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Brief Communication

Silviculture

Preliminary Evidence that Intraspecific Competition Increases Size of Restoration-Planted Pitch and Shortleaf Pines in a Mixed-Hardwood Clearcut in the Southern Appalachians

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Abstract

Oak-pine (*Quercus* L. - *Pinus* L.) forest communities on low ridges in the southern Appalachian Mountains are losing diversity as mature pitch (*P. rigida* Mill.) and shortleaf (*P. echinata* Mill.) pines die and do not regenerate under a hardwood canopy. Restoration of biodiversity by planting pine seedlings is well known, but little is known regarding whether the configuration of planted seedlings affects growth and subsequent size (diameter at breast height, dbh) as trees age. The purpose of this study was to test the hypothesis that pines growing in groups of two or more trees respond with increased growth (expressed by dbh) to intraspecific competition with other pines compared to single trees subjected only to interspecific competition with surrounding hardwoods. For 13-year-old pitch and shortleaf pines, trees were larger in dbh when occurring in groups than trees occurring singly. Regression indicated that intraspecific competition accounted for 16% of the dbh variation of pitch pine and 29% for shortleaf pine. This study originated from chance observations in a small study of pine restoration. If a designed study confirms these results, resource managers could restore biodiversity with reduced site disturbance and establishment costs by planting pine seedlings in small groups rather than rows.

Keywords: Forest ecosystem restoration, interspecific competition, intraspecific competition, *Pinus rigida*, *Pinus echinata*

Ecological restoration of forest vegetative communities often requires planting seedlings of indigenous species, because natural sources of reproduction are not present (Dobson et al. 1997) or are not regenerating because of altered disturbance regimes, such as wildland fire (Brose et al. 2001). Because of intense interspecific competition with existing native species, successful establishment of planted seedlings can be problematic and often requires supplemental fertilization, cultivation, competition control, and browsing protection (Migues et al. 2020, Holl et al. 2000). Seedlings are typically planted as either uniformly spaced rows for ease of mechanized establishment on suitable sites or clusters to achieve naturalness of appearance of the regenerated stand or where complex topography requires hand-planting (Schonenberger 2001, Saha et al. 2017). Compared to conventional row-planted seedlings that undergo interspecific competition with established native vegetation, clusters provide increased intraspecific competition, which may be beneficial for success of restoration plantings for some species and sites (Silvertown 2004). Large cluster plantings (>50 trees and associated increased intraspecific competition) have long been used successfully in European restoration studies (Anderson 1951, Saha et al. 2014) and recently for commercial restoration of shortleaf pine (Clabo and Clatterbuck 2020). Unreported, however, are findings on the effects of intraspecific competition on growth of small groups of pines (<10 trees), which would be useful for economical ecological restoration of small areas to increase biodiversity primarily for wildlife habitat purposes.

Reported here are results from part of a long-term study of pine restoration (McNab In Prep), where a chance observation suggested increased size (dbh) of pines present in groups compared to solitary trees (Figure 1). My primary study objective was to evaluate dbh differences of surviving pine seedlings associated with their type of occurrence (solitary versus groups) 13 years after row planting in a clearcut opening. I hypothesized no difference of dbh between pines occurring singly (responding to interspecific competition from surrounding hardwoods) compared with dbh of pines present in groups of ≥2 (experiencing interspecific and intraspecific competition with adjacent pines). Conversely, my alternative hypothesis of different dbh sizes would provide evidence of the effects of intraspecific competition on growth of pines occurring in groups. On acceptance of the alternative hypothesis, my secondary study objective was to determine whether the effect of intraspecific competition on dbh of the surviving pines was influenced by the configuration (linear versus nonlinear) of the groups.

Methods

The study was installed at Boyd Gap (35.4915°N, -82.6383°W) in the Bent Creek Experimental Forest in the

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Figure 1. Dormant-season vertical view in the center of a group of 3 codominant, crown-touching (dark foliage), 13-year-old shortleaf pines (mean dbh = 10.1 cm) present in a triangle shape surrounded by stems and bare branches of mixed-hardwood regeneration consisting primarily of yellow-poplar. Note that pine branches with foliage are present in the interior of the group but are mostly missing on the exterior side facing hardwood competition. This group represents intraspecific competition among pines with interspecific competition from adjacent hardwoods. In contrast, a single pine would experience interspecific competition only.

southern Appalachian Mountains of western North Carolina. Annual temperature averages 12.5°C; precipitation averages 1,200 mm and is uniformly distributed among seasons. Soils are deep (>100 cm) and predominantly Ultisols of the Evard-Cowee complex. Preharvest forest vegetation was an overstory of intolerant mixed oaks chestnut (*Q. montana* Willd.) and scarlet (*Q. coccinea* Muenchh.), a midstory of mixed shade-tolerant hardwoods, including black gum (*Nyssa sylvatica* Marshall), red maple (*Acer rubrum* L.), sassafras (*Sassafras albidum* [Nutt.] Nees), and sourwood (*Oxydendrum arboretum* [L.] DC.), an evergreen shrub understory of mountain laurel (*Kalmia latifolia* L.), and advance hardwood reproduction (Table 1). The study location was in the broad ecotone between two southern yellow pine species: shortleaf, common at lower elevations, and pitch pine, prevalent on mountain slopes (Burns and Honkala 1990). Forest composition of the study area was typical of xeric oak-pine communities on narrow ridges that have been maintained historically by periodic disturbance from low-intensity wildland fires (Elliott and Vose 2005). Loss of mature pines from lightning strikes and insect-related mortality coupled with lack of pine reproduction has resulted in decreased biodiversity.

The 0.57 ha southwest-facing study area was located along a low elevation (775 m) ridge crest and extended downhill across the upper slope (28 m wide) into the middle slope. The 0.2 ha study site was restricted to the upper slope position (20% gradient), leaving a buffer zone of 35 m on the middle slope (25% gradient) to the uncut mature forest. A log deck was at one end of the study site; a logging skid road was at the other end and along the ridge crest. The relatively small study site was not shaded between 9:00 am and 7:00 pm during the growing season. Shortleaf pine site index (50-year base age) was estimated as 17.4 m (Carmean et al 1989, Fig. 78) from a 124-year-old (22 cm dbh) codominant tree in a similar hardwood-pine stand nearby on the same ridge crest.

The study area was clearcut in fall 2005. Merchantable tree-length logs were skidded to the landing using a wheeled logging tractor. All residual trees >2.54 cm dbh were felled and stumps of undesirable species (midstory, shade-tolerant hardwoods, and shrubs) were sprayed with a 50:50 ratio of triclopyr amine and water <1 hour after cutting. Two 0.10 ha blocks were established along the upper slope position of the study area. Each block was subdivided into two 0.05 ha treatment plots. Each plot was dibble-bar-planted in early March 2007, with either pitch pine or shortleaf pine 1-0 unimproved seedlings from state nurseries. Mean seedling spacing was approximately 1.8 m within and 2.4 m between rows (2,315 seedlings/ha) but varied to avoid obstacles such as stumps or logging debris. All seedlings on each plot were planted by the same person during mid to late afternoon on the same day when temperature was >0° C. Seedlings were visually graded by discarding those damaged or with smaller-than-average tops or root systems. Pine seedlings were released from hardwood competition three growing seasons after harvest (two years after planting) with a herbicide mixture of 17% solution of tricoplyr ester in mineral oil applied in February to undesirable tree stems using a streamline method. Mean second-year survival was >95% for both pine species. Observed hardwood competition to the pine seedlings was primarily from black gum and sourwood sprouts.

All living planted pines in each plot were inventoried in fall 2019 by dbh, competition type, and configuration. Competition type was classified as either: (1) interspecific, a pine surrounded only by hardwoods (hereafter single) or (2) intraspecific, a pine mostly surrounded by hardwoods but also touching the crown of one or more adjacent pines (hereafter group). Configuration of a group of pines, which refers to the arrangement of trees formed by survival, was classified as either: (1) linear (≥2 pines in a straight line, usually along a planted row) or (2) nonlinear (a group of ≥3 pines that included ≥1 crown-touching tree in an adjacent row). Nonlinear groups were recorded as common geometric shapes (triangle, square, polygon) (Figure 2). Inventoried also was dbh of the largest (by diameter) hardwood stem in each of the three tertiants around each single or group of pines as a measure of soil disturbance or site quality variation independent of pine dbh. In summary, measurement units were pines of each species within the four plots that had responded in dbh to competition only from hardwoods or competition from hardwoods and adjacent pines. Overall composition and structure of the hardwood reproduction across the 0.2 ha study site was estimated from five 0.001 ha subplots installed in each 0.05 ha-treatment plot for the parent restoration study (McNab In Prep).

Normality of the two pine dbh distributions was assessed with Kolmogorov-Smirnov tests. ANOVA of mean sample plot pine dbh was used to evaluate pooling of block replications. Welch's unequal variance *t*-test was used to evaluate mean dbh of: (1) single versus grouped pines and sur-

Table 1. Preharvest basal area and 13-year postharvest basal area and stem density by species of the mixed-hardwood restoration study area at Boyd Gap.

Species*	Shade Tolerance	Basal Area (m^2/hectare)				Stem Density (n/hectare)	
		Preharvest (%)		Postharvest (%)		Postharvest (%)	
Pitch pine	Intolerant	--		0.45	(5)	150	(<1)
Shortleaf pine	Intolerant	--		0.84	(9)	250	(1)
Yellow-poplar	Intolerant	--		2.09	(22)	2,300	(12)
Oaks	Intolerant	17.45	(65)	1.60	(17)	4,550	(24)
Blackgum	Tolerant	0.46	(2)	1.18	(12)	1,750	(9)
Red maple	Tolerant	3.21	(12)	1.80	(19)	4,200	(22)
Sassafras	Tolerant	0.46	(2)	0.31	(3)	700	(4)
Sourwood	Tolerant	3.21	(12)	0.54	(6)	350	(2)
Mountain laurel	Tolerant	1.83	(7)	0.39	(4)	4,600	(24)
*Other**	*Various*	--		*0.36*	*(3)*	*500*	*(2)*
Overall	-	26.62	(100)	9.56	(100)	19,350	(100)

*Other: American chestnut (*Castanea dentata* [Marsh.] Borkh.), black cherry (*Prunus serotina* Ehrh.), sweet birch (*Betula lenta* L.), serviceberry (*Amelanchier arborea* [F.Michx.] Fernald.).

rounding hardwoods and (2) linear versus nonlinear group shapes of pines and surrounding hardwoods. Regression was used to estimate the proportion of pine dbh variation explained by competition type and group configuration. All tests were by pine species; comparisons between pine species and with hardwoods were not necessary for the hypothesis tests. 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

Seventy-five pine trees (29 pitch, 46 shortleaf) were inventoried, either singly or grouped (Figure 3), for an overall survival of 12.5% for pitch and 19.8% for shortleaf. The dbh distributions did not deviate from normality for either pitch (P = 0.55) or shortleaf (P = 0.60) pines. ANOVA indicated no difference (P = 0.44) of dbh between blocks, which allowed pooling of inventory data. Planted pitch pines were present as 18 single trees (not touching another pine) and 11 in groups of two to four crown-touching trees. The 46 inventoried shortleaf pines occurred as 15 single and 31 in groups. Seven of the 29 pitch pines (24%) were small (1-cm dbh class) single trees; trees in larger dbh classes were generally equally distributed between single and grouped trees (Figure 4). For shortleaf pine, the largest trees were present in dbh classes greater than 5 cm.

Welch's *t*-tests indicated significant differences of mean dbh between single and grouped pines but not for surrounding hardwoods (Table 2). For pitch pines, mean dbh of grouped trees (6.79 cm) was larger (P = 0.02) than single trees (4.58 cm). Mean dbh of grouped shortleaf pines (8.30 cm) was greater (P = <0.01) than single trees (5.37 cm). Hardwoods surrounding single and grouped pines of both species did not differ in dbh (P > 0.05). Regression indicated the type of occurrence (single, grouped) explained significant dbh variation for pitch pine (P = 0.03, R^2 = 0.16) and shortleaf pine (P = 0.0001, R^2 = 0.29). Group configuration (linear, non-linear) accounted for significant dbh variation for shortleaf pine (P = 0.009, R^2 = 0.21); pitch pine was not tested because of insufficient observations. Although the regressions of pine configurations accounted for significant variation of dbh, the relatively small values of R^2 indicates the relationships were weak. Field data were too sparse to allow analysis of dbh differences between shapes of pine groups, such as triangle versus square.

Discussion

The purpose of this opportunistic investigation was to examine dbh of surviving row-planted pine seedlings in a restoration study area to determine whether type of competition (intraspecific versus interspecific) affected their size after 13 years of growth. In support of my alternate hypothesis, I found that dbh of grouped pitch and shortleaf pines was significantly larger than dbh of trees occurring singly. Although both single and grouped pines experienced interspecific competition with surrounding hardwoods, these results suggest the environment and biological conditions associated with intraspecific competition resulted in larger dbh of the pines. Physiological processes associated with differing light availability resulting from conifer versus hardwood foliage were likely the most important factors affecting tree size (Gratzer et al. 2004). Compared to the mutual shading resulting from the relatively broad leaves of most hardwoods, the needle-like foliage of pines could have allowed nearly double light penetration through the upper canopy of grouped trees to reach foliage of lower branches (Figure 1) (Baker et al. 1996, Sterck et al. 2001), where those photosynthetic resources could then be redistributed for increased growth of the upper crown (Henriksson 2001). Genetic variability of the introduced nursery-grown pine seedlings likely accounted for some of the size variation of single and grouped pines (van Andel 1998).

Soil properties were contributing but probably minor factors influencing pine dbh compared with effects of shading by the hardwood competition. Because the study site was relatively small and restricted to the generally uniform convex topography of the upper slope position, variation of soil moisture and fertility properties, such as organic matter content, was probably minimal (Lister et al. 2000). Size of hardwood competition around the pine trees was an imperfect measure of site quality variability; however, its generally uni-

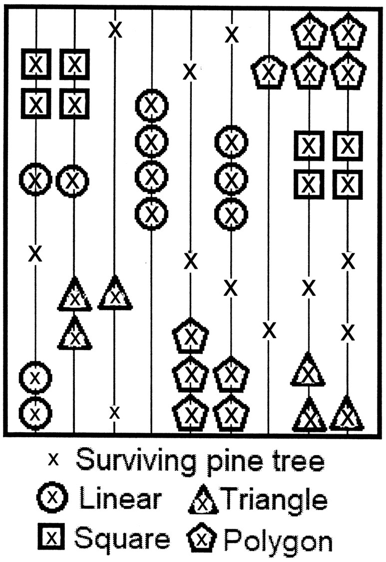

Figure 2. This diagram represents a restoration plot where either pitch or shortleaf pine seedlings were planted at uniform spacing in rows. After 13 years of growth, surviving trees (indicated by X) occurring in groups of ≥2 crown-touching trees were classified by configuration (linear vs nonlinear) and recorded as common geometric shapes. (Figure prepared using MicroSoft Paint.)

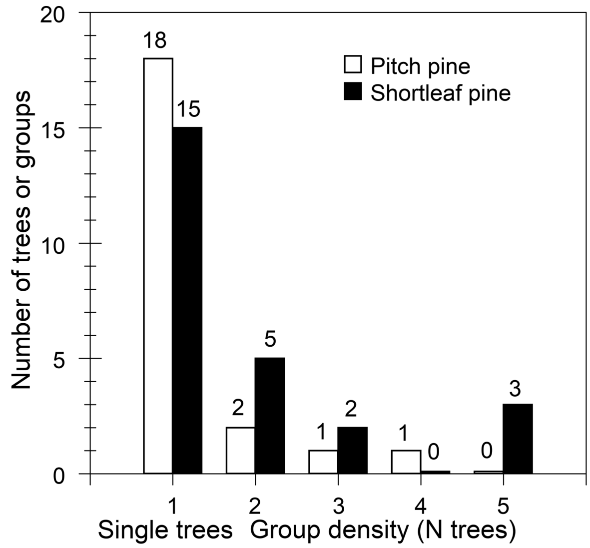

Figure 3. Distribution by type of occurrence (single versus grouped) and group stem density of the 75 surviving 13-year-old southern yellow pines planted in the restoration study site. The 33 surviving pitch pines were distributed as 11 (38%) grouped trees compared with the 42 surviving shortleaf pines that were distributed as 31 (74%) grouped trees.

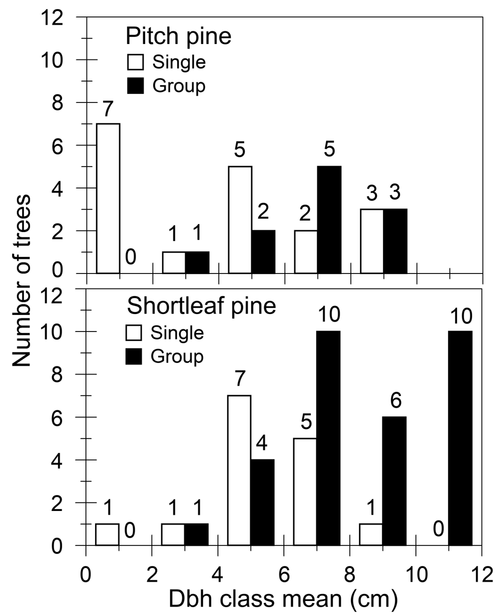

Figure 4. Distribution by type of occurrence (single versus grouped) and diameter breast height size classes of the 33 surviving pitch pines and 42 surviving shortleaf pines 13 years after row planting in the restoration study site.

form dbh compared to different sizes of single versus grouped pines (Table 2) also suggests minimal variation of soil properties. More variable across the study site, however, was soil disturbance associated with removal of the timber, including scarification of the forest floor and damage to the well-rooted hardwood advance reproduction. Also, careful seedling planting practices reduced variation of pine survival, and the lack of shading by the mature forest on the south and west sides of the study area reduced a possible source of growth variation of both the pines and hardwoods.

Lesser survival and size of pitch pines compared to shortleaf is unclear. Lawson (1990) reported juvenile shortleaf pine seedlings are somewhat tolerant of shade and grow more slowly than other species of southern pines soon after establishment. In a New Jersey comparison study, however, McQuilkin (1935) reported that shortleaf was less tolerant of shading than pitch pine. Burns and Honkala (1990) reported the rate of height growth of young seedlings is approximately the same for both pine species. Environmental differences between the study area and the seed source provenance for the pitch pine seedlings grown by the Tennessee nursery could also be a partial explanation for their lower survival and growth (Wells and Wakeley 1966).

Pine size variation also likely resulted from the unquantified effects of differential competition presented by various hardwood species, particularly by yellow-poplar (*Liriodendron tulipifera* L) (Figure 1), a light-seeded pioneer species that can grow rapidly in height after seed germination. A surprising result of this restoration study was the high basal area of yellow-poplar reproduction in the regenerated stand, a species that was absent in the preharvest stand (Table 1) but was present on the middle and lower slopes below the study area. Differences in early age competition with yellow-poplar and other hardwood species could be a partial explanation of poor pine survival but likely not dbh (Cain 1999, Wagner et al. 1999). Although not recorded, yellow-poplar stem density was probably greater in places where the forest floor had been scarified by logging equipment and timber removal. In comparison with pine seedlings planted in logging debris, those planted in places of disturbed soil could have experienced greater mortality from early competition by the dense numbers and rapidly growing yellow-poplar seedlings. Size of the study area was sufficiently large (0.57 ha) and on a sloping land surface (~20%) such that full sunlight was admitted during

Table 2. Number of samples (N), mean diameter breast height (dbh, cm, and standard deviation [SD]) of surviving row-planted pitch and shortleaf pines and adjacent hardwood natural reproduction by type of tree occurrence and group configuration 13 years after clearcut harvesting of the restoration study area at Boyd Gap.

Surviving Planted Pines	Pitch Pine		Hardwoods*		Shortleaf Pine		Hardwoods	
	N	Dbh (SD)	N	Dbh (SD)	N	Dbh (SD)	N	Dbh (SD)
Tree occurrence*								
Single	18	4.58 (2.86)	18	5.40 (0.66)	15	5.37 (2.19)	15	5.24 (1.21)
Group	11	6.79 (1.80)	4	5.60 (0.54)	31	8.30 (2.36)	10	5.44 (0.52)
Difference*	--	2.21	--	0.20	--	2.93	--	0.20
*P**	--	0.02	--	0.55	--	<0.01	--	0.58
Group configuration*								
Linear	7	6.54 (2.21)	3	5.82 (0.38)	10	6.75 (2.50)	5	5.20 (0.39)
Nonlinear	4	7.22 (0.82)	1	4.92 (NA*)	21	9.03 (1.95)	5	5.68 (0.56)
Difference*	--	0.68	--	0.90	--	2.28	--	0.48
*P**	--	0.48	--	NA	--	0.02	--	0.16

*Hardwoods: hardwood reproduction adjacent to each sampled single or group of pitch or shortleaf pines. Hardwood sample sizes differ from pines for group, linear and nonlinear because all pines were measured in each designation, but only the three largest hardwood stems were measured. For example, dbh was measured for each of the 11 pitch pines that were present in four groups of two or more trees; however, hardwood dbh was measured for the three largest stems around each of the four groups.
*Tree occurrence: single, one pine surrounded by adjacent hardwoods (interspecific competition); group, two or more crown-touching pines surrounded by hardwoods (intraspecific competition.
*Group configuration: linear, two or more crown-touching pines in a line; nonllinear, three or more crown-touching pines arranged as a triangle, square, or other geometric shape (see Figure 2). Note that N for group occurrence = N for linear configuration + N for nonlinear configuration.
*Difference is the absolute value of the difference between the two values.
*NA, not applicable because the number of observations was too small for analysis.
*P, probability evaluated using Welch's unequal variance *t*-test.

much of the day, thereby increasing competition from the rapidly growing, intolerant yellow-poplar saplings, which likely reduced pine survival (Dale et al. 1995). Long-term suppressing effects by this mesophytic species on pine growth will probably be reduced during dry years as the regenerated stand ages (Hilt 1985).

I found no results from similar studies of interspecific versus intraspecific competition in small groups of conifers for direct comparison with my results. The closest comparisons were casual observations on performance of older (~20 year) conifer group plantings in Scotland and northern England (Anderson 1951) and evaluations of competition type in long-term European studies of small, densely planted oak clusters (Saha et al. 2014). Those studies primarily report survival, stem form, and growth associated with intraspecific competition of oaks within clusters and not with interspecific competition. Several intraspecific versus interspecific comparisons reviewed by Saha et al. (2017) were from separate studies with inconsistent results confounded with site and climatic differences. Clabo and Clatterbuck (2020) reported that large clusters (64 trees) of closely spaced seedlings were successful for restoration of shortleaf pine for timber management in mixed hardwood stands of eastern Tennessee.

This sub-study of pine response to intraspecific competition was an unanticipated component of a typical restoration study and thus had several weaknesses and perhaps a few strengths. An important limitation was lack of replication on other ridge sites to investigate the low survival of pines, and particularly the influence of yellow-poplar, compared to other hardwood species on pine size. Although the poor pine survival was adequate for restoration purposes of the parent study, the low sample size was marginal for hypothesis tests of shortleaf pine but was inadequate for pitch pine. Despite the small sample sizes, however, significant differences of intraspecific versus interspecific competition were evident. Possible strengths of this study were the small study site, which reduced other variation except for intraspecific and genetic sources, and the side-by-side comparisons of pine competition. For example, Saha et al. (2014) reported conclusive results from study of intraspecific competition of two species of European oaks with successional vegetation on the same sites compared with inconclusive findings from widely separated stands used in other studies. The relatively small area used for this study approximates that generally accepted for group selection openings in uneven-aged management (Dale et al. 1995). Results from a larger harvested study area would have required down-scaling to meet possible opening size restrictions of management policy, perhaps with lower confidence of likely outcomes. However, results from this small study area can be scaled up to larger stand-size areas if a pine management option is desired (Clabo and Clatterbuck 2020). Similar dbh responses by the two pine species in relation to intraspecific competition was a minor strength of the study.

In conclusion, results from this opportunistic study of southern yellow pine restoration in a mixed-hardwood stand demonstrate that intraspecific competition of conifer seedlings growing in small groups rather than singly had a significant positive effect on dbh. Although my hypotheses were tested with a small and poorly replicated data set, the significant results suggest that further investigation is desirable, particularly investigating the differential effects of various hardwood species on pine size. Also, additional study of pine group plantings could show that satisfactory restoration results can be obtained by excluding herbicide treatments entirely on dry ridge sites. If these findings are confirmed, resource managers could have a cost-effective method for restoration of southern yellow pines to increase biological diversity of mixed-hardwood sites in small project areas in the southern

Appalachians. Economics of labor and materials can likely be achieved by planting small groups of seedlings on clearcut sites with minimal site preparation.

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