structured to match the experimental design of the analysis of all regenerating trees within the UAM and EAM sites. Individual tree heights and the number of trees per hectare were averaged by species group at the plot level of each treatment. The significance of each aspect and treatment on species group heights was studied through the previously mentioned model examining the fixed effects of harvest treatment, aspect, and the interaction of treatment with site block as a random effect. Hickories were shown to exhibit inconsistent variance throughout the data distribution after administering Levene's test for equality of variances, and data were transformed through the application of a sin function. Four species groups exhibited unequal variances for tree density after administering Levene's test for equality of variances. Log10 transformations were necessary for total, hickories, and others. Red oaks data were transformed through square root.

Developmental reference charts have been used in assessing the growth progress of humans for many years, and Vickers et al. (2017) sought to apply the same principles to review trees early in stand development. The reference charts designed for stand development are quantitative tools to assess the height-age relationship of seven genera: blackgum (*Nyssa sylvatica*), dogwood (*Cornus florida*), hickories (*Carya tomentosa, Carya ovata*, etc.), others (*Vaccinium arborium*, etc.), red oaks (*Quercus velutina, Quercus rubra*, etc.), sassafras (*Sassarfas albidum*), and white oaks (*Quercus alba, Quercus stellata*, etc.) on two aspects: protected and exposed backslopes (Vickers et al. 2017). The age classes used in the charts span from two to 16 years of development and are designed to be used for regeneration in sites with initial residual basal area $\leq 5m^2\ ha^{-1}$.

These reference charts were used to review a subset of the data from the previous analysis: trees with heights greater than the 90^{th} percentile. Here, these reference charts are used to assess the regeneration of all trees regenerating on EAM sites at MOFEP. The reference charts were recreated using reference values defined by Vickers et al. (2017)

using SigmaPlot graphing software (SigmaPlot Software, San Jose, CA). Tree species were compiled into species groups to match the reference charts Vickers et al. (2017) developed. The thresholds of 10^{th}%, 25^{th}%, 50^{th}%, 75^{th}%, 90^{th}%, 99^{th}% were used to recreate the height growth charts represented in Vickers et al. (2017) The height data for each species group were separated to fit the appropriate percentile threshold, and a distribution of trees per hectare was displayed next to each of the 5 height thresholds. The distribution curve was then compared to the charts based upon values from Vickers et al. (2017). The final assessment of data within this thesis uses and tests the reference charts developed by Vickers et al (2017), and this review and analysis conforms to the review of interspecific and intraspecific competition within the Missouri Ozarks.

CHAPTER 4

RESULTS

FULL REGENERATING COHORT

The mixed hardwoods species group was the most abundant for clearcuts on both exposed (32.3%) and protected (43%) aspects (Figure 4). White oaks were the second most abundant on exposed sites (28.2%), and maples were second on protected sites (22.7%). Shortleaf pines were the least abundant overall when both aspects were combined, and shortleaf pines were not found within plots on protected slopes.

The mixed hardwoods group was the most abundant for group openings on both exposed (27.9%) and protected (46.7%) aspects. White oaks were the second most abundant on exposed sites (25.5%) and on protected sites (17.8%). Maples were the least abundant group within exposed aspect plots. Shortleaf pine was not found on protected aspect group openings plots. Shortleaf pine was also the least abundant overall when both aspects were included.

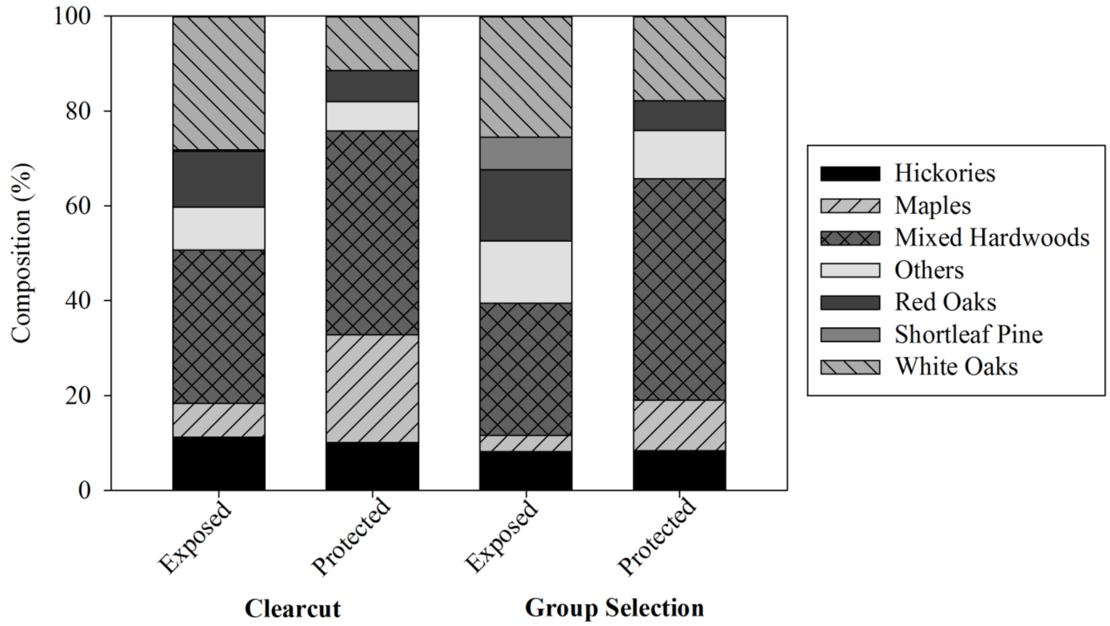

Figure 4. Species percent composition of seven species groups growing within clearcuts and group openings on both exposed and protected backslopes.

The diameter distribution for all species combined is asymmetrical for each treatment and associated aspect (Figure 5). The group opening data have a unimodal distribution curve, whereas the clearcut dad have a reverse j distribution. The shape of the clearcut distribution curve displays the greater quantity of regenerating trees as compared to the group opening distribution curve. The greatest quantity of individuals occurred in the smallest size classes for each of the treatments and aspects. The only exception to this occurs within protected aspect group openings that had a small increase in diameter frequencies within the second size class compared to the first size class.

The minimum, 0-1 cm, size class for diameter was populated for all treatment and aspect combinations. However, differences in maximum diameter were apparent for both treatments. The maximum diameter found within clearcuts and group openings on an exposed aspect was within the 23+ cm size class. However, on protected sites, group openings resulted in a maximum diameter 4 cms greater than the 19 cm size class within clearcuts.

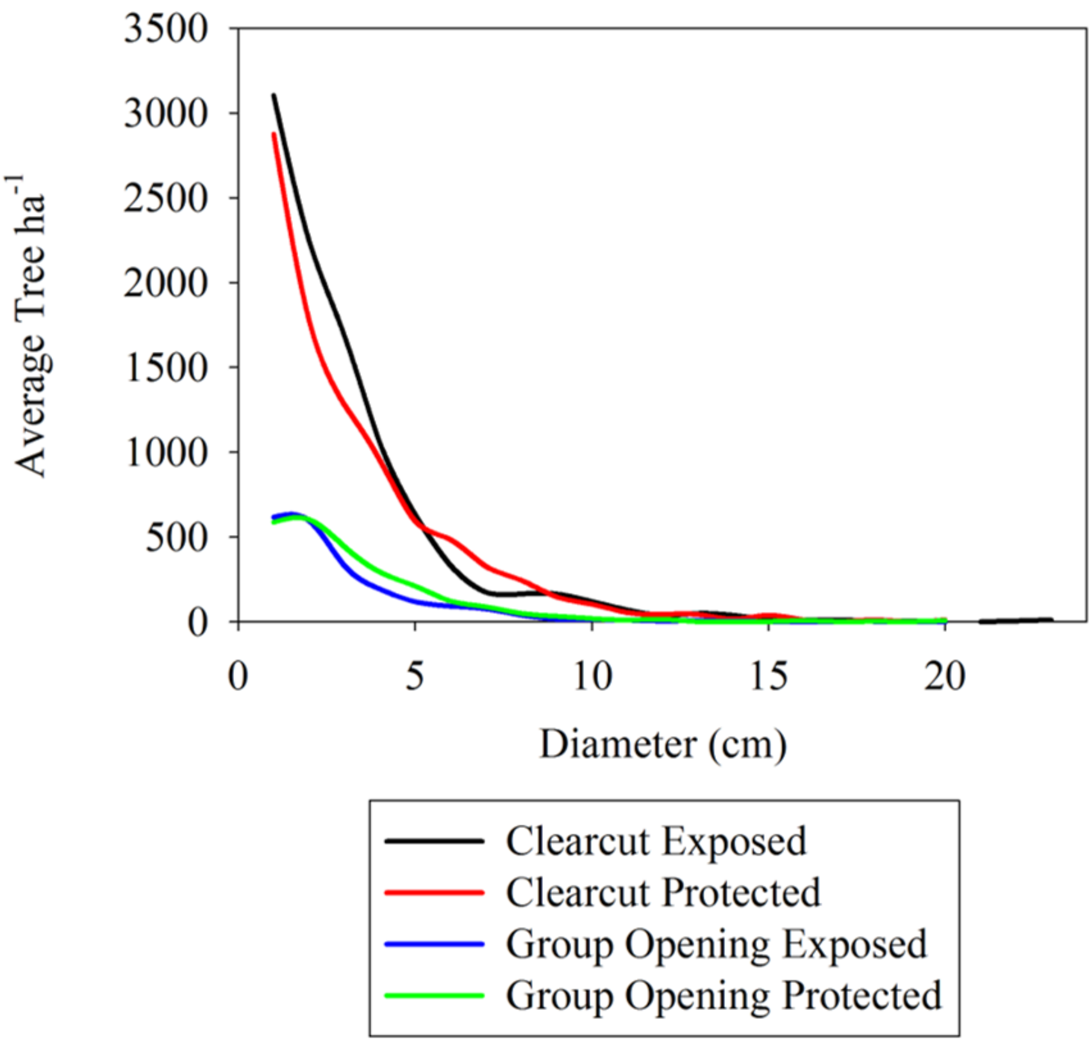

Figure 5. Diameter distribution of the total species group within clearcuts and group openings on both exposed and protected aspects.

Among the species groups, hickories' general trend was unimodal and skewed to the right (Figure 6), but skewness of each treatment and aspect distribution is likely the result of mature residual trees left after each treatment. Hickories occurred most frequently within the 1 cm size class regardless of treatment or aspect. When discussing range without considering the residuals, hickories regenerating within protected aspect group openings were found to have the greatest range of diameters between the 1 and 12 cm size classes. The smallest ranges from 1 cm – 10 cm classes were found in both clearcut and group opening exposed aspects.

For maples, group openings on exposed and protected sites had a general trend that was uniform, whereas for the clearcuts the diameter distribution was a reverse j with a modal increase in the 5 cm size class (Figure 6). Maples within both exposed and protected clearcuts occurred most frequently in the 1 cm class. Within exposed group openings, maples were found to have the greatest frequency in the 2 cm class, and in the protected group openings they had the highest frequency in the 1 cm class. In both protected aspect clearcuts and protected aspect group openings, maples were found to have a greater range of diameters as compared to exposed aspect clearcuts and group openings.

Mixed hardwoods data was unimodal and skewed to the right, with the exposed aspect being the most influenced by outliers for both treatments (Figure 6). Group openings on protected slopes were found to have a skewed distribution, but the skew was due more to population size classes throughout the range as opposed to just a single size class outlier. Diameters measured within both treatments and aspects were less numerous in the smallest size class than the subsequent class. This increase in frequency did not last for more than a single size class before the amount of trees decreased.

The other species group had a diameter distribution that was skewed to the right, and the data for protected clearcuts indicate a modal increase within the 6 cm size class (Figure 6). Others in all categories (clearcut, group opening, exposed, and protected) had the highest frequencies in the 1 cm size class. Excluding the outliers in the 23 cm+ size class, the greatest range of diameters occurred within protected aspect group openings. Overall, group openings had a greater range of diameters than the others group regenerating within clearcuts.

The diameter distribution of red oaks was generally multimodal with low peaks particularly found in group openings (Figure 6). Outliers in the 23+ category skewed all the distributions excluding protected aspect clearcuts. The highest frequencies were all found in the 1cm size class, except for exposed group openings, which was found in the 2 cm size class. Diameter distributions were characterized as having greater ranges for both treatments on exposed slopes when compared to the same treatments on protected aspects.

Unlike the other species groups, shortleaf pine exhibited a bimodal distribution that was generally skewed to the left (Figure 6). However, shortleaf pine in group openings exhibited a multimodal distribution that was nominally skewed to the right. Sampled shortleaf pines within clearcuts were between the 10-13 cm size classes except for one instance in the smallest size class. Shortleaf pine was subject to review on the exposed slopes for both treatments, but shortleaf pines were not present within plots sampled on protected slopes.

The reverse j curve is the dominant feature of the diameter distribution of white oaks growing within clearcuts (Figure 6). Group openings produced a more muted distribution that had mild multimodal peaks. The exposed aspect group opening curve was the most influenced by skewness with the majority of sampled individuals measured under 10cm. White oaks in both exposed and protected clearcuts had the greatest frequency in the 1cm size class. In group openings, however, the greatest frequency was found in the 2 cm size class.

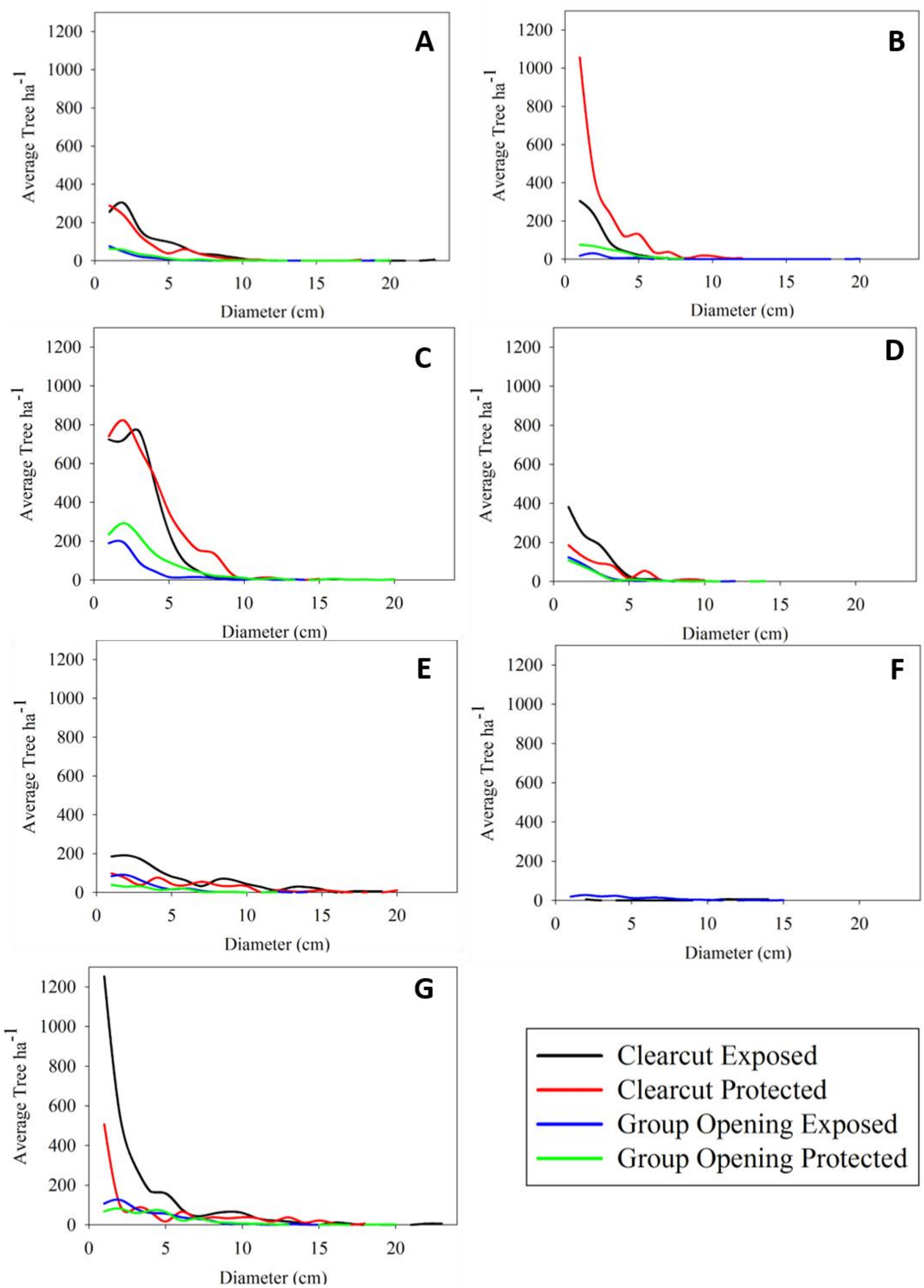

Figure 6. Diameter distributions of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) within clearcuts and group openings on both exposed and protected aspects.

Every size class for the total species grouping was populated in the sampled group openings on protected backslopes (Figure 7). Clearcuts regenerated on protected slopes had the smallest range for the heights measured. Each height distribution displayed for total is unimodal with a right skew, but group opening distributions on both aspects are more symmetrical than the height distributions of clearcuts.

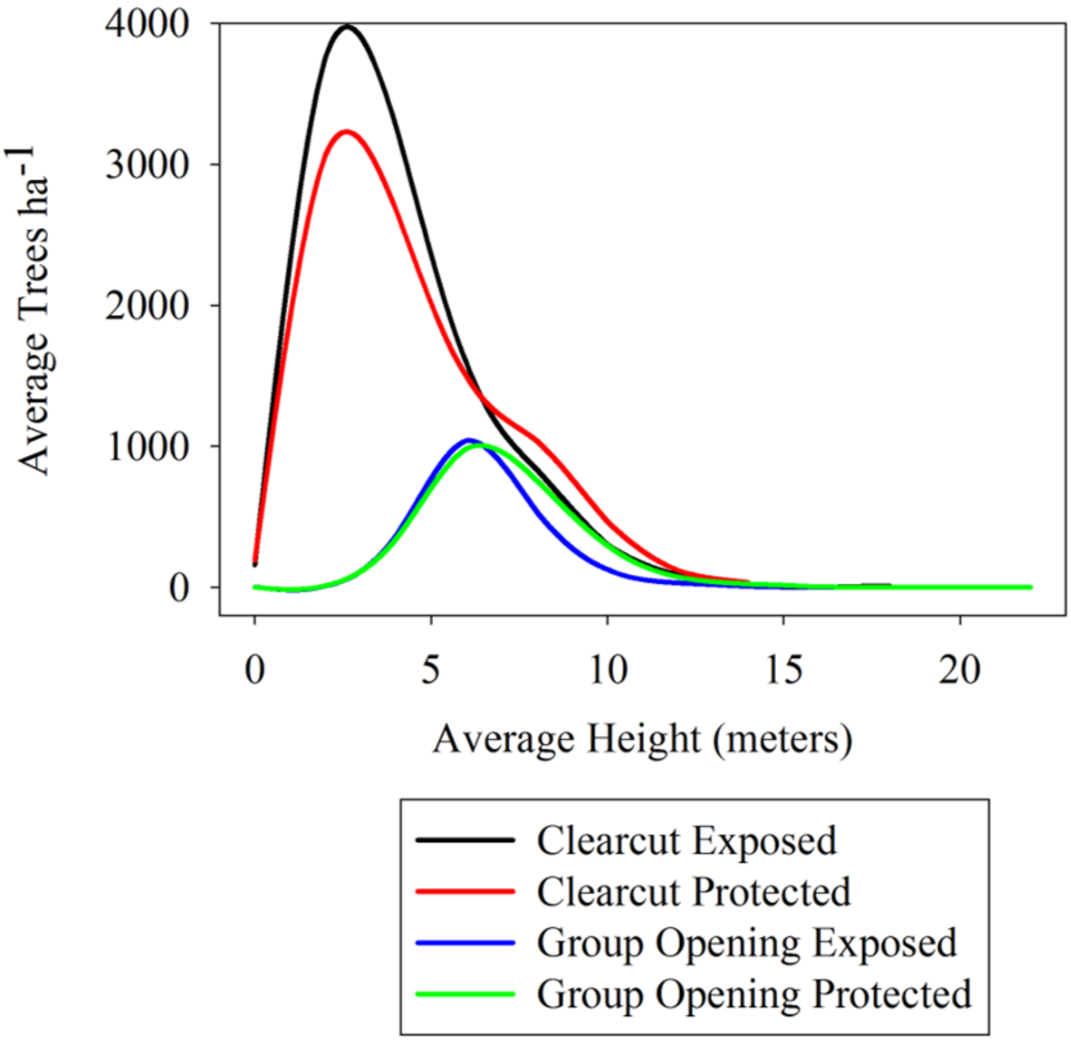

Figure 7. Height distributions of the total species group within clearcuts and group openings on both exposed and protected aspects.

Hickories had a unimodal height distribution when growing within each of the treatments (Figure 8). The range of the hickories height distributions was similar for both treatments, but the mode is several size classes larger for group openings compared to clearcuts. Hickories measured as outliers existed on exposed slope group openings, and this expanded the height distribution range from 4-10 m to 4-18 m.

Maples height distributions exhibited a much more uniform shape when originating from group opening data compared to clearcuts (Figure 8). The modal peaks present in the maples height distribution within clearcuts were much more pronounced, but the height distribution range within group openings exceeded that of maples within clearcuts. Maples were found between 0-12 m tall within clearcuts, and the range for group openings began at 4m and continued through the 12+ m size class.

The unimodal height distribution of mixed hardwoods occurred within each treatment and aspect combination (Figure 8). While there was not a difference found in the distribution ranges of clearcuts, mixed hardwoods were found within a greater range of size classes on the protected aspect of group openings compared to group openings on exposed slopes. Group openings had a mixed hardwood outlier within the 21+ size class on the protected aspect,

Others height distribution appeared as a unimodal curve for each treatment and aspect except for clearcuts on the protected backslopes (Figure 8). In the case of others growing within protected aspect clearcuts, the height distribution curve edged toward a bimodal curve. The ranges for each distribution curve were similar, but one other outlier located within protected group openings resulted in a heavily skewed distribution.

The red oaks height distributions appear more influenced by treatment than aspect (Figure 8). Red oak height distribution curves derived from clearcut data resulted in bimodal distributions, but red oaks growing in group openings produced a more normal distribution. The protected clearcut and exposed group opening were skewed to the right resulting from outliers.

Shortleaf pine were present in three size classes within exposed aspect clearcuts, but the range extends throughout five height class sizes (Figure 8). Shortleaf pine regenerating within exposed aspect group openings were also present within five size classes, but there were no gaps in the height distribution curve. Unlike many of the other species group height distribution curves, the distribution curve of shortleaf pine within clearcuts was skewed to the left.

The height distribution curves of white oaks growing in clearcuts were asymmetrical and approaching a bimodal curve (Figure 8). White oaks regenerating within group openings resulted in distribution curves that are more uniform and skewed to the right. Height distributions developed from exposed clearcuts and protected group openings were most influenced by outliers. Protected group openings depicted data throughout all size classes, but three gaps in data are present.

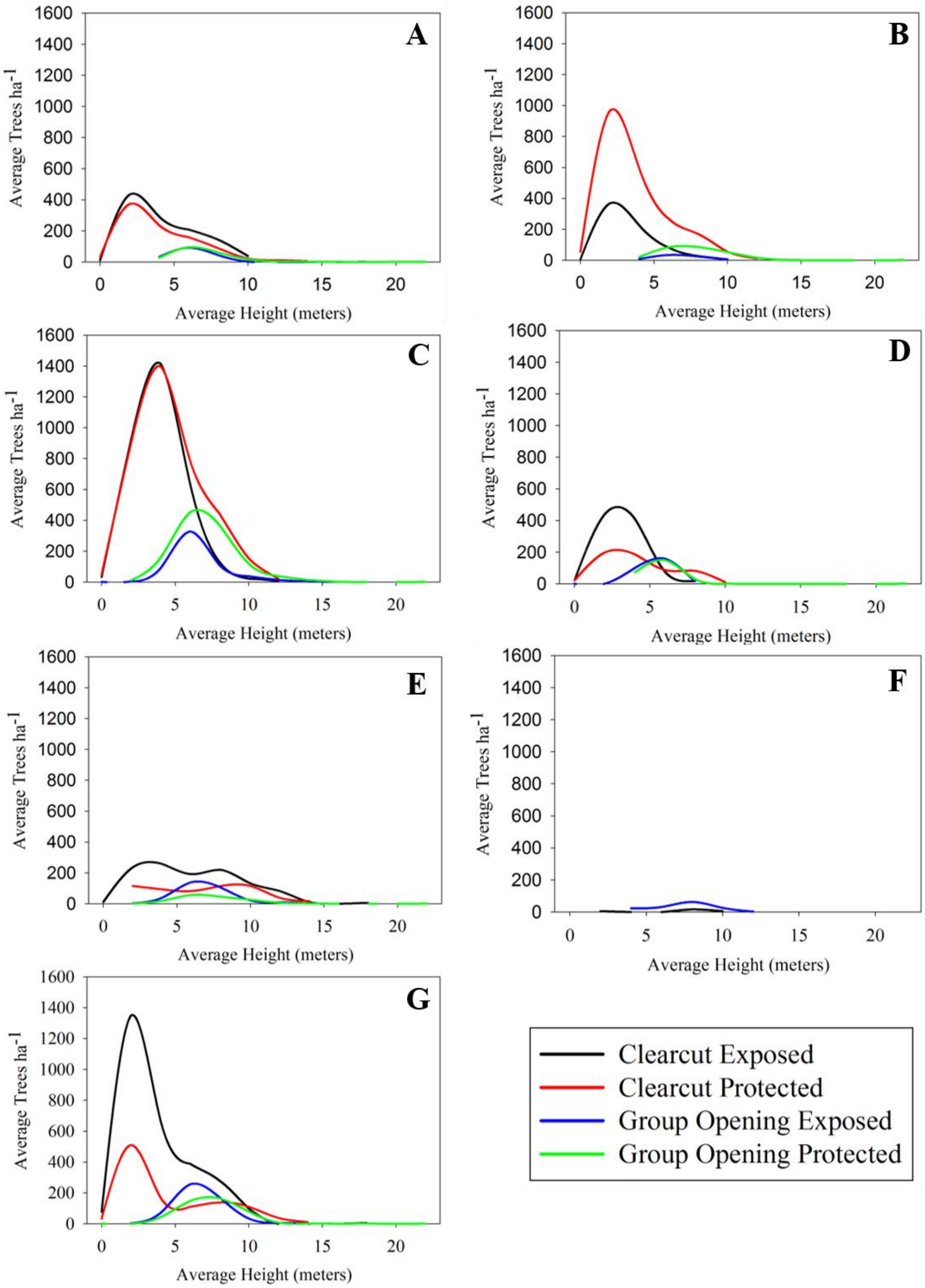

Figure 8. Height distributions of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) within clearcuts and group openings on both exposed and protected aspects.

The fixed effects of aspect, treatment, and the interaction of aspect and treatment related to mean height were analyzed through ANOVA. The fixed effects of treatment and aspect were significant ($p<0.001$), and group openings had a mean height significantly greater than clearcuts, but there was no interaction between treatment and aspect. The combination of all species into the total group resulted in mean heights of 4.2 meters within clearcuts and 6.6 meters within group openings, and a protected aspect resulted in trees that were on average greater than 0.5 meter taller than those growing on exposed sites (Figure 9).

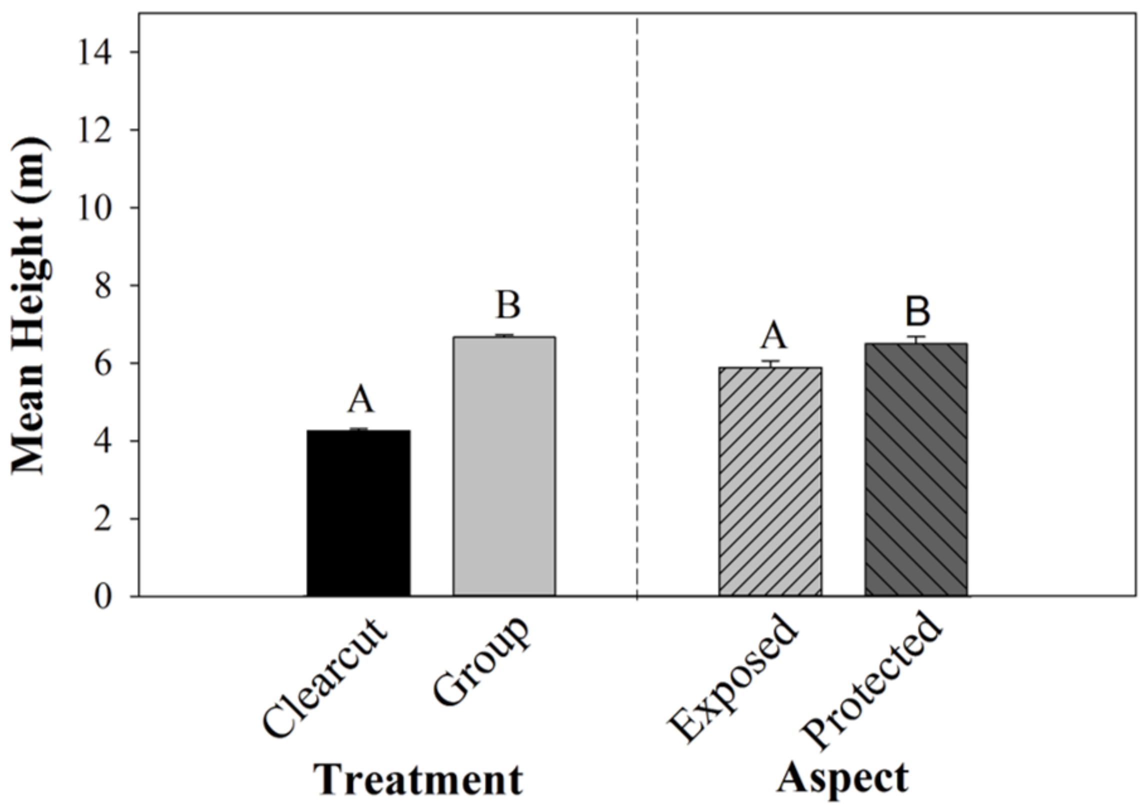

Figure 9. Mean height by treatment and aspect of the total species group. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

A comparison of interspecific species characteristics indicate that shortleaf pine had the greatest mean heights for all species on exposed aspects of clearcuts, 7.5 m, and red oaks had the greatest mean heights for all species on protected aspects of this same treatment, 14.26 m. Maples had the lowest mean heights for both aspects when accounting for the absence of shortleaf pine on protected slopes. The tallest tree measured on exposed aspect clearcuts was a 25.4 m white oak, and the tallest tree, 14.26 m, was a red oak on protected slopes.

Shortleaf pine had the greatest mean height on exposed group openings, 7.32 m, followed by red oaks, 6.91 m. Maples had the greatest mean height in protected group openings, 7.69 m, followed by white oaks at 7.4 m. The others group had the lowest mean height for both aspects of group openings, below 5.2 m. The tallest tree measured for both aspects was hickory.

Hickories had the greatest mean height on exposed aspects for both treatments. White oaks and red oaks both had greater mean heights on protected slopes, and the average heights were greater in group openings when compared to clearcuts. This trend held true for all species groups except for shortleaf pine which had a greater mean height when found in clearcuts.

Species specific analysis resulted in the finding that treatment had a significant effect on mean height of hickories, and the mean height of hickories were greater in group openings than in clearcuts (Figure 10). Hickories mean heights within group openings were significantly greater ($p = 0.001$) than hickories within clearcuts, and the difference in mean height was greater than 2.5 meters. There was no significant effect of aspect (p=0.363) or the interaction of treatment and aspect (p=0.065) on hickories mean height.

The mean height of maples was significantly influenced by the fixed effects of aspect (p=0.001) and treatment (p<0.001), but there was no significant interaction between aspect and treatment (p=0.484) (Figure 10). Maples within group openings had a mean height of 6.7 meters after 16 years, and that is more than 3 meters taller than maples within clearcuts. Maples within group openings had significantly greater mean heights for every aspect and treatment combination.

Treatment and aspect were both significant (p=0.006, p<0.001) fixed effects for the mean height of mixed hardwoods within both clearcuts and group openings, but there was no significant interaction between treatment and aspect (p=0.774) (Figure 10). Mixed hardwoods had an average height nearly one meter greater on protected slopes compared to exposed slopes.

There was a significant interaction effect of treatment and aspect (p=0.029) for others (Figure 10). The effect of aspect within clearcuts was significant (p=0.006), but aspect was not a significant effect (p=0.497) for others regenerating in group openings. Others were nearly one meter taller within group openings, and there was almost a 0.5 meter difference when assessing aspect. Others were found to have significantly greater mean heights within group openings compared to clearcuts on both exposed (p<0.001) slopes and protected (p=0.001) slopes.

Red oaks had a mean height of 6.3 meters within clearcuts and 7.0 meters within group openings (Figure 10). The difference in mean height related to aspect was less than

0.5 meters. There was no significant difference between the mean height of group openings and clearcuts (p=0.055) or between protected and exposed slopes (p=0.077), and there was also no significant interaction between treatment and aspect (p=0.755).

Shortleaf pine grew to an average height of 5.7 and 5.6 meters within clearcuts and group openings respectively (Figure 10). Shortleaf pine were not present in plots measured on protected slopes, and the mean height of shortleaf pine on exposed slopes was 6.02 meters. The fixed effects of treatment, aspect, and the interaction of treatment and aspect were found to have no significant difference.

After 16 years of growth, white oaks were found to have significantly greater mean heights within group openings compared to clearcuts (p<0.001), and there was no significant interaction between treatment and aspect (p=0.103) (Figure 10). White oaks mean height were also found to be significantly affected by the fixed effects of aspect (p=0.002). The mean height of white oaks within group openings was 2.6 meters greater than that of clearcuts, and the difference between white oaks growing on the protected slopes compared to exposed slopes was 0.6 meters.

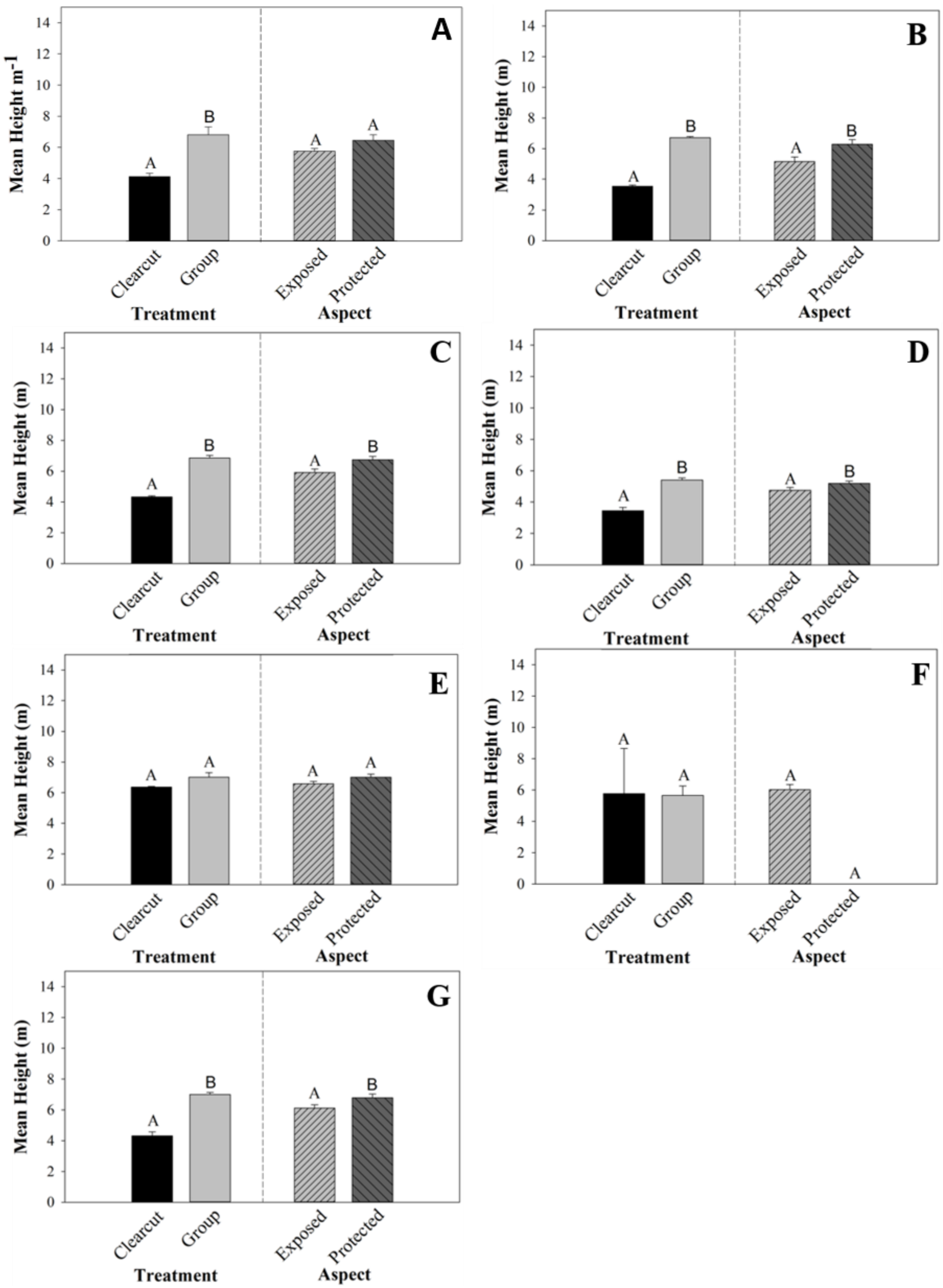

Figure 10. Mean height by treatment and aspect of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)). Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

REGENERATION DENSITY

Treatment was found to have a significant influence on regenerating tree density ($p<0.001$). Clearcutting resulted in over 7000 more trees per hectare than group openings (Figure 11). There was no significant influence of aspect ($p=0.817$) found for the regenerating density of trees when both treatments were combined, and there was no significant interaction between treatment and aspect ($p=0.322$) for the combined species.

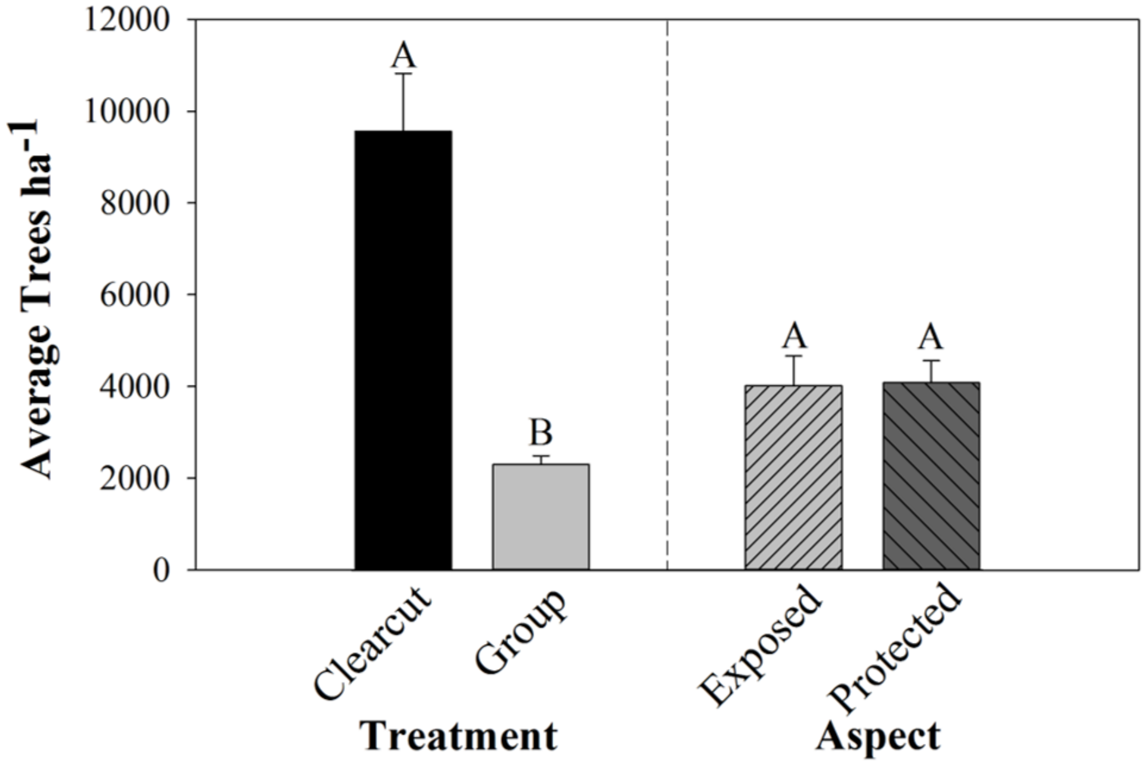

Figure 11. Average trees per hectare by treatment and aspect of the total species group. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

Hickories were found to be significantly ($p<0.001$) more prevalent within clearcuts than group openings, and the difference of hickories per hectare exceeded 900 trees per hectare (Figure 12). The overall test of aspect and the interaction of aspect and treatment did not show any significance. Neither treatment exhibited a significant difference in trees per hectare relating to aspect.

The assessment of maples resulted in a statistical significance found for both aspect (p=0.008) and treatment (p=0.001) but not the interaction of the two (p=0.839) (Figure 12). Clearcuts regenerated greater than 1000 more maples per hectare than group openings. The amount of maples within treatments on the protected aspect resulted in an average of 417 more than treatments on exposed slopes.

While there was no significant fixed effect of aspect (p=0.182), treatment did have a significant effect (p=0.001) on the amount of mixed hardwoods per hectare (Figure 12). Clearcuts regenerated 2500 more mixed hardwoods than group openings. There was no significant interaction (p=0.991) of treatment and aspect for the quantity of regenerating mixed hardwoods.

Clearcuts regenerated 776 others per hectare which was significantly greater (p=0.001) than the 264 others per hectare found within group openings (Figure 12). Aspect was not a significant fixed effect (p=0.067) on the amount of regenerating Others with 414 individuals on exposed slopes and 316 individuals on protected slopes.

The data collected for red oaks was non-normal, and a log10 transformation was applied to test significance on the fixed effects of aspect, treatment, and the interaction of the two variables. There was an overall significance for both aspect (p=0.025) and treatment (p=0.003) (Figure 12). Clearcuts regenerated more than 700 additional red oaks compared to group openings, and an average of 250 more red oaks on exposed aspect treatments was evidenced by the data analysis.

The normality of data for shortleaf pine was confirmed, and the test for the fixed effects of treatment, aspect, and the interaction of treatment and aspect was unique for shortleaf pine. Shortleaf pine were not found present within either treatment on the protected aspect. Therefore, only the effect of treatment was assessed for this species group. There was no significant effect of treatment on the amount of shortleaf pine per hectare (Figure 12). Clearcuts developed an average of 13 shortleaf pine per hectare, and group openings had an average of 72 shortleaf pine per hectare.

White oaks had a normal data distribution and no transformations were necessary to determine the significance of fixed effects. Analysis of white oaks resulted in a significant fixed effect for aspect (p=0.002), treatment (p=0.001), as well as the interaction of treatment and aspect (p=0.004) (Figure 12). Clearcuts on average had 1500 more white oaks per hectare than group openings, and treatments on the exposed aspect developed an average of 426 more white oaks than the protected aspect. Exposed clearcuts had a significantly (p=0.001) greater amount of white oaks than exposed group openings, but there was not significant difference for protected clearcuts and protected group openings. There were also significantly (p=0.002) more white oaks per hectare within clearcuts on the exposed aspect compared to the protected aspect.

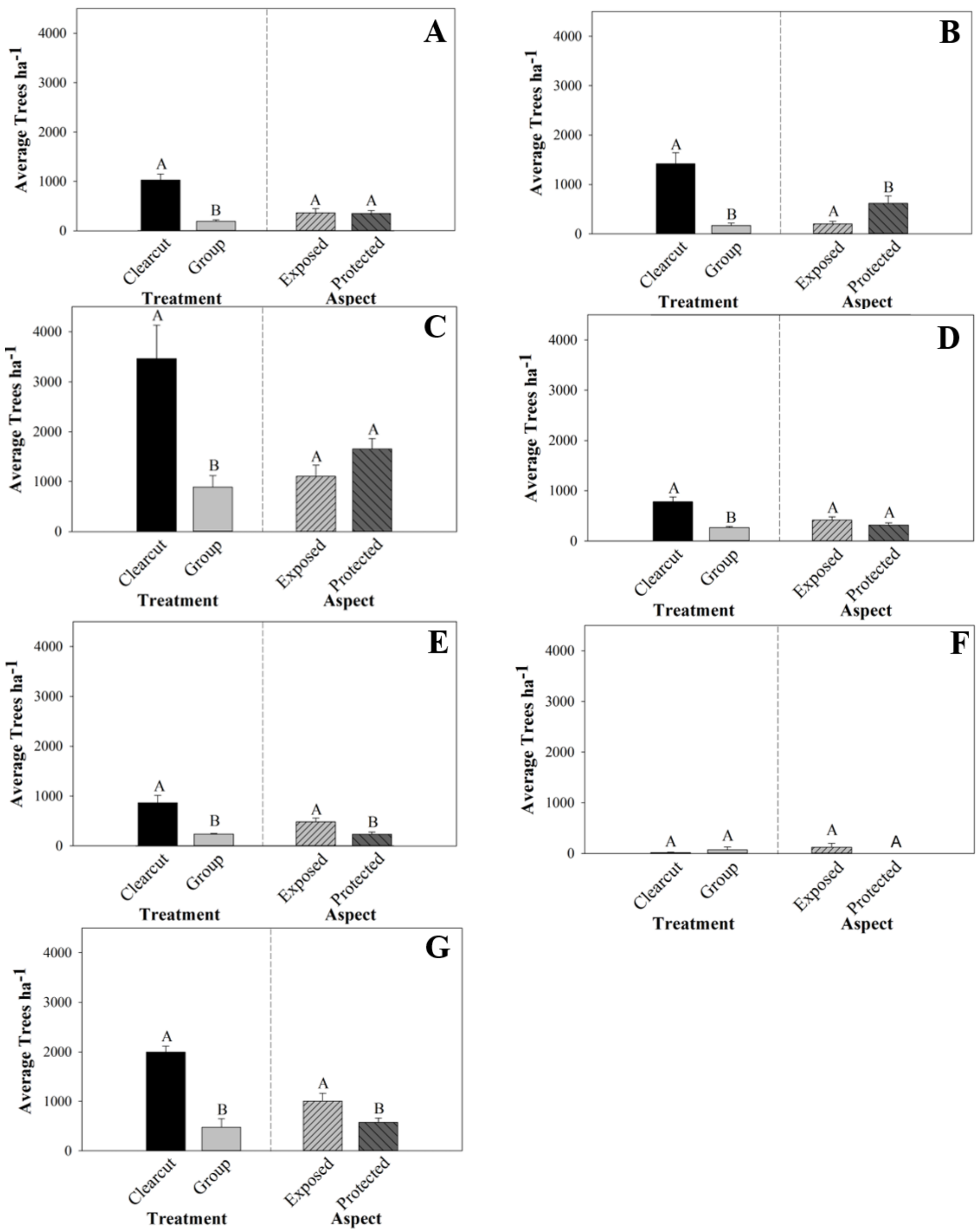

Figure 12. Average trees per hectare by treatment and aspect of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)). Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

90^{TH} PERCENTILE

Red oaks were the greatest proportion of sampled trees in clearcuts, and mixed hardwoods had the highest composition percentage within group openings. Shortleaf pine and others were consistently the two least abundant species groups for both treatment types. Red oaks and mixed hardwoods comprise approximately one third of all trees within clearcuts when the 90^{th} percentile threshold is applied on exposed and protected slopes respectively. Mixed hardwoods make up greater than one third of all trees above the 90^{th} percentile in group openings irrespective of aspect. The application of clearcut thresholds on group selection data (group $opening^{CC}$) resulted in mixed hardwoods being most abundant on exposed aspects and white oaks as the dominant species group on protected slopes (Figure 13). Shortleaf pine and others remained the least dominant compositional groups with the clearcut thresholds in place on data from group openings.

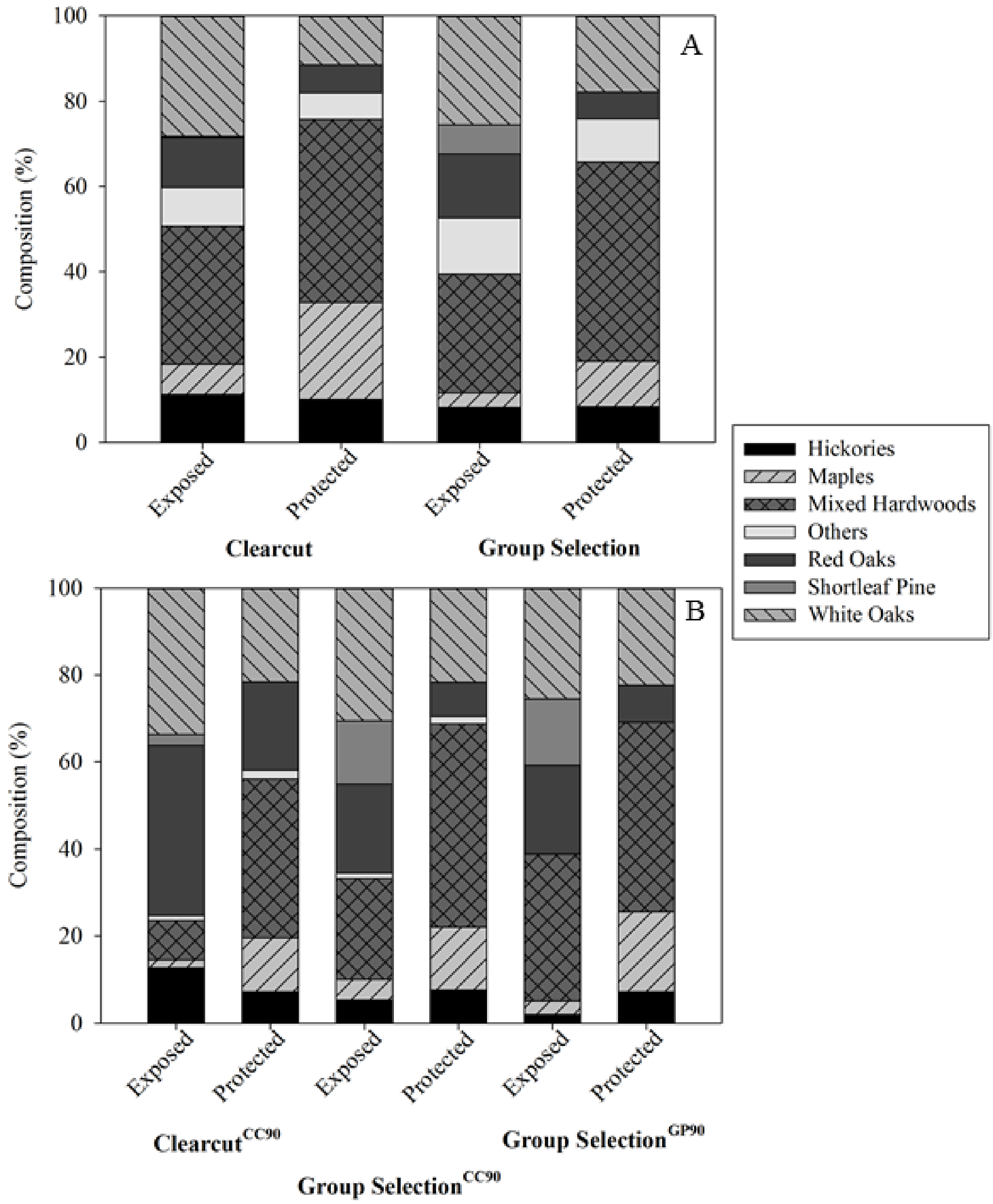

Figure 13. Comparative analysis of species composition based on treatment and aspect for total sampled population (A) and individuals greater than the associated 90th percentile (B).

The greatest frequency in diameters was found to be between 5 centimeters and 10 centimeters for individuals over the 90th percentile thresholds (Figure 14). All species groups compared above the 90th percentile thresholds, excluding red oaks, had a wider range of diameters in group openings compared to clearcuts. When all species groups were combined, group openings had a greater average diameter than both the clearcut and Group^{CC} treatments. Each treatment had greater average diameters when occurring on exposed aspects.

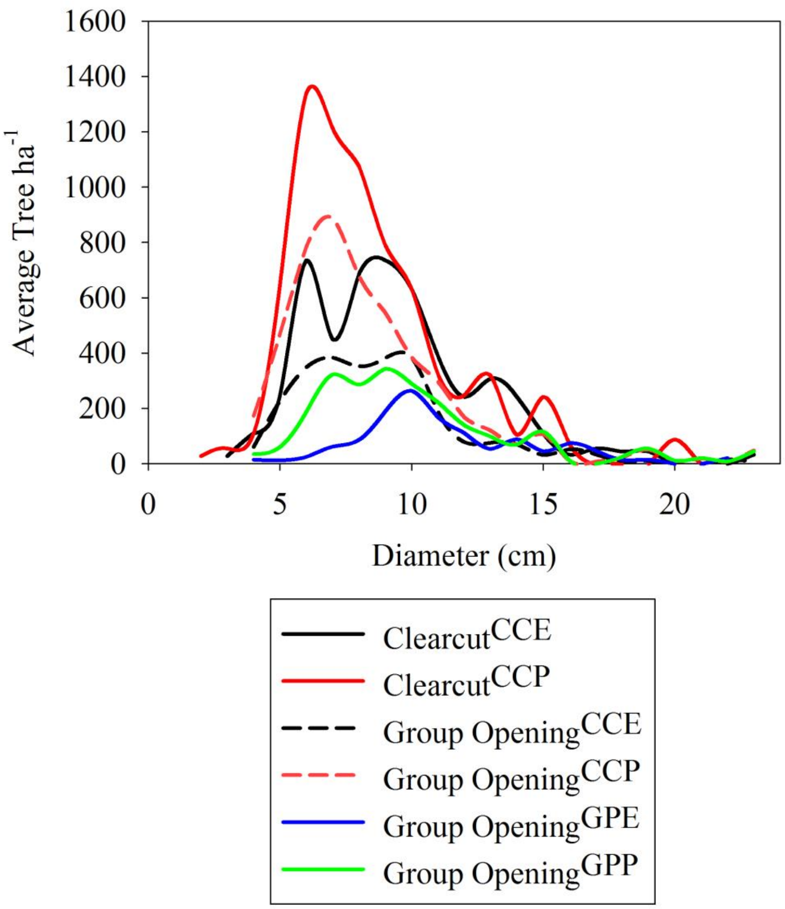

Figure 14. Diameter distribution of the total species group within clearcuts and group openings on both exposed and protected aspects for tress with height measured heights above the associated 90th percentile thresholds.

The distribution of hickories was most influenced by treatment. Hickories within clearcuts had the smallest distributive range, and hickories within the group opening^{CC} treatment had the greatest range (Figure 15). The increased diameter distribution range found within the group opening data was a result of outliers in the largest size classes. The diameter distribution curves of hickories were almost exclusively multimodal. The majority of measured hickories fell between the 5-10 m range.

The diameter distribution curves of maples varied from a simple line found with exposed clearcuts and group openings, unimodal distribution for group opening^{CCP}, and a range of modes for the remaining treatment and aspect combinations (Figure 15). Maples measured on exposed slopes had a shorter range than their counterparts on protected slopes, and this carried through each of the treatments. Clearcuts had the least expansive diameter range of all treatments on exposed slopes and the widest range on protected slopes.

The depiction of mixed hardwood diameters of individuals greater than the associated 90th percentile thresholds generally resulted in multimodal diameter distribution curves (Figure 15). The mixed hardwood distribution range began with smaller size classes within clearcuts compared to the start of group opening data two size classes greater. Clearcuts also resulted in the least expansive range of all the treatments.

The distribution curves of clearcuts and group opening^{CC} were created for others, but this species group did not have any individuals greater than the 90th percentile threshold of group openings. Therefore, only the treatments utilizing the clearcut thresholds are displayed (Figure 15). Others growing within exposed clearcuts and group opening^{CCE} were found in two size classes, but the ranges of each treatment were different. Others found within exposed clearcuts span three size classes beginning with the 2cm size class, and others span nine size classes throughout the group opening^{CCE} treatment. The distributions of others for each treatment and aspect were not extensive enough to determine modality.

Red oak diameter distribution above the 90th percentile thresholds depicted a complex interaction of treatment and aspect resulting in bimodal and multimodal distributions (Figure 15). The greatest distribution ranges of red oaks belonged with clearcuts on both examined aspects. Clearcuts on exposed slopes resulted in red oaks within the smallest size classes, and clearcuts on protected slopes displayed red oaks within the 20cm size class. The application of the clearcut height thresholds upon group opening data did not have a major effect on the distributions of group opening^{CC} aside from shifting the mode to the left.

Shortleaf pine diameter distributions were only apparent for the treatments on exposed slopes due to the absence of any measured shortleaf pine on protected slopes (Figure 15). The shortest distribution range belonged to clearcuts, and the greatest range was found within the group opening^{CC} treatment. Gaps in size class data provided a multimodal curve for both group opening^{CC} and group opening^{GP} treatments.

Multimodal diameter distributions characterized each treatment and aspect that white oaks were measured on (Figure 15). The majority of individuals sampled were within the 5-14 cm size classes. Outliers influence each of the treatment and aspect distributions. Exposed clearcuts and protected group opening^{CC} and group opening^{CCP}

distributions were the most influenced by larger diameter outliers, and clearcuts on protected slopes were skewed left.

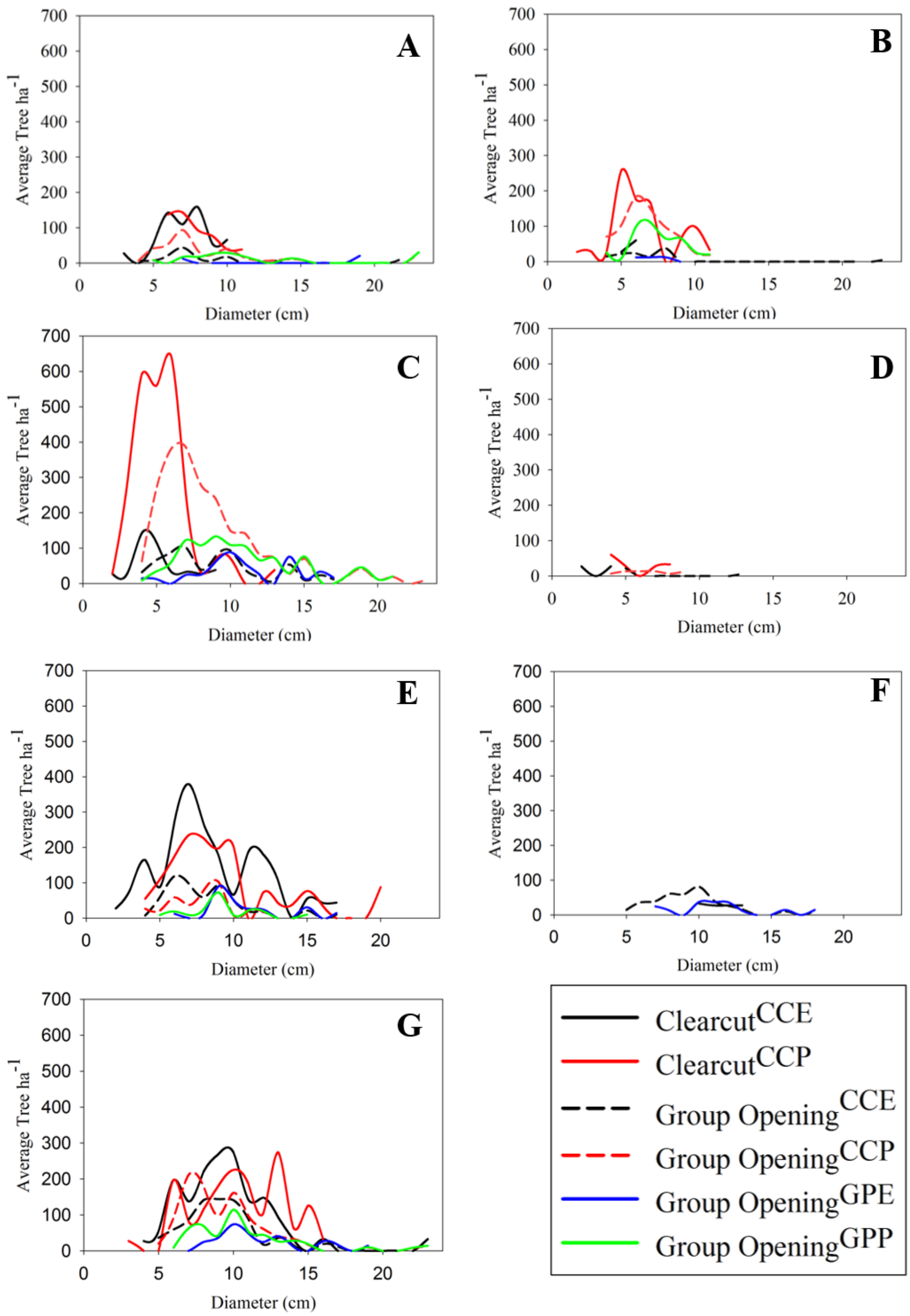

Figure 15. Diameter distribution of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) within clearcuts and group openings on both exposed and protected aspects for tress with height measured heights above the associated 90th percentile thresholds.

The exclusion of all measured trees below each calculated 90th percentile threshold provided a magnified view of the height distribution of individuals most likely to recruit to the canopy. The first notable change in height distribution was the lack of trees present below the 10m size class, while clearcut^{CC90} and group opening^{CC90} depicted trees within the 8m size class. The distribution of each treatment and aspect were defined as asymmetrical and skewed to the right due to the threshold on the smaller end of the measurements (Figure 16). The greatest amount of measured individuals fell between the 8-14m size class with limited presence in the larger size classes. Group opening^{CCP} and group opening^{GPP} had outliers extending into the 21+m size class, but clearcuts^{CC90} did not. The application of the clearcut^{CC90} height thresholds skewed the distribution of group opening^{CCE} and group opening^{CCP} an addition size class to the left, smaller, but the upper limits were the same due to the presence of taller trees, likely residual trees.

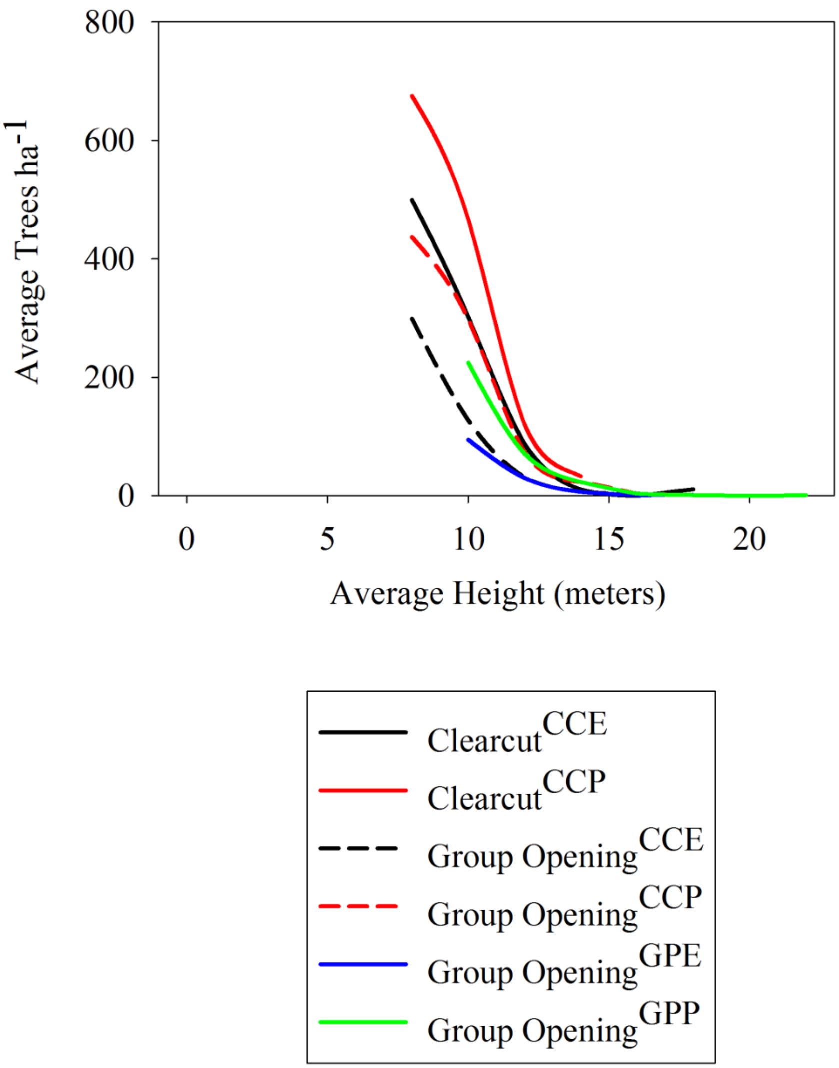

Figure 16. Height distributions of the total species group within clearcuts and group openings on both exposed and protected aspects for tress with height measured heights above the associated 90th percentile thresholds.

Hickories exhibit an asymmetrical right skewed distribution when found within clearcuts on both the exposed and protected slopes (Figure 17). The range of the height distribution of individuals on clearcuts was greater on the protected aspect locations. Hickories growing within group openings exhibited a bimodal distribution as opposed to the unimodal curve of clearcuts. Group openings with the clearcut threshold had the greatest range of all the treatment and aspect combinations. The peaks of the group opening distributions were shifted to the right of the mode of the clearcuts and group opening^{CC}.

The general distribution trends of maples found on all treatments and aspects was asymmetrical with a right skew (Figure 17). A trend was found to exist related to aspect, and each treatment had a wider range of measured heights on the protected slopes. Maples above the group opening^{GPE} threshold were only found within the 10m size class. There were no maple height outliers present within the collected data for any of the treatment or aspect combinations

Asymmetrical and right skewed distributions were evident for each of the treatment and aspect combinations for mixed hardwoods (Figure 17). Mixed hardwood height distribution peaks were similar in range group opening^{GP} and clearcut^{CC}, but mixed hardwoods above the group opening^{CC} threshold were shifted to the right. There were no outliers present within the collected data for any of the aspect and treatment combinations. Group opening^{CCE} had the widest ranging distributions, and clearcuts had the narrowest range.

Others had the most diminutive distribution of all species groups. Others were not found to be taller than the group opening^{GP} thresholds (Figure 17). Only a single size class was populated by others for both clearcut^{CCE} and group opening^{CCE}. The limited size class range resulted in an asymmetrical line trending downward.

Red oaks examined with the 90th percentile thresholds created height distributions that were generally asymmetrical and right skewed, but there were no major outliers (Figure 17). The widest distribution range was found to be within clearcuts on exposed slopes, and group openings with the group opening^{GP} threshold had the smallest range. The tallest red oak measured extended the range of the clearcut clearcut^{CCE} curve two size classes beyond distributions created with the group opening data.

The height distribution of shortleaf pine above the 90th percentile thresholds developed for clearcuts and group openings were applied to the measured trees, and only the exposed aspect could be assessed. The distributions depicting the frequency and height of shortleaf pine showed a similar shape for both clearcuts and group openings, but group opening^{GP} shortleaf pine were shifted to the right due to the absence of trees within the 8m size class (Figure 17). Shortleaf pine with the group opening^{CC} threshold had the widest range of data, and it appears as a larger version of the shortleaf pine within group opening distribution.

Examination of white oak height distribution result in asymmetrical and right skewed curves (Figure 17). The smallest height ranges were found to be on the protected slopes of clearcuts^{CC} and exposed slopes of group openings^{GPCC} group openings^{GP}. Outliers are absent for all treatments and aspects except for data taken from group openings on protected slopes. White oaks are most abundant close to the height threshold, and this results in the modal peak of the distributions within the 8m and 10m size classes for all treatments and aspects.

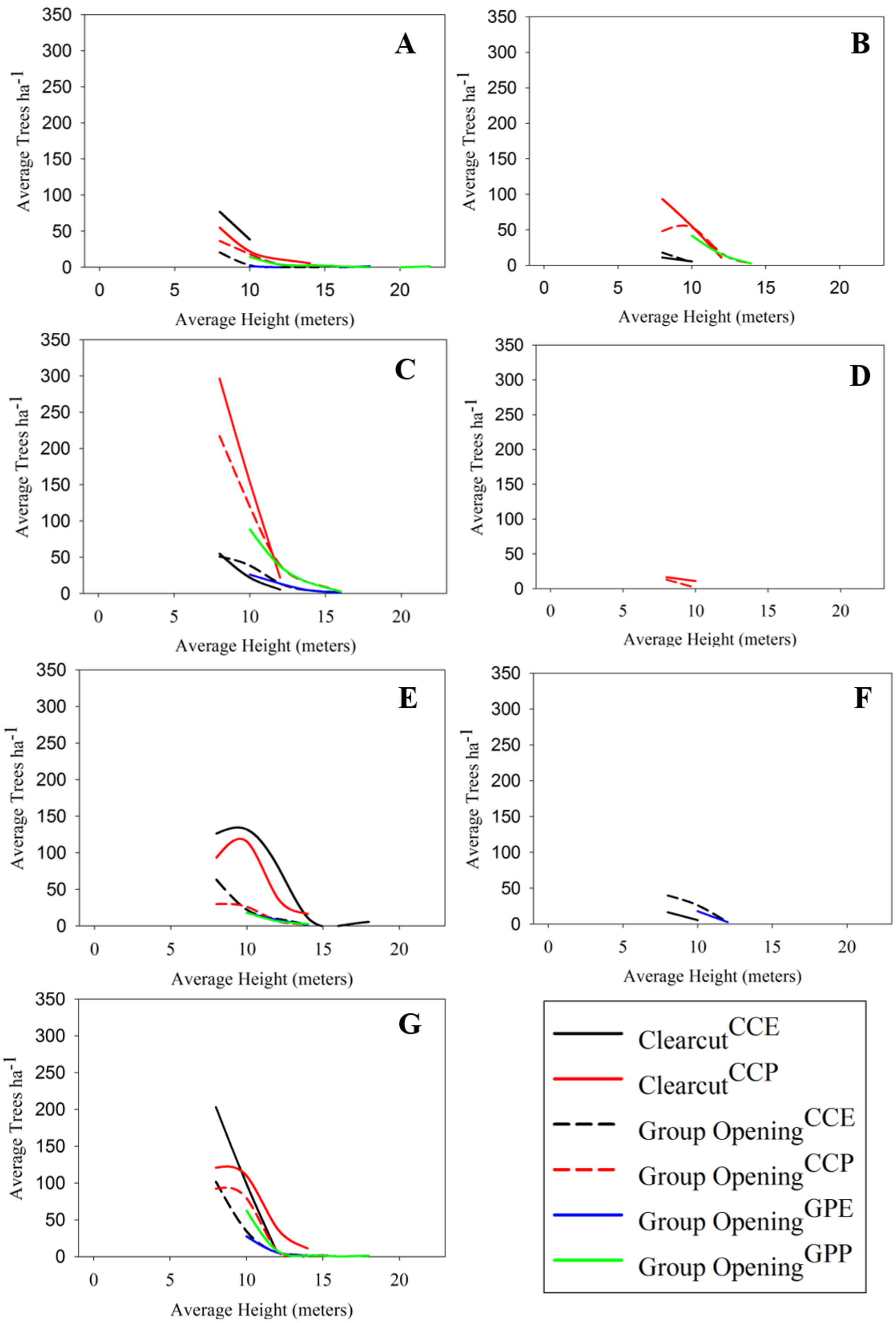

Figure 17: Height distributions of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) within clearcuts and group openings on both exposed and protected aspects for tress with height measured heights above the associated 90th percentile thresholds.

The statistical analysis of mean height for all species groups above the 90^{th} percentile combined resulted in no significant difference with regard to aspect (p=0.175) (Figure 18). Treatment had a significant effect (p<0.001), and mean height was significantly greater for group openings compared to $clearcut^{CC}$ and group $opening^{CC}$. However, there was no significant interaction (p=0.519) between treatment and aspect.

The analysis of trees above the 90th percentile provided a magnified view of the top performing trees after 16 years of growth, and the inclusion of a third treatment, group $opening^{CC}$, provided a more direct comparison for trees growing within clearcuts and group openings. The only significant fixed effect was treatment (p<0.001). Within treatment, group openings had the tallest mean height of 10.85m, and that was significantly greater than both of the treatments utilizing the clearcut threshold. There was no significant difference for all species combined between the $clearcut^{CC}$ and group $opening^{CC}$. There was no significant interaction found between treatment and aspect.

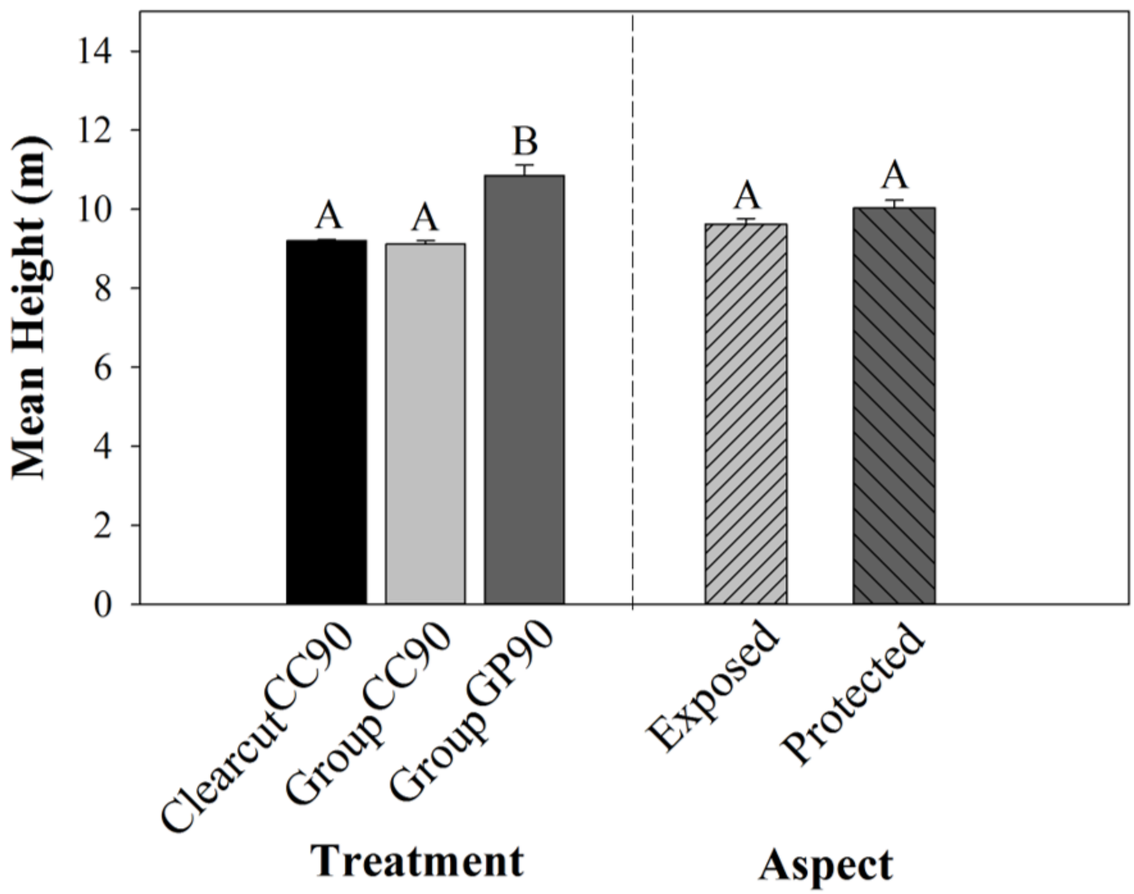

Figure 18. Mean height by treatment and aspect of the total species group for trees above the 90th percentile thresholds. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

The data for hickories was found to have unequal variances after applying Levene's test, and a sin transformation was applied to the data. Hickories above the 90th percentile had mean heights of 8.76m, 9.77m, and 13.00m for clearcut^{CC}, group opening^{CC}, and group opening^{GP} respectively (Figure 19). Despite the gap in mean heights, there were no significant fixed effects for treatment (p=0.254) for hickories greater than the respective 90th percentile thresholds. Hickories had greater mean heights on protected slopes, but there was no statistical significance due to aspect (p=0.602).

Maples above the 90th percentile height thresholds had mean heights between 8.6 and 8.8 m within clearcut^{CC} and group opening^{CC} respectively. The mean height for group opening^{GP} was significantly greater (p=0.006) than both clearcut^{CC} and group opening^{CC} at 10.74m (Figure 19). There was no significant different between mean heights for exposed and protected slopes (p=0.335), and there was no significant interaction of treatment and aspect (p=0.785).

The mean height of mixed hardwoods only differed by <0.1m by aspect, and there was no statistical significance to the variation (p=0.574) (Figure 19). There was however, a significant treatment effect on the mean height of mixed hardwoods (p<0.001). The mean heights of clearcut^{CC}, group opening^{CC}, and group opening^{GP} were all significantly different from each other. Clearcut^{CC} had the smallest mean height of 8.71m, and group opening^{GP} had the tallest mean height of 10.87m.

Others had mean heights of 8.40m and 8.32m within clearcut^{CC} and group opening^{GP}. Others were not represented above the 90th percentile threshold of group opening^{GP}, and therefore are not shown (Figure 19). There were no significant fixed effects for aspect (p=0.162) or treatment (p=0.596). Analysis of the interaction of treatment and aspect also lacked any significance (p=0.342).

The mean height of red oaks above the 90th percentile height threshold was subject to treatment as a significant effect (p<0.001) (Figure 19). Group opening^{GP} had the greatest mean height of 10.54m followed by clearcut^{CC} at 9.87m. The difference between mean height of each aspect was less than 0.2m, and this difference was not statistically significant (p=0.191). There was no significant interaction of treatment and aspect on the mean height of Red Oaks (p=0.131).

Shortleaf pine were not found within any treatment on the protected slope, and that absence is reflected in Figure 19. Treatment acted as a significant fixed effect upon the mean height of shortleaf pine (p=0.026). The tallest mean height belonged within group opening^{GP} at 10.44m followed by group opening^{CC}, 9.29m, and clearcut^{CC} 8.65m. Each of the treatments were significantly different from each other.

The mean height of white oaks greater than the 90th percentile thresholds developed for clearcut and group openings range from 9.09m to 10.34m between the three treatments with treatment having a significant effect (p<0.001) (Figure 19). The difference between mean heights of white oaks on the protected slopes was nearly 0.5m greater than treatments affected on exposed slopes, and there was a significant effect of aspect (p=0.009). There was no significant effect from the interaction of treatment and aspect on the mean height of white oaks (p=0.135).

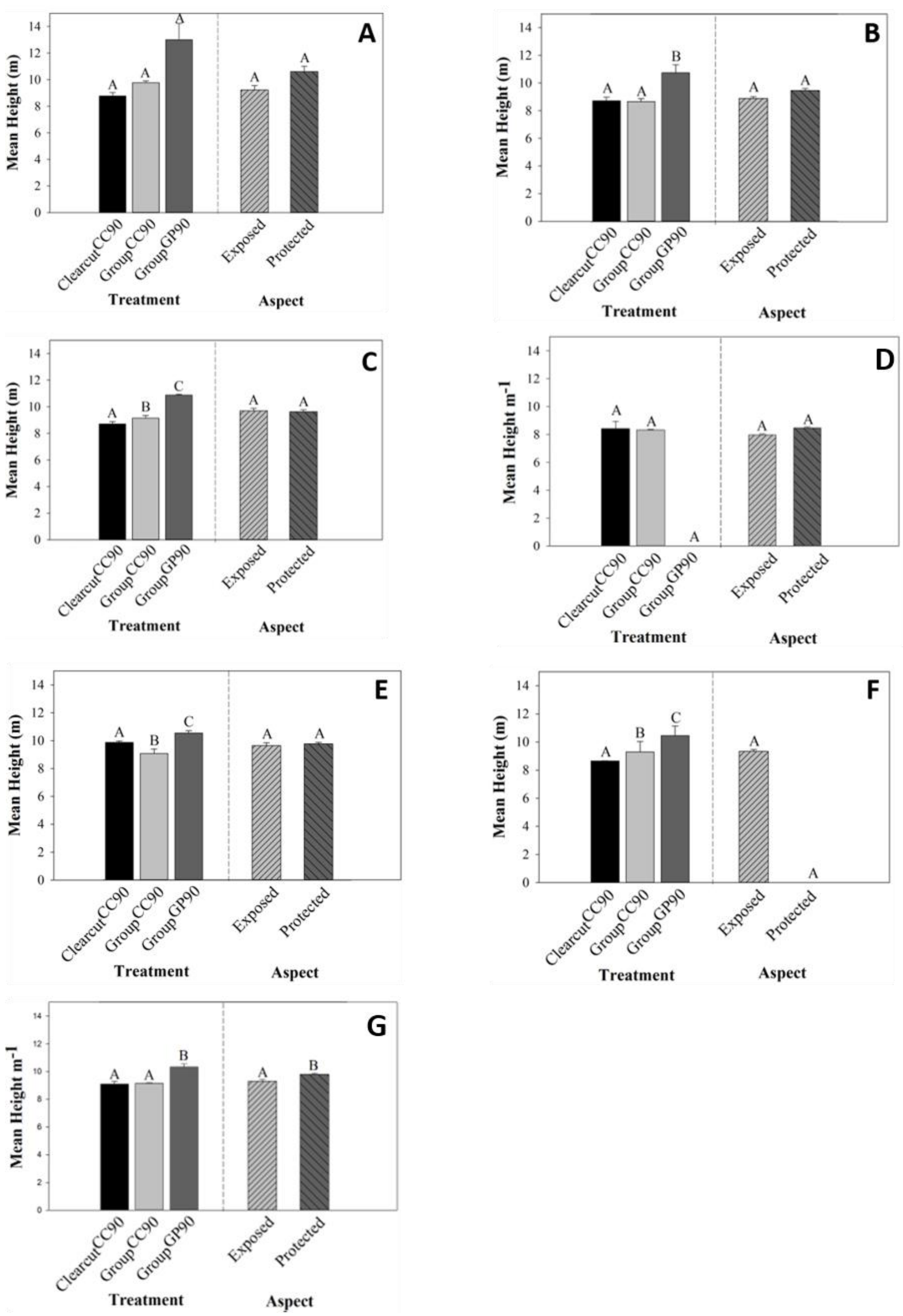

Figure 19. Mean height by treatment and aspect of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) for trees above the 90th percentile height threshold. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

The analysis of trees above the 90th percentile provide a magnified view of the top performing trees after 16 years of growth, and the inclusion of a third treatment, group opening^{CC}, provides a more direct comparison for trees growing within clearcuts and group openings. When all species groups are combined into a total group for each treatment, the trees per hectare data for all species groups combined were confirmed to have a non-normal distribution after applying Levene's test, and a log10 transformation was applied. The fixed effects of treatment ($p<0.001$) and aspect ($p<0.001$) were statistically significant (Figure 20). The three treatments analyzed through height thresholds resulted in significantly different trees per hectare within each treatment. Clearcut^{CC} resulted in the greatest amount of trees, and group opening^{GP} was found to have the least amount of trees per hectare. Clearcuts were found to have an average of 1103 trees per hectare compared to group opening^{CC} and group opening^{GP} with 650 and 227 trees per hectare respectively. There were significantly more trees per hectare on protected slopes compared to exposed slopes, and protected slopes had more than 260 additional trees per hectare than exposed slopes.

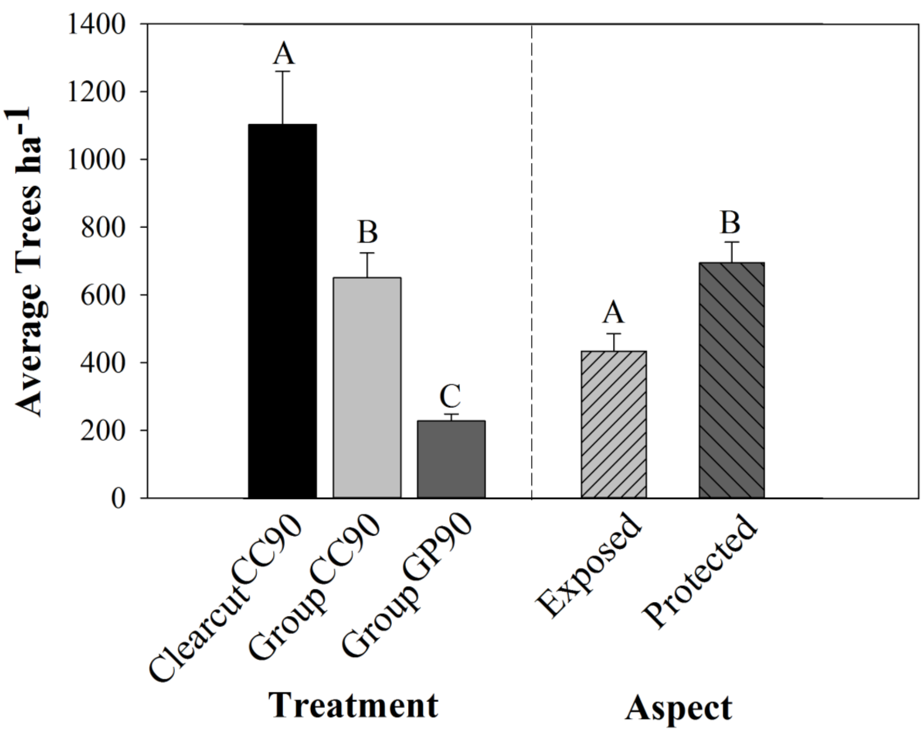

Figure 20: Average trees per hectare by treatment and aspect of the total species group for trees measured above the 90th percentile thresholds. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

The data for all hickories was confirmed to have a non-normal distribution after applying Levene's test, and a log10 transformation was applied. There was a significant interaction between treatment and aspect for the amount of hickories present (p=0.049) (Figure 21). Hickories were found to have significantly more trees per hectare within clearcut^{CC} compared to group opening^{CC} on exposed slopes (p=0.048) but not on protected sites (p=0.981). Clearcut^{CC} also had significantly more hickories per hectare compared to group opening^{GP} on both exposed (p=0.001) and protected sites (p=0.034). On exposed slopes group opening^{CC} had significantly more hickories than group opening^{GP} (p=0.029), but there was no significant difference in the amount of hickories within group opening^{CC} and group opening^{GP} on protected slopes. There was no significant effect of aspect within clearcuts (p=0.998), group opening^{CC} (p=0.223), and group opening^{GP} (p=0.065).

Maples were not found to have significantly different densities per hectare based on treatment (p=0.177), and the range of trees per hectare was between 31 to 87 trees for the three treatments (Figure 21). However, aspect was a significant fixed effect (p=0.002) resulting in significantly more maples per hectare within treatments on protected slopes. There was no significant interaction of treatment and aspect on the quantity of maples regenerating (p=0.339).

The amount of mixed hardwoods per hectare was significantly influenced by the fixed effects of treatment (p=0.011) and aspect (p<0.001) (Figure 21). Clearcut^{CC} and group opening^{CC} did not result in significantly different quantities of mixed hardwoods per hectare, but group openings had significantly fewer mixed hardwoods than the clearcut^{CC} and group opening^{CC} treatments. Clearcuts had nearly 200 more mixed hardwoods per hectare than group opening^{GP}. Protected slopes resulted in significantly more mixed hardwoods per hectare than exposed slopes. The dramatic difference in the average mixed hardwoods per hectare by treatment is mimicked by aspect, and this resulted in an average of more than 200 additional mixed hardwoods per hectare than exposed slopes. There was no overall significant effect of the interaction of treatment and aspect (p=0.055).

The data for others was confirmed to have a non-normal distribution after applying Levene's test, and a log10 transformation was applied. The amount of others per hectare was not significantly influenced by the fixed effects of treatment (p=0.127) or aspect (p=0.243) (Figure 21). Others were very infrequently found to measure above the 90th percentile height thresholds, and this resulted in fewer than 20 others per hectare regardless of treatment or aspect. Clearcut^{CC} and group opening^{CC} did not result in significantly different quantities of trees within the others species group per hectare, but group openings had significantly fewer others than the clearcut^{CC} and group opening^{CC} treatments. There were no others measured with heights above the 90th percentile calculated for group opening^{GP}, and this absence of trees is displayed in Figure 21.

Red oaks were found in greatest quantity within clearcuts^{CC}, and this is confirmed by the significant fixed effect of treatment (p<0.001) (Figure 21). There were an additional 282 red oaks per hectare on average compared to group opening^{GP}, and group opening^{CC} had nearly three times the average number of red oaks per hectare of group opening^{GP}. Group opening^{CC} and group opening^{GP} did not result in significantly different quantities of red oaks above the 90th percentile thresholds. However, there was no significant aspect effect (p=0.236) or treatment and aspect interaction effect (p=0.747)

Shortleaf pine were found in greatest numbers within group opening^{CC}, but there were no significant fixed effects of aspect (p=0.081) or treatment (p=0.527) (Figure 21). Group opening^{GP} and clearcut^{CC} had an average of 10 shortleaf pine per hectare, and group opening^{CC} had over 30 shortleaf pine per hectare. There were no shortleaf pine present within treatments on exposed slopes, and this absence is reflected in Figure 21.

Treatment was a significant fixed effect in the number of white oaks regenerating within MOFEP (p<0.002) (Figure 21). Clearcuts resulted in significantly more white oaks than group opening^{CC} and group opening^{GP}, and this translated to 293 white oaks per hectare within clearcut[CC]. Group opening[GP] resulted in the lowest quantity of white oaks, 51 per hectare. Both protected and exposed aspects resulted in less than a 20 tree per hectare difference, and aspect was not a significant main effect (p=0.759).

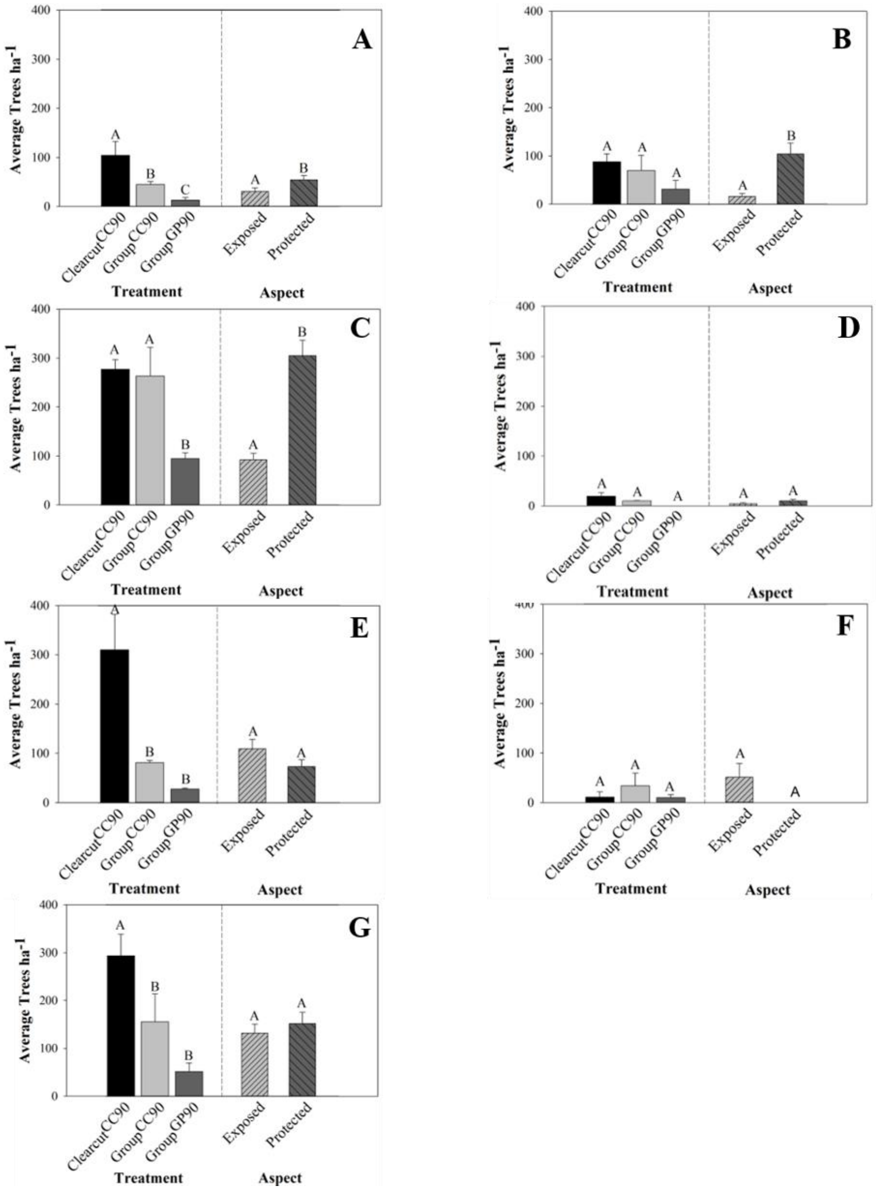

Figure 21. Average trees per hectare by treatment and aspect of seven species groups (hickories (A), maples (B), mixed hardwoods (C), others (D), red oaks (E), shortleaf pine (F), white oaks (G)) for trees measured above the 90th percentile thresholds. Statistical significance within treatment or within aspect is denoted by differing letters above standard error bars.

HEIGHT REFERENCE CHARTS

The application of each species group according to Vickers (2017) height reference charts had mixed results between the species groups as well as between each treatment and aspect. Overall, the combined species, or total, was a good predictor for the clearcut 90th percentile on both exposed and protected aspects (Figure 22). This success in predicting the trees within clearcuts is likely due to the fact that the trees used to create the reference charts are from within these same clearcuts. The reference charts provided a 90th percentile value below that achieved by group openings for the total species group on both exposed and protected aspects.

Blackgum were predicted well on both aspect charts for clearcut values. Whereas, blackgum 90th percentile from group openings were greater than the 99th percentile for the reference charts (Figure 23). Dogwood also mimicked the reference charts for clearcuts, but dogwood of group openings outperformed the 90th percentile predicted for both aspects (Figure 24). Hickories were consistent with the reference charts for both exposed clearcuts and group openings (Figure 25). Hickories from clearcuts were slightly underpredicted by the reference charts, but hickories in group openings had a greater 90th percentile than the reference chart. The reference charts were a good consistent match for clearcut others, but within group openings, others fell above the 90th percentile for both aspects (Figure 26). Sassafras reference charts were similar to the 90th percentile found within the exposed aspect of both treatments and aspects (Figure 27). Red oaks were consistent with the reference charts for clearcuts, but red oak 90th percentile values for both aspects of group openings fell below the 90th percentile of the reference charts (Figure 28). White oaks on the protected aspect for both treatment types matched the 90th

percentile of the reference charts (Figure 29). White oak 90th percentile for exposed group openings had a mean height that was above that level of the reference charts.

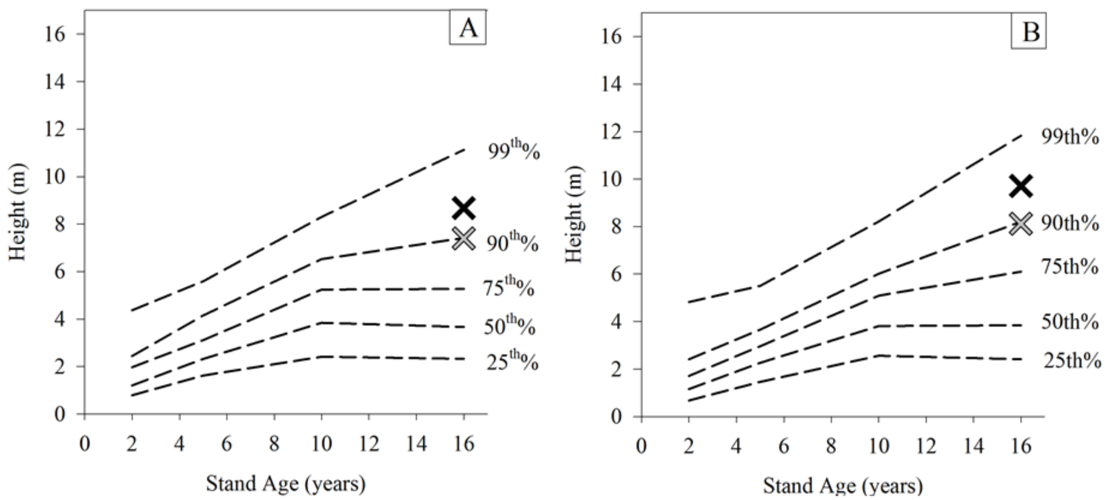

Figure (22). Reference charts for the total species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

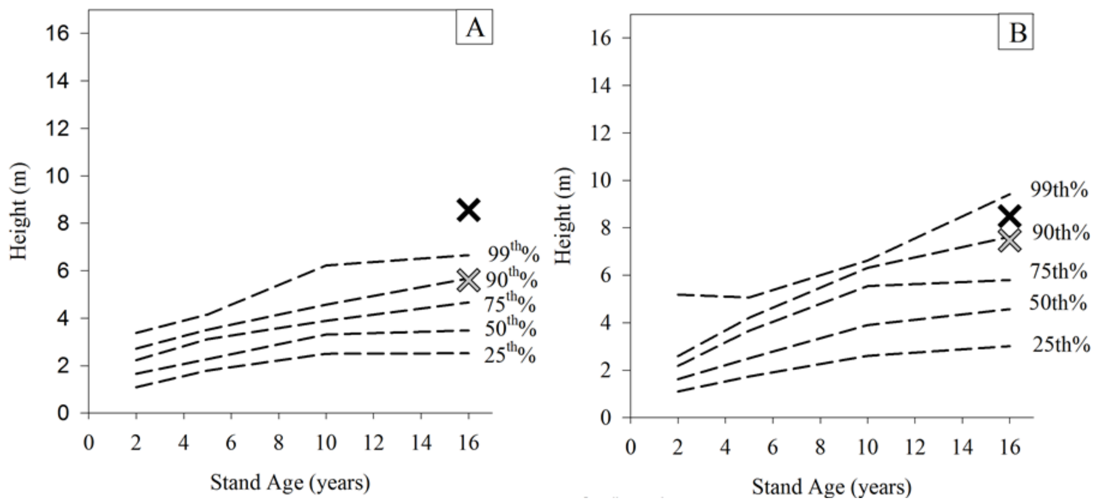

Figure (23). Reference charts for the blackgum species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey “X” depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black “X” depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

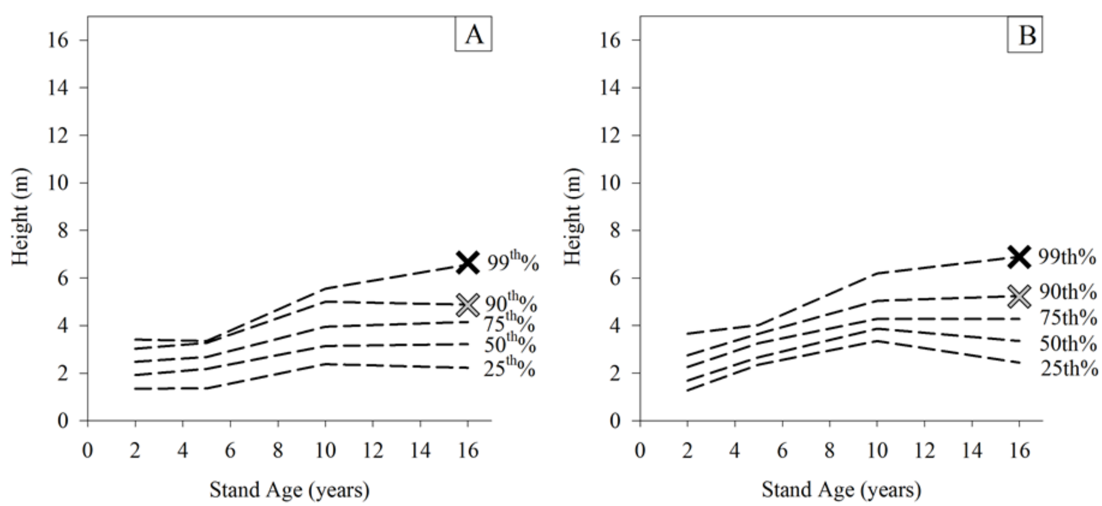

Figure (24). Reference charts for the dogwood species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey “X” depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black “X” depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

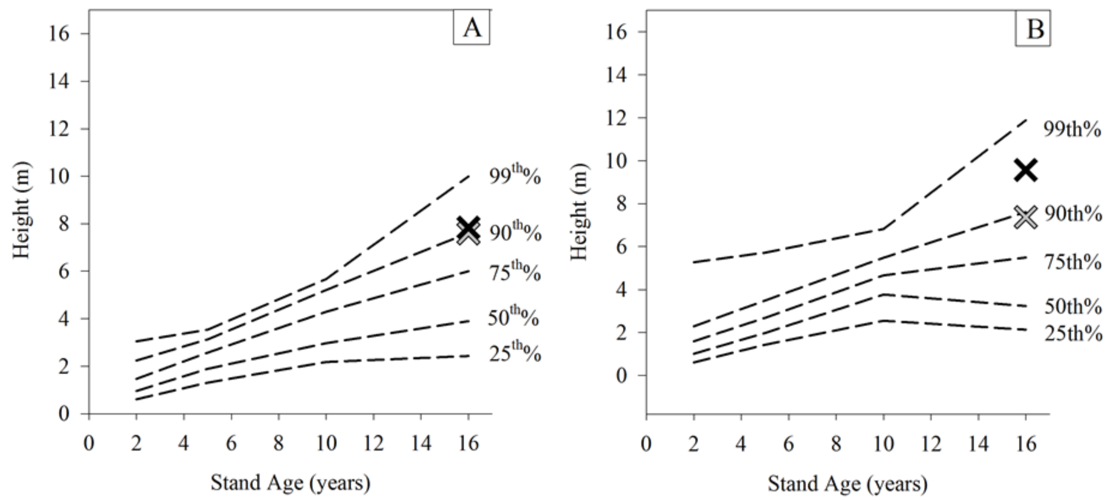

Figure (25). Reference charts for the hickories species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

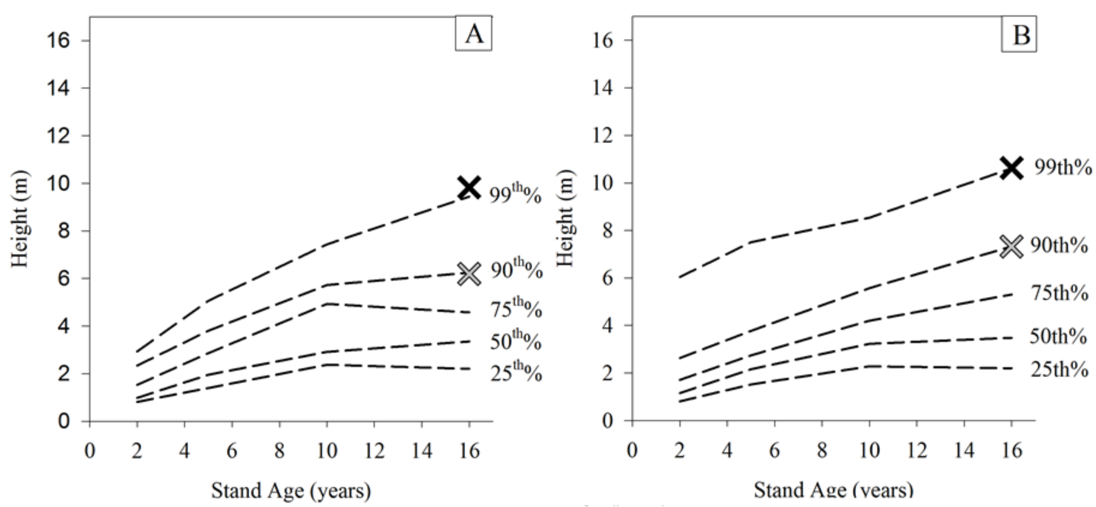

Figure (26). Reference charts for the others species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

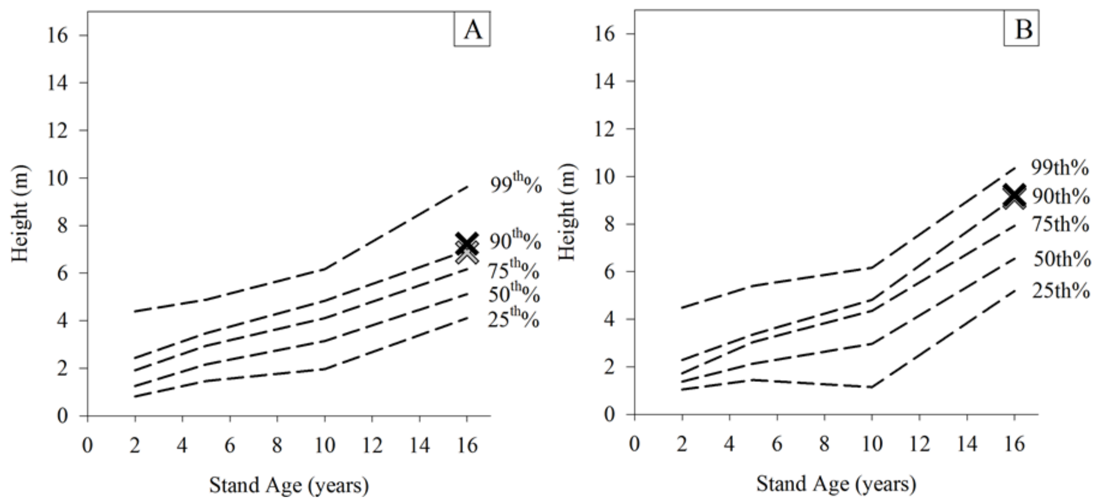

Figure (27). Reference charts for the sassafras species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

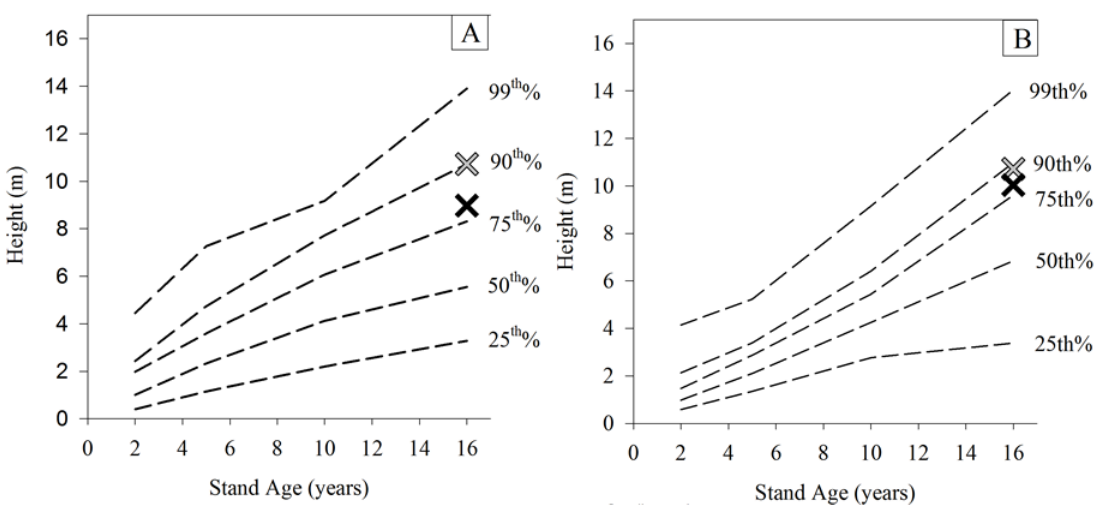

Figure (28). Reference charts for the red oaks species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

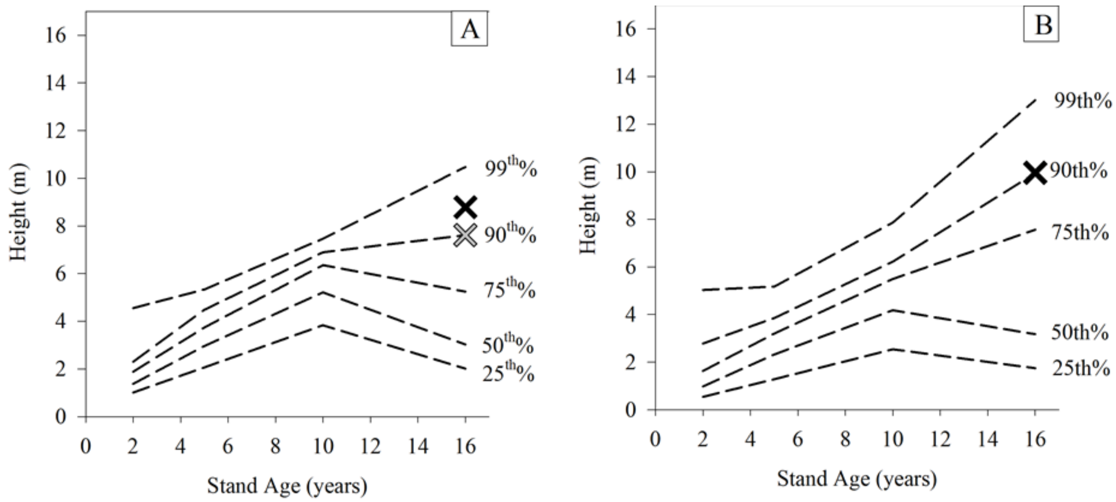

Figure (29). Reference charts for the white oak species group developed by Vickers et al. (year) are separated by aspect: exposed aspect (A) and protected aspect (B). Each reference chart has a grey "X" depicting an individual representing the observed 90th percentile threshold of the clearcut data collected for this study as well as a black "X" depicting an individual representing the observed 90th percentile threshold of the group opening data collected for this study.

CHAPTER 5

DISCUSSION

There is a mounting body of evidence that oak regeneration can be completed through varying prescriptions. Some research and assessment of oak regeneration has resulted in the assumption that oaks should be managed with even-aged stands (Roach, 1962; Roach, 1963). Upland hardwood management for oaks uses clearcutting as the historically recommended regeneration harvest (Roach, 1963). However, there are several documented instances in Southern Appalachia where even-aged management has not resulted in successfully regenerating oaks (Beck & Hooper, 1986; Loftis, 1983; McGee & Hooper, 1970). These studies provide evidence that prior to overstory removal, oak regeneration needs to be present in the form of advanced reproduction (Loftis, 1990; Carvell & Tryon, 1961; Loftis, 1983; Sander & Clark, 1971). While even-aged management can be successful in regenerating oaks, there is not a consensus that only even-aged management will successfully regenerate oaks. Minckler et al. (1961) indicates that the removal of only a few trees will not be sufficient to regenerate oaks, but single-tree selection within the Pioneer Forest appears to be a sustainable method for oak regeneration (Loewenstein, 1996). Additionally, Law and Lorimer (1989) developed a guideline for uneven-aged oak management. Group selection could function as an intermediary for clearcutting and single-tree selection, but do the resulting dynamics function as a disturbance too small for oak regeneration, a clearcut, or something altogether different?

Following the use of two regeneration treatments, clearcutting and group selection, the total regenerating tree density was significantly greater within clearcuts. Mixed hardwoods had the greatest percent composition of species sampled for all treatments and aspects, and both red oaks and white oaks were never greater than 28% of the total tree population for either treatment or aspect combination (Figure 4). However, due to the growing space needed for mature trees, the greater number of trees regenerating after 16 years did not result in more trees recruiting to the canopy. This display of a greater amount of smaller trees indicates that stem exclusion was still in progress within clearcuts during the time of this study, and the lower light levels within group openings might have restricted regeneration or accelerated the progression of stand dynamics. Interspecific and intraspecific competition during stem exclusion will result in mortality or the suppression of less competitive individuals.

The retention of overstory surrounding a site treated with group selection resulted in fewer individuals for all species groups examined when compared to clearcuts on the same aspect. Due to the lower light levels within the group openings, the onset of stem exclusion could have been initiated earlier than within the clearcuts. However, the lack of many smaller seedlings within group openings may be a result of the regeneration source. It is likely that within group openings the regeneration was sourced from existing advanced reproduction, and clearcuts had a larger pool of seedlings from advanced reproduction combined with smaller seedlings from nearby seed sources. Group openings were shown to have a lower quantity of red oaks in the larger size classes compared to red oaks within clearcuts. The lack of dominant red oaks within group openings indicates that the effect of overstory retention and subsequent reduction in sunlight made group openings less suitable for regenerating red oaks than clearcuts. White oaks were also found to be significantly more numerous in the regenerating clearcut stands when compared to the group openings. The greater sunlight within clearcuts appear to give a greater number of oak seedlings the chance to grow to a competitive size prior to stem exclusion. While the quantity of oaks is diminished within group openings compared to clearcuts, the desired seedling density (greater than 100 seedlings per acre) for successful regeneration as determined by the Missouri Department of Conservation is achieved (Missouri Department of Conservation, 2013).

The landscape of the Missouri Ozarks has been shown to promote the competitiveness of oaks on exposed slopes, but the success of oaks is less likley on protected slopes (Johnson, et al., 2009; Sander, Johnson, & Rogers, 1984). Oaks have been shown to be well adapted to drought conditions that can be experienced on exposed slopes, and this greater competitiveness on exposed slopes likely contributes to the greater oak component on exposed slopes (Abrams, 1990). The regeneration harvests that took place within this study on exposed aspect slopes resulted in a greater amount of oaks than the same regeneration harvests taking place on protected aspects. Therefore, it appears that the greatest chance to regenerate competitive oaks through group selection should take place on exposed slopes or to enlarge the size of group openings on protected slopes.

Mesophication of sites historically dominated by oaks has become a concern for forest managers within the eastern hardwoods (Nowacki & Abrams 2008). Through mesophication, more shade tolerant species such as maples can become more competitive and replace oak as the dominant canopy tree. Where fire has been excluded from the landscape in the Missouri Ozarks, there is evidence that this area could be in the early stages of mesophication (Olson et. al, 2014). Olson et al. (2014) further provides hypotheses that indicate that mesophication is occuring slower in the Ozarks compared to more eastern portions of the Central Hardwoods Region, and due to the common low quality soils, complete mesohpication may not fully occur. The data collected for this study indicate that despite the greater competitiveness of maples in areas of lower light levels, maples were significantly more abundant in clearcuts than group openings. Within the two treatments though, maples were most abundant on the protected aspect, and this conforms to the understanding of maple physiology and performance within more mesic sites. The overall density and height of maples within the group openings and clearcuts does not indicate that they will outcompete oak within these cohorts or regenerating trees (Loewenstein, 1996).

The most notable effect of aspect was the absence of shortleaf pine within the protected aspect plots of either treatment. Shortleaf pine have been found to be more competitive on xeric sites (Guldin, 1986; Stambaugh, 2001), and this study reinforces the assumption that more mesic sites provide a competitive advantage to species other than shortleaf pine. The results suggest that shortleaf pine cannot persist in the high-density of the smaller size classes through the process of stem exclusion. Therefore, if efforts to support early shortleaf pine dominance are not used, shortleaf pine may not successfully regenerate.

Group selection resulted in significantly greater mean heights for all species groups except red oaks and shortleaf pine, and these two species groups are also the least shade tolerant of the seven species groups. These results indicate that there is a greater opportunity for competitive red oaks and shortleaf pine following a clearcut regeneration compared to group selection. The taller mean heights for the remaining five species groups could be the result of an accelerated course through stem exclusion where the less competitive individuals already experienced mortality. Further examination of the individual species group mean heights showed that the mean height of all species groups except red oaks and shortleaf pine were significantly affected by the aspect, and a similar lack of aspect effect on northern red oak was found by Fekedulegn et al. (2003).

The curves expressed in the diameter distributions depict a striking difference between the smaller size classes of clearcuts and group openings as well. Clearcuts depict a greater complement of smaller diameter stems as evinced in the white oaks diameter distribution for clearcuts, and the common pattern for group openings is a lack a strong complement of small stems. The diameter distribution curves of oak and mixed hardwoods indicate a dearth for group openings on both aspects. Although there is a higher quantity of stems within clearcuts, stem exclusion will reduce the cohort size as trees experience mortality.

The basis for the second tier of analysis in this study were height thresholds designed to focus on only the trees most likely to recruit to the canopy, and the 90th percentile thresholds provided the basis for studying this selection of highly competitive individuals. The results indicate that clearcuts and group openings promote the development of trees in significantly different ways based upon tree density. The lower height threshold of the clearcuts applied to trees within group openings generally increased the amount of trees per hectare of each species group, and this is based on the fact that the lower threshold was more inclusive of smaller trees. This resulted in more trees per hectare within the group opening^{CC} compared to the group opening^{GP} treatments. The threshold values for both group openings and clearcuts highlight the greater quantity of shorter trees within the total population of clearcuts, and this distribution can be seen in Figure 20. The greater density of small trees within clearcuts will result in greater competitive pressure on shorter oak individuals.

Examination of trees above the 90th percentile thresholds depict a significant difference in tree densities for clearcut^{CC}, group opening^{CC}, and group opening^{GP}. The lower quantity of trees within the group openings is due in part to the greater mean heights found within the general tree population of group openings as well as the lower quantity of individuals within the smaller size classes. Red and white oaks had significantly more trees per hectare within clearcuts than the group openings with either threshold applied. This shows that even though the 90th percentile is taller in group openings, there is a greater amount of oak spp. within the taller size classes within clearcuts. Most notably, there is no significant difference for aspect when the oaks above the threshold are examined. The lack of aspect affect illustrates that the most competitive oaks for both group openings and clearcuts perform well despite aspect derived differences in resources, but regenerating oaks must contend with the better success of mixed hardwoods and maples on protected aspect sites.

Regarding tree height, the 90th percentile thresholds were the same for clearcut data from both exposed and protected aspects, 7.62 meters, and data from the group openings resulted in almost identical thresholds for both exposed and protected slopes, 9.35 meters and 9.36 meters respectively. The lower threshold for clearcuts is a result of the greater abundance of small stems compared to the limited quantity of smaller stems in group openings. With this basic assessment, it can be determined that the overstory retention surrounding the group openings resulted in accelerated stand dynamics compared to clearcuts of the same age or that regeneration potential was reduced. It is likely that residual trees surrounding group openings decrease the available light reaching regenerating trees through side shading and eventual gap closure. These residual trees result in peripheral regenerating trees approaching the stem exclusion stage earlier than if all trees in in the surrounding area had been removed. Further studies could be conducted to determine the variable light levels within the circular group openings and subsequent competitive pressure increase.

The results of this study indicate that the assumption that all oaks will be taller on average within clearcuts is not as definitive as predicted. Red oaks and white oaks developed in different ways based upon both treatment and aspect. The effects of aspect and treatment had no significant effect on the average height of red oaks, but white oaks were found to have greater mean heights within group openings and on protected slopes. White oaks over the 90^{th} percentile continued the trend of significantly greater mean height and tree quantity within group openings and on protected slopes. Red oaks with a height greater than the 90^{th} percentile threshold were taller on average within group openings, and this may be due in part to the fact that group opening 90^{th} percentile thresholds are taller than those of clearcuts.

The reference charts developed for assessing the height percentile of trees regenerating within the Ozark Highlands (Vickers et al., 2017) is a tool that can help forest managers determine where the height of a given individual tree falls within the typical height distribution of that species of tree. This study applied 90^{th} percentile values from sampled clearcuts as well as group openings for two purposes. First, the reference charts were used to verify that the data collected from clearcuts for this study fit within the broader distribution identified by Vickers et al. (2014). Secondly, the 90th percentile heights of species groups for group openings were applied in a similar fashion to determine if trees regenerating within group openings had heights similar to trees within clearcuts at a similar age.

Data acquired from the 16-year-old group opening trees were combined into species groups that conform to the height reference charts to determine whether the height reference charts could also be used as an assessment of group openings. Similar to the clearcut review, 90th percentile heights for each species group analyzed in the reference charts were plotted on the reference charts. Red oaks were the only species group that had a 90th percentile value from group openings that fell below the referenced value, and this is likely the result of the less shade tolerant red oaks falling behind the competitive curve developed for clearcuts. All other applications of field data for group opening 90th percentile values were found to be higher than the reference charts for both aspects.

The height reference charts and 90th percentile height for trees 16 years old are an effective review of trees regenerating within clearcuts since the data was collected from the similar locations within the MOFEP study sites. Generally, trees growing in group openings were found to have 90th percentile thresholds greater than those found in the reference charts. The greater 90th percentiles of the field values for group openings indicates that the reference charts can be used as baseline assumptions for tree height references. Developing group opening specific reference charts will be necessary for forest managers needing more specific assessments of individual regenerating trees.

CHAPTER 6

CONCLUSION

The size and type of regeneration treatments are often driven by factors outside of a forest manager's control. Public opinion or competing management objectives may encourage a forest manager to retain overstory within or surrounding a treatment area to meet additional forest management objectives. Considering the challenges of sustained forest management with multiple objectives results in a need to understand how the effects of overstory retention influence the composition, growth, and density of regenerating trees. The selection of even-aged and uneven-aged management requires an understanding of site and species characteristics.

This study confirms the ability to regenerate competitive oaks within the Missouri Ozarks. Forest management intent on promoting the greatest quantity of oaks can be achieved using clearcuts, and the greatest success will occur on exposed slopes. However, if the management objectives are to recruit oak seedlings to the canopy through alternative methods, uneven-aged management in the form of group openings is a viable alternative to clearcuts. The results from this study indicate that forest managers in the Ozarks can utilize group openings without fear of overstory retention stunting the growth of competitive oak seedlings. However, clearcuts are maintained as the most effective prescription to promote red oak regeneration.

The development of additional tools to determine regeneration success such as the stocking charts made by Roach and Gingrich (1968) can provide a wealth of information to guide forest management. The reference charts developed by Vickers et al. (2017)

provide an effective way to examine the success of individuals after even-aged management has been affected within the Missouri Ozarks. However, these reference charts do not provide the detailed accuracy needed to assess group openings within the same landscape.

FUTURE OPPORTUNITIES FOR STUDY

This study assessed the height and density of trees 16 years after two regeneration treatments were completed. MOFEP is designed as a long-term study, and further examination of these data could provide a greater understanding of the stand dynamics within both clearcuts and group openings. Comparison of these data to plot sampling at a later point in stand dynamics can shed light on the success of the total tree population as well as those above the 90th percentile thresholds. Future study could determine the effectiveness of the 90th percentile as a threshold for success or determine that an alternative threshold provides a better insight into trees that will recruit to the canopy.

Clearcuts provide an evenly distributed access to sunlight for all regenerating trees, but the use of group selection in this study focused on the access to 33% sunlight at the center of the group openings. The gradient of light levels within a clearcut due to the “edge” could influence both the composition, density, and height of regenerating individuals radiating from the center of the group openings to the more shaded sides. Based on a greater understanding of how the light levels change the growth of trees within group openings, forest managers could improve the size and shape of group selection treatments to better suit the desired species.

The reference charts developed by Vickers et al. (2017) provided an accurate tool to assess trees within the 90th percentile within clearcuts based upon the examination of this study. However, future assessment of the other percentile checkmarks will develop a better understanding of the effectiveness of this tool for other trees within clearcuts. Additionally, a similar reference chart system would be useful in examining trees regenerating within group openings.

Table 1. Species presence by species group, treatment, and aspect.

Scientific Name	Common Name (Species Group)	Treatment	Exposed Aspect	Protected Aspect
Acer negundo	Boxelder (Mixed Hardwoods)	Clearcut		
		Group Openings	X	x
Acer rubrum	Red Maple (Maples)	Clearcut	X	x
		Group Openings	X	x
Acer saccharum	Sugar Maple (Maples)	Clearcut	X	x
		Group Openings		x
Amelanchier arborea	Serviceberry (Others)	Clearcut	x	x
		Group Openings	x	
Carpinus caroliniana	Hornbeam (Mixed Hardwoods)	Clearcut	x	x
		Group Openings		
Carya cordiformis	Bitternut Hickory (Hickories)	Clearcut		x
		Group Openings		x
Carya glabra	Pignut Hickory (Hickories)	Clearcut	x	x
		Group Openings	x	x
Carya texana	Black Hickory (Hickories)	Clearcut	x	x
		Group Openings	x	x
Carya tomentosa	Mockernut Hickory (Hickories)	Clearcut	x	x
		Group Openings	x	x
Celtis occidentalis	Hackberry (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Cercis canadensis	Redbud (Mixed Hardwoods)	Clearcut	x	x
		Group Openings		x
Cornus florida	Flowering Dogwood (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x

Table 1. CONT

Scientific Name	Common Name (Species Group)	Treatment	Exposed Aspect	Protected Aspect
Crataegus phaenopyrum	Washington Hawthorn (Others)	Clearcut	x	x
		Group Openings	x	
Diospyros virginiana	Persimmon (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Fraxinus pennsylvanica	Green Ash (Mixed Hardwoods)	Clearcut		x
		Group Openings		
Frraxinus americana	White Ash (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Gymnocladus dioicus	Kentucky Coffeetree (Mixed Hardwoods)	Clearcut	x	
		Group Openings		
Juglans nigra	Black Walnut (Mixed Hardwoods)	Clearcut		
		Group Openings	x	x
Juniperus virginiana	Eastern Redcedar (Others)	Clearcut	x	x
		Group Openings		
Morus rubra	Red Mulberry (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Nyssa sylvatica	Blackgum (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Ostrya virginiana	Ironwood (Mixed Hardwoods)	Clearcut		x
		Group Openings		
Pinus echinata	Shortleaf Pine (Shortleaf Pine)	Clearcut	x	
		Group Openings	x	
Platanus occidentalis	American Sycamore (Mixed Hardwoods)	Clearcut	x	
		Group Openings	x	x

Table 1 Cont.

Scientific Name	Common Name (Species Group)	Treatment	Exposed Aspect	Protected Aspect
Prunus americana	Plum (Others)	Clearcut	x	x
		Group Openings	x	x
Prunus serotina	Black Cherry (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Quercus alba	White Oak (White Oaks)	Clearcut	x	x
		Group Openings	x	x
Quercus coccinea	Scarlet Oak (Red Oaks)	Clearcut	x	x
		Group Openings	x	x
Quercus marilandica	Blackjack Oak (Red Oaks)	Clearcut		
		Group Openings	x	x
Quercus muehlenbergii	Chinkapin Oak (White Oaks)	Clearcut		x
		Group Openings		x
Quercus rubra	Northern Red Oak (Red Oaks)	Clearcut	x	x
		Group Openings		
Quercus stellata	Post Oak (White Oaks)	Clearcut	x	x
		Group Openings	x	x
Quercus velutina	Black Oak (Red Oaks)	Clearcut	x	x
		Group Openings	x	x
Rhamnus caroliniana	Carolina Buckthorn (Others)	Clearcut	x	x
		Group Openings	x	x
Rhus copallinum	Winged Sumac (Others)	Clearcut		
		Group Openings	x	x
Rosa Carolina	Carolina Rose (Others)	Clearcut	x	
		Group Openings		

Table 1. Cont.

Scientific Name	Common Name (Species Group)	Treatment	Exposed Aspect	Protected Aspect
Sassafras albidum	Sassafras (Mixed Hardwoods)	Clearcut	x	x
		Group Openings	x	x
Sideroxylon lanuginosum	Gum Bumelia (Others)	Clearcut		x
		Group Openings		
Ulmus alata	Winged Elm (Others)	Clearcut	x	x
		Group Openings	x	x
Ulmus Americana	American Elm (Mixed Hardwoods)	Clearcut	x	x
		Group Openings		x
Ulmus rubra	Red Elm (Mixed Hardwoods)	Clearcut	x	x
		Group Openings		x
Vaccinium arboreum	Farkleberry (Others)	Clearcut	x	x
		Group Openings	x	
Viburnum rufidulum	Rusty Blackhaw (Others)	Clearcut		x
		Group Openings		x

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