HEIGHT OF PITCH AND SHORTLEAF PINE IS INCREASED BY INTRASPECIFIC COMPETITION 13 YEARS AFTER PLANTING IN THE SOUTHERN APPALACHIANS

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ABSTRACT

Predicted total height of surviving pitch pine (*Pinus rigida*) and shortleaf pine (*P. echinata*) was evaluated in response to intraspecific and interspecific competition 13 years after seedlings were row planted in a clearcut, oak (*Quercus* spp.) dominated, mixed hardwood stand on a dry ridge site. Surviving pines of each species occurring in groups of greater than or equal to two crown-touching trees (intraspecific competition) were significantly taller compared with single pines surrounded entirely by hardwood saplings (interspecific competition). Shortleaf pines in large groups (greater than or equal to three trees) were taller than those in small groups of two crown-touching trees. Grouped pines of each species were typically codominant with yellow-poplar (*Liriodendron tulipifera*), the primary competitor in the hardwood reproduction, but individual pines were generally shorter. If further studies confirm the increased height growth of pine seedlings planted in groups of two to five trees, resource managers can reduce supply and labor costs of ecological restoration of hardwood-pine communities on dry ridge sites by planting seedlings in scattered groups in small clearcut openings.

INTRODUCTION

Shortleaf pine (*Pinus echinata)* is not regenerating as a minor component of mixed hardwood stands on dry slopes and ridges in the Southern Appalachians (Elliott and others 1999), primarily because the historical occurrence of wildland fires has been reduced during the 20th century (Guldin and Black 2019). Restoration of shortleaf pine and other southern yellow pines, such as pitch pine (*P. rigida*), is desirable to maintain ecological diversity for wildlife habitat (Masters 2007). Prescribed burning, however, has not been successful for recruiting natural pine reproduction (Elliott and Vose 2005, Vose and others 1999). Planting pine seedlings can be successful for restoration of hardwood-pine communities in the North Carolina Piedmont (Schnake and others 2021), Georgia Piedmont (Waldrop 1997) and Arkansas (Brissette and Barnett 2004).

Tree communities on dry sites (typically ridges and upper west-facing slopes) consist of a mixed composition of overstory oaks (*Quercus* spp.), hickory (*Carya* spp.) and scattered shortleaf pine, a midstory of shade tolerant hardwood species, and an understory of advance reproduction (Elliott and others 1999). Because root systems and stems of most hardwood species sprout vigorously when cut or damaged during harvesting, site preparation of some form (e.g., herbicide, mechanical, burning) is necessary to temporarily reduce interspecific competition from hardwoods while the newly planted pine seedlings become established and begin height growth (Baker and others 1996, Knowe 1992, Phillips and Abercrombie 1987). In addition to intensive site preparation for pines in commercial plantings seedlings are typically planted in uniformly spaced rows, not only for mechanical operational efficiency, but also to quickly occupy growing space to exclude hardwood competition (Fox and others 2007). Applying the principle of growing space occupation on a smaller scale, European foresters have demonstrated that planting small groups of closely spaced seedlings can be successful for establishing European oak (*Q. robur*) (Jensen and Lof 2017, Saha and others 2012) and European cherry (*Prunus avium*) (Saha 2018) in regenerated stands. Except study of site preparation methods and large group plantings (64 trees) of closely spaced shortleaf pine seedlings in central Tennessee (Clabo and Clatterbuck 2020), information is not available on the growth of yellow pines in small groups in response to hardwood competition after crown closure.

A chance observation in a restoration planting of shortleaf pine seedlings suggested the configuration of surviving trees in small groups had influenced their size after 13 years of growth (McNab 2021). Initially planted in rows, high mortality of seedlings in that study resulted in a mosaic of surviving pines occurring either as individuals surrounded

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by hardwood reproduction or small groups of two to five pines, also surrounded by hardwoods. Casual observations elsewhere in the study area revealed that pines appeared to be larger when present in groups compared with pines not in groups (fig. 1), which conflicts with the much-studied Darwinian theory that intraspecific competition between individuals of the same species is greater compared to interspecific competition between species (Becker 2000, Darwin 1859, Harper 1967). Based on that rationale, pines in groups should have been smaller than pines occurring as individuals. However, if pines in groups can compete better with hardwoods and gain a size advantage compared to single trees, this information could have practical application when seedlings are planted for biological restoration projects.

The purpose of this unplanned follow-up study as a component of the parent study was to investigate effects of intraspecific competition among surviving 13-year-old pines planted for restoration. My primary objective was to test for height differences of trees occurring as individuals compared with pines in groups. If a significant group response was found, a second objective was to test for the effect of group size on tree height. The scope of this investigation was restricted to observations in an existing study that had

Figure 1—Example of intraspecific competition between two, 13-year-old crown-touching yellow pines and their interspecific competition with surrounding hardwoods, which have smaller diameters compared to the pines but have similar heights (USDA Forest Service photo by W. Henry McNab).

been installed to evaluate clearcutting and planting as a regeneration method for ecological restoration of pitch and shortleaf pine in a mixed hardwood stand.

METHODS

Study Site

The study was conducted in the Bent Creek Experimental Forest compartment of the Pisgah Ranger District, in the Pisgah National Forest (35.4915° N, -82.6383° W). The mean annual temperature of this mountainous watershed is 12.5 °C and the seasonally uniform precipitation averages 1,200 mm. Geologic formations consist of Precambrian gneisses and schists that have weathered to form soils that are generally deep (>100 cm) and predominantly acidic (pH ≤ 6.0). The study was situated on the southwest-facing slope of a broad ridge crest with an elevation of 775 m. Forest vegetation was a multilayered stand structure of deciduous hardwoods. The overstory was dominated by two species of xerophytic, shade-intolerant oaks: chestnut oak (*Q. prinus*) and scarlet oak (*Q. coccinea*). Until recently, a minor component of yellow pines (pitch pine and shortleaf pine) was also present but had been eliminated resulting from wind throw, insects, or lightning strikes or other types of disturbance. The midstory consisted of shade-tolerant red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), and sourwood (*Oxydendron arboretum*). The tall (>3 m) shrub layer was dominated by shade-tolerant mountain laurel (*Kalmia latifolia*). Advance regeneration under the shrub layer was predominantly hardwood tree species. Basal area composition of the preharvest stand was distributed as 67 percent in the canopy consisting primarily of two oak species (chestnut and scarlet); 26 percent in the shade-tolerant midstory consisting of black gum, red maple and sourwood; and 7 percent in the mountain laurel shrub layer (table 1). The large stems of mountain laurel were an indication of a lack of fire, probably since about 1915 when the Bent Creek watershed was purchased for inclusion in the Pisgah National Forest. An area of 0.57 ha, extending across the upper and into the middle slope position, was harvested in fall 2005 by clearcutting merchantable trees and felling residual trees >2.54 cm diameter at breast height (d.b.h.). Site preparation consisted of spraying cut stumps of undesirable species (primarily shade tolerant) within an hour of felling with a 50:50 ratio of triclopyr amine and water to reduce basal sprouting.

Study Design and Field Data

The study design consisted of two, 0.10-ha blocks located along the narrow upper slope of the southwest facing ridge crest. Each block was subdivided into two 0.05-ha plots for planting with bare-root, nursery grown seedlings of either pitch pine or shortleaf pine. In spring 2007, each plot was hand planted in a rectangular grid pattern with seedlings

Table 1— Mean preharvest basal area and 13 years postharvest stem density (stem den.), basal area (BA), and quadratic mean diameter at breast height (qdbh) by species in the restoration study area

Species	Shade tolerance	Preharvest	Postharvest				
		BA	Stem den.	(SD)	BA	(SD)	qdbh
		m²/ha	*n/ha*		*m²/ha*		*cm*
Pitch pine	Intolerant	0	150	(483)	0.448	(1.694)	6.2
Shortleaf pine	Intolerant	0	250	(707)	0.836	(2.706)	6.5
Yellow-poplar	Intolerant	0	2,300	(2,736)	2.094	(2.549)	3.4
Oaks[a]	Intolerant	17.45	4,550	(2,104)	1.596	(1.176)	2.1
Sassafras	Intolerant	0.46	700	(1,129)	0.310	(0.731)	2.4
Minor species[b]	Intolerant	0	500	(560)	0.362	(0.488)	3.0
Black gum	Tolerant	0.46	1,750	(1,410)	1.183	(2.237)	2.9
Red maple	Tolerant	3.21	4,200	(3,592)	1.800	(3.181)	2.3
Sourwood	Tolerant	3.21	350	(933)	0.542	(1.974)	4.4
Mountain laurel	Tolerant	1.84	4,600	(5,355)	0.394	(0.520)	1.0
All species	NA	26.63	19,350	(2,538)	9.565	(1.672)	2.5

SD = standard deviation; NA = not applicable.

[a]Oak species were primarily chestnut and scarlet.

[b]Minor species: black cherry, American chestnut, serviceberry, black birch.

spaced 1.83 m within rows and 2.44 m between rows. The (approximately) 112 seedlings planted in each 0.05-ha plot were released from hardwood competition in May 2011 using a streamline basal spray of 20 percent triclopyr ester herbicide mixed with mineral oil. Mean second-year survival was about 95 percent for each pine species.

All living planted pines in the two blocks were inventoried by species and d.b.h. in fall 2019. Each pine was classified by the type of competition surrounding it as either interspecific or intraspecific. Interspecific competition was present when the subject pine was surrounded entirely by hardwoods and its foliage was not touching that of another pine. Competition was classified as intraspecific when the subject pine was surrounded mostly by hardwoods, but its foliage was touching that of one or more adjacent pines. Intraspecific competition occurred typically from adjacent pines in the same planted row but occasionally from one or more pines in an adjoining parallel row. Therefore, because all planted pines (the experimental units) experienced interspecific competition from adjacent hardwoods, the treatment applied to each living planted pine was the presence or absence of intraspecific competition resulting from one or more adjacent crown-touching pines. For pines experiencing intraspecific competition, a second treatment on pine size was effect of the amount, or level, of intraspecific competition, which was quantified by the number of crown-touching pines in each group. The level of intraspecific competition was classified as either low, if the group of pines consisted of two trees, or high, if the group consisted of three or more trees. In summary, each pitch or shortleaf pine was an experimental unit, the intraspecific competition treatment consisted of two factors: absent or present, and the amount of intraspecific competition treatment was evaluated at two levels: low or high. The treatment of each living pine (presence or absence of an adjacent pine) had been applied over a period of 13 years as random events causing natural mortality of the uniformly planted seedlings, which resulted in a mosaic of variously spaced single and grouped pine trees in the study area. Duration of the intraspecific competition for grouped pines varied depending on mortality of adjacent trees and was unknown because the study was inventoried only once, at 13 years of age. Treatment response differences between the two pine species were not a study objective and were not evaluated.

The treatment response variable was height of each surviving pine. Because of time constraints, tree heights were not measured when the study was initially inventoried in fall 2019. Height data were obtained later, however, to supplement treatment responses initially assessed using d.b.h. (McNab 2021) and to better evaluate present structure and future stand development (see Acknowledgments). In April 2021, d.b.h. and height were sampled across the range of tree sizes present for each pine species and three selected hardwood species groups or individual species. The three hardwoods included pooled oak species, yellow-poplar (the predominant shade-intolerant hardwood), and red maple (the predominant shade-tolerant hardwood) (table 2).

Data Analysis

Linear regression was used to quantify the relationship between tree d.b.h. and total height for each of the two species of pine, pooled oaks, yellow-poplar, and red maple. The curvilinear relationship between d.b.h. and height was transformed using natural logarithms (Meyer 1940). I used a covariance form of linear regression to test for differences between the pitch and shortleaf pine height-d.b.h. models to determine if species could be pooled (Gujarati 1987). Predicted tree heights were used to evaluate the response of each pine species to the two competition treatments. Pine single and group sample sizes and their locations in the study site were determined by natural mortality occurring over 13 years within the grid of 112 seedlings initially planted in each plot. One-way ANOVA was used to test first for a significant difference of mean heights in response to the two competition treatments (interspecific vs. interspecific and intraspecific) by each pine species. If a significant response to competition type was evident, a second ANOVA was then used to test for effects of the level of intraspecific competition (low vs. high) on mean predicted height of each pine species. Tree d.b.h. was not tested for differences because it was used to predict height and therefore the responses to competition type would be similar. Treatment response differences between the two pine species were not tested because the study objectives were to evaluate competition effects on pines and not to decide which species to plant for restoration. Version 3.5.1 of R was used for data analysis (R Core Team 2020); significance was determined at the P = 0.05 level.

RESULTS AND DISCUSSION

Regenerated Stand Characteristics

Thirteen years postharvest basal area was distributed as 17 percent oaks, 37 percent midstory species, and 4 percent shrubs (table 1). Basal area composition of new species in the postharvest stand included 13 percent yellow pines, 22 percent yellow-poplar, and 7 percent other species. The reproduction stem density was dominated by oaks, red maple, and mountain laurel. Composition changes following the harvest, particularly for yellow-poplar, were similar to results reported elsewhere in the Southern Appalachians (Elliott and others 1999, Shure and others 2006). Additional detail on composition and diameter structure of the hardwood reproduction is provided elsewhere in these proceedings.

Height—Diameter Models

The ranges of d.b.h. and height were sampled for 15 trees of each pine species and 10 trees each for pooled oak species, yellow-poplar, and red maple (table 2). The pooled oak species consisted primarily of chestnut and scarlet, yellow-poplar was the predominant shade-intolerant species, and red maple represented the shade-tolerant species. Predicted heights across the range of d.b.h. present for each sampled species are shown in figure 2. The slope coefficients for the prediction models for height of pitch and shortleaf pines were significantly different (P = 0.041), which did not allow further testing of common

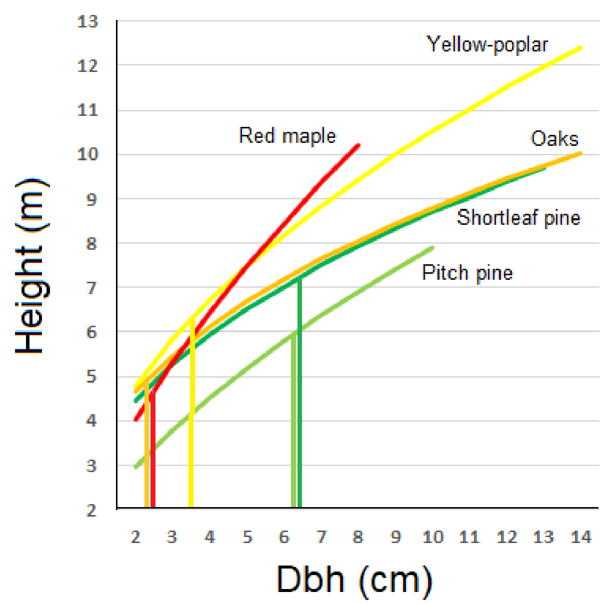

Figure 2—Predicted height in relation to diameter at breast height (d.b.h.) of planted pitch and shortleaf pines and three species of predominant hardwood regeneration 13 years after clearcutting. Length of the height curve for each species represents the range of tree sizes occurring and sampled in the regenerated stand (table 2). The vertical line projecting from each curve to the horizontal axis indicates the quadratic mean d.b.h. of that species in the regenerated stand (table 1).

Table 2—Number (n), ranges of diameter at breast height (d.b.h.), and total height (ht) of trees sampled and parameter estimates (standard error [SE]) of d.b.h.-based models for total height of selected species in a 13-year-old mixed hardwood clearcut stand on a dry site in the Pisgah National Forest, NC

Species	N	Range		Parameter		R^2	RMSE
		d.b.h (cm)	*ht (m)*	*Intercept (SE)*	*Slope (SE)*		
Pitch pine	15	2.2–9.5	3.1–8.3	0.6624 (0.146)	0.6100 (0.077)	0.83	0.671
Shortleaf pine	15	3.6–11.7	5.5–9.5	1.1999 (0.090)	0.4183 (0.043)	0.88	0.440
Yellow-poplar	10	2.6–14.0	5.8–12.5	1.2225 (0.079)	0.4921 (0.041)	0.95	0.533
Oaks[a]	10	2.6–14.7	4.9–10.5	1.2635 (0.784)	0.3954 (0.046)	0.90	0.420
Red maple	10	1.0–7.3	2.1–8.9	0.9340 (0.111)	0.6681 (0.078)	0.90	0.713

Note: all model formulations are natural logarithm of height (m) = a + (b*ln(dbh-cm)); RMSE: Root mean square error.

[a]Oak species are *Quercus coccinea* and *Q. montana*.

intercepts between models or for pooling species data for a single model. Although allometric models were available for predicting biomass of small pines and hardwoods, I found no similar height-d.b.h. models for comparisons.

Competition Type

A total of 29 (26 percent) pitch and 46 (41 percent) shortleaf pines survived 13 years after planting (fig. 3). For the 29 pitch pine seedlings, 18 (62 percent) were single trees and 11 (38 percent) were in groups of greater than two conspecific trees. Fifteen (33 percent) of the surviving shortleaf pines occurred as individuals; 31 (67 percent) trees were in conspecific groups. Single compared to group survival could not be tested for either species because of the study design. Although second-year survival was high (95 percent) for both pine species, growing season precipitation was 60 percent of normal for both years, which probably affected planted seedling height growth and competition with the natural hardwood seedlings and sprouts. Other factors that could have affected seedling performance include seed provenance, nursery practices, genetic variability, and insect damage, such as defoliation by pine sawflys (Neodiprion spp.) (Hallgren and others 1993, Leland and others 2016, Schnake and others 2021).

Predicted mean height of the 18 pitch pines responding to interspecific competition (single trees) was 4.68 m (sd = 1.88 m) and 6.19 m (sd = 1.05 m) for the 11 trees responding to intraspecific competition (grouped trees). The difference in mean height (1.51 m) was significant (P = 0.02). For the 46 shortleaf pines, mean height of the 15 trees occurring singly was 6.39 m (sd = 1.67 m) and 7.96 m (sd=1.02 m) for trees in groups (fig. 3). The difference in mean height of 1.57 m between single and grouped shortleaf pines was significant (P < 0.01).

A reasonable explanation for the increased height of both pine species in response to intraspecific competition can only be speculated because environmental and competition data were not collected. A previous analysis of the pine competition data based on d.b.h. suggested no differences in soil moisture or fertility as indicated by hardwood competition (McNab 2021). A plausible explanation for taller trees being associated with groups could result from the combined effects of crown and foliage architecture. For example, branches of grouped pines could decrease shading from hardwood foliage on one or more sides of the trees by physically restricting the presence of broadleaf foliage leaves. The needle-like foliage of pines allows near maximum penetration of light into their crowns to reach earlier flushes of seasonal growth (McGarvey and others 2014) and lower branches (Baker and others 1996).

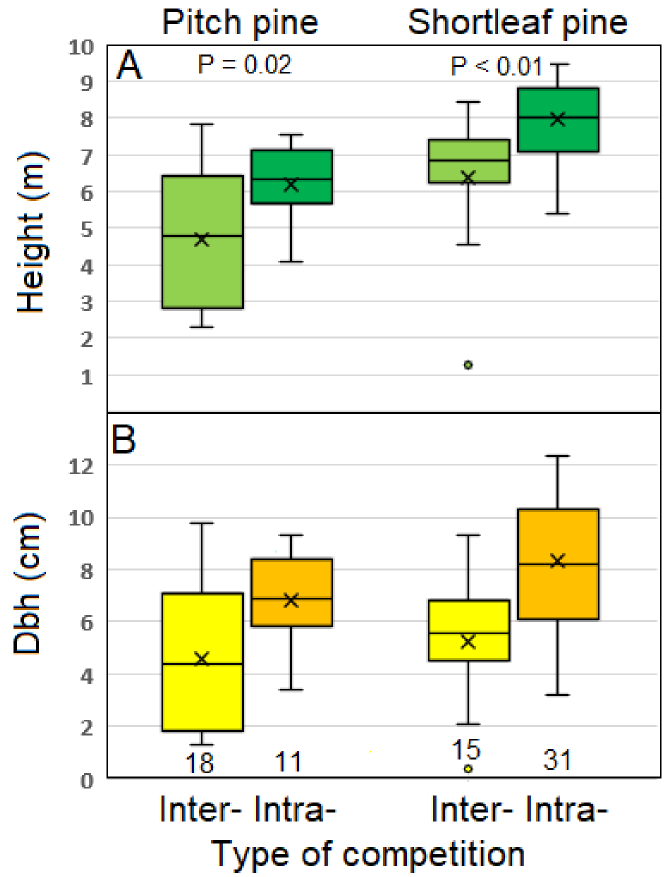

Figure 3—Distributions of diameter breast height (d.b.h.) and predicted height of surviving pitch and shortleaf pines in relation to interspecific (Inter-; single tree) competition or intraspecific (Intra-; grouped trees) competition of trees 13 years after row-planting of 1-year-old seedlings. The number of trees in each competition category is provided above the x-axis of panel B. Above the pair of whiskers in panel A is the probability (P) of significant height differences between single and groups of trees. Each box represents the interquartile range of data and shows the median (horizontal line), mean ("x"), and range (whiskers); data outliers are represented by small open circles.

Intraspecific Competition Level

The effects of the level (group size) of intraspecific competition were evaluated using heights for 11 pitch pine groups and 31 shortleaf pine groups (fig. 4). Mean pitch pine heights of the low and high levels of intraspecific competition were 6.02 m (sd = 1.29 m) and 6.47 m (sd = 0.44 m) respectively, resulting in a difference of 0.45 m, which not significant (P = 0.52). For the effects of level size on shortleaf pines, mean height was 7.27 m (sd = 1.14 m) for low (n = 2) and 8.29 m (sd = 0.78 m) for the high level (n ≥ 3) of intraspecific competition. The difference of mean tree heights was 1.02 m, which was significant (P < 0.01). Results of this analysis agree with and extend the results for competition type, indicating that the effects of intraspecific competition on tree height increased with larger numbers of trees present in groups of shortleaf pines. Because the effects of competition type were similar for both pine species, the small sample size (n = 11) available for pitch pine level of competition was probably a factor contributing to its lack of significance.

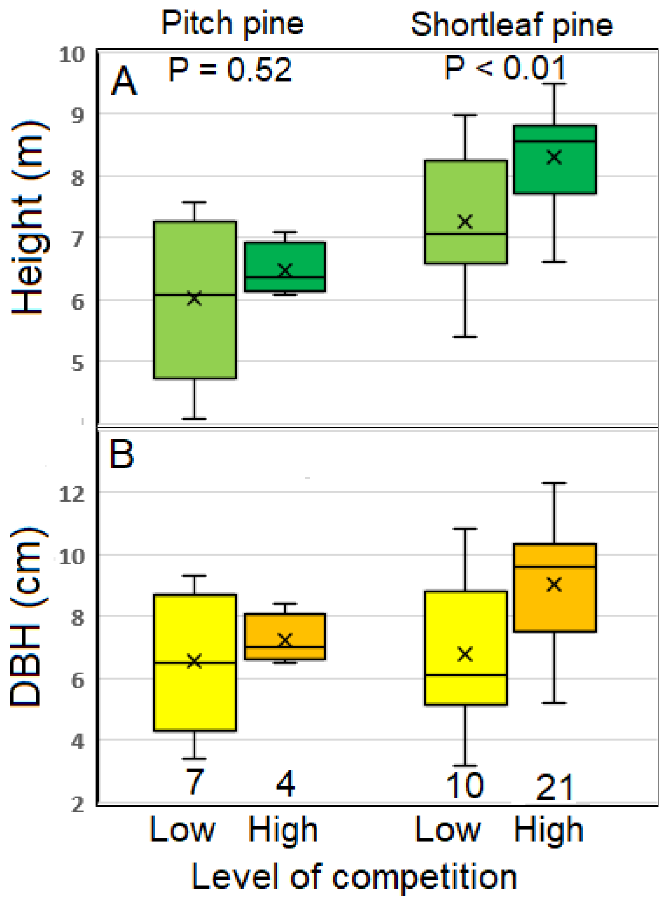

Figure 4—Distributions of diameter at breast height (d.b.h.) and predicted height of surviving pitch and shortleaf pines in relation to the level (low, group size, n = 2 trees; high, n ≥ 3 trees) of intraspecific competition for trees 13 years after row-planting of 1-year-old seedlings. The number of trees sampled by level of intraspecific competition is shown above the x-axis of panel B. Note that the total trees of each pine species is equal to the number of intraspecific competition sample trees in figure 3. Above the pair of whisker boxes in panel A is the probability (P) of significant height differences between low and high levels of intraspecific competition. Each box represents the interquartile range of data and shows the median (horizontal line), mean ("x"), and range (whiskers).

Because my study involved two unusual silvicultural topics in the Southern Appalachians: (i) species restoration by clearcutting and planting yellow pines and (ii) intraspecific competition of pines and hardwoods, I found no other studies for direct comparison of results. Clabo and Clatterbuck (2020) planted shortleaf pine seedlings in large clusters (64 trees) following four site preparation methods but did not include a non-cluster treatment for comparison. The closest comparisons were from several studies of interspecific competition in Germany where *Quercus robur* and *Q. petraea* seedlings were planted in small groups to facilitate their establishment in competition with other species of hardwoods (Jensen and Lof 2017, Saha and others 2012) and improve form of a central crop tree (Skiadaresis and others 2016). Results from my study provide a meager test of the effects of intraspecific competition as proposed by Darwin (1859), which he based primarily on population dynamics rather than size of individuals (Becker 2000, Howler and others 2019).

Size differences of pines occurring singly compared with groups could have resulted primarily from foliage competition for light and somewhat from root competition for water and nutrients. Competition for light was enhanced by physical exclusion of hardwood foliage by the touching pine branches, which allowed increased light transmittance through the thin needle-like conifer foliage to lower levels of interior branches (Baker and others 1996, Guo and Shelton 1998). Also, the rapid rate of height growth of stump sprouts compared to that of seedlings could have been a retarding influence on height of some individual pines compared to groups of trees (Wendel 1975). Because ectomycorrhiza are beneficial (and perhaps essential) for survival and growth of planted pine seedlings in competition with other vegetation, the degree of nursery and subsequent natural colonization by fungi of root systems was likely a factor affecting the early survival of pines on the study site (Jorgensen and Shoulders 1967, Ruehle and others 1981, Wright 1957). As the regenerated stand matured, development of mycorrhizal networks between roots of closely spaced pine trees could have allowed sharing of moisture and nutrients during droughts, thereby benefitting growth of pines in groups compared to individuals (Booth and Hoeksema 2010, Simard and others 2012, Teste and Simard 2008). Also, the wide host range of ectomycorrhizal fungi increases the possibility that pines could share networks with some hardwood species, particularly oaks (Rasmussen and others 2017).

This opportunistic study had several weaknesses. Perhaps the most important was insufficient replication and lack of data on progressive pine mortality and development of pines in competition with hardwoods as the study aged. Unfortunately, the only suitable site available for this study did not allow space for additional replication. Because the regenerated stand consisted of many hardwood species (table 1), detailed data on the composition of species competing with each planted pine would have provided useful information for targeted application of the herbicide release treatment following planting (Canham and others 2004). More important for the study objectives, however, would have been analysis of the measured height of each pine, rather than predicted heights. A minor strength of the study was evaluation of the response of pines in relation to competition after crown closure, when the effects of early juvenile growth differences among species had largely passed (Gauthier and others 2013).

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Although cumulative seedling mortality was high for both species, the population of large surviving pines (mostly in groups) was equivalent to 110 and 310 trees/ha for pitch and shortleaf pines, respectively, which could be considered adequate to meet the ecological objective of restoring a conifer component in the regenerated stand. Most of the pines in groups were in a codominant or dominant crown position and should continue their upper canopy position as the stand develops. Study results showed that heights of pitch and shortleaf pines in groups greater than or equal to two trees were significantly taller compared to individual pines not in groups when planted on a dry ridge site following clearcut harvesting. With further study to confirm and refine those findings, resource managers could decide that extensive use of herbicides for site preparation and release treatments may not be needed for ecological restoration, thereby resulting in cost savings and reduction of possible environmental impacts. In summary, the significant height response of planted pines growing in groups provides a logical reason for additional investigation of intraspecific competition of conifers for conifer restoration on dry sites in the Southern Appalachians.

ACKNOWLEDGMENTS

I am grateful for the constructive comment by a person attending my virtual webinar presentation of results from this study in March 2021, which were based only on tree d.b.h. That person said pine heights would provide a better evaluation of competition compared to diameter. Consideration of that comment prompted my return to the study site in April for data to develop diameter-height regression models (while continuing to observe Forest Service, U.S. Department of Agriculture (USDA), guidelines for field work during the ongoing Covid-19 pandemic). Funding was provided by the Forest Service, Southern Research Station. I thank Erik Berg and Theodore Oprean for their reviews of a previous draft of this manuscript. I particularly appreciate a comment by Ted Oprean on the importance of ectomycorrhiza for successful establishment of conifer regeneration. This article was written and prepared by a U.S. Government employee on official time, and it is therefore in the public domain. The findings and conclusions in this publication are those of the author and should not be construed to represent any official USDA or U.S. Government determination or policy.

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