EFFECTS OF LATE ROTATION THINNING ON LIGHT AVAILABILITY AND RED OAK REGENERATION WITHIN A MINOR STREAM BOTTOM IN MISSISSIPPI

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Abstract–Recent studies suggest a troubling decline in the abundance of red oak species (*Quercus* spp., Section *Erythrobalanus*) in bottomland forests of the southeastern United States. We assessed red oak advance regeneration and associated tree species in relation to light availability in a 77-year-old oak-dominated stand 5 years after late rotation thinning. Residual basal areas across four thinning treatments ranged between 48 and 69 square feet per acre and were compared to an unthinned control (108 square feet per acre). Available understory light was significantly greater in the most intensive treatment (48 square feet per acre) compared to the unthinned control. Red oak advance regeneration was significantly taller in thinned areas. For the tallest height class (48+ inches), the control area contained only 44 red oak seedlings per acre, while the highest thinning intensity treatment contained more than six times the number of large red oaks (272 red oak seedlings per acre). Relative height of red oak seedlings (the tallest red oak as a proportion on the tallest non-oak seedling) did not differ among treatments. Higher intensity late rotation thinning regimes appeared to be beneficial to increasing red oak advance regeneration vigor, which may aid their progress into the overstory canopy level upon a harvest release. Further monitoring through harvest is needed. Late rotation thinning may provide managers an effective means for enhancing the regeneration of red oak species in future regeneration treatments.

INTRODUCTION

Oaks are dominant components of minor stream bottom hardwood forests in the southeastern United States. Recent studies suggest a troubling decline in the abundance of red oak species in the Southeast (Oliver and others 2005). The presence of oak seedlings can be variable depending on factors such as mast production, flooding duration, light levels, and species present, among others. Once red oak seedlings become established, progressing these seedlings from the understory into the overstory canopy can be difficult, especially with a lack of available understory light.

Most oaks are classified as shade-intolerant, so their exposure to ample understory light is vital for their survival and growth in bottomland hardwood forests (Carvell and Tryon 1961, Logan 1965, McGee 1968). Hodges and Gardiner (1993) reported that low light availability may be the most limiting factor to oak regeneration, and the range of 27 to 53 percent light exposure resulted in maximum growth of these oak seedlings (Gardiner and Hodges 1998). Studies examining the effects of canopy gap conditions on regeneration have indicated that oak seedlings are found more often in larger (> 0.25 acre) gaps (Holladay and others 2006). As further evidence of light limitation of oak seedlings, silvicultural treatments such as midstory control have been used to increase light penetration to the understory to increase understory oak seedling growth (Ezell and others 1993, Loftis 2004, Peairs and others 2004). As a stand-alone treatment, midstory removal may not be sufficient to increase light levels to understory seedlings in closed canopy riparian forests (Cunningham and others 2011, Ostrom and Loewenstein 2006); however, studies have shown that a combination of midstory removal and partial overstory harvest can increase light levels and provide favorable conditions for oak regeneration (Cunningham and others 2011, Peairs 2003).

Bottomland hardwood forests typically contain variable spacing of desirable species and high-quality stems (Meadows and Skojac 2012). Therefore, bottomland thinning operations are more likely to create gaps than thinning operations in more uniform stands with frequently occurring crop trees (e.g. simple conifer stand types, plantations, or upland hardwoods) (Meadows and Skojac 2012). Thinning is an intermediate treatment that develops residual stems by regulating stand density and aims to improve growth and development, modify species composition, and improve overall bole quality of residual stems

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Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

(Meadows 1996, Smith and others 1997). Although not the intent, thinning treatments may aid in establishment of advance regeneration that could be released upon final harvest (Lockhart and others 2004). Gaps created during thinning provide increased light availability, which is favorable to developing oak advance regeneration (Collins and Battaglia 2008, Lockhart and others 2004). Thus thinning may provide a critical opportunity for developing oak regeneration (Meadows and Stanturf 1997). Thinning may negatively impact oak regeneration due to machine traffic. However, Lockhart and others (2000) reported that damage during thinning operations would have a negligible effect on the development of the advance regeneration of red oaks prior to final harvest. At the same time, increased light conditions provided by thinning operations can also create opportunities for growth and development of competitors of red oak. These tradeoffs associated with thinning effects have not been well investigated.

An improved understanding of the impacts of thinning on regeneration of red oaks is needed, particularly in terms of relationships among residual basal area, available understory light and development of advance regeneration. The objectives of this study were: (1) to evaluate the light levels across different thinning intensities, and (2) to evaluate the effects of thinning on the development of bottomland hardwood red oak and associated species. In this way, this study should help managers determine the efficacy of late-rotation thinning for enhancing the regeneration of red oak species in future regeneration treatments.

MATERIALS AND METHODS

Study Area

This study was conducted within a 77-year-old minor stream bottom hardwood stand within the Samuel D. Hamilton Noxubee National Wildlife Refuge (Noxubee NWR) in Noxubee County, in east-central Mississippi (N33°15' W88°43', elevation ca. 250 feet). Noxubee NWR received 60.75 inches precipitation in 2012, with the highest monthly average occurring in July (National Climatic Data Center 2013). The predominant soil type in this area is the Urbo-Mantachie association (NRCS 2012). This area is adjacent to the Noxubee River and is subject to periodic flooding events, especially through the winter months. The site supports an approximately 70-year-old mixed species hardwood stand, dominated by red oaks (*Quercus* spp.) and sweetgum (*Liquidambar styraciflua* L.). The red oak species represented 51 percent of stand basal area prior to treatment and were primarily comprised of cherrybark (*Q. pagoda* Raf.) and water oak (*Q. nigra* L.), with a lesser component of willow oak (*Q. phellos* L.). Sweetgum comprised 23 percent of stand basal area prior to treatment, with hickory (*Carya* spp.), green ash (*Fraxinus pennsylvanica* Marsh.), swamp chestnut oak (*Q. michauxii* Nutt.), overcup oak (*Q. lyrata* Walt.), and American elm (*Ulmus americana* L.) comprising the remaining basal area (Meadows and Skojac 2012).

Experimental Design

This study area was established in 2007 to investigate effects of late rotation thinning on stand development and mast production (Meadows and Skojac 2012). The study was established as a completely randomized block design containing four thinning intensities (48, 57, 61, and 69 square feet per acre residual basal area) and an uncut control (108 square feet per acre residual basal area) with three replications of each totaling 15 treatment areas of 264 feet by 330 feet each (table 1). Sites were thinned using Stand Quality Management specifications, which favor the retention of the highest quality trees (species and form) regardless of spacing (Meadows and Skojac 2012).

Regeneration Sampling

Each experimental unit was sampled using a series of subplots, centered off a randomly located point halfway between the bole and dripline of individual red oak canopy trees. Seedlings were sampled at 53 individual red oak stems within the study area, averaging 2 to 3 sample points per treatment. At each sampling

Table 1—Basal area (BA) by treatment pre-and post-thinning in a minor stream bottom hardwood forest in east-central Mississippi: initial, residual, and year 3 BA (modified from Meadows and Skojac 2012)

Treatment	Initial BA Oct 2007	Residual BA Apr-May 2008	Year 3 BA Jan 2011
	----------------*square feet per acre*-------------------		
Control	113	108	112
Acceptable/superior	122	69	68
Acceptable/no pole	108	61	64
Desirable/superior	126	57	59
Desirable/no pole	112	48	51

point, four circular 0.002-acre (5.3-foot radius) subplots were positioned at 90° angles at a distance of 19.7 feet from each randomly selected point. In each subplot, individual seedlings were identified by species, and seedling heights were recorded.

Understory Light Sampling

Hemispherical photography was used to estimate light availability based on global site factor (GSF) indices derived from processed digital images. GSF is the proportion of global radiation (direct plus diffuse radiation) at a specific location (i.e. under the forest canopy) in relation to that in the open condition (Anderson 1964, Delta-T Devices 1999). Hemispherical photographs were taken at the center of each regeneration plot at the study area in July and August 2012. Photographs were taken in the morning before sunrise using a 3.34 megapixel Nikon Coolpix 990 camera with a Nikon LC-ER1 fisheye lens attachment (Nikon, Melville, NY). The camera system was placed into a self-leveling mount (Delta-T Devices, Cambridge, United Kingdom) attached to a camera tripod. The camera position was 5 feet above ground level, oriented north, and the timer setting was used. Hemispherical canopy images were analyzed with HemiView Analysis 2.1 software (Delta-T Devices 1999) to calculate GSF. Threshold values were determined for individual photographs (Anderson 1964, Rich 1990).

Data Analysis

Data were analyzed using analysis of variance (ANOVA) by PROC GLM procedure in SAS 9.3 (SAS Institute Inc., Cary, NC). Significance was evaluated at $\alpha = 0.05$. We compared light availability (GSF), seedling height, and red oak relative height (tallest red oak as percent of tallest non-oak) across treatments (averaged at the plot level, n = 3 per treatment). GSF and seedling height values were square root transformed to meet ANOVA assumptions. Tukey's HSD test was used for multiple comparisons.

RESULTS

Light

Across the treatments, GSF was significantly different (P = 0.0409). The highest intensity thinning treatment (48 square feet per acre; mean GSF = 0.2896; SE = 0.094) provided over twice the amount of light to the understory than the control (108 square feet per acre; mean GSF = 0.1324; SE = 0.010) (fig. 1). There were no differences among the other thinning treatments and the control.

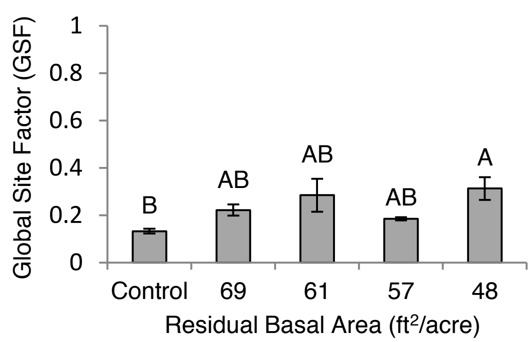

Figure 1—Mean global site factor (GSF) by treatment (shown as residual basal area square feet per acre) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Letters signify differences at α = 0.05, using Tukey's HSD for multiple comparisons. Error bars represent ± standard error of the mean.

Composition and Frequency

Across the entire site, frequency of red oak advance regeneration was between 20 to 35 percent, depending upon species (fig. 2).

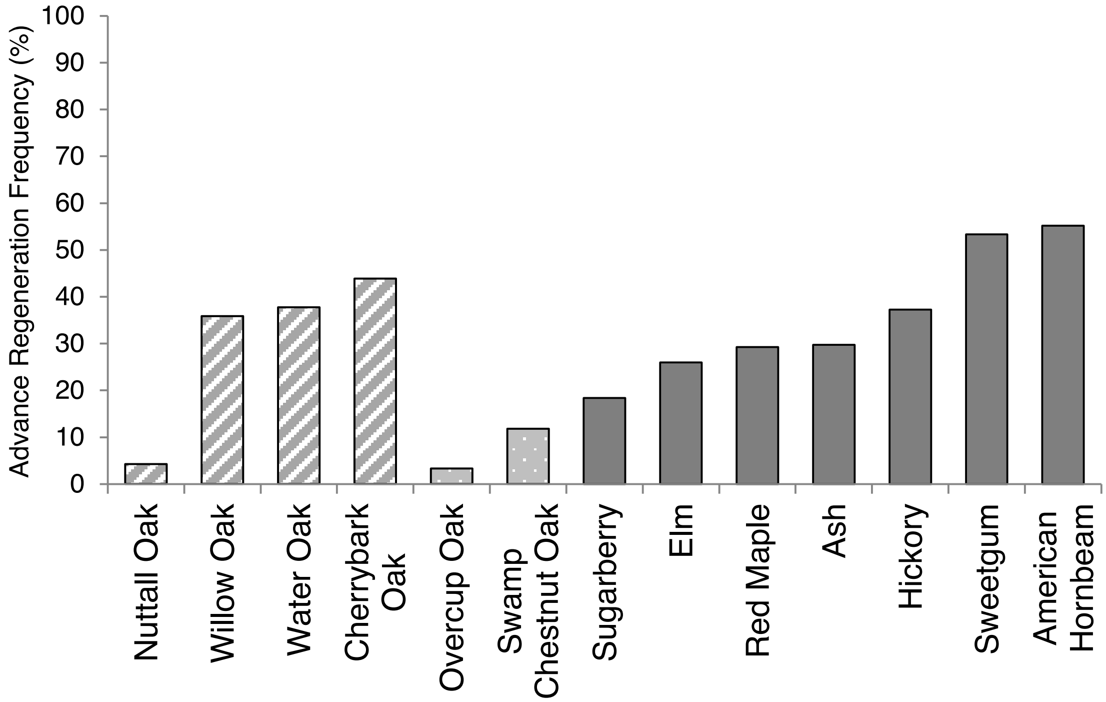

Figure 2—Frequency (percent) of advance regeneration by species 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Red oaks are indicated by striped bars, white oaks by dotted bars, and non-oak species by solid bars.

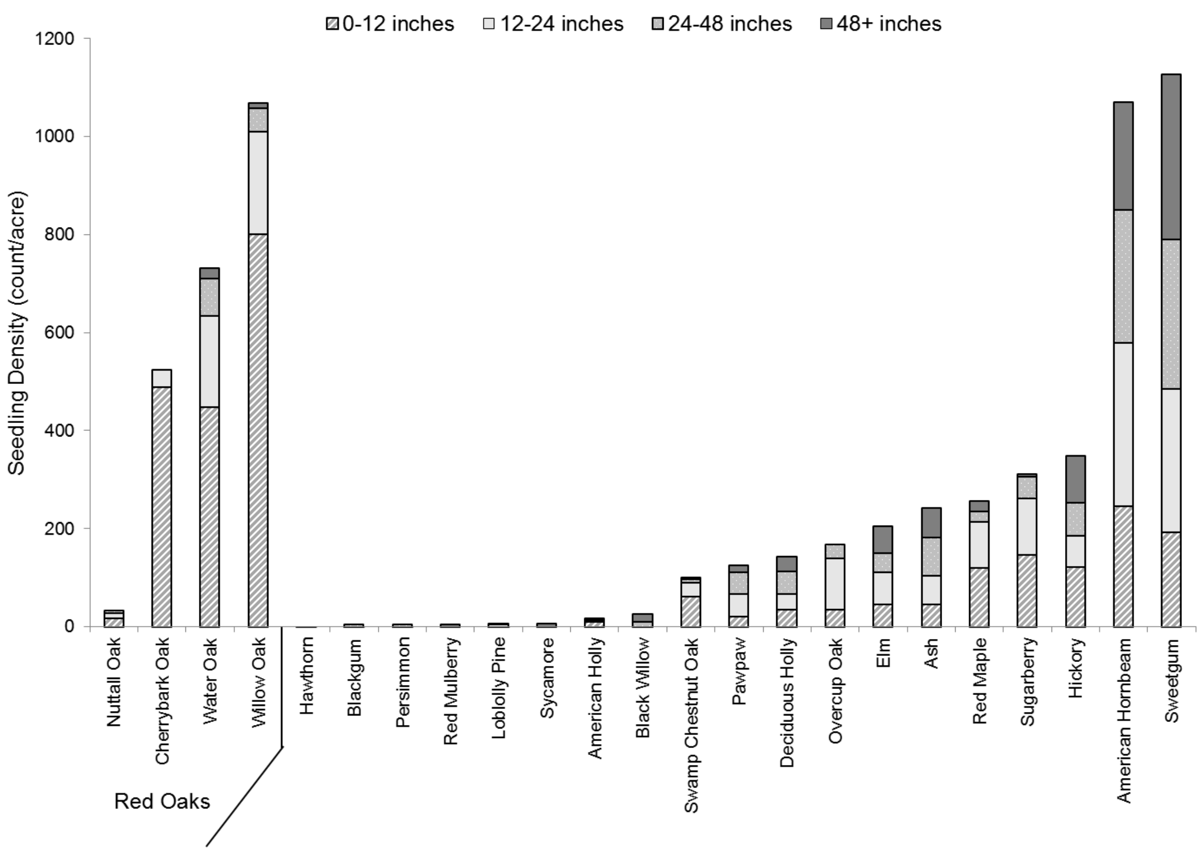

Figure 3—Seedling density per acre of advance regeneration by species and height class (0-12, 12-24, 24-48, and 48+ inches) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Species not previously identified in the text: hawthorn (*Crataegus* spp.), black gum, (*Nyssa sylvatica* Marsh.), persimmon (*Diospyros virginiana* L.), red mulberry (*Morus rubra* L.), loblolly pine (*Pinus taeda* L.), sycamore (*Platanus occidentalis* L.), American holly (*Ilex opaca* Aiton), black willow (*Salix nigra* Marsh.), pawpaw [*Asimina triloba* (L.) Dunal], and deciduous holly (*Ilex decidua* Walt.).

Willow oak, water oak, and cherrybark oak were the most abundant red oaks; Nuttall oak (*Q. texana* Buckl.) seedlings were rare on the site in any size class. The most frequent non-oak species were American hornbeam (*Carpinus caroliniana* Walt.) and sweetgum (50 to 60 percent); however, other frequent non-red oak species included hickory (*Carya spp.*), ash (*Fraxinus spp.*), red maple (*Acer rubrum* L.), elm (*Ulmus spp.*), and sugarberry (*Celtis laevigata* Willd.) (fig. 2). Across the entire site, most red oaks fell within the 0 to 12 inches height class and had few stems within the largest height classes (fig. 3). Most of the advance regeneration in the largest height classes (24 to 48 inches and 48+ inches) included sweetgum, American hornbeam, hickory, ash, and elm (fig. 3).

Seedling Density and Height

There were no treatment effects on red oak mean seedling density (P = 0.8441) or aggregate height (P = 0.8721). When red oak seedling density was separated into height classes (0-12, 12-24, 24-48, and 48+ inches) little variation in seedling density was apparent in the shorter (0-12, 12-24 inch) height classes. However, there were more seedlings in the taller height classes (48+ inches) in the higher intensity thinning treatments (especially 48 square feet per acre) than in the control (108 square feet per acre) (fig. 4). For the tallest seedlings (48+ inches), the control contained only 44 red oak seedlings per acre, while the most intensive thinning treatment (48 square feet per acre) contained more than six times the number of red oaks (272 red oak seedlings per acre). Red oak mean height was also significantly (P = 0.0238) greater in the highest intensity thinning treatment (48 residual square feet per acre) compared to the control (108 residual square feet per acre) (fig. 5).

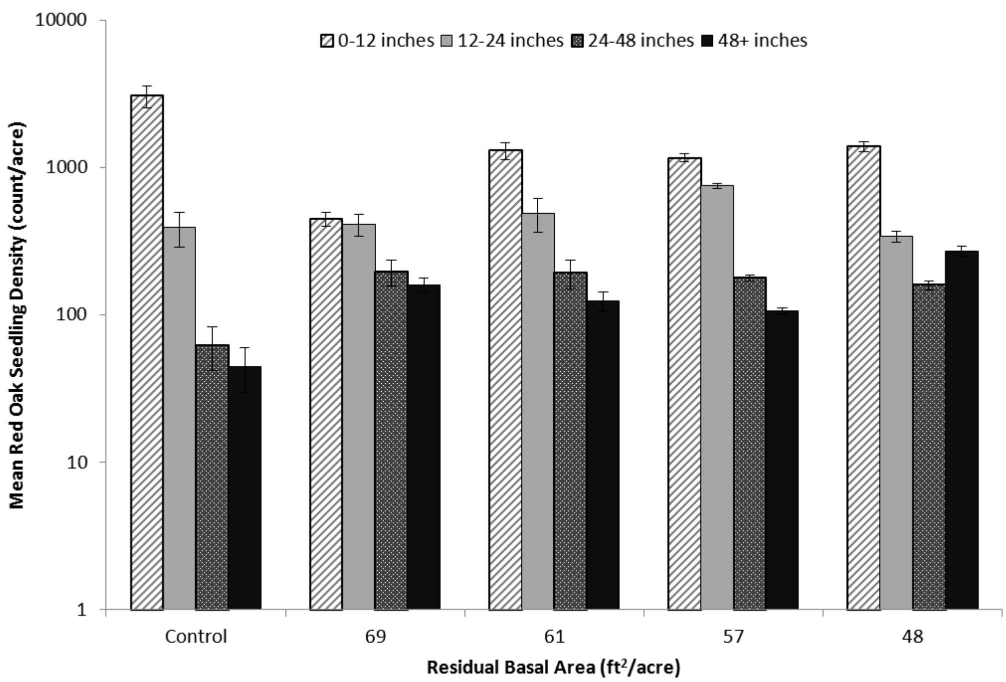

Figure 4—Density of red oak advance regeneration per acre by treatment (residual basal area; square feet per acre) and height class (0-12, 12-24, 24-48, 48+ inches) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Error bars represent ± standard error of the mean. Note: seedling density is presented on a logarithmic scale

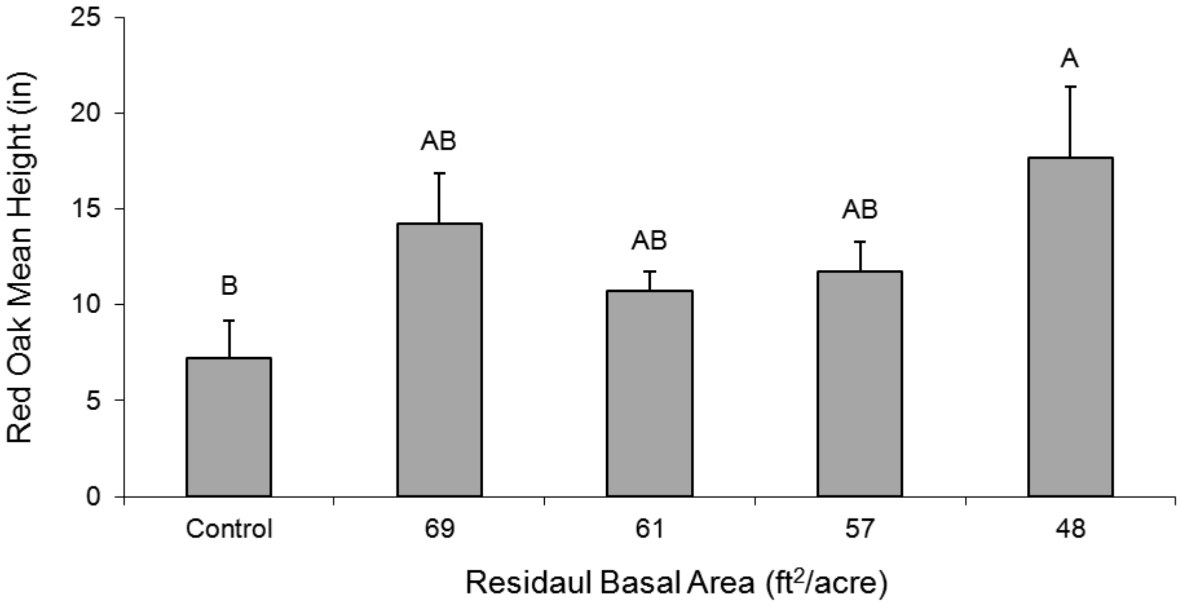

Figure 5—Mean height (inches) of red oak advance regeneration by treatment (shown as residual basal area square feet per acre) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Letters signify differences at α = 0.05, using Tukey's HSD for multiple comparisons. Error bars represent ± standard error of the mean

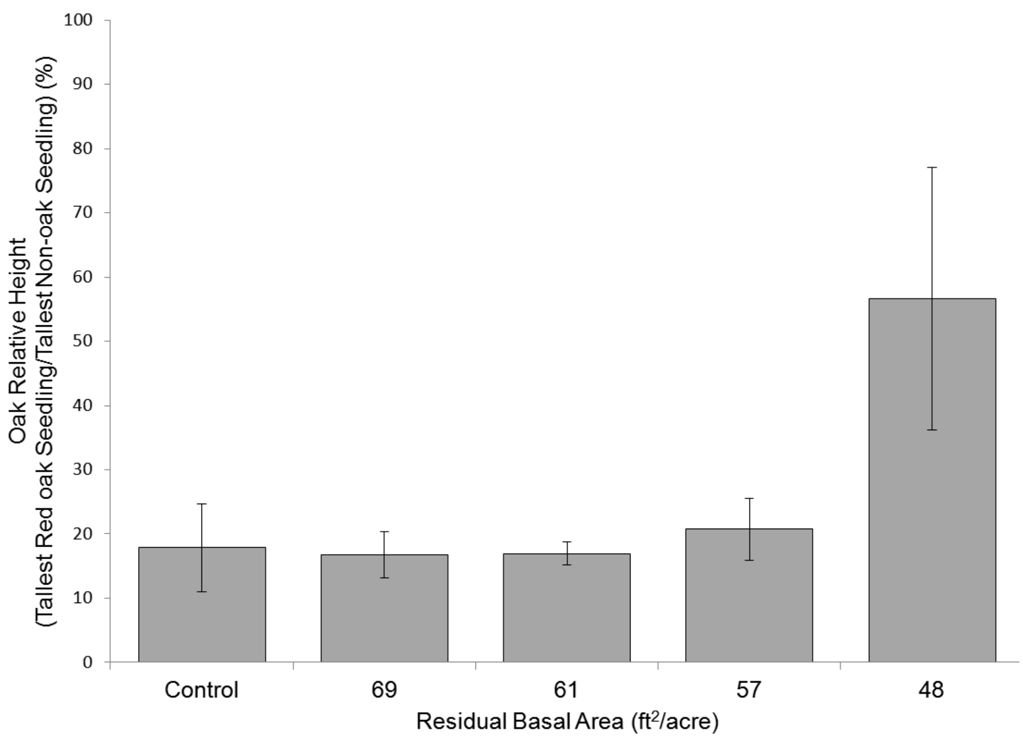

Figure 6— Relative height of oak seedlings as a percent of the tallest non-oak seedling by treatment (residual basal area; square feet per acre) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi. Error bars represent ± standard error of the mean.

Competition

The difference between the single tallest non-oak seedling and single tallest red oak seedling was determined at 53 individual overstory stems. The oak relative height (tallest red oak seedling divided by tallest non-oak seedling) was not significantly different by treatment (P = 0.0731) (fig. 6). The overall average difference in height of these tallest seedlings across the entire site was 9.2 feet. The most common tallest red oak species were water oak and willow oak, while the most common tallest non-oak species included sweetgum, ash, and American hornbeam. The mean height of the most common species varied by species (fig. 7)

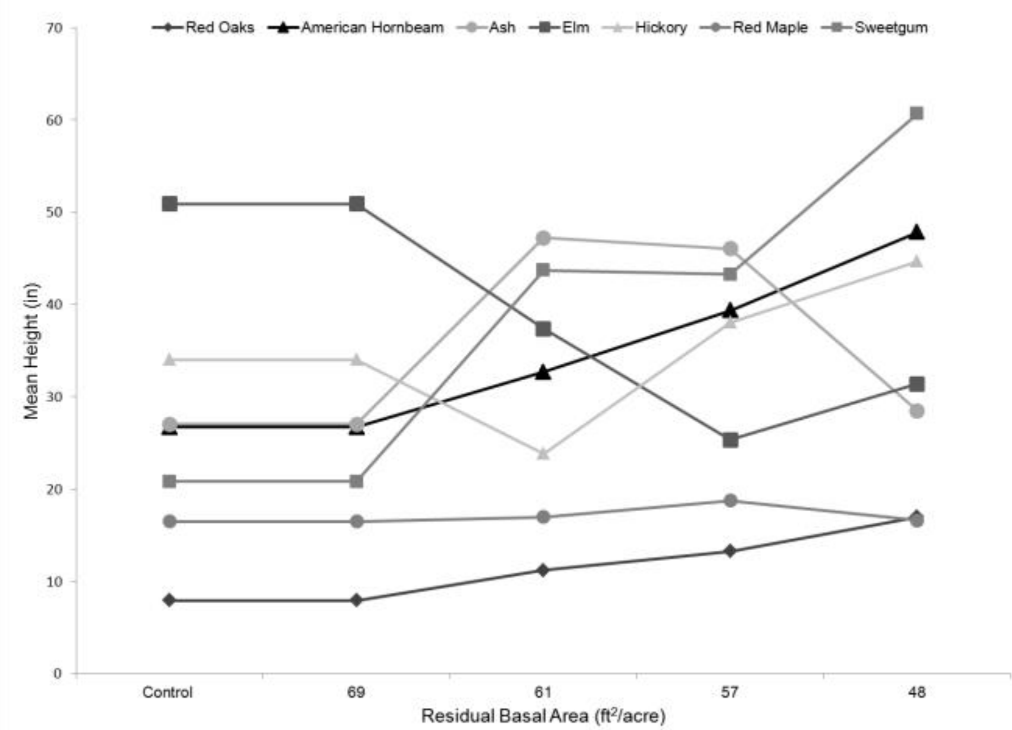

Figure 7— Mean height (inches) of red oaks, American hornbeam, ash, elm, hickory, red maple, and sweetgum species by treatment (residual basal area; square feet per acre) 5 years after implementing thinning treatments in a minor stream bottom hardwood forest in east-central Mississippi.

DISCUSSION

Five years after thinning, available understory light increased with thinning intensity in a minor bottom hardwood forest. Light regimes are a critical determinant of red oak seedling survival and growth, especially after the first year when oak seedlings are no longer reliant on seed reserves (Crow 1988). Although it is possible for red oak seedlings to persist at very low light levels, such as those in the control treatments, the optimal range of light reported for red oak seedling growth is typically moderate levels between 20 to 53 percent (Gardiner and Hodges 1998, Gottschalk 1994, Guo and others 2001, Phares 1971). Light levels recorded in unthinned controls in this study were comparable to those found in midstory removal in closed canopy forests (14 percent; Cunningham and others 2011), uninjected greentree reservoir control areas (12.5 to 15.3 percent; Guttery and others 2011), and slightly higher than the untreated bottomland stands in the region (8.8 percent; Peairs 2003). As for thinned areas, the most intensively thinned areas in this study were similar in range (22.47 to 44.7 percent) for midstory injection reported by Guttery and others (2011) Significantly higher numbers of tall red oak seedlings occurred in thinning treatments compared to the control, indicating an increase in seedling vigor. The mean red oak seedling height was significantly greater in the most intensive thinning treatment (48 square feet per acre), which suggests that intensive late-rotation thinning treatments aid in increasing the vigor of red oak advance regeneration 5 years after thinning. Larsen and others (1997) also reported overstory basal areas > 87.1 square feet per acre failed to meet the standards necessary for adequate oak regeneration size and density. Although the intent of thinning regimes is solely to increase the quality of the residual timber, the simultaneous opening of the canopy can provide additional benefits by increasing the vigor of advance regeneration (Lockhart and others 2004). These benefits gained through thinning treatments should be kept in mind for stand management plans and could potentially reduce the need for further management to obtain adequate oak regeneration or reduce undesirable competition after final harvest (Meadows and Stanturf 1997).

CONCLUSIONS

Five years after thinning, light availability increased with increasing thinning intensity and provided favorable conditions for red oak advance regeneration. Significantly higher numbers of tall red oak seedlings occurred in thinning treatments than in the control, indicating an increase in seedling vigor. Consequently, late rotation thinning treatments can aid in development of red oak advance regeneration to increase their stature and place them in a more competitive position for advancement upon release by final harvest. Future observations of advance regeneration through harvest are needed. Additionally, species composition and competition are important factors controlling regeneration, and evaluation of these dynamics will improve our knowledge of oak regeneration.

ACKNOWLEDGEMENTS

We acknowledge the Samuel D. Hamilton Noxubee National Wildlife Refuge for access to research sites, and Steve Meadows (USDA Forest Service) for project installation. This project was supported by the Forest and Wildlife Research Center (College of Forest Resources, Mississippi State University). We also acknowledge the many students from the Department of Forestry who provided field assistance for this project.

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