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EFFECTS OF MIDSTORY REMOVAL ON BLACK OAK (*QUERCUS VELUTINA*) AND WHITE OAK (*QUERCUS ALBA*) REGENERATION

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ABSTRACT OF THESIS

EFFECTS OF MIDSTORY REMOVAL ON BLACK OAK (*QUERCUS VELUTINA*) AND WHITE OAK (*QUERCUS ALBA*) REGENERATION

The formation of dense understories in eastern forests has created low light environments that hinder the development of advance oak reproduction. Studies have shown that a midstory removal can enhance these light conditions and promote the development of competitive oak seedlings. Previous studies have been primarily focused on oaks found on productive sites, and there is little knowledge of this treatment's potential on intermediate sites and the typically associated oak species. This study investigates the seven-year effects of midstory removal on natural and underplanted white (*Quercus alba L.*) and black oak (*Quercus velutina L.*) reproduction, as well as competing red maples (*Acer rubrum* L.), on intermediate sites within the western rim of the Cumberland Plateau. In addition to its effect on stand reproduction, this study also investigates the impact of this treatment on microclimate. Results from this study can provide a look at the long term success of midstory removal on intermediate quality sites and serve as a basis for future oak management in the region.

KEYWORDS: Oak regeneration, Midstory Removal, Shelterwood, Red Maple Competition, Oak Management

David Parrott

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EFFECTS OF MIDSTORY REMOVAL ON BLACK OAK (*QUERCUS VELUTINA*) AND WHITE OAK (*QUERCUS ALBA*) REGENERATION

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THESIS

David Lee Parrott

The Graduate School

University of Kentucky

2011

EFFECTS OF MIDSTORY REMOVAL ON BLACK OAK (*QUERCUS VELUTINA*) AND WHITE OAK (*QUERCUS ALBA*) REGENERATION

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture at the University of Kentucky

By

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Lexington, Kentucky

Director: Dr. John M. Lhotka, Assistant Professor of Silviculture

Lexington, Kentucky

2011

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CHAPTER ONE: INTRODUCTION

Oaks (*Quercus* spp.) are one of the most commercially valuable species groups in the Central Hardwood Region and have historically been a dominant member of the region's forest composition. In 2005, 41% of the south central region's sawtimber hardwood was comprised of oak species. Of this region's sawtimber production, 40% of growing stock volume is within Tennessee and Kentucky (Luppold and Bumgardner, 2008). Aside from the marketability of oaks, they also fill a significant ecological role as mast providers for wildlife. Acorns have high nutritional value and are a major food source for many wildlife species such as quail (*Colinus virginianus*) , turkey (*Meleagris gallopavo silvestris*), squirrels (*Sciurus* spp.), deer (*Odocoileus virginianus)*, and mice (Dalke *et al.*, 1942; Goodrum *et al.*, 1971). They can provide over 50% of white tailed deer diets in the Northeast and in the Missouri Ozarks (Korschgen, 1962; Pekins and Mautz, 1987). Acorn production can also affect small mammal population size and black bear reproduction rates (Eiler *et al.*, 1989; McShea, 2000). Among the region's oak species, white oak acorns are preferred as they are more palatable (Short, 1976; Pekins and Mautz, 1987).

Difficulties in oak regeneration

While oaks have historically dominated eastern forests through natural and anthropological disturbances (Lorimer, 1993), changes in disturbance regimes have created problems with oak regeneration in recent decades (Clark, 1992). These difficulties are most prevalent on moist sites that develop dense understory competition (Abrams and Nowacki, 1992; Clark, 1992). In eastern oak forests, even-aged management favors shade intolerant species, such as yellow-poplar (*Liriodendron* *tulipifera* L.) (Beck and Hooper, 1986; Kolb *et al.*, 1990), while single tree selection management often results in the recruitment of shade tolerant species (Lorimer, 1984; Della-Bianca and Beck, 1985). Twenty years after a clearcut, Beck and Hooper (1986) observed a species composition shift from predominately oak to a stand dominated by yellow-poplar, sweet birch (*Betula lenta* L.), and red maple (*Acer rubrum* L.). Loftis (1983) witnessed similar results when shelterwood cuts, which removed 33 to 72% of original basal area, resulted in a stand of mainly yellow-poplar. Since small oak seedlings are unable to outcompete faster growing shade intolerant species and large shade tolerant species, oak recruitment into the overstory is reliant on the release of large, vigorous advance reproduction following harvest (Sander, 1972; Loftis, 1983; Sander *et al.*, 1984; Larsen and Johnson, 1998; Steiner *et al.*, 2008). The absence of this large advance reproduction is associated with the development of dense understories of shade tolerant species such as American beech (*Fagus grandifolia* Ehrh.), red maple, and sugar maple (*Acer saccharum* L.) throughout eastern forests (Abrams and Nowacki, 1992; Barton and Gleeson, 1996).

A main component of these shade tolerant understories is red maple, which Abrams (1998) labels as a “super-generalist” that is able to thrive in varying conditions of soil and light availability. While historically restricted to wetland areas, over the past 100 years, it has expanded its range into upland oak forests (Abrams, 1998). The relative importance (IV) of red maple increased from 30.1% to 60% in Kentucky between 1980 and 2006 (Fei and Steiner, 2007). Red maple’s rise in eastern forests may have been influenced by disease, disturbance, deer preference for oak browse, and fire suppression (Abrams, 1998). However, reintroduction of fire into upland oak forests has shown limited success in eliminating well established red maple competition (Alexander *et al.*, 2008; Green *et al.*, 2010). Alexander (2008) found that burning increased red maple mortality, however, did not place oak seedlings in an advantageous position since they were slow to respond and the surviving red maple displayed increased growth. Although slow growing in the understory, when released, red maple has the ability to exploit the increased light conditions and ascend into the overstory (Lorimer, 1984). With its increased abundance in oak forests, red maple is a factor in oak regeneration difficulties due to its ability to hinder oak recruitment (Nowacki *et al.*, 1990). Without the periodic harvest and burning regime that occurred during European settlement, eastern forests are expected to continue gravitating toward a composition of shade tolerant species (Abrams and Nowacki, 1992; Fei and Steiner, 2007).

Low light availability under shade tolerant midstories limits the development of suitable oak advance reproduction (Abrams and Nowacki, 1992; Kaelke *et al.*, 2001; Dey, 2008). Although individual oak species possess unique light requirements (Johnson *et al.*, 2002), oaks are considered to have intermediate shade tolerance, and studies have shown that they can maximize growth with light levels >20 % of full sunlight (Phares, 1971; Guo *et al.*, 2001; Dillaway and Stringer, 2006). This warrants silvicultural prescriptions for oak management to increase light availability to a level that will support oak regeneration, without increasing light to levels to a point that will encourage competition from shade intolerant species (Johnson *et al.*, 1989; Lhotka, 2006).

Currently, regenerating oak is not a universal issue. Clearcutting and shelterwood harvests are still practiced with success on lower quality, xeric sites where there is little competition and sufficient advance reproduction pools are present (Johnson *et al.*, 2002).

In these conditions, oaks have the ability to sustain without rigorous management; however, this may change over time if red maple continues to deviate from its original habitat preferences as it has done on mesic sites.

On higher quality sites, Loftis (1983) suggested the use of a modified shelterwood system to promote northern red oak development. This method involves the removal of the subcanopy with limited removal of the overstory basal area. Adopting this concept, other studies have shown that removing the midstory can create diffuse light conditions that enhance oak regeneration without promoting growth in fast growing, shade intolerant species (Lorimer *et al.*, 1994; Lockhart *et al.*, 2000; Lhotka and Loewenstein, 2009). However, on productive sites, midstory removal may not fully hamper progress of yellow-poplar (Lhotka, 2006). A midstory removal is performed by removing a predetermined amount of basal area or all of the midstory trees working from the smallest diameter (> 2.54 cm) up to the largest trees in the suppressed and intermediate crown classes. This is only recommended when abundant oak seedlings are present or after a large acorn crop (Loftis, 1990; Lockhart *et al.*, 2000). Long suppressed seedlings may not respond to treatment as well as new seedlings, and treatment should occur 10 years prior to final harvest to allow reproduction to reach appropriate competitive height (Loftis, 1990).

In order to ensure a sufficient supply of oak reproduction, underplanting prior to harvest can be used in conjunction with midstory removal (Dey *et al.*, 2008). Research has demonstrated the success of cherrybark and northern red oak artificial regeneration under different levels of retention with shelterwood harvests. In Arkansas bottomlands, cherrybark oaks planted under a partial shelterwood with competition removal displayed a ~98% survival after 5 years (Gardiner, 1999), and northern red oak underplantings have displayed increased growth under shelterwoods with competition removal (Dey *et al.*, 2008).

Microclimate

Microclimate elements other than light may also limit oak regeneration since soil moisture can affect seedling growth (Hodges and Gardiner, 1992). On drier sites, soil moisture could be a critical factor in seedling development. While oaks are generally drought tolerant, low soil moisture can slow root development (Larson and Whitmore, 1970). Studies have shown that soil moisture increased with canopy removal treatments in Michigan oak forests (Buckley *et al.*, 1998), and that areas under canopy gaps have higher soil moisture than under an intact overstory in mixed hardwood forests (Minckler and Woerheide, 1965). Not only does water availability affect growth rate, it can also influence carbon allocation and hence development of organs responsible for capturing limited resources. As indicated in Kolb (1990), northern red oak shoot: root ratios decreased in scenarios where soil moisture was low, and increased when grown in shaded conditions.

While microclimate influences vegetation, vegetation also influences microclimate. By providing shade, intercepting precipitation, transpiring, and uptaking water, woody species can alter local environmental conditions (Breshears *et al.*, 1998). Manipulation of forest structure through harvests and silvicultural prescriptions have been shown to influence microclimate variables such as light, air temperature, soil moisture, and relative humidity. Buckley et al. (1998) found that soil moisture was similar between clearcuts and shelterwoods harvest of varying levels of retention, but these levels were higher than those found within intact oak forests after two years. However, differences in soil temperature were higher in clearcuts and shelterwoods with 25% retention compared to 75% retention shelterwoods and undisturbed forests (Buckley *et al.*, 1998).

Need for and Significance of Project

Experimentation on midstory removals has focused on high quality sites, and little is known about the effectiveness of midstory removals on intermediate quality sites (Site index = 18.24 to 22.9 m; Johnson *et al.*, 2002) within the Cumberland Plateau or on the white and black oaks that are common to the region. Research has mainly examined the effects of midstory removal on red oaks on mesic sites. For northern red oak (*Quercus rubra* L.) this practice increases seedling survival and growth (Loftis, 1990; Lorimer *et al.*, 1994; Miller *et al.*, 2004; Dey *et al.*, 2008), and cherrybark oak (*Quercus pagoda* Raf.) seedlings have responded similarly (Lockhard *et al.*, 2000; Lhotka and Loewenstein, 2009). However, effectiveness of midstory removal on underplanted and natural oak regeneration on intermediate sites is uncertain. A slower growing species such as white oak may not have the same response as other faster growing oak species (Dillaway, 2005).

Results from this study can provide information to aid in oak silviculture and serve as a basis for oak management on intermediate sites within the region. Observations made after seven growing seasons after treatment will provide insight into the long term effects of treatment on oak and red maple seedlings. Evaluation of environmental conditions altered by midstory removal will provide information to allow comparison of our results to other studies and may indicate possible mechanisms affecting seedling response to treatment in our study.

Objectives

- **Objective 1**: To evaluate effects of midstory removal on growth of natural regeneration of white and black oak and red maple seven years after removal.
- **Objective 2**: To evaluate effects of midstory removal on microclimate seven years after implementation.

CHAPTER TWO: THE EFFECTS OF MIDSTORY REMOVAL ON BLACK AND WHITE OAK NATURAL REGENERATION

INTRODUCTION

Historically, fire and other disturbances contributed to the dominance of oaks (*Quercus* spp.) throughout eastern forests (Lorimer, 1993), but in recent decades, problems with oak regeneration have emerged (Clark, 1992). Oak forest understories are being replaced with shade tolerant species such as American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), and sugar maple (*A. saccharum* L.) (Abrams, 1992; Barton and Gleeson, 1996). This shift in forest composition has been attributed to fire suppression, disease, changes in harvest practices, and deer preference for oak browse (Abrams, 1998). Of the shade tolerant species, red maple has dramatically expanded its abundance in the past 100 years (Abrams 1998). Labeled as a "super-generalist" (Abrams, 1998), red maple is able to thrive in an array of soil and light conditions that coincide with oak habitat and has the ability to exploit the increased light upon release while growing in the understory (Lorimer, 1984). With its increased abundance in oak forests, red maple has become a threat to successful oak regeneration (Nowacki *et al.*, 1990).

Given oak regeneration problems seen across eastern hardwood forests, an array of approaches have been evaluated as a means to enhance the regeneration of oak. In Appalachian oak forests, clearcutting has been shown to favor shade intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.), which can outcompete oaks in the high light environments (Beck and Hooper, 1986; Kolb *et al.*, 1990). In contrast, single tree selection often results in the recruitment of shade tolerant species that can grow in the understory and into open canopy gaps (Lorimer, 1984; Della-Bianca and Beck, 1985). Since small oak seedlings are unable to compete with faster growing shade intolerant species and large shade tolerant advance reproduction, oak regeneration has been most successful following treatments that promote large, vigorous oak reproduction in an advantageous position prior to final release (Sander, 1972; Loftis, 1983; Sander *et al.*, 1984; Larsen and Johnson, 1998; Steiner *et al.*, 2008).

Natural development of advance oak reproduction is thought to be limited by low light intensities present under shade tolerant midstory canopies, which can be as low as 3% full light (Abrams and Nowacki, 1992; Kaelke *et al.*, 2001; Dey *et al.*, 2008). Midstory removal is a modification of the shelterwood method and has been suggested as a means to create diffuse light conditions that enhance the development of oak reproduction without promoting growth of intolerant species (Dey *et al.*, 2008). Research concerning this treatment has been mainly focused on its use with northern red (*Querus rubra* L.) and cherrybark (*Quercus pagoda* Raf.) oaks on mesic sites. Northern red oak seedlings have responded favorably following midstory removal (Loftis, 1990; Lorimer *et al.*, 1994; Miller *et al.*, 2004; Dey *et al.*, 2008). For cherrybark oak, this practice has been shown to increase seedling survival and growth (Lockhart *et al.*, 2000; Lhotka and Loewenstein, 2009). Few studies have examined the success of this technique on oak species common to intermediate quality sites within the Cumberland Plateau. The objective of this study is to investigate the effects of midstory removal on natural and underplanted white oak and black oak (*Quercus velutina* Lamb.) reproduction as well as red maple natural reproduction seven years after implementation. Red maple observations were included in addition to oak seedling response since it acts a primary competitor species. A second objective was to document the light environment created by a midstory removal.

METHODS

Study Sites

In 2003, Dillaway et al. (2005) established four study sites within the Knobs region on the western rim of the Cumberland Plateau. Sites were located on Berea College Forest andwere of intermediate quality (upland oak site indices ranged from 22 to 24 m). The four sites are referred to as Horsecove, Water Plant, Pigg House, and Fentress Spur. Soils were largely acidic, well drained silt loams (Captina, Rockcastle, Shelocta, and Weikert series) (Soil Survey Staff). Dominant overstory trees had a mean age of 90 to 116 years and were primarily mixed oak species. American beech, red maple, and sugar maple were the primary components of the midstory prior to treatment. Among sites, initial basal areas ranged from 23.6 to 28.0 m^2ha^{-1} (Dillaway, 2005).

Study Design

At each site, a 0.2 ha rectangular area was divided into two 0.1 ha experimental units. Experimental units were randomly assigned one of two treatments: midstory removal or undisturbed control. In February and March of 2004, midstory removal treatments were performed by removing approximately 20% of the basal area beginning with stems possessing a dbh of 2.54 cm and moving up until the target basal area was reached (Dillaway, 2005). After treatment implementation, basal area ranged from 18.8 to 22.5 m^2ha^{-1}. Dominant and codominant overstory trees were retained in this process. Slash was removed from experimental units to allow easy access, and stumps were sprayed with 100% Roundup Pro (Monsanto Company, St. Louis, Missouri) to prevent sprouting. After seven growing seasons (2011), post-treatment stand structure was reassessed using nested circular plots; .04 ha for trees > 9 cm dbh and 0.01 ha for trees > 2.5- 9 cm dbh. Data showed that only two midstory trees (2.54 cm – 9 cm) where present in the midstory removal treatment across all four study sites and that no disturbance of the overstory canopy had occurred. These results suggest stand structure of the midstory removal plots after seven growing seasons (2011) is comparable with structure present immediately following treatment.

In March 2004, black oak and white oak 1-0 bareroot seedlings were planted and tagged to facilitate long-term monitoring (Dillaway *et al.*, 2007). Initial seedling ground line diameter (gld) and heights were recorded at planting. Seedling sample sizes after seven growing seasons ranged from 50 to 65 on each site. Variation was due to mortality and missing tags. Due to vandalism in the Fentress Spur site, underplanted white oak seedlings could no longer be tracked; therefore, Fentress Spur was not used for underplanted white oak seedling analyses. In addition to underplanted seedlings, fifty naturally regenerated white oak, black oak, and red maple seedlings were randomly selected in each treatment at all four sites. The height and ground line diameters were also measured for these seedlings within each experimental unit.

Data Collection and Analysis

Seedling Measurements

Height and gld measurements were taken for underplanted white and black oak and for naturally regenerated white oak, black oak, and red maple seedlings immediately following treatment and after seven growing seasons (August 2010). Seedling height was measured using a meter stick held perpendicular to ground. Height corresponding to the tallest shoot was recorded to the nearest 0.5 cm. Gld was measured at the convergence of the stem and ground using digital calipers. Two perpendicular measurements were taken, and the average of these measurements represented the gld for the seedling. Measurements were recorded to the nearest 0.1 mm. In addition to height and gld measurements, competitive position was assessed for seedlings in August 2010. A technique employed by Gottschalk and Marquis (1982) was used to classify a seedling's competitive position among neighboring vegetation into the following categories: free-to-grow, intermediate, and suppressed. Freedom to grow was evaluated using a hypothetical 90° cone that extended 120 cm from a seedling's terminal bud. Dividing the cone into quarters, it was oriented to encompass as much competitive vegetation into as few quadrants as possible. The total number of quadrants occupied by competition was recorded for each seedling. A stem with no competitors within any quadrant was considered free-to-grow while a seedling with all four quadrants occupied or with its apical stem completely overtopped was considered suppressed. All other conditions were classified as intermediate. For each natural and underplanted species, pretreatment mean height and diameter data were analyzed using a paired two-tailed t-test to test for any differences in initial seedling sizes between treatments. One-tailed t-tests were then used to detect any differences in mean total height and mean total gld between treatments for each natural and underplanted species. Experimental units within the same sites were used as pairs for analyses.

Leaf area

Seedling leaf area was observed since it serves as an indicator of growth. To facilitate nondestructive determination of leaf area, regression equations were developed to predict individual leaf area based on midrib length. For oak leaves, midrib length included the petiole, but for red maples, this measurement ended at the bottom of the leaf blade. Leaves were randomly collected from seedlings within the experimental units. Twenty leaves were collected from each treatment for each species. The initial leaf samples for white and black oaks did not span a wide enough range to encompass the larger and smaller leaves within the population; therefore, an additional sample of 20 leaves was selected from each treatment. Final sample totals were 40 red maple, 75 black oak, and 75 white oak leaves (five white oak and five black oak leaves were damaged and not used in analysis). Using these destructively sampled leaves, regression equations were developed. A natural log transformation was used to linearize the relationship between midrib length (cm) and area of individual leaves (cm^2). Treatment had no significant effect on the relationship between leaf area and midrib length for any species ($p > 0.05$).

To assess the treatment effect on leaf area, ten white oak seedlings were selected from each experimental unit. Selected seedlings represented the distribution of diameters of present regeneration within each experimental unit. Midribs were measured for every leaf on each seedling. Measurements were then used to calculate the necessary sample size to estimate mean midrib length with an allowable error of 10% at a 95% confidence interval. It was determined that a random sample of 40% of a seedling's leaves was required to get an accurate estimate of mean midrib length.

In the field, 15 seedlings of each species were randomly selected from tagged seedlings within each experimental unit. For each seedling, 40% of the leaves were systematically selected and midribs were measured. Total leaf counts were taken for each seedling and total seedling leaf area was estimated by multiplying the average predicted leaf area based on the mean midrib by the total leaf count of the seedling. Mean per seedling leaf area between treatments were analyzed using a two-tailed paired t-test.

Light measurements

In order to quantify changes in available light associated with the midstory removal, photosynethically active radiation (PAR) (400-700 nm) was measured in µmols/m^2/s using a Accupar PAR ceptometer (Decagon Devices, Inc., Pullman, WA) within each experimental unit. Measurements were taken within 2 hours of solar noon in uniformly overcast conditions where the solar disk was not visible in order to reduce influence of sun flecks (Messier and Puttonen, 1995). Measurements were taken in all treatments on May 18 and19 and again between July 13 and 19 of 2010. Samples were collected at 5 points within each experimental unit: one in the center and one in the center of each quadrant of the experimental unit. At each point, a reading was taken 3 times at breast height (1.37 m above ground) at the three cardinal directions away from technician’s shadow. Accompanying these measurements, open light measurements were taken simultaneously with a stationary Licor quantum sensor (LI-190SB, Li-Cor, Lincoln, NE) connected to a datalogger (CR1000, Campbell Scientific, Logan, UT) that measured PAR every minute and recorded mean PAR every 15 minutes. Percent of interception for each experimental unit was calculated using concurrent PAR measurements from experimental unit samples and open sunlight samples. While these measurements represent the percentage of available light seven growing seasons following the midstory removal treatment, the continued absence of a midstory throughout this period expressed in the 2010 inventory suggests that current light levels are analogous to those at the time of the initial treatment implementation.

RESULTS

Seedling Growth and Competitive Position

Analysis of pretreatment data showed no differences in mean height between treatments for underplanted white oak (p = 0.8247) and black oak (p = 0.719) reproduction, as well as natural white oak (p = 0.1578), black oak (p = 0.1613), and red maple (p = 0.3059) advance reproduction (Table 1.1). There were also no differences in mean gld between treatments for underplanted white oak (p = 0.8247) and black oak (p = 0.719) as well as natural white oak (p = 0.1578), black oak (p = 0.1613), and red maple (p = 0.3059) advance reproduction (Table 1.1).

After seven growing seasons, trends across oak species and reproduction type suggest midstory removal increased seedling growth (Table 1.2). Average heights of natural (p = 0.0156) and underplanted white oak (p = 0.0253) reproduction were 16.4 cm and 15.3 cm taller on average in the midstory removal treatment. Average height for natural black oak reproduction was 24.8 cm taller in the removal treatment (p = 0.0799), but was only statistically different at an alpha = 0.10. Height of underplanted black oak was 14 cm larger in the removal treatment than in the control (p= 0.1529), but differences were not statistically significant.

Gld analyses suggest midstory removal increased seedling growth. Average gld of natural white oak (p = 0.0017), red maple (p = 0.0027), and underplanted black (p = 0.0240) and white oak (p = 0.0308) and were significantly larger in the removal treatment than in the control treatments (Table 1.2). Natural black oak gld was significantly greater in the midstory removal treatment at an alpha level = 0.10 (p = 0.0862). For natural white oak, black oak, and red maple reproduction gld was increased by at least 53% following midstory removal. Underplanted white and black oak gld increased by more than 25% in the midstory removal treatment.

Red maple seedlings also displayed a positive response to removal treatment, and exhibited a 68% larger height (69.8 cm; p = 0.0063) and 55% larger gld (10.1 mm; p = 0.0027) in the removal treatment (Table 1.2). Additionally, 51% of red maple seedlings in midstory removal treatments were 60 cm or taller (Figure 1.1).

Trends in height distributions differed between treatments (Figure 1.1). Within the control, less than 10 percent of the natural and underplanted black oak were greater than 79.5 cm. Conversely, in the removal treatment, 37 percent of the natural black oak seedlings and 22 percent of the underplanted black oak seedlings were greater than 79.5 cm. Among these larger seedlings, almost all were in intermediate or free-to-grow positions. Among natural and underplanted white oaks, less that 10 percent were larger than 59.5 cm in the control treatment. In the removal treatment, 23 and 20 percent of the natural and underplanted white oaks were taller than 59.5 cm, respectively. These larger white oak seedlings had a much smaller proportion of suppressed seedlings. As seedlings entered the larger height classes, they were more likely to be in intermediate and free-to-grow positions. Among the red maple seedlings, less than 10 percent were greater than 79.5 cm in the control, but 37 percent were greater than 79.5 cm in the removal treatment. Similar to the oak seedlings, stems in higher height classes were less likely to be in suppressed positions.

Leaf Area

Using natural log transformations, regression equations for predicting leaf area from midrib lengths indicated that midrib length explained at least 92% of the variation in single leaf area for all species (Table 1.3). Regression equations were as follows:

Black oak: $\ln(\text{Leaf Area}) = -1.10 + 2.02 * \ln(\text{Midrib Length})$
White oak: $\ln(\text{Leaf Area}) = -0.97 + 1.93 * \ln(\text{Midrib Length})$
Red maple: $\ln(\text{Leaf Area}) = -0.97 + 2.20 * \ln(\text{Midrib Length})$

where leaf area is measured in cm and midrib length was measured in cm^2.

All observed species had over a 100% greater average estimated leaf area and at least double the leaf count in the midstory removal treatment compared to the control. Within removal areas, there were higher estimated leaf areas per seedling for white oak ($p = 0.0044$) and red maple ($p = 0.0241$) natural regeneration. Underplanted black ($p = 0.1711$) and white oak ($p = 0.3058$) and natural black oak ($p = 0.2405$) reproduction also had higher estimated leaf area in the removal treatment; however, results were not statistically significant. Leaf counts were doubled in the removal treatment for underplanted white ($p = 0.3617$) and black ($p = 0.1737$) oaks, natural white ($p = 0.0036$)

and black oak (p = 0.2197), and red maple (p = 0.0156). However, only natural white oak and red maple reproduction were statistically significant.

Light Measurements

Since the midstory was still absent after seven growing seasons, it was reasonable to assume that observed light conditions after seven years were analogous to those present upon treatment implementation. Light availability was significantly higher under the midstory removal treatments (p = 0.0098) with a mean 14% full light available and 5.3% full light available under intact canopies during overcast sky conditions. Among sites, light levels in control treatments ranged from 2.18 to 9.58% full light available, and 5.27 to 24.31% in midstory removal treatments.

DISCUSSION

The midstory removal treatment in this study was successful in increasing light levels to aid oak development. The light levels we observed under intact and treated midstories were similar to those presented in previous studies. Although increased, light levels under removal treatments were often below the recommended 20% available light for optimal oak growth (Gottschalk, 1994; Guo *et al.,* 2001); however, they were enough to elicit a positive response from the oak regeneration.

Although results imply oak seedlings were positively influenced by midstory treatment, observed responses were not of the same magnitude as seen in other studies. Lorimer (1994) found that underplanted northern red oaks grew to 52 cm under an understory removal and were < 35 cm under intact canopies after 5 growing seasons. Lockhart et al. (2000) found cherrybark oaks grew 120 cm after 9 growing seasons.

However, comparisons between these studies and ours are inadequate since growth rates among observed oak species differ (Johnson *et al.*, 2002). Slower growth rates seen in white and black oaks compared with northern red and cherrybark oaks, may represent differences in growth potentials of these species (Kobe *et al.*, 1995). The oak seedling growth in our study may have also been hindered by understory competition, primarily red maple.

Gottschalk (1994) found a positive reponse by red maple to light levels associated with shelterwood and midstory removal treatments which supports the results observed in this study. Red maple seedlings occurred at high densities in the study area (> 42,000 stems ha^{-1}) and displayed significantly larger mean height and gld in the removal treatment. Additionally, 51% of red maple seedlings in midstory removal treatments were 60 cm or taller (Figure 1.1). Taller seedlings had increased likelihood of being free-to-grow and acting as a potential competitor for neighboring oak seedlings. Hartman et al. (2005) found that red maple was able to overtop oak seedlings within 10 years following a thinning.

This is important to note since the treatment could potentially increase the height of oak seedlings while also promoting competitor species thus creating a regeneration pool of tall, overtopped oaks. Therefore, the positive response in red maple and the competitive position of oak seedlings in treated areas suggest that a midstory removal alone may not be sufficient to produce a competitive population of oak regeneration prior to release in these conditions with these oak species.

Management Implications

In order to be competitive, oak regeneration is recommended to be at least 137 cm upon release (Sander, 1972). The midstory removal in this study was shown to increase the size of seedlings after seven growing seasons; however, the mean height for the oak species observed had not reached this threshold. Among all 422 oak seedlings in treated areas, there were only 62 stems that were 80 cm or taller, and of these only 31 were free from direct competition from neighboring vegetation. With current mean yearly growth rates, observed artificial and natural white oak and black seedlings would suggest that the oak seedlings in this study would not reach competitive height within the next 5 years or longer if growth rates remain constant. This is assuming that seedlings are not overtopped by competing shade tolerant species, which is possible (Hartman *et al.*, 2005). Subsequent release of these seedlings through overstory removal may be necessary to increase these growth rates and encourage seedlings to reach competitive heights. However, the amount of release necessary for further white and black oak development is unknown.

The significant increase in red maple growth under the midstory removal treatment suggests that while hindering competition from shade intolerant species, midstory removal may not alleviate competitor pressures from shade tolerant species. Therefore, competition removal treatments may be necessary to place oak in an advantageous position for release especially if further overstory removal is completed. Fire in conjunction with shelterwood harvests have been shown to be effective in enhancing competitive position of oaks against shade intolerant species in the Virginia Piedmont (Brose *et al.*, 1999); however, single and repeated burning without silvicultural treatments within the Cumberland Plateau has not eliminated red maple competition (Blankenship and Arthur, 2006; Alexander *et al.*, 2008). Further studies should investigate the combination of fire and midstory removal in this region and its effects on oak competitive capacity. While red maple competition is a concern, results from this study indicate that midstory removal can positively enhance the development of oak reproduction in the region and may serve as an important step for successful management for oak regeneration.

Table 1.1. Pretreatment mean height, gld, leaf area, and leaf count for all observed species in control and midstory removal treatments.

	Natural Regeneration			**Underplanted**	
	Black Oak	White Oak	Red Maple	Black Oak	White Oak
Mean Height (cm)					
Control	32.8	23.1	28.5	31.6	24.8
Midstory Treatment	30.1	21.2	30.4	32.0	24.6
Mean GLD (mm)					
Control	4.8	3.3	5.2	6.2	6.0
Midstory Treatment	4.6	3.2	4.5	6.1	5.6

Table 1.2. Mean height, gld, leaf area, and leaf count for all observed species in control and midstory removal treatments.

	Natural Regeneration			**Underplanted**	
	Black Oak	**White Oak**	**Red Maple**	**Black Oak**	**White Oak**
Mean Height (cm)					
Control	52.3 *	28.9 **	41.6 **	37.4	31.0 **
Midstory Treatment	77.1 *	45.3 **	69.8 **	51.4	46.3 **
Mean GLD (mm)					
Control	8.5 *	4.7 **	6.5 **	7.0 **	7.4 **
Midstory Treatment	13.0 *	7.8 **	10.1 **	9.9 **	9.1 **
Mean Leaf Area (cm^2)					
Control	1385.7	434.6 **	450.2**	518.0	397.2
Midstory Treatment	4164.8	1256.2 **	1210.9**	1187.2	1954.2
Mean Leaf Count					
Control	19.4	16.4 **	17.5 **	8.6	13.3
Midstory Treatment	57.2	34.1 **	45.5 **	16.8	26.8

**Signifies a difference between treatments ($p < 0.05$).

* Signifies a difference between treatments ($p < 0.10$).

Table 1.3. Regression parameters and fit statistics for predicting leaf area (cm^2) from leaf midrib length (cm) for observed species.

Species	**n**	**R^2**	**b_0**	**b_1**
Black oak	75	0.9626	-1.09842	2.02231
Red maple	40	0.9977	-0.97193	2.19282
White oak	75	0.9260	-0.97324	1.93104

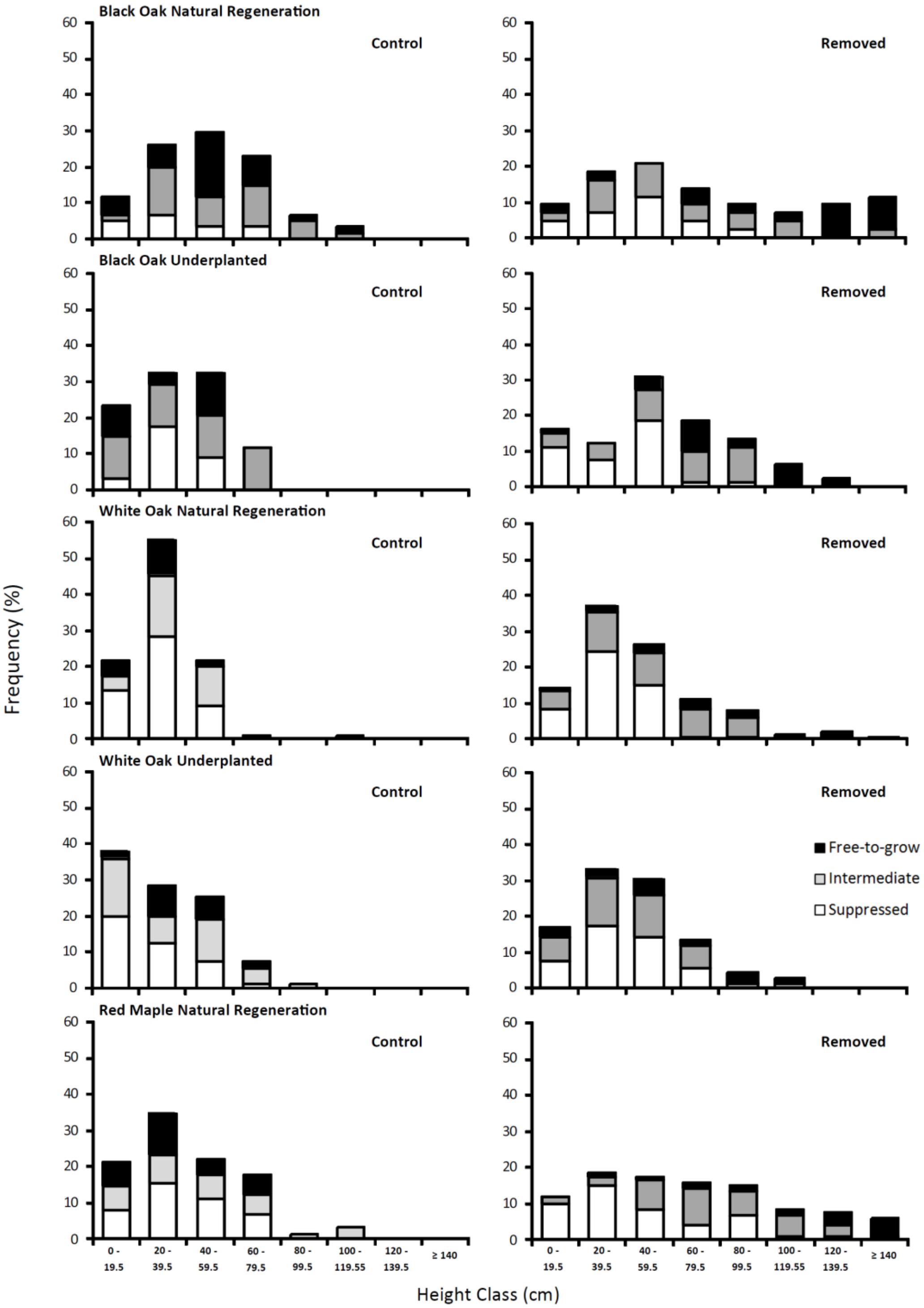


Figure 1.1. Height class and competitive position distributions of tagged seedlings in control and midstory removal treatments for each observed species.

CHAPTER THREE: SEVEN YEAR EFFECT OF MIDSTORY REMOVAL ON REGENERATION COMPOSITION, DIVERSITY, AND HEIGHT

INTRODUCTION

In past decades, difficulties emerged in recruiting oaks into the overstory of previously oak dominated forests following harvests. Problems regenerating oak have been linked to the absence of large advance reproduction prior to regeneration events (Sander, 1972). Historically, periodic disturbances such as fire and grazing, maintained environmental conditions conducive for oak reproduction development. Fire suppression and changes in land use have led to the development of dense understories of shade tolerant species such as red maple (*Acer rubrum* L.) throughout the Central Hardwood Forest Region (Abrams and Nowacki, 1992; Barton and Gleeson, 1996). This midstory canopy layer stifles oak development by reducing light levels to as low as 3% available light, and although oaks are intermediately shade tolerant, prolonged periods under low light conditions will leads to a loss of vigor and eventual mortality (Dey and Parker, 1997).

Full release of advance reproduction by means of clearcutting or low retention shelterwoods result in stands dominated by shade tolerant species such as red maple released by harvest and shade intolerant species like yellow-poplar established after harvest (*Liriodendron tulipifera* L.) (Loftis, 1983; Beck and Hooper, 1986; Kolb *et al.*, 1990). These results are most prevalent on high quality sites that support a large suite of competitor species. Silvicultural prescriptions must increase the amount of light available to oak reproduction, but maintain enough shade to discourage competition from shade intolerant species. Loftis (1983) designed a type of shelterwood that met this criteria. The prescribed treatment entails the removal of the midcanopy layer to enhance the light environment and maintaining a high residual basal area of the overstory to decrease competition from shade intolerant species (Loftis, 1983). Treatments must coincide with large acorn crops, the presence of abundant natural regeneration, or underplanted seedlings and must precede final overstory removal by at least ten years to ensure sufficient seedling development (Loftis, 1990). This method has been shown to be successful in encouraging development of northern red oak (*Quercus rubra* L.) (Lorimer *et al.*, 1994) and cherrybark oaks (*Quercus pagoda* Raf.) on productive sites (Lockhart *et al.*, 2000). However, research is limited on the effectiveness of midstory removal to enhance pools of oak reproduction on intermediate quality sites dominated by white oak and black oak within the Central Hardwood Forest Region. The objectives of this study were to examine the seven-year effects of a midstory removal on composition, density, and height of natural regeneration and to quantify whether midstory removal appreciably alters the understory microclimate. Our work focused on four upland oak sites.

METHODS

Study Sites

Four study sites were established in Madison County, Kentucky in 2003 by Dillaway (2005). Sites were located in the oak-hickory stands on Berea College Forest, which is within the Knobs physiographic region. Study areas had acid soils were of intermediate quality with site index ranging from 22 to 24 m. Overstory trees ages ranged from 90 -116 years old among sites at the time of treatment and were primarily mixed oak species. A density midstory canopy of American beech (*Fagus grandif*olia Ehrh.), red maple, and sugar maple (*Acer saccharum* Marsh.) was present prior to treatment implementation.

Study Design

Paired 0.1 ha experimental units were established at the four study sites and were randomly assigned as a midstory removal or control treatment. The midstory removal treatment involved removing 20% of the basal area starting with stems > 2.54 cm dbh and working up through the larger trees until the basal area reduction target was met or only dominant/codominant overstory trees remained.. In midstory removal treatments, basal areas were reduced to 82 to 98 ft^2ac^{-1} from 103 to 122 ft^2ac^{-1} prior to treatment. Stumps were sprayed with 100% Roundup Pro ® (Monsanto Company, St. Louis, Missouri) to prevent sprouting and slash was pulled from experimental units to permit access and sampling. Each site was considered a block within the experimental design.

Regeneration Data and Analysis

To estimate composition and height distributions of regeneration occurring within experimental units, circular 0.004 ha plots were established at the center of each experimental unit and 0.0005 ha plots were located in the center of each experimental unit quadrant. Species and height class were recorded for all stems. Height classes were 0-9.5 cm, 10-29.5 cm, 30-79.5 cm, 80-129.5 cm and greater than 130 cm. A one-way ANOVA was used to detect differences in overall stem density between treatments while a two-way ANOVA was also used to identify differences in seedling abundance among treatments and species within height classes. For all analyses, an alpha = 0.05 was used. Species diversity of the seedling populations were calculated using the Shannon-Weiner index (H').

In order to assess the competitive potential of the oak advance reproduce within the removal treatment, a simulation model was used. This would provide an indication as to whether or not the oak reproduction had elicited a strong enough response, after seven years, from the midstory removal to have a high probability of recruitment into the overstory following a regeneration event. This would also display potential competitors that may outcompete the present oak regeneration and replace it in the overstory, and indicate possible competition removal actions that are necessary to improve oak competitive capacity. Future forest stand regeneration from current seedling composition was predicted using REGEN Agent for Excel (Boucugnani *et al.*, 2003). This application predicts future stand composition following a regeneration event based on the Loftis regeneration model (Boucugnani *et al.*, 2003). Species rankings based on the submesic Cumberland region knowledge within the program, and model was set to undergo 100 runs with no mortality. Entered regeneration data was based on the mean stems densities of all observed plots. Data was entered into the model as mean stems ha^{-1} by species and size classes, which ranged from new germinants, small seedlings (< 2ft). medium seedlings (2 to 4 ft.), and large seedlings (>4 ft). Model results produced a predicted percentage of overstory occupancy by species.

Understory Microclimate Data and Analysis

To understand whether midstory removal appreciably altered the understory microenvironment, light availability, air temperature, relative humidly, soil moisture, and soil temperature were quantified. These data were collected in the summer of 2010. Because microclimatic data were not available immediately post treatment, we needed to assess if stand structure in 2010 was comparable to stand data immediately following treatment. This relationship is critical since stand structure primarily controls understory microclimate (Brown and Parker, 1994; Breshears *et al.*, 1998; Buckley *et al.*, 1998). If stand structure were comparable between 2010 and 2004, it could be assumed that microclimate measurements at year seven were analogous to initial post-treatment conditions. Using 0.01 ha inventory plots in the center of each experimental in the summer of 2010 showed that midstory has not reestablished in treated experimental units as there was there were only 2 trees tallied that were within 2.45 – 12.7 cm dbh range. Due to the scarcity of trees in this diameter range, it was safe to assume that trees in the removal treatment had not filled the midstory removed in the treatment. Since overstories were left intact at the time of treatment and had remained undisturbed throughout past seven years, we considered that environmental conditions at the time of this study were similar to those present upon treatments implementation.

Canopy structure seven growing seasons following treatment was also quantified by measuring canopy cover and closure. We used a vertical sighting tube to measure canopy cover. Sighting tube observations were spaced on a 5 x 5m sampling grid (~200 points) in each experimental unit to ensure that sample size was large enough to give an accurate estimation of canopy cover (Jennings *et al.*, 1999). Each point was identified as covered or open and the following equation was used to calculate canopy cover (Jennings *et al.*, 1999):

$$\text{Canopy cover \%} = \frac{Number\ of\ points\ covered}{Total\ number\ of\ points} \times 100$$

Canopy closure was estimated using hemispherical photograph. Photos were taken at the center of each experimental unit using a camera equipped with a 180º fisheye lens. Photographs were taken in uniformly overcast conditions, dawn, or dusk in which the solar disk is not visible to ensure precision of photographs (Jennings *et al.*, 1999). Hemiview 2.1 (Delta-T Devices, Cambridge, UK) analysis software was used to analyze photographs and calculate percent closure.

In order to calculate photosynethically active radiation (PAR), an Accupar ceptometer (Decagon Devices, Inc., Pullman, WA) was used to measure PAR in µmols/m^2/s within each experimental unit. Measurements were taken in uniformly overcast conditions in which the solar disk was not visible in order to reduce influence of sun flecks (Jennings *et al.*, 1999). Samples were collected at 5 points within each experimental unit: one in each quadrant and one in the center. At each point, measurements were taken 3 times at breast height (1.37 m above ground) at the three cardinal directions away from technician's shadow. Accompanying these measurements, open field measurements were taken simultaneously with a stationary Licor quantum sensor (LI-190SB, Li-Cor, Lincoln, NE) connected to a datalogger (CR1000, Campbell Scientific, Logan, UT) that measured PAR every minute and recorded mean PAR every 15 minutes. Percent light transmittance for each experimental unit was calculated using mean PAR from experimental unit samples and open field samples. Mean light transmittance by treament was analyzed using a one way ANOVA (alpha = 0.05) with site as a blocking factor.

To observe the effect of midtstory removal treatment on soil moisture, measurements were taken. Having only enough equipment to record data from three sites, Pigg House, Waterplant, and Horsecove were selected for observation. Within each experimental unit, three water content reflectometers (CS616, Campbell Scientific, Logan, UT were connected to a datalogger (CR1000, Campbell Scientific, Logan, UT) to measure soil moisture content by volumetric water content (VWC). The 30 cm probes were inserted at a 48 degree angle to measure the top 15 cm. Sensors measured soil moisture content every 15 minutes, and dataloggers recorded the average every hour. Sensors were evenly distributed down the center of each experimental unit, and data was collected simultaneously from all experimental units (midstory removal treatment and control) from May 17 - September 17. After field data had been collected, dates experiencing rain events and the following 48 hours were removed from the dataset (Heithecker and Halpern, 2006). Diurnal curves were constructed to display average soil moisture over the course of an average day for June, July, and August (where a full month of data was available). Weekly means were then analyzed using repeated measures ANOVA with alpha = 0.05.

Air temperature and relative humidity measurements were also taken from the same three sites. Temperature and relative humidity sensors were placed 1 m above the ground in the center of each experimental unit and connected to a CR1000 Measurement and Control Datalogger. Temperature sensors were programmed to take measurements every minute and record the mean for every hour while relative humidity was sampled every 15 minutes. Data was collected simultaneously in two-week intervals from each site for three rotations. Biweekly means were then analyzed using repeated measures ANOVA with alpha = 0.05.

Soil temperature was collected using Thermochron iButton temperature loggers. Within each experimental unit, 4 loggers were placed 10 cm under the soil in each quadrant of the experimental unit. Temperature was recorded hourly for paired experimental units over the two-week intervals rotating through each of the sites three times. Biweekly means were then analyzed using repeated measures ANOVA with alpha = 0.05.

RESULTS

Regeneration

Comparing the total seedling abundance, there was no significant difference between treatments (p = 0.6071). Mean seedling density in the control and mistory removal treatment was 85,873 stems ha^{-1} 126,541 stems ha^{-1}, respectively. Species richness was slightly higher in undisturbed control treatments with 28 species present compared to the 26 species growing in midstory removal treatments. The same species were found in both treatments; the only exceptions were American hornbeam (*Carpinus caroliniana* Walter), Shumard oak (*Quercus shumardii* Buckley), and blackjack oak (*Quercus marilandica* Münchh.), which were only found in the control treatments, and pitch pine (*Pinus rigida* Mill.), which only occurred in the removal treatment. Midstory removal treatments also had a lower amount of species diversity (H’= 1.88) than the controls (H’ =1.68). The largest components of the reproduction population were white oak, red maple, and sassafras in the control and removal treatment.

As a valuable timber and wildlife species, white oak was of particular interest. Red maple, which can act as a direct competitor to oak seedlings (Lorimer *et al.*, 1994; Hartman *et al.*, 2005), was also a species of concern. Due to their importance and high abundance, these species were the focus of further analysis. In the control treatments, white oak and red maple made up 11 and 50% of the stems, respectively, and in the removal treatments white oak and red maple respectively comprised 15 and 57% of the stems. White oaks averaged twice as many stems in the removal treatments than the control treatments, and red maple was 1.7 times more abundant in the removal treatments. In the control treatments, white oak had a mean density of 9,744 stems ha^{-1} and 19,533 stems ha^{-1} in the removal treatment; however, difference between treatments was not statistically different ($p = 0.6970$). Red maple had a mean density of 42,536 stem/ha in the control treatment and a significantly higher ($p= 0.0378$) mean density of 71,902 stems ha^{-1} in the removal treatment (Table 2.1). Between species, red maple had a significantly higher density than white oaks in the control ($p = 0.0213$) and in the removal treatment ($p = 0.0011$).

Among height classes, the removal treatment was found to have a significantly higher total number of combined white oak and red maple stems in the 10 - 29.5 cm ($p = 0.0022$) and 30 - 79.5 cm height class ($p= 0.0264$) (Figure 2.1). In the 0 to 9.5 cm height class, species had a significant effect on stem density ($p < 0.0001$) as on average there were 29,900 and 37,464 more red maple than white oak stems ha^{-1} in the control and removal treatments, respectively. However, in this height class, the removal treatment had no significant effect on density ($p = 0.8073$). In the 10 to 29.5 cm height class, removal treatment had a significant effect on density, and there was no difference between species ($p = 0.0746$). Only red maple displayed a significant difference between treatments ($p = 0.0152$) with 16,774 more stems ha^{-1} in the removal treatment. In the 30 to 79.5 cm height class, combined white oak and red maple stem density was a significantly different between treatments; but was no difference was detected between treatments for either species individually ($p > 0.05$). In the 80 to 129.5 cm and >130cm height classes, there were no significant differences between species or treatments ($p > 0.05$)

Regeneration prediction results from REGEN Agent for Excel indicated that a regeneration harvest with the current conditions ignoring stump sprouting potential would result in a stand comprised of 74% yellow-poplar in dominant and codominant positions. Red maple and Virginia pine (*Pinus virginiana* Mill.) the other largest components with 6% each. Northern red oak was the only oak predicted to attain a dominant position making up an estimated 1% of the overstory. To assess whether a management operation would alter these results in favor of oaks, models were repeated with the addition of a competition removal that would remove all red maple and yellow-poplar > 60 cm. The resulting predicted stand had a similar composition as with no management, only without the red maple component. Yellow-poplar continued to obtain approximately 70% of the dominant/codominant positions with Virginia pine and blackgum (*Nyssa sylvatica* Marsh.) as the other largest overstory components comprising 8 and 12% of the dominant position, respectively.

Microclimate

Mean canopy cover was 97 % within the controls and 88% within the midstory removal treatments but were not significantly different ($p > 0.05$) (Table 2.2). Canopy closure was analyzed at both a 180° and 120° angle. At 180°, mean canopy closure was 91% and 87% for control and removed experimental units, respectively. Mean canopy closure was 84% in the control units and 77% in the midstory treatment units when analyzed at 120°. Differences between treatments were not significant for either analysis ($p >0.05$); however, light availability was significantly higher in midstory removed treatments ($p = 0.0098$) with a mean 5.3% full light available under intact canopies and 14% full light available under the midstory removal treatments.

There was no significant difference in soil temperature at a depth of 10 cm, which averaged 20.67°C in the control and 21.26°C in the midstory removal treatments. Air temperature had similar results with no difference between treatments ($p > 0.05$). Control treatments had a mean temperature of 23.4°C while mean temperature in the midstory removal treatments was 23.4°C. Relative humidity was significantly higher ($p= 0. 0068$) in the control treatment at with a mean of 86.6% compared to the removed 82.14%. Soil moisture between treatments maintained a similar pattern through observation period (Figure 2.2). Soil moisture diurnal curves displayed a trend of consistent higher soil moisture in removal treatments (Figure 2.3 to 2.7); however, soil moisture was not significantly different between treatments. Mean soil moistures were 20% and 21% in the control and removal treatments, respectively.

DISCUSSION

The results of this study indicate that although midstory removal treatment increases overall white oak and red maple density; however, red maple more abundant than white oak in either treatment. This supports Gottschalk (1994) who suggested that red maple would be highly competitive under a shelterwood harvest since it showed higher plasticity than oaks in altered light conditions. Increased white oak density under midstory removal treatments increases the probability for oak success; however, this also applies to red maple. In the current conditions of this study, the overwhelming abundance of red maple seedlings gives them a much higher probability of securing competitive positions over white oaks. This has been observed before by Hartman et. al (2005) who found that red maple was in high abundance and overtopped white oak after 10 years under shelterwood treatments that did not include the mechanical removal of red maple seedlings. Our study also suggests that competition removal may be necessary to secure a competitive position for white oaks.

Predicted composition of the regenerated stand with and without competition removal was primarily dominated by yellow-poplar. This prediction is in accordance with other studies that have found that yellow-poplar is a dominant competitor following a regeneration event (Loftis, 1983; Beck and Hooper, 1986; Lockhart *et al.*, 2000). While the model did not include stump sprouting as a source of regeneration, which can be an important component of oak regeneration (Johnson *et al.*, 2002), the size and abundance of oak advance regeneration was not adequate to ascertain a large component of the predicted overstory. The results from the predictive models are in accordance with recommendations that require a significant amount of oaks at least 137 cm for successful oak management (Sander, 1972). White oak had no stems over 130 cm tall in either treatment while red maple had 133 stems ha^{-1} >130 cm in the removal treatment. While stems of competitive height were lacking, results indicate that the removal treatment was successful in producing a 42% more oak seedlings than the control. This would suggest that the midstory removal with competitor removal may be able to produce an oak cohort that could be managed for future oak development.

The greater abundance of these species within removal treatments may be attributed to altered microclimate under the midstory removal treatment. Although canopy cover and closure were not significantly different, light levels observed in the removal treatment were significantly higher. Since available light was the only microclimate that was significantly altered by treatment, other than relative humidity, it is reasonable to assume that the changes in light levels played a role in the increased white oak and red maple seedling densities within the removal treatments.

Although soil moisture content showed a trend of higher soil moisture in removal treatments, differences between treatments were not detected. While canopy conditions were assumed similar to those present at the time of treatment, soil moisture measurements seven years after treatment implementation may not accurately represent the soil moisture present in the first years following the treatment. Overstory trees within experimental units have continued to grow over the past seven growing seasons, and there has been increase in overall increase seedling density. This could have increased the demand for water within the experimental units and reduced the levels of soil moisture content through the years following treatment implementation. In addition, results could also have been influenced by the size of the experimental units used. The relatively small size and close proximity of experimental units may have muted effects of the treatment on microclimate. The midstory removal treated areas were surrounded by intact midstory, which would reduce wind flow through treated areas, and reduce potential differences in temperature and relative humidity between control and removal treatments (Chen *et al.*, 1993). Air temperature, soil temperature, and soil moisture results in the study are similar to other studies that found that substantial removal of overstory was necessary to yield significant changes in these microclimate variables (Heithecker and Halpern, 2006). Barg and Edmunds (1999) found no difference in soil moisture between undisturbed forests, ~78% open canopy shelterwood, and clearcuts in Douglas-fir and western hemlock forests. However, in oak forests, Buckley (1998) found that on moderate quality sites, soil moisture and soil temperature was increased by shelterwood harvests that removed 25% of canopy cover. Therefore, the 9% decrease in canopy cover in our study sites may not have been drastic enough to alter these microclimate variables.

Management Implications

Predicted stand composition from the current seedling regeneration pool indicates that the treatment has not yet produced competitive cohort of oak regeneration seven years after midstory removal treatment. However, the increased white oak and red maple density in our midstory removal treatments suggests that treatment had a positive effect on both species. Considering the greater number of red maple seedlings, competition removal is likely necessary for further oak reproduction development. Fire has been suggested as a control mechanism for red maple competition (Abrams, 1992; Hartman *et* *al.*, 2005); however, periodic fall and winter burning has not been shown to improve oak position against red maple competition. While fire has reduced red maple survival in the Cumberland Plateau, surviving red maple has responded in an equivalent or greater manner than the oaks (Blankenship and Arthur, 2006; Alexander *et al.*, 2008; Green *et al.*, 2010). In these studies, damaged midstory tree sprouts have also been problematic as they shaded out oak seedlings before they could respond to the enhanced light environment (Blankenship and Arthur, 2006).

While fire has been unsuccessful in advancing oak development in previous studies in the region, it may be an effective treatment when applied several years following a midstory removal. Seven years following the midstory removal, we found that the midstory layer had not redeveloped, thereby reducing the sprouting potential of midstory trees noted after burns in the region (Blankenship and Arthur, 2006). In addition, increased white oak density would increase the probability for oak sprouting success. White oaks have a conservative growth strategy and have been shown to have increased soluble root carbohydrates after growing one year under a midstory removal treatment, which may indicate possible vigor and sprouting capability (Dillaway *et al.*, 2007). Considering the potential root enhancements from midstory removal treatment and sprouting ability of oaks (Hodges and Gardiner, 1992), burning several years following a midstory removal may be sufficient to remove the competing red maple enough to provide a window of opportunity for oak seedlings to improve their competitive position and growth. Therefore, further avenues of research should explore the use of fire in the years following midstory treatments.

Table 2.1. Stem densities of white oak and red maple in control and midstory removal treatments (stems ha-1) within height classes.

Density (stems ha^{-1})

	0- 9.5 cm		10- 29.5 cm		30 - 79.5 cm		80- 129.5 cm		>130 cm		Total	
	Control	Removed	Control	Removed	Control	Removed	Control	Removed	Control	Removed	Control	Removed
Red maple	31724^{A}	40133^{A}	7475^{a}	24249^{a}	2403	6452	534	934	400	133	42536^{aA}	71901^{aA}
White oak	1824^{A}	2670^{A}	6897	12903	979	3604	44	356	0	0	9744^{A}	19533^{A}
Total	33548^{a}	42802^{a}	14371^{a}	37152^{a}	3382^{a}	10056^{a}	578	1290	400	133	52280^{a}	91434^{a}

^{a} Signifies a difference between treatments within height classes ($p < 0.05$).

^{A} Signifies a difference between species within treatments within height classes ($p < 0.05$).

Densities without superscript had no significant differences between treatments or species within treatment ($p > 0.05$).

Table 2.2. Mean structure and microclimate variables of control and removal treatment seven years after implementation.

Variable	Control	Removal	p values
Canopy cover (%)	97	88	0.0538
Canopy closure (%)	84	77	0.0896
Available light (%)	5.3	14	0.0098
Air temperature (°F)	73.4	73.5	0.4601
Soil temperature (°F)	69.2	70.3	0.6157
Relative humidity (%)	86.6	82.1	0.0068
Soil volumetric water content (%)	19	20	0.3733

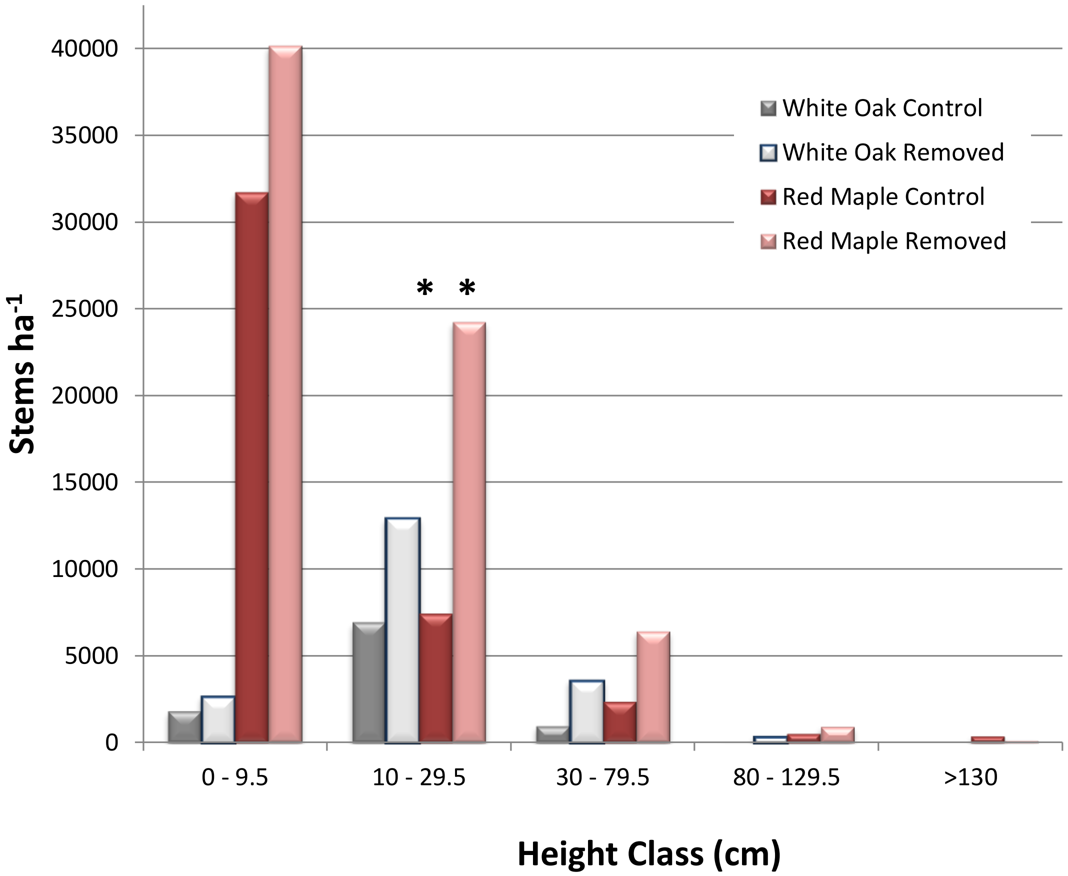


Figure 2.1. Stems per hectare of white oak and red maple regeneration within height classes in the control and removal treatment. * Signifies significant difference between treatments ($p < 0.05$).

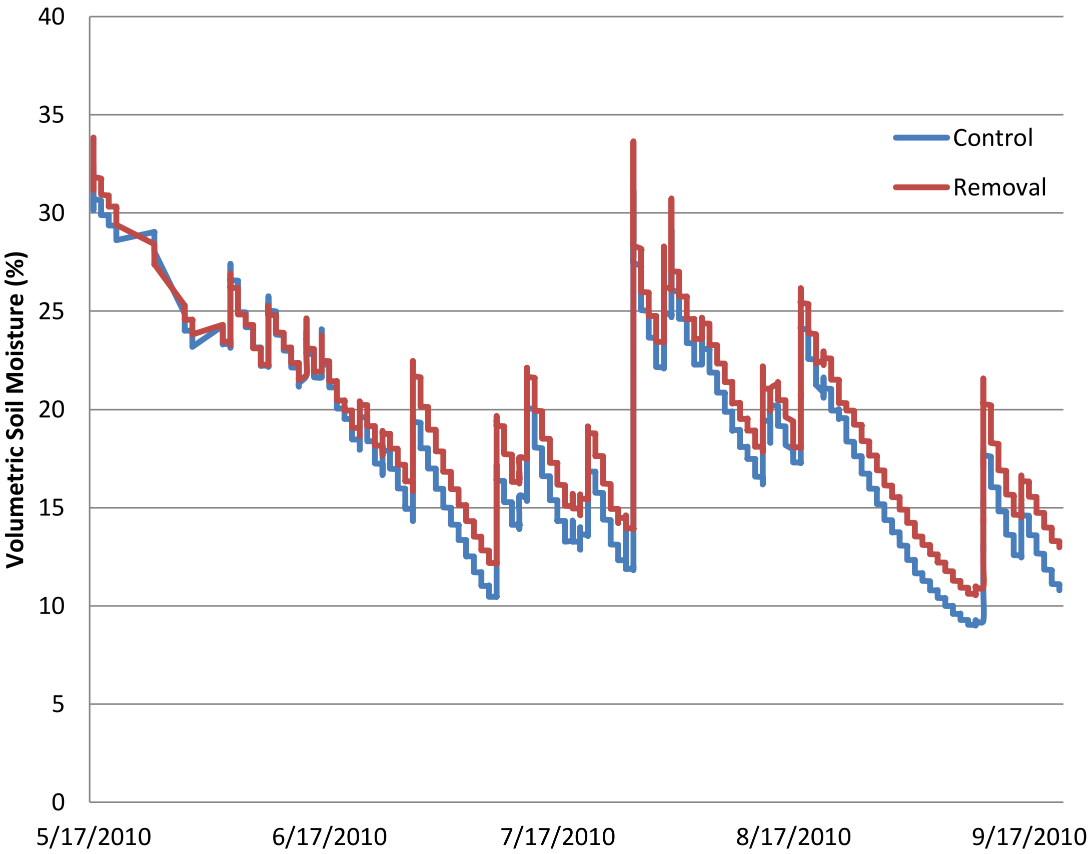


Figure 2.2. Mean volumetric soil moisture content for control and midstory removal treatments throughout the data collection period.

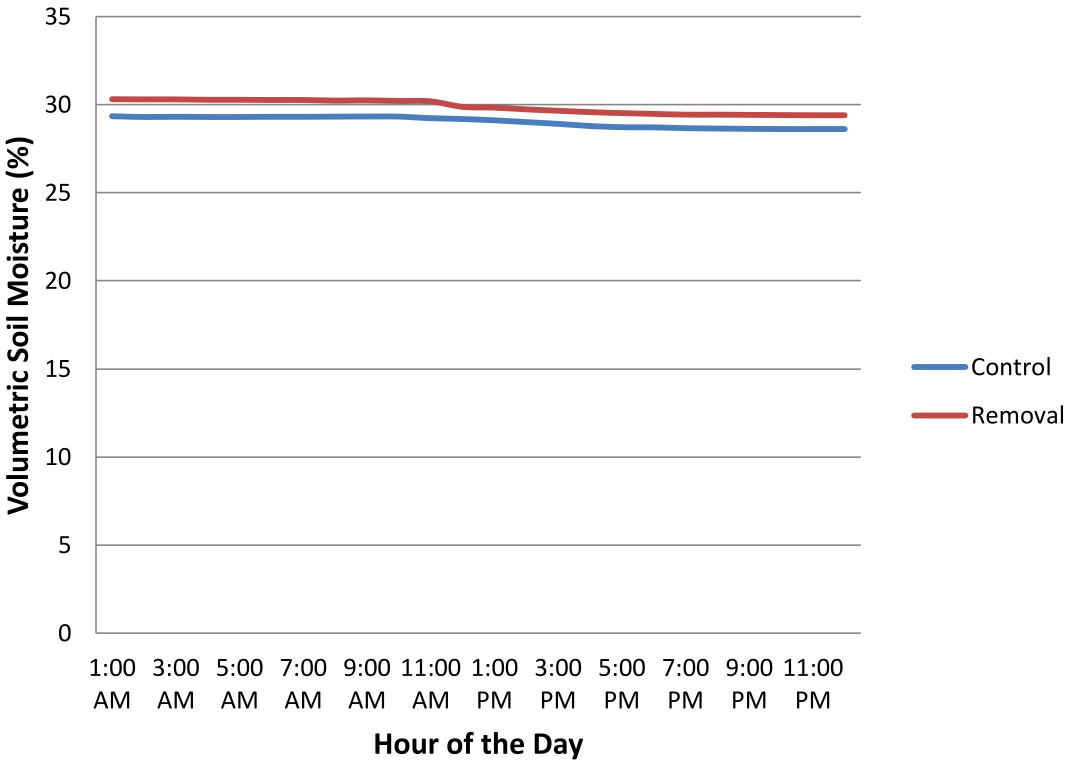


Figure 2.3. Mean hourly volumetric soil moisture content for the month of May for control and midstory removal treatments. No error bars could be constructed due to small sample size from rain events.

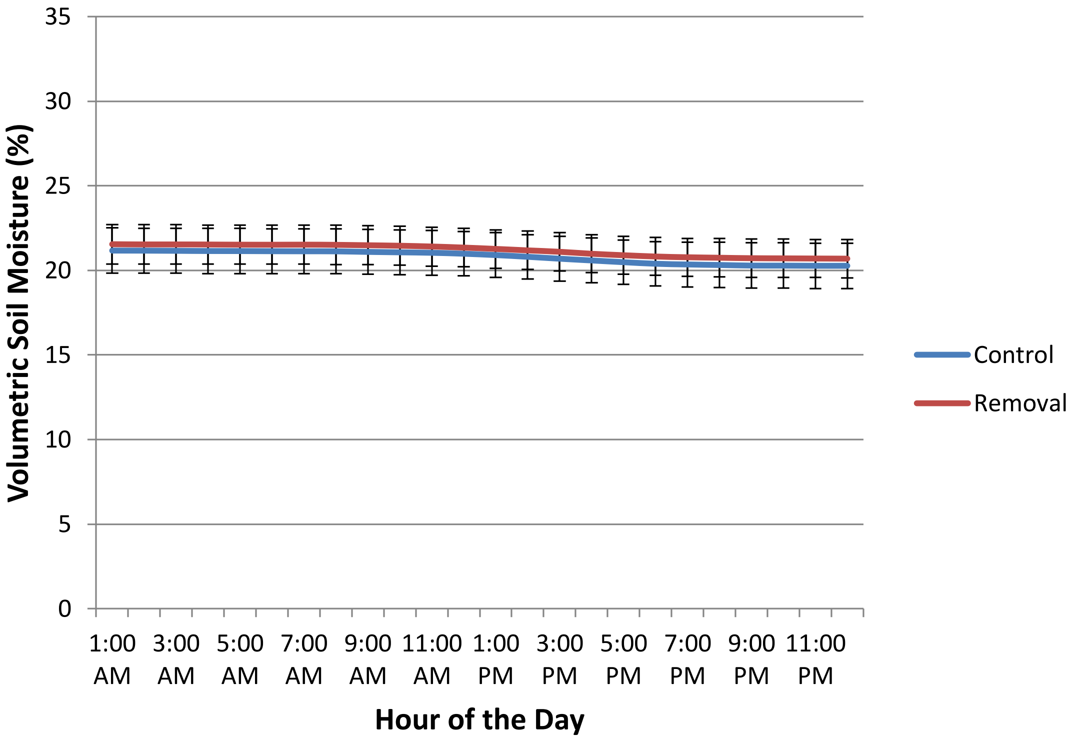


Figure 2.4. Mean hourly volumetric soil moisture content for the month of June for control and midstory removal treatments.

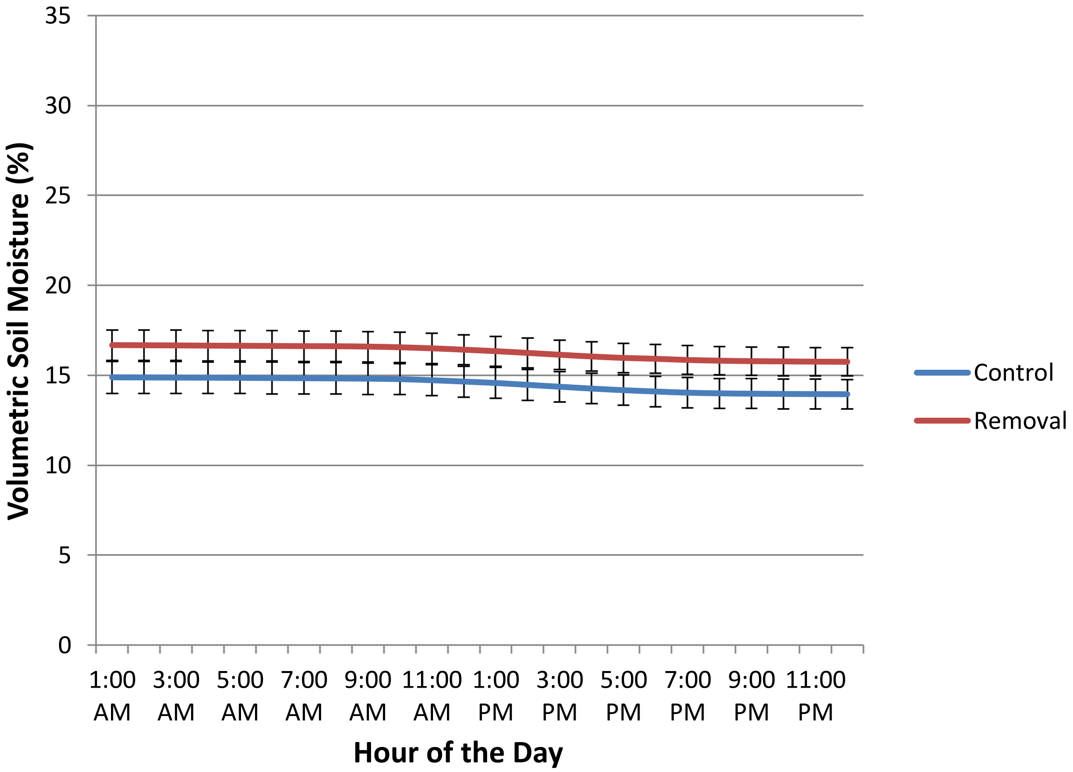


Figure 2.5. Mean hourly volumetric soil moisture content for the month of July for control and midstory removal treatments.

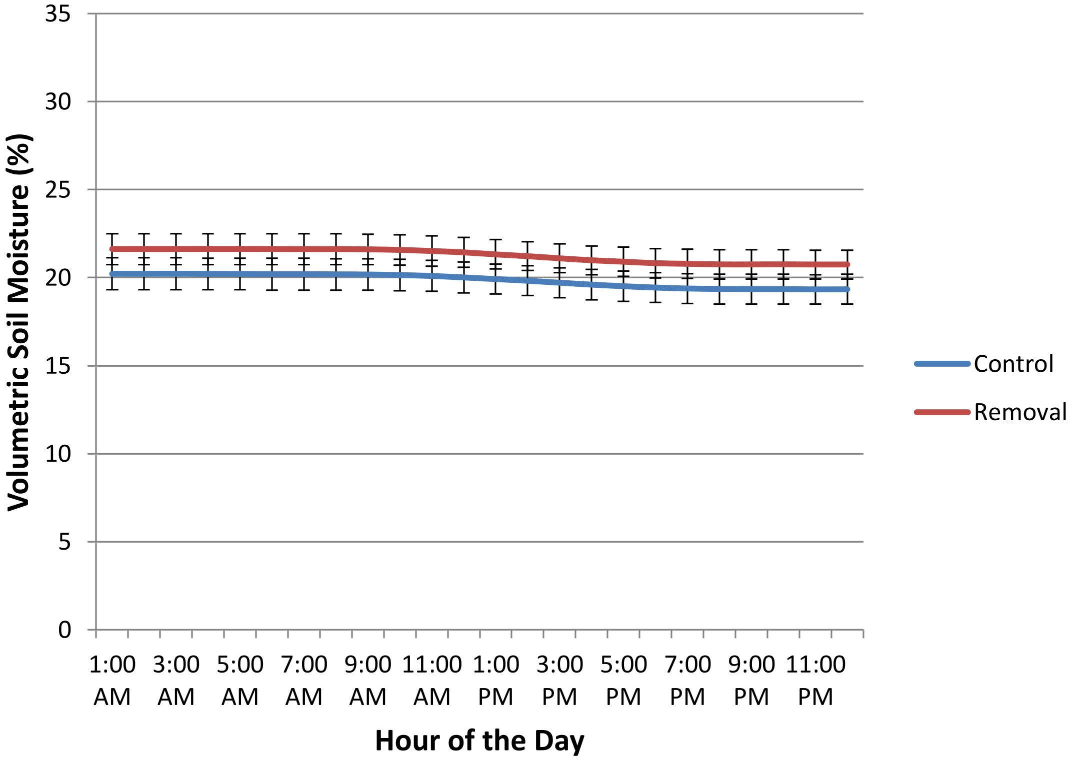


Figure 2.6. Mean hourly volumetric soil moisture content for the month of August for control and midstory removal treatments.

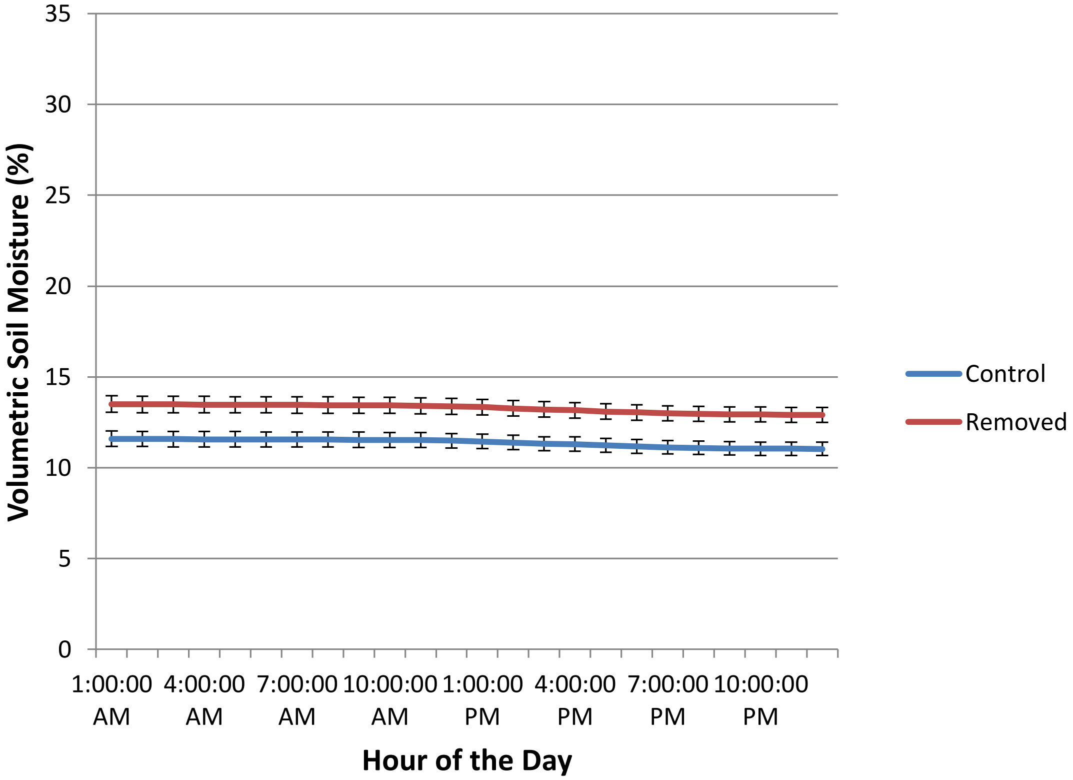


Figure 2.7. Mean hourly volumetric soil moisture content for the month of September for control and midstory removal treatments.

CHAPTER FOUR: CONCLUSIONS

Removal of the midstory canopy was shown to have a positive effect on natural and artificial white oak regeneration as increased height and diameter were observed in treated areas. While a response was observed, the response was not of the same magnitude of those seen in previous studies that focus on faster growing species associated on more mesic sites. Mean heights of tagged oak regeneration ranged from 45.3 – 77.1 cm. Among all 422 oak seedlings in treated areas, there were only 62 stems that were 80 cm or taller, and of these only 31 were free from direct competition from neighboring vegetation. The lack of dramatic height growth found in treated areas may be attributed to many factors. As previously mentioned, observed black and white oaks may exhibit the conservative growth strategy associated with oak, and be utilizing increased resources provided by the treatment to allocate more carbon to root development and potential carbohydrate reserves. This assumption is evidenced by the higher ground line diameter growth found in treated plots. If true, this would suggest that despite a lack of extreme increase in height, seedlings have increased in vigor and response potential if further released or subjected to top kill.

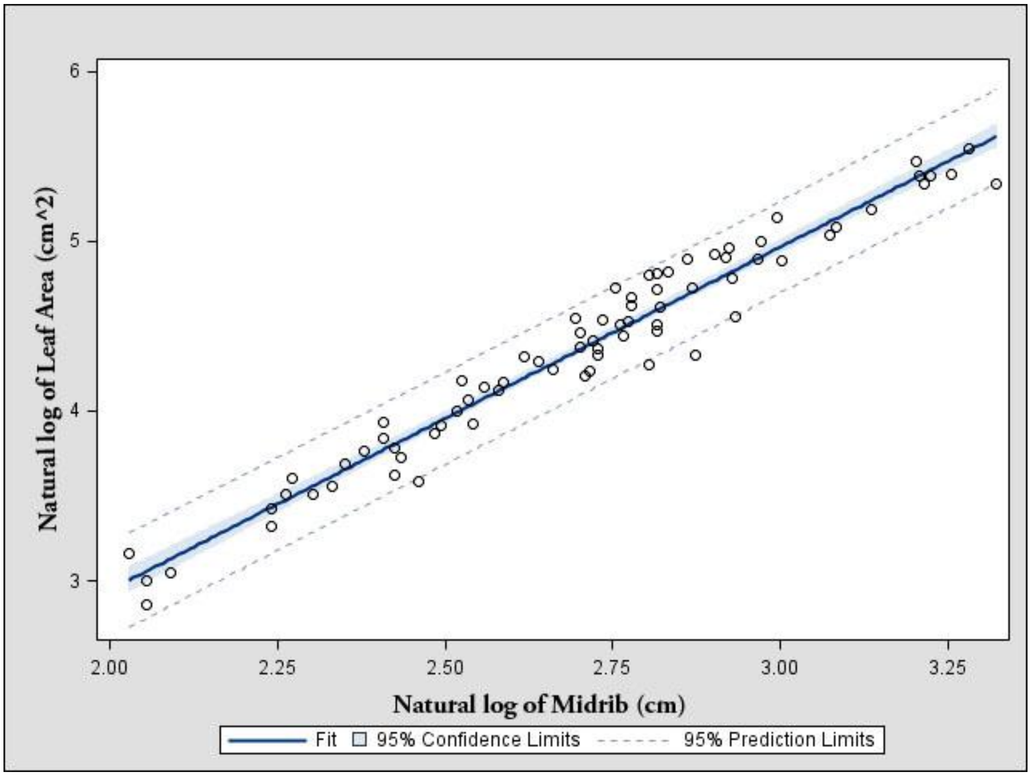
Insufficient heights in observed oaks could also be attributed to the concurrent response found in red maples. Treated areas not only had higher red maple densities, differences in heights of tagged red maple seedlings between treatments also suggest that they were also positively impacted by the treatment. This positive response in red maple and the competitive position of oak seedlings in treated areas suggest that a midstory removal alone may not be sufficient to produce a competitive population of oak regeneration prior to release in these conditions with these oak species. Management of competition may be necessary to alleviate the stresses accompanying neighboring vegetation on oak seedlings.

The limitations on oak regeneration in this study include the competition from shade tolerant species and need for greater height growth. Future management prescriptions to assuage these issues could include burning. Fire has been cited as a keystone process that historically maintained oak dominance in these forests, and it would seem beneficial to the regeneration found within the study areas. Burning these areas may reduce the competition from less fire tolerant species and would also allow oak seedlings to capitalize on their assumed root development and increased vigor attained after the seven years under the midstory removal treatment. This would not only increase oak's competitive edge by maximizing oak's sprouting capabilities, it could also increase the light to levels 20 % of full light or higher where oaks can obtain optimal growth. This process may need to be performed further in the future when seedling basal diameters are at least 1.27 cm or greater to increase the probability of sprout success (Sander, 1971). Others studies that have experimented with burning within the Cumberland Plateau have found red maple to remain competitive and has not improved the competitive position of oak seedlings (Blankenship and Arthur, 2006; Alexander *et al.*, 2008); however, in these studies, midstories had not been removed prior to treatments. Implementing a burn several years following a midstory removal should elicit different results since oak seedlings should have increased root development for better sprouting response and there is no midstory to reinitiate after the burn.

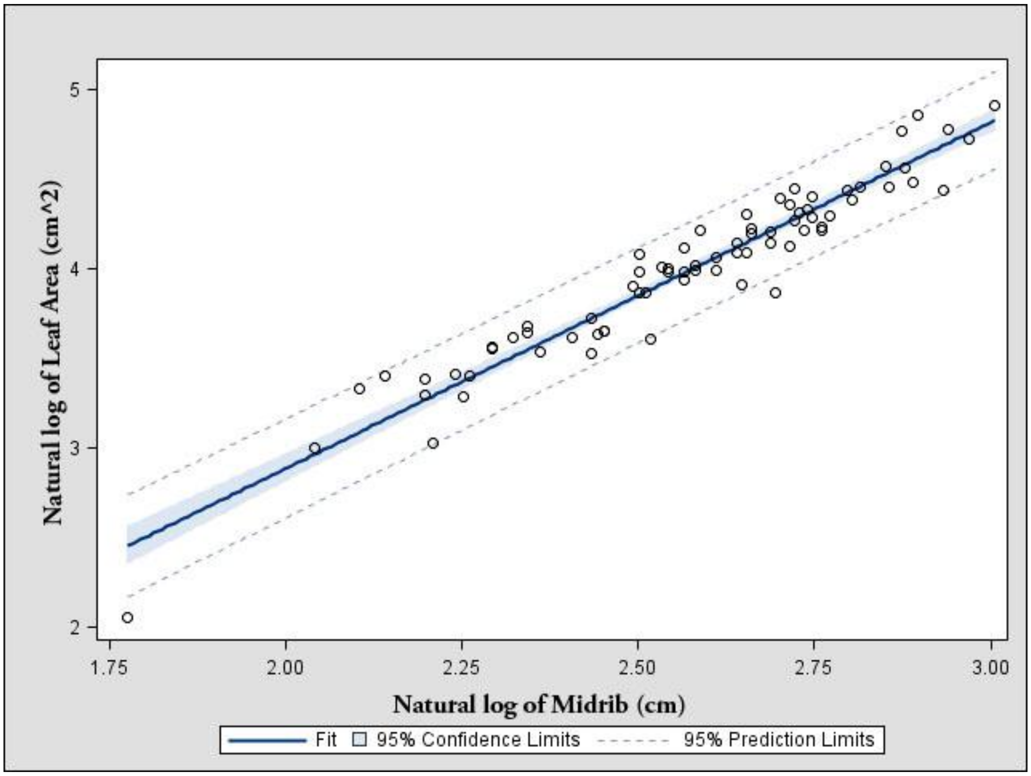
To elicit faster growth from these seedlings, a burn would ideally reduce overstory canopy to increase light levels. The feasibility of initiating a burn of this magnitude is not feasible from a management perspective; however, mimicry of past disturbances may not be necessary to replicate the results. Mechanical removal of a portion of the overstory could be used in conjunction with these burns to increase the light available. The recommended amount of overstory to be removed would be approximately 20% of the overstory basal area as done by Loftis (1990). Although Loftis performed this overstory thinning at the time of the midstory removal, he was dealing with red oaks, which have a faster growth rate. This concurring overstory reduction may have benefitted the oak species seen in his study; however, the initial duration under the midstory removal in this study may be a necessary component for regenerating white oaks that could require a period of diffuse light to sequester carbon to prepare for exploitation of future, higher light conditions that may become available.

Future research should investigate the optimal light conditions that optimize oak growth and competitive position in relation to surrounding vegetation. This would set a target light level of light to make available in initial implementation of a release treatment to increase oak regeneration vigor. Not only would this information benefit future prescriptions of oak shelterwoods, it could also guide subsequent release treatments following a midstory removal which seem necessary to produce oaks of a competitive height as evident from the results of this study. The timing, extent, and necessity of these releases should be investigated as well as the response of oaks to other treatments such as fire, competition removal, or the combination treatments.

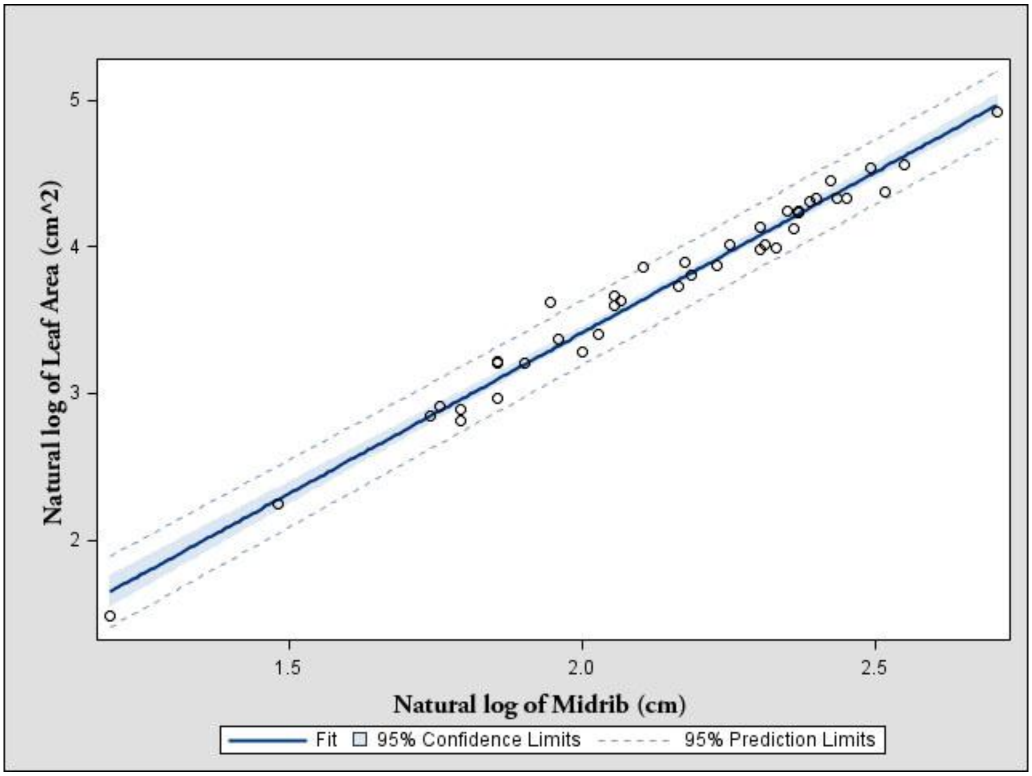
APPENDIX



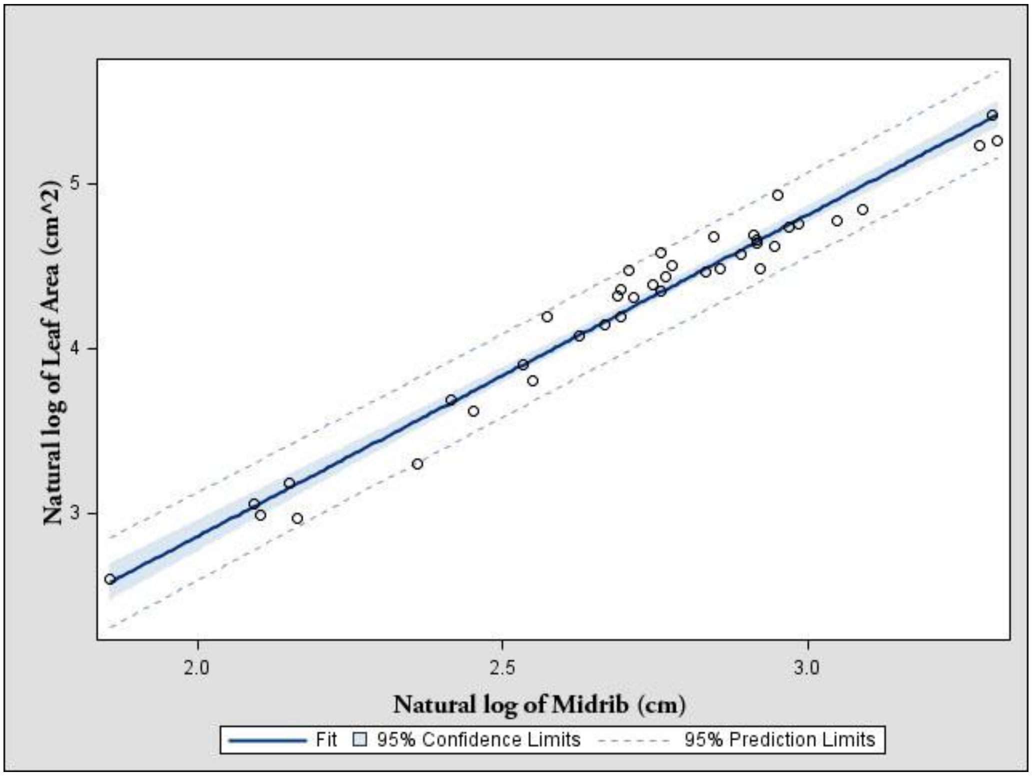
Appendix A. Fit plot for regression curve created to predict leaf area from leaf midrib for black oaks after a natural log transformation.



Appendix B. Fit plot for regression curve created to predict leaf area from leaf midrib for white oaks after a natural log transformation.



Appendix C. Fit plot for regression curve created to predict leaf area from leaf midrib for red maple after a natural log transformation.



Appendix D. Fit plot for regression curve created to predict leaf area from leaf midrib for northern red oaks after a natural log transformation.

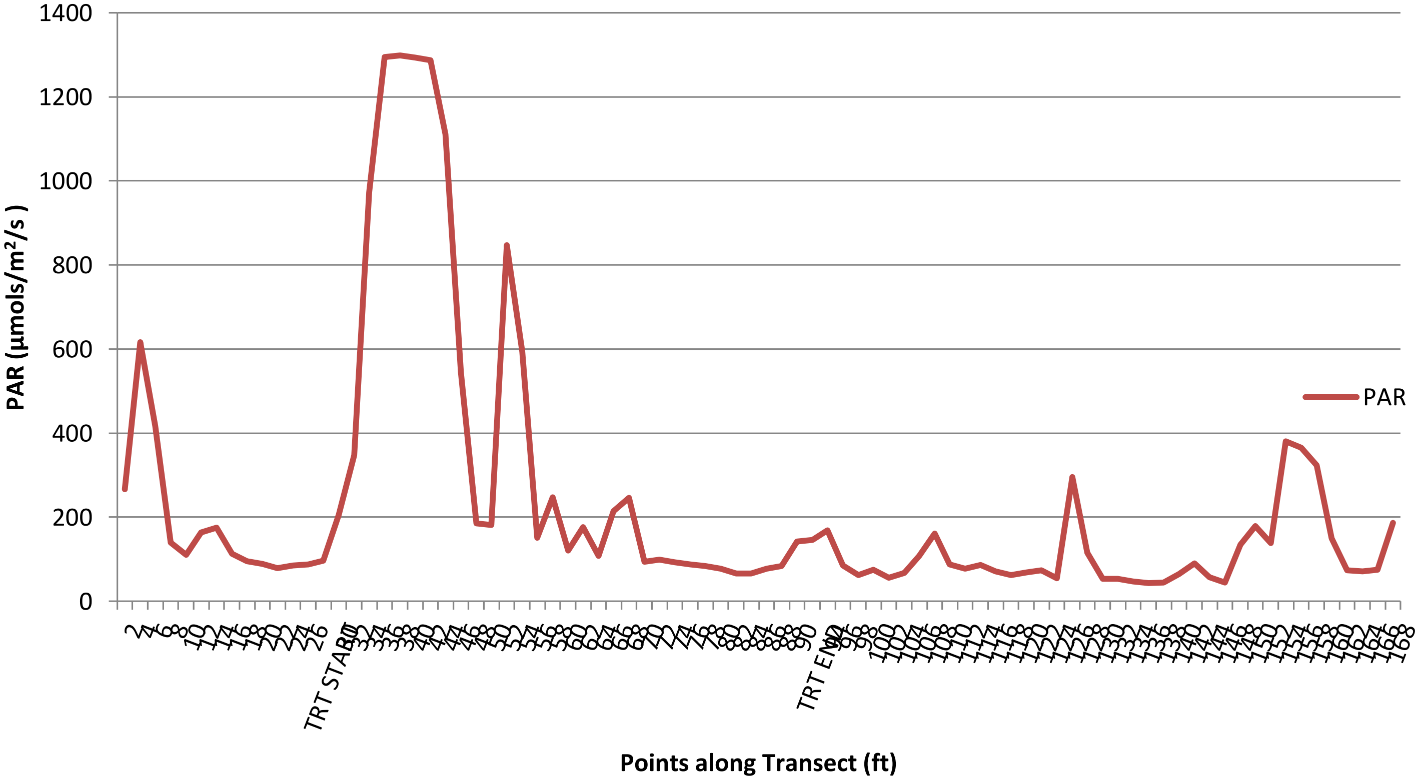
Appendix E. Means and associated p values for tagged red oak species (Q. coccinea, Q. rubra, and Q. shumardii) within control and removal treatments. Leaf areas estimated based on regression equations developed to predict leaf area from midrib length for northern red oak.

Variable	Treatment	Mean	p-value
Height			
	Control	45.4	0.1259
	Removed	60.3	
Gld			
	Control	8.4	0.0591
	Removed	11.3	
Height growth			
	Control	12.7	0.0630
	Removed	28.8	
Gld growth			
	Control	3.3	0.0267
	Removed	6.6	
Leaf area			
	Control	1111.6	0.1904
	Removed	1700.3	
Leaf count			
	Control	19.8162	0.1480
	Removed	30.3722	

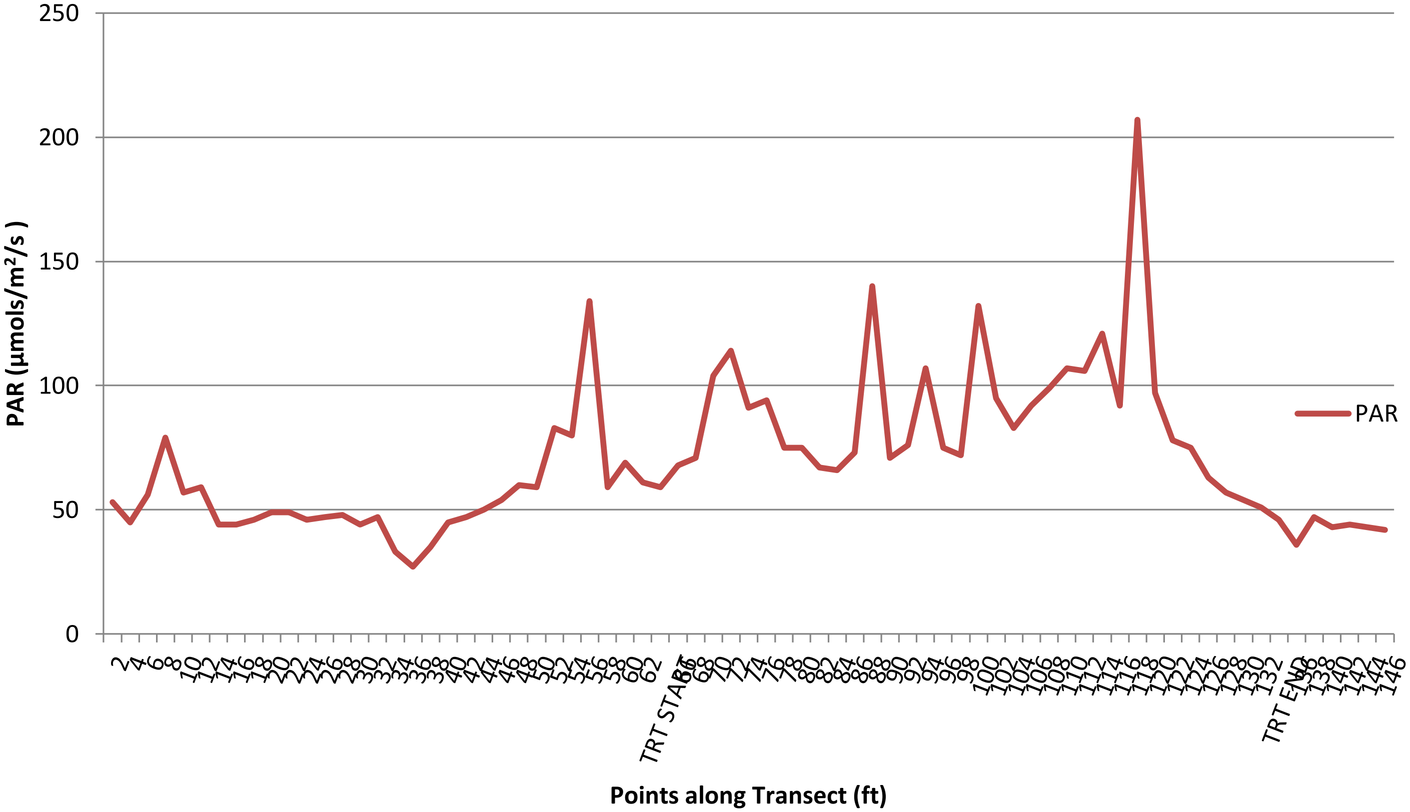
Appendix F. Stems ha^{-1} of regeneration recorded in under midstory removal and control treatment.

Seedling density (stems ha^{-1})

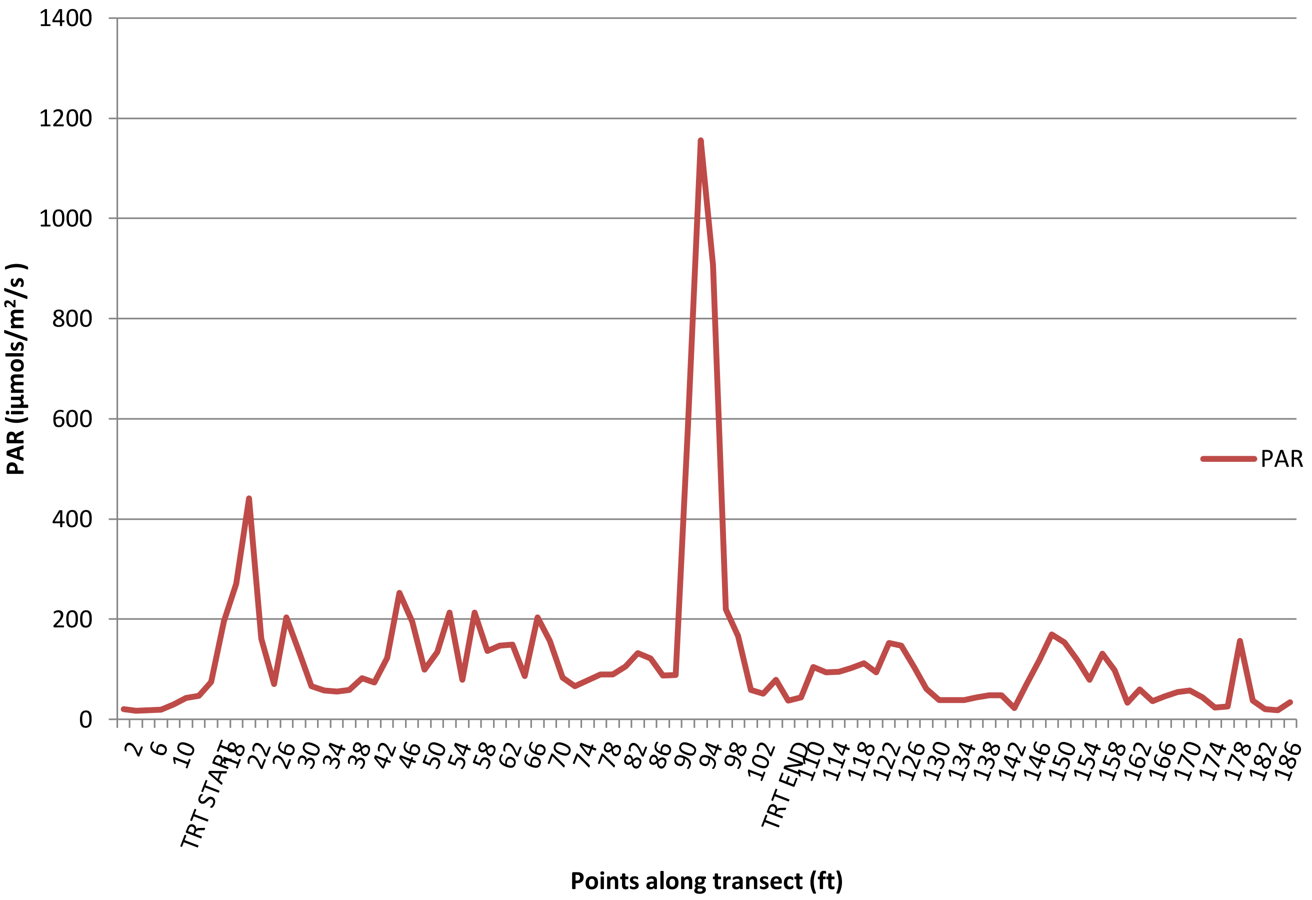
	0-10 cm		10-30 cm		30-80 cm		80- 130 cm		>130 cm		Total	
	Control	Removed	Control	Removed	Control	Removed	Control	Removed	Control	Removed	Control	Removed
Fagus grandifolia	0	0	44	0	44	178	44	133	89	267	222	578
Carpinus caroliniana	0	0	0	0	0	0	44	0	0	0	44	0
Fraxinus sp.	222	489	1379	1691	801	1335	44	311	44	89	2492	3915
Prunus serotina	178	44	222	489	44	133	0	133	0	44	445	845
Nyssa sylvatica	534	534	1023	1468	178	1157	267	489	44	178	2047	3826
Quercus marilandica	0	0	0	0	44	0	0	0	0	0	44	0
Quercus velutina	89	267	1112	623	801	801	178	222	44	0	2225	1913
Quercus prinus	0	44	178	0	44	0	0	0	0	0	222	44
Amelanchier arborea	178	178	934	712	489	445	89	178	44	44	1735	1557
Cornus florida	89	178	178	1780	267	1112	311	1112	44	400	890	4583
Ulmus sp.	0	0	0	0	44	44	0	0	0	0	44	44
Ostrya virginiana	0	0	0	44	89	44	133	0	267	133	489	222
Carya sp.	222	222	2225	1513	311	890	0	89	44	89	2803	2803
Juniperus virginiana	0	44	0	89	0	44	0	0	44	0	44	178
Morus sp.	0	0	44	0	178	89	0	0	44	0	267	89
Pinus rigida	0	0	0	0	0	0	0	44	0	0	0	44
Quercus shumardii	0	0	89	0	44	0	0	0	0	0	133	0
Cercis canadensis	0	178	133	356	44	89	0	0	0	0	178	623
Acer rubrum	31724	40134	7475	24249	2403	6452	534	934	400	133	42536	71902
Quercus rubra	89	44	534	178	489	44	534	89	178	44	1824	400
Oxydendrum arboreum	0	133	0	89	44	44	0	44	0	44	44	356
Acer saccharum	0	89	0	356	0	222	44	133	0	44	44	845
Quercus coccinea	267	178	1735	934	1513	534	267	133	0	0	3782	1780
Sassafras albidum	2002	667	7697	3515	1468	1557	0	623	44	89	11212	6452
Liquidamber styraciflua	0	133	311	89	222	222	44	0	89	0	667	445
Betula lenta	89	0	0	89	89	0	0	0	0	0	178	89
Pinus viginiana	0	0	44	356	0	178	44	89	44	0	133	623
Quercus alba	1824	2670	6897	12903	979	3604	44	356	0	0	9744	19533
Liriodendron tulipifera	534	667	400	489	222	1246	89	400	133	44	1379	2848
Total	38042	46897	32659	52013	10857	20467	2714	5517	1602	1646	85873	126541



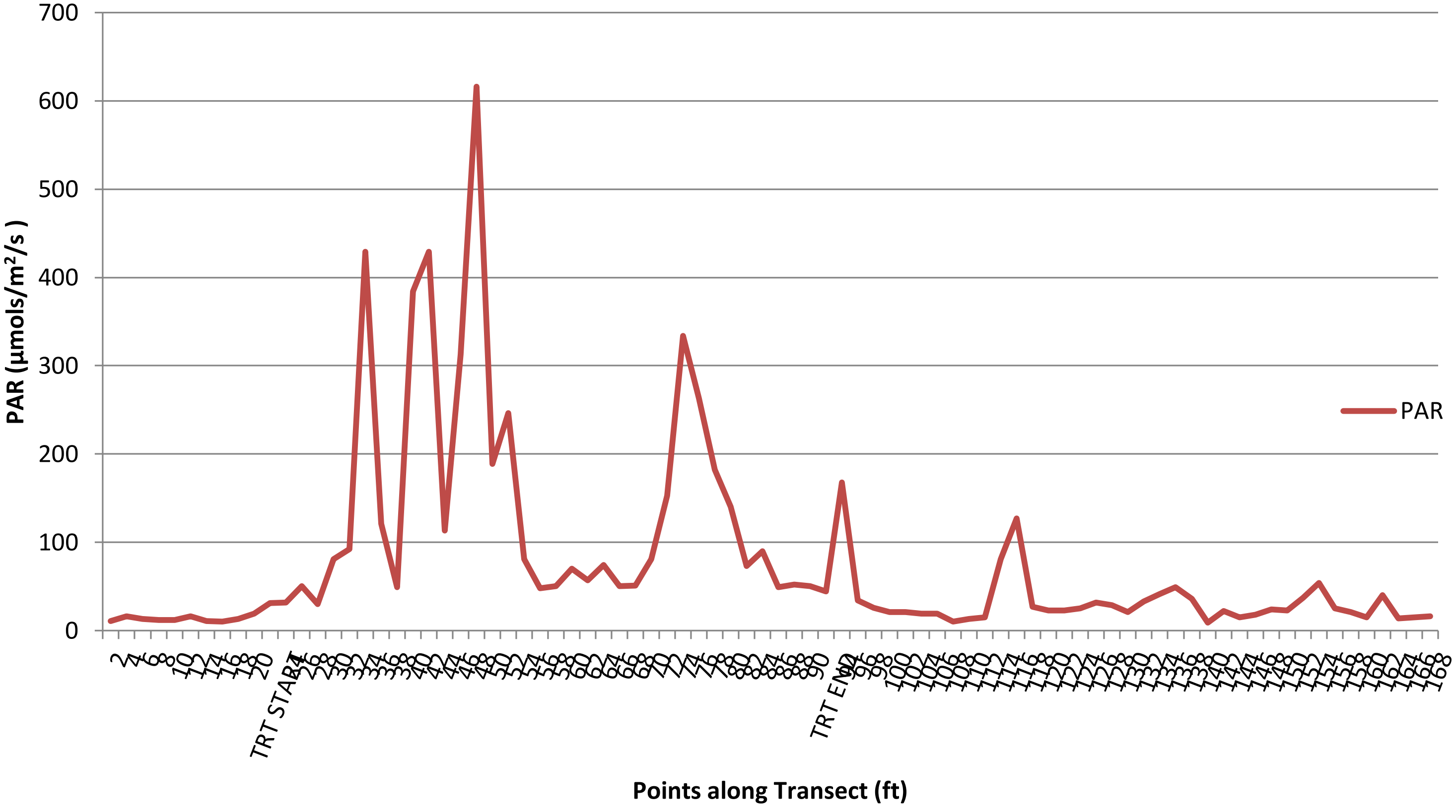
Appendix G. PAR measurements were taken every 2 feet along a transect that bisected the control and removal treatments in the Fentress Spur site. Measurements were taken during clear sky conditions with AccuPAR ceptometer at breast height.



Appendix H. PAR measurements were taken every 2 feet along a transect that bisected the control and removal treatments in the Horse Cove site. Measurements were taken during clear sky conditions with AccuPAR ceptometer at breast height.



Appendix I. PAR measurements were taken every 2 feet along a transect that bisected the control and removal treatments in the Pigg House site. Measurements were taken during clear sky conditions with AccuPAR ceptometer at breast height.



Appendix J. PAR measurements were taken every 2 feet along a transect that bisected the control and removal treatments in the Pigg House site. Measurements were taken during clear sky conditions with AccuPAR ceptometer at breast height.

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May 2011

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Parrott, D.L., Lhotka, J.M., Stringer, J.W., 2010. Effects of midstory removal on underplanted black oak (Quercus velutina) and white oak (Quercus alba) in the western Cumberland Plateau. In: Fei, S.L., Lhotka, J.M., Stringer, J.W., Gottschalk, K.W., Miller, G.W. (Eds.), 17th Central Hardwood Conference. USDA Northern Research Station, Lexington, KY.

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