CHERRYBARK OAK 7-YEAR GROWTH RESPONSE IN INTERMIXED SPECIES, COMPETITIVE NEIGHBORHOODS

Martin R. Schubert, Wayne K. Clatterbuck, and John M. Zobel

Abstract—In 2009, 6.5 acres on the University of Tennessee's Cumberland Forest in Morgan County, TN, were identified for hardwood afforestation. Twenty-seven plots were planted in one of three species of hardwoods: yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), and sweetgum (*Liquidambar styraciflua*) at three spacings. Cherrybark oak (*Quercus pagoda*) was intermixed in these plantings such that each oak was completely surrounded by a competitor species. These unique, species-specific neighborhoods act on oak growth and development particular to variations in competitor crown architecture. After 7 years, oak survival ranged from 84.8 percent in 6-foot by 6-foot sweetgum plots to 100 percent survival in the 10-foot by 10-foot yellow-poplar plots. Oak diameter at breast height (d.b.h.) showed significant effects within spacing (p = 0.0002) and species (p = 0.0015), but not their interaction (p = 0.9110). Total mean cherrybark oak d.b.h. was 1.6 inches, ranging from 1.4 inches in the 6-foot by 6-foot yellow-poplar plots to 2.17 inches in the black cherry 10-foot by 10-foot plots. There were significant effects of spacing on cherrybark oak height growth (p = 0.0164) but no significant differences at the species level (p = 0.2410) or in the interaction of spacing and species (p = 0.7451). Comparisons of mean plot heights by spacing indicates significant cherrybark oak height differences between the 10-foot by 10-foot spacing (16.6 feet) and the 6-foot by 6-foot spacing (13.4 feet; p = 0.0091) but not between the 6-foot by 6-foot and 8-foot by 8-foot (14.9 feet; p = 0.3901) or the 8-foot by 8-foot and 10-foot by 10-foot spacings (p = 0.2905).

INTRODUCTION

Although oaks (*Quercus* spp.) are typically the most dominant trees in the overstory of the Central Hardwood region, they are not consistently regenerating, especially on better sites (Abrams 2003, Fei and others 2011, Moser and others 2006, Thomas-Van Gundy and others 2014). This apparent oak regeneration crisis, a "paradox of a species that is dominant on the landscape, yet difficult to regenerate" (Crow 1988: 19) has confounded forest managers for decades. The long-term effect of this paradox on stand dynamics is a decline of an oak-dominated overstory with other species taking their place (Fei and others 2011, Luppold and Bumgardner 2018).

In response, work has been done to mimic historical fire regimes that might effectively perpetuate the establishment of oak regeneration and subsequent recruitment in size class. These efforts have had mixed results with some studies showing prescribed fire promoting oak regeneration by successfully reducing vegetative competition (Brose 2010, Brose and Van Lear 1998, Huddle and Pallardy 1999, Royse and others 2010, Signell and others 2005). Others have found little positive impact of fire on oaks or minimal negative impact on its competitors (Albrecht and McCarthy 2006, Alexander and others 2008, Gilbert and others 2003 Granger and others 2018, Green and others 2010, Hutchinson and others 2005). Other work has focused on developing thinning regimes, midcanopy removals, or a variety of basal area reductions (Albrecht and McCarthy 2006, Fahey and others 2016, Loftis 1990, Parrott and others 2011) and utilizing various regeneration harvest techniques such as shelterwood, seed tree, femelschlag, etc. (Beckage and others 2000, Granger and others 2018, Kellner and Swihart 2016, Loftis 1990 Motsinger and others 2010) to encourage oak establishment and development.

But whether exploring fire regimes, stand manipulation, or some combination of these broad treatment types, it is evident that there is a need to investigate interspecies-specific competition and its explicit impact on the development of oak. It is foundational to understand long-term competitor interactions with oak and impacts on the growth and development of oak crowns and subsequently their general form and function before exploring oak response to other confounding factors such as fire or prescriptive removals.

The rich diversity of taxa throughout the eastern hardwood forests forming the competitive

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neighborhoods with which oak interacts in its ontogeny suggests a vast array of unique competitive influences on oak. What role does competitor species crown architecture play in shaping the growth environment for oak and does that interaction change over time? For example, the excurrent form of sweetgum (*Liquidambar styraciflua*) has been shown to allow cherrybark oak (*Quercus pagoda*) to assume latent dominance in natural (Clatterbuck and Hodges 1988) and artificial mixed stands (Lockhart and others 2012).

We hope to 1) quantify the unique competitive pressures inherit to oak in mixed stands, 2) assess cherrybark oak response to these pressures, and 3) develop practical guidelines for quality oak management for landowners and natural resource practitioners. This is a first step in these efforts and this paper reports on 7-year survival, height, and d.b.h. of intermixed cherrybark oak and assesses early interspecies interactions with cherrybark oak in Tennessee.

METHODS

Study Site

In 2009, 6.5 acres of slightly rolling land on the University of Tennessee's Cumberland Forest in Morgan County, TN, were identified for afforestation. This area was located at latitude N36° 3.116' and longitude W84° 28.952' on a broad upland interfluve at an elevation of 1340 feet above sea level (Griffith and others 1998, Smalley 1982). The climate was characterized by long, moderately hot summers and short, mild winters. Average annual temperature ranged from a January mean minimum of 27.5 °F to a July mean maximum of 80.6 °F with an annual daily average of 57.3 °F. Average annual precipitation was 57.5 inches which was fairly evenly distributed throughout the year (Logan and others 1990). Soils were classified as Lonewood silt loam (LoB) with 2 to 5 percent slopes. These tended to be well drained with moderate permeability and high available water capacity with strongly to very strongly acidic soil pH. Depth to soft sandstone bedrock was 40 to 60 inches or more (Davis and Yaeger 2007, Evans 1992). Site indexes ranged from 75 feet at base age 50 years for shortleaf pine (*Pinus echinata*) and white oak (*Quercus alba*), 80 feet for northern red oak (*Quercus rubra*), 90 feet for sweetgum and eastern white pine (*Pinus strobus*), and 100 feet for yellow-poplar (*Liriondendron tulipifera*) on the Wartburg Basin – Jellico Mountains subregion (Smalley 1982). The area had been left fallow for 8 years following a white pine and loblolly pine (*Pinus taeda*) salvage harvest. It was bush hogged and burned annually during that time. While generally homogenous, some microsite variability existed in the form of two linear depressions that carried overland flow in significant rain events. By avoiding these depressions, 6.5 acres were delineated as plot land for this project. Immediately prior to establishment, the area was disked.

Planting Design and Establishment

This study used cherrybark oak, one of the most highly valued and quickly growing of the red oaks (Section *Lobatae*), as the focal tree. It was intermixed in plantings of yellow-poplar, sweetgum, or black cherry (*Prunus serotina*) as trainer trees in part to utilize the unique crown characteristics these competitor species provide. Aside from being one of the most common regional competitors of oak, yellow-poplar is also one of the most quickly growing trees in the Eastern United States with broad leaves that shade out competition underneath a dense canopy. It also sprouts vigorously when cut. Although expected to quickly overtop the cherrybark oak, its physiological characteristics allow investigation of oak crown response to severe competition at crown closure and affords opportunity to develop a complimentary thinning regime thereafter. Sweetgum's excurrent crown architecture should allow cherrybark oak to occupy the space above the base and widest section of the sweetgum crowns regardless of the overall height of the sweetgum. Black cherry is a fast-growing pioneer species like yellow-poplar but differs in that its sparse crown and small leaves result in a low light extinction rate through its canopy allowing cherrybark oak to assume latent dominance. Yellow-poplar and black cherry 1-0 seedlings were purchased from the Indiana Department of Natural Resources State nursery at Vallonia in southern Indiana. Cherrybark oak and sweetgum seedlings were purchased from the Tennessee Division of Forestry nursery located in Delano, TN.

In March 2009, the seedlings were planted on 27 plots. Each was planted with one competitor species and cherrybark oak. Odd numbered rows consisted purely of the competitor and even rows alternated with cherrybark oak such that every oak was surrounded by eight trees of a trainer species. Three replicates of each competitor were planted at three spacings (6-foot by 6-foot, 8-foot by 8-foot, and 10-foot by 10-foot). Six-foot by 6-foot plots were 0.19 acre in size (15 rows) with 49 cherrybark oak intermixed with 176 competitors. Eight-foot by 8-foot plots were 0.25 acre (13 rows) with 36 cherrybark oak and 133 competitors. The 10-foot by 10-foot plots were 0.28 acre in size (11 rows) with 25 cherrybark oak trees in 96 competitors (fig. 1). After planting, glyphosate was applied by backpack sprayer between rows three times during the first growing season, twice in the second growing season, and once during the third growing season to minimize ingrowth.

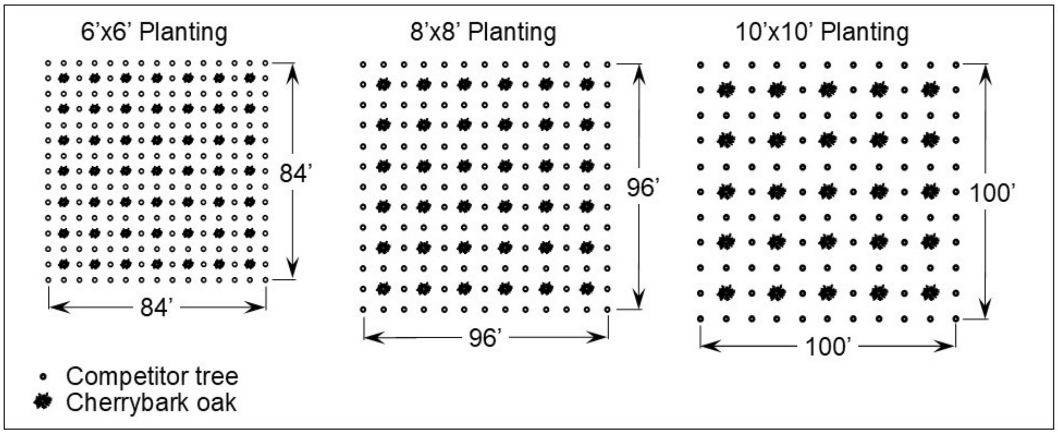

Figure 1--Mixed cherrybark oak and competitor species experimental unit layouts. From left to right: 6-foot by 6-foot spacing, 8-foot by 8-foot spacing, and 10-foot by 10-foot spacing.

Two linear depressions precluded blocking on spacing/species replicates. Maximizing uniformity within plots, the study was blocked on spacing with replicates of species within spacing blocks. This allowed distribution of the smaller 6-foot by 6-foot plots in conformity to the known site restrictions and resulted in the greatest plot homogeneity.

Early Treatments

It was expected that cherrybark oak would not successfully compete with yellow-poplar especially at closer spacings. By the end of the fourth growing season, in the 6-foot by 6-foot spacing, the cherrybark oak averaged 4.9 feet tall and were completely overtopped by the yellow-poplar (mean 17 feet total height) (Clatterbuck 2016). The yellow-poplar was systematically thinned, removing every poplar in each cardinal direction to a cherrybark oak. In that way, the four yellow-poplars closest to each cherrybark oak were removed and the four ordinal yellow-poplar remained. The cut yellow-poplar was removed from the plot by hand, minimizing damage to the stumps and residual stems. No chemical was applied allowing the yellow-poplar to coppice. Successful timing of the thinning application would prevent increased mortality and reduce growth inhibition caused by the complete yellow-poplar crown closure above the oak.

Measurements

Survival, total height, and diameter at breast height (d.b.h.) were measured for every tree in the study during the winter of 2016 after seven growing seasons. Diameters to the nearest tenth of an inch were measured using calipers and total heights to the nearest tenth of a foot were estimated using ocular estimation of tree tops next to height poles. These data were collected prior to additional release treatments conducted in late winter of 2016.

Analysis

Statistical analysis of the 995 cherrybark oak diameters and heights across all spacings and species were conducted using R software (R Core Team 2012). Although part of a larger investigation into tree crown development and interactions in which each cherrybark oak and its surrounding competitors were considered individual experimental units, this iterative analysis treated the plot as the experimental unit and therefore was treated as a completely randomized design with species plot replication within spacing. Cherrybark oak d.b.h. and heights were therefore averaged for each species x spacing x replicate plot and an analysis of variance performed with subsequent pairwise comparisons using t-tests with pooled standard deviations and Bonferroni's p value adjustment method.

RESULTS

Survival

Cherrybark oak seedling survival across the entire study ranged from a low of 84.8 percent in the 6-foot by 6-foot sweetgum to a high of 100 percent survival of cherrybark oak in the 10-foot by 10-foot yellow-poplar (table 1). Despite being overtopped by the end of four growing seasons, the oak in the thinned 6-foot by 6-foot yellow-poplar treatment exceeded that of the 6-foot by 6-foot black cherry and sweetgum treatments.

Diameter at Breast Height

Total mean cherrybark oak d.b.h. after 7 growing seasons was 1.6 inches, ranging from a low of 1.4 inches in the 6-foot by 6-foot yellow-poplar treatment to a high of 2.2 inches in the black cherry 10-foot by 10-foot treatment (fig. 2). Cherrybark oak d.b.h. showed significant effects within spacing ($p = 0.0002$) and species ($p = 0.0015$) but not the interaction term ($p = 0.9110$). The 10-foot by 10-foot spacing trees had

Table 1—Seven-year survival of planted cherrybark oak intermixed in competitor species plantings by spacing

Spacing	Plot size	Competitor	Planted	Surviving	Survival
	acres		*number*	*number*	*percent*
6 x 6	0.19	YEP	147	143	97.3
		SWG	147	125	84.8
		BLC	147	135	91.9
8 x 8	0.25	YEP	108	107	99.1
		SWG	108	104	96.3
		BLC	108	104	96.3
10 x 10	0.28	YEP	75	75	100.0
		SWG	75	73	97.3
		BLC	75	73	97.3

YEP = yellow-poplar, SWG = sweetgum, BLC = black cherry.

Planted = initial number of cherrybark oak planted.

Surviving = number of cherrybark oak that were alive at the time of measurement.

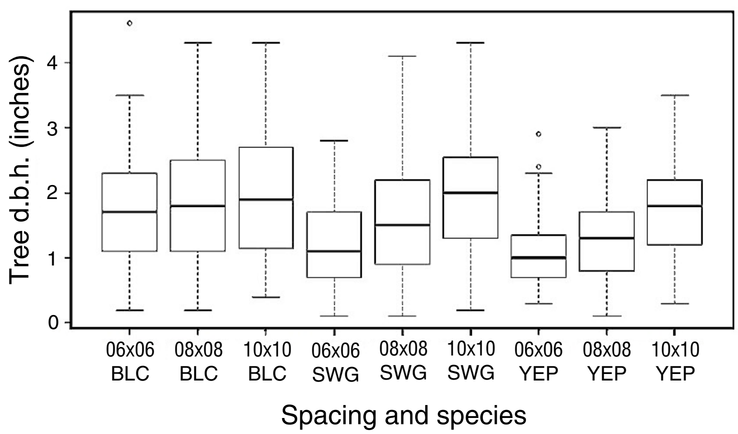

Figure 2—Boxplots of d.b.h. of cherrybark oak distributions after 7 years, by spacing and competitor species. YEP = yellow-poplar, SWG = sweetgum, BLC = black cherry.

a significantly larger average d.b.h. than the cherrybark oak in the 6-foot by 6-foot (p = 0.0007) or in the 8-foot by 8-foot spacing (p = 0.0446). There was no statistically significant difference between d.b.h. in the 6-foot by 6-foot and the 8-foot by 8-foot spacings (table 2).

Cherrybark oak also had significantly greater average diameter growing with black cherry compared to yellow-poplar (p = 0.0170). There was no significant differences between cherrybark oak in the black cherry mixture as compared to the sweetgum mixture (p = 0.1960) or between the sweetgum and yellow-poplar mixtures (p = 0.8540) (table 2).

Total Height

Mean height for cherrybark oak after 7 years was 15.0 feet with maximum heights approaching 30 feet (fig. 3). Significant effects of spacing on cherrybark oak height were evident (p = 0.0164) but not at the species level (p = 0.2410) or in their interaction (p = 0.7451). Comparisons of mean heights by spacing indicated significant differences between the 10-foot by 10-foot spacing and the 6-foot by 6-foot spacing (p = 0.0091) but no statistically significant differences between the 6-foot by 6-foot and 8-foot by 8-foot (p = 0.3901) or the 8-foot by 8-foot and the 10-foot by 10-foot spacings (p = 0.2905) (table 2).

Table 2—Mean d.b.h. and height by spacing and species

	d.b.h.				Height			
Treatment	Yellow-poplar	Sweetgum	Black cherry	Total	Yellow-poplar	Sweetgum	Black cherry	Total
6 x 6	1.07	1.21	1.67	1.3 ± 0.37 a	11.6	14.7	13.9	13.4 ± 2.4 a
8 x 8	1.32	1.54	1.87	1.6 ± 0.27 a	14.1	16.1	14.6	14.9 ± 1.9 ab
10 x 10	1.78	1.98	2.17	2.0 ± 0.32 b	16.6	16.6	16.6	16.6 ± 1.8 b
Total	1.38 ± 0.34 a	1.57± 0.35 ab	1.9 ± 0.40 b	1.6 ± 0.41	14.1± 2.7 a	15.8 ± 1.8 a	15.1 ± 2.7 a	15.0 ± 2.4

Total means (± standard deviation) followed by the same letter are not significantly different.
d.b.h. = diameter at breast height.

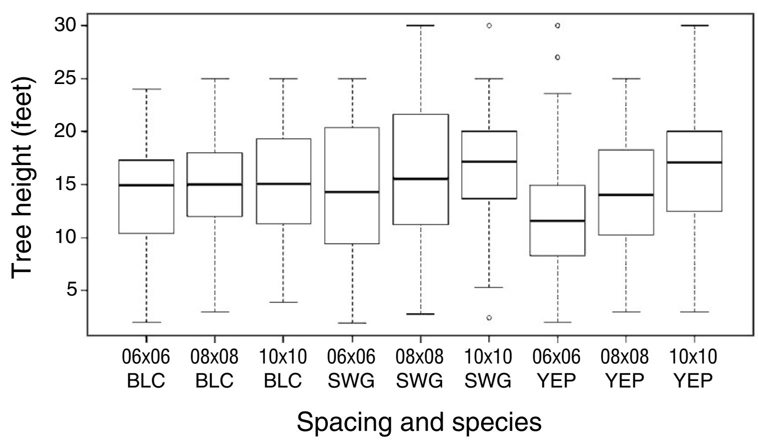

Figure 3—Boxplot of heights (feet) of cherrybark oak distributions after 7 years, by spacing and competitor species. YEP = yellow-poplar, SWG = sweetgum, BLC = black cherry.

DISCUSSION

Yellow-poplar outgrows most commercial species on productive sites in the Southeastern United States. After four growing seasons, yellow-poplar overtopped the oak in the 6-foot by 6-foot spacing such that complete yellow-poplar crown closure occurred over the oak. The thinning treatment implemented to release the cherrybark oak in this species and spacing combination was successful given the high survival of the oak in the 6-foot by 6-foot poplar treatment 3 years after the removal in comparison to the survival of the oak in the sweetgum and black cherry 6-foot by 6-foot treatments. Yellow-poplar coppice from the thinning reached a mean height of 4.9 feet in the subsequent 3 years and added pruning pressure from below to the oak crowns (Clatterbuck 2016). While there were no significant differences in height between cherrybark oak growing in these treated yellow-poplar neighborhoods, oak d.b.h. in the 6-foot by 6-foot poplar treatment was significantly smaller than the black cherry treatment with the same spacing.

Black cherry, though also a quick-growing species on productive sites, had a low light extinction rate through its canopy due in part to its small leaves, their arrangement, and its branching pattern. These characteristics were evident in the even growth distribution of the cherrybark oak regardless of the initial planting density. A potential issue arising in this mixture is the recruitment of weeds such as honeysuckle (*Lonicera* spp.) after initial herbicide treatments were concluded. This would explain the difference in the survival of the oak intermixed with black cherry in comparison to yellow-poplar.

The excurrent crown form of sweetgum afforded the slower-developing oak growing space above the widest part of the sweetgum crowns which was roughly equal in height to the base of their live crowns. The relatively low survival of the 6-foot by 6-foot sweetgum can be partially attributed to early vole (*Microtus* spp.) damage in these treatments. The lagging oak survival in the 6-foot by 6-foot sweetgum plantings is also indicative that sweetgum crown closure occurred above the height of the oak crowns. This suppressive action is evident in the d.b.h. and height distributions of the oak in these sweetgum neighborhoods at this density. The height and diameter growth of the oak at the 8-foot by 8-foot and 10-foot by 10-foot spacings would seem to align with the complimentary natural and artificial cherrybark oak/sweetgum stand development as reported by Clatterbuck and Hodges (1988) and Lockhart and others (2012).

CONCLUSIONS

Intraspecies competitive neighborhoods appear to play an important role in the development of cherrybark oak as they begin to express themselves at an early age. Differences in these competitor species' influence can have dramatic complimentary or adverse impacts over time. Continued investigation of these influences and additional parameters exploring cherrybark oak crown development within these plots are needed to better quantify these interactions.

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