SHORTLEAF PINE REPRODUCTION ABUNDANCE AND GROWTH IN PINE-OAK STANDS IN THE MISSOURI OZARKS

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ABSTRACT.—We conducted an operational study to evaluate effect of site preparation treatments on pine reproduction density and the impact of overstory basal area and understory density on pine reproduction height and basal diameter in pine-oak stands in the Missouri Ozarks. Stands were harvested to or below B-level stocking, but patchiness of the oak decline lead to some plots having no overstory and some having over 200 ft^2/ac basal area at the end of the study. In all stands, the midstory and understory were chainsaw felled. If stands were inadequately stocked with pine reproduction, then mechanical scarifying or prescribed burning treatments were applied to increase the density of shortleaf pine reproduction. Pine reproduction basal diameter, height, and crown class within the understory were measured three to eight growing seasons later.

We found no long-term difference in pine reproduction density by treatment. Overstory density and reproduction competition both affected the growth of shortleaf pine seedlings. The basal diameter and height of pine reproduction were greatest when overstory basal area was low, reproduction density was low, and pine seedlings were dominant or codominant to competitors within the understory. Pines had an 80 percent chance of being dominant/codominant with 2,000 TPA of mixed-species reproduction with no overstory, but only a 50 percent probability with 6,000 TPA of reproduction and 70 ft^2/ac of overstory basal area.

INTRODUCTION

Foresters, conservationists and ecologists have expressed interest in restoring shortleaf pine (*Pinus echinata* Mill.) throughout its native range in the Ozark Highlands. Restoring shortleaf pine is a long-term strategy for mitigating chronic oak decline and bringing back natural mixed species forests and woodland communities that are important to wildlife (Nelson 2005, Dickson et al. 1995).

At varying times throughout the Missouri Ozarks, patches of oak decline have resulted in 30 to 70 percent mortality in the overstory. Scarlet oaks (*Quercus coccinea* Muenchh.) and black oaks (*Q. velutina* Lam.) , especially those that are older than 70 years, are particularly susceptible to oak decline (Starkey et al. 1989). Shortleaf pine and white oak (*Q. alba* L.) are longer-lived than scarlet and black oak, and where present they can lengthen the biological rotation age of mixed-species stands.

Shortleaf pine once was extensive in the Ozarks and was a major component of most forest types. Past forest uses have resulted in even- and mixed-aged scarlet, black, and white oak stands dominating former shortleaf pine sites. Mortality from oak decline is exacerbated in scarlet and black oaks grown on these poor sites (Starkey et al. 1989). Oaks on poor quality, droughty sites have slow growth due to nutrient and moisture deficiencies. Drought and insect defoliation and wood boring insects in turn weaken oaks, making them more susceptible to Armillaria root disease, which further weakens or damages black, scarlet, and some white oak trees. Shortleaf pine is not affected by most oak pests and pathogens, but it is susceptible to annosum root disease (*Heterobasidion annosum*) and southern pine beetle (*Dendroctonus frontalis* Zimmermann), among others (Woodward et al. 1988). However, shortleaf pine pathogens and pests tend to not be a problem in natural pine and pine-hardwood stands (Brinkman and Smith 1969).

There is growing interest in restoring pine and pine-oak mixes because of their ecological importance and their capacity to mitigate oak decline. Mixed species stands have several advantages. A mixed species stand may decrease

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the continuity of food sources for species-specific pests and decrease the occurrence of root grafts, thereby limiting the spread of pathogens. A mixed species stand may provide managers more options in the case of an insect or disease outbreak by allowing for partial thinnings. Although there is much research about growing pine monocultures, there is little information about restoring and managing pine and oak mixes. Pines and oaks have very different ecological strategies that makes regenerating them together a challenge, as upland oaks often readily regenerate on former pine sites in the Ozarks, whereas shortleaf pine may require some site preparation and release treatments.

Stands that were salvaged due to oak decline between 1997 and 2000 were selected for an operational management study as part of a collaboration between forest managers and researchers to evaluate success of site-preparation treatments and to begin evaluating the effects of retained overstory trees and same-age reproduction on pine reproduction growth. This paper has three objectives:
1) to evaluate pine reproduction densities several years after scarifying or burning compared with stands that had adequate pine reproduction densities after harvest;
2) to analyze the roles of overstory density and understory competition on growth of pine reproduction; and 3) to analyze the roles of overstory and understory densities on the density of oak and other hardwood species that were within 5.3 ft of the pine.

METHODS

Study Sites

Study sites were located in northern Texas County on the Houston Ranger District of the Mark Twain National Forest in Missouri. Sites fall within the Big Piney River Oak-Pine Woodland/Forest Hills within the Gasconade River Hills Subsection of the Ozark Highlands (Nigh and Schroeder 2002). Ecological land types included narrow to broad ridges, and slopes on all aspects. Soils are mostly mapped as Coulstone (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults), and include Clarksville (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults), Hobson (fine-loamy, siliceous, active, mesic Oxyaquic Fragiudalfs), and Lebanon (fine, mixed, active, mesic Typic Fragiudults). Slopes range from 6 to 32 percent with a mean of 15 percent. Growing seasons last 210-230 days with a mean annual temperature of 54-57 °F (Wendland et al. 1992). Shortleaf pine site indices range from 51 to 64 ft, with a mean of 58 ft (Table 1).

We classified stands with 25 to 48 percent pine as pine/oak and stands with more than 49 percent pine as pine (Table 2). Stands were fully stocked prior to salvaging, but had varying degrees of oak decline (Rogers 1982). Oak decline salvage operations left mature pine and pine/oak stands at or below B-level.

Table 1.—Acreage, ecological land types, site indices, and soil types of stands in the study.

Compartment-Stand	Size (ac)	Ecological Landtype	Site Index (ft at age 50 yr)	Soil Type
2-21	4	narrow ridge	Black Oak 55	Clarksville
2-25	9	narrow ridge	Shortleaf P 60	Clarksville
2-29	10	south or west slope	Shortleaf P 55	Coulstone
2-33	11	south or west slope	Shortleaf P 60	Coulstone
2-34	4	narrow ridge	Shortleaf P 59	Clarksville
2-45	7	south or west slope	Shortleaf P 56	Coulstone
2-46	7	north or east slope	White Oak 58	Coulstone
2-48	13	north or east slope	Shortleaf P 64	Coulstone
2-74	16	south or west slope	Shortleaf P 60	Lebanon
13-36	47	north or east slope	Shortleaf P 51	Clarksville
13-58	8	narrow ridge	Shortleaf P 64	Hobson
16-04	19	north or east slope	Shortleaf P 55	Coulstone
16-27	8	broad ridge	Shortleaf P 58	Coulstone

Table 2.—Overstory stocking and stand treatments.

		Timeline (yr)				
		Harvested		Site-Preparation		
Compartment Stand Type[1]	Post-Harvest Basal Area (ft^2/ac)	Shelter-wood	Uneven	Scarified	Burned	Chainsaw Follow-up[2]
2-21 Pine/Oak[3]	50	1997			2000, 2002	2000
2-25 Pine	80	1997			2000, 2002	2000
2-29 Pine/Oak	80	1997			2000, 2002	2000
2-33 Pine/Oak	40	1997			2000, 2002	2000
2-34 Pine	80	1997			2000, 2002	2000
2-45 Pine	70		1997			2000
2-46 Black Oak	40		1997			2000
2-48 Pine/Oak	40	1997				2000
2-74 Pine/Oak	80		2000	2000		2000
13-36 Pine/Oak	92		1996	1998		1998
13-58 Pine	103		1996	1998		1998
16-04 Pine	70	1998		2000[3]		2000
16-27 Pine/Oak	100		1998			2000

[1]Pine/Oak = 25-48 percent pine; Pine = >49 percent; Black oak = >50 percent
[2]Cut undesired trees and sprouts
[3]Also filled in with pine seed

Site Preparation

We surveyed shortleaf pine reproduction after loggers completed the overstory salvage harvests. Even-aged stands with 435 shortleaf pine seedlings per acre and uneven-aged stands with a growing stock in 60 percent of the 0.2-ac openings were adequately stocked, received no further treatments, and are used as a benchmark in this study. Stands with inadequate stocking were either mechanically scarified or burned (Table 2).

The site was mechanically scarified to improve the seedbed in stands that had patches of pine reproduction already established. To scarify, we pulled an anchor chain assembly—two 25-lb anchor chains with round rods welded across the links—behind a bulldozer at about 5 ac/hr, focusing on areas within the stand that were inadequately stocked[2]. The anchor chain assembly appears to be less damaging to hardwoods than the heavy disk method recommended by Haney (1962). We then used chainsaws to fell residual unmerchantable mid- and understory trees according to even-aged or uneven-aged (removing the worst and leaving the best) guidelines after scarifying or before burning.

Burning was used in stands that required additional pine reproduction throughout. Logistic delays resulted in an ineffective initial burn, requiring a second prescribed fire (Table 2). We burned five stands 2 years after harvest to allow slash to decompose prior to burning. Unfortunately, the burn occurred after seed fall, so we did not expect much seedling establishment. The burn did not control hardwoods very well but did establish some pine reproduction. We conducted a second (and final) burn in November of 2002.

Data Collection

We inventoried the stands in the winter of 2005-2006. We ran transects with data collection nodes every 100 ft, used a 10 BAF prism to measure the overstory, and collected pine reproduction data using the point-centered quarter method (Fig. 1; Mitchell 2001). At each node, we recorded the distance to the closest pine in each of four quadrants. We measured the height and basal diameter of the tallest of the four pines and tallied understory competition within a 5.3-ft radius. Then, we recorded height and species of the tallest understory competitor within the circle.

[2]Contact Doyle Henken for more information on building the anchor chain scarifier.

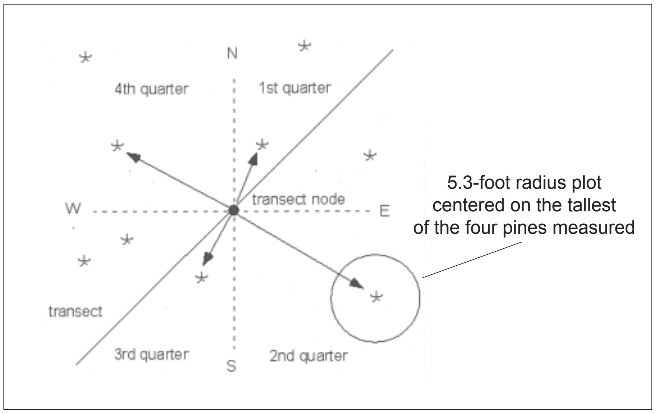

Figure 1.—Example of four-quarter sampling. Distance from the transect node to the closest pine seedling or sapling (*) in each quadrant was measured. The circled pine is the tallest of the four measured pines; all pine, oak, and other hardwood competition was tallied within a 5.3-ft radius of the tallest pine. Height of the tallest competitor was also recorded.

Data Analysis

We used linear and logistic regression to analyze the data (Proc Reg, Proc Logistic, SAS 2003). We used $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i$ for all models, except the probability of a given pine being dominant/codominant for which we used $P = (e\string^(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))/(1+ e\string^(\beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_iX_i))$. We tested combinations of indicator variables that we thought best modeled the stand dynamics that occur between a given pine seedling/sapling, the overstory and other reproduction. Some of the models tested are shown in Table 3. Most models tested had three components: overstory basal area, reproduction density, and age. Pine growth and density models included combinations of the following predictor variables: the pine's crown class within the understory, total basal area (or oak, other hardwood, and pine basal areas; ft^2/ac), density of total reproduction (TPA), density of non-pine reproduction (oak and other hardwoods; TPA), and age (yrs). Age was designated as the number of growing seasons since last treatment. Oak and other hardwood density models included the above predictor variables except pine crown class.

We differentiated the significant stand dynamics models using Akaike Information Criterion (AIC) scores (Table 3; Burnham and Anderson 2003, Proc Mixed, Proc Logistic, SAS 2003). Models with the lowest AIC scores best describe the stand dynamics with the fewest indicator variables. We considered models ≥ 2 AIC units apart to be different (Burnham and Anderson 2003).

RESULTS

Indicator Variables

We selected stands to include a wide range of overstory densities at the plot level. Overstory basal area at the plot level ranged from 0 to 200 ft^2/ac, with a mean of 63 ft^2/ac 3 to 8 years after regeneration (Table 4). Because of the wide range in basal area, the density of understory competitors with pine ranged considerably from 0 to 20,732 TPA, with a mean of 4,615 TPA. Understory competitor heights ranged from 0 to 19 ft, with heights relative to the sample pine of -10 ft to 15 ft.

Pine Density

Prescribed burning and mechanical scarification both maintained stocking levels comparable to stands that were adequately stocked after harvest (Benchmark, Fig. 2). Benchmark stands had a mean of 201 ±98 TPA, prescribed burned stands had a mean of 345 ±98 TPA, and mechanically scarified stands had a mean of 257 ±126 TPA. Thus, both prescribed burning and mechanical scarification operation treatments were successful.

Pine Basal Diameter

The basal diameter of pine reproduction increased as its crown class in the understory improved, and as the overstory basal area decreased (Fig. 3). Canopy class (within the understory), overstory basal area, and height of the tallest competitor were the strongest predictors of pine basal diameter (Table 5). The total reproduction density was not found to be a significant factor affecting the basal diameter of pine reproduction. Models with overstory basal area and/or other reproduction specified by species group did not improve the prediction of pine basal diameter based upon AIC scores. These results suggest that the basal diameter of pine is primarily affected by its crown class within the understory but also by the basal area of the overstory.

Pine Height

Pine height increased with increasing crown class and decreased with increasing overstory basal area (Fig. 4). A combination of crown class, overstory basal area, age, density of reproduction, and height of the tallest competitor best predicted pine height (i.e., lowest AIC value) and had an R^2 of 0.47 (Table 5). The species of neither the overstory nor the understory added sufficient information to warrant their inclusion in the model based upon AIC. The results also show that relatively large changes in overstory basal area are required to have the same impact on pine reproduction height compared to the effect of crown position.

Probability of a Given Pine Being Dominant/Codominant

Because of the importance of crown class for predicting height and diameter growth, we examined factors related to the crown position of the pine reproduction. Crown class is determined in part by the density of reproduction in the understory and by density of the overstory. Factors included in modeling crown class were density of non-pine

Table 3.—Linear and logistic models with diagnostic statistics for measures of pine growth and density of competition around the pine. Models are ordered by inclusion of components. Models with the lowest Akaike Information Criterion (AIC) scores best describe the stand dynamics with the fewest indicator variables. Models with < 2 AIC units apart were similar (∆AIC).

			Statistics	
MODELS[1,2]	**AIC**	**∆AIC**	**F-value**	**R^2**
PINE BASAL DIAMETER[3]				
OverBA Age TotalRepro. Compht'	464	146	10	0.12
Dom Codom Inter OverBA Age TotalRepro.'	354	36	32	0.38
Dom Codom Inter OverBA Age TotalRepro.' Compht	318	0	39	0.46
Dom Codom Inter OverBA Age Nonpinecomp' Pine' Compht	325	7	34	0.46
Dom Codom Inter OakBA PineBA HwdBA Age PineRepro.' Non-PineRepro.' Compht	345	27	27	0.47
PINE HEIGHT[3]				
OverBA Age TotalRepro. Compht'	1377	159	11	0.12
Dom Codom Inter OverBA Age TotalRepro.' Compht	1218	0	40	0.47
Dom Codom Inter OverBA Age Non-PineRepro.' PineRepro.' Compht'	1223	5	35	0.47
Dom Codom Inter OakBA PineBA HwdBA' Age NonPineRepro.' PineRepro.' Compht	1237	19	28	0.48
DENSITY OF NON-PINE[3]				
OverBA' Age' PineRepro.'	1859	0	2'	0.01
OakBA HwdBA' PineBA' Age'	1861	2	3	0.04
OakBA HwdBA' PineBA' Age' PineRepro.	1860	1	3	0.05
DENSITY OF OAK[3]				
OverBA' Age'	1567	23	1'	0.01
OverBA' Age' Non-OakRepro.'	1552	9	8	0.07
OakBA Age'	1561	18	3	0.02
OakBA Age' Non-OakRepro.'	1544	0	10	0.09
OakBA PineBA' HwdBA' Age' PineRepro. HwdRepro.	1555	12	6	0.11
DENSITY OF HWD[3]				
OverBA' Age' Non-HwdRepro.	1817	4	67	0.06
OakBA PineBA' HwdBA' Age	1835	22	2'	0.03
OakBA Age	1825	12	3	0.02
OakBA Age Non-HwdRepro	1813	0	8	0.07
OakBA PineBA' HwdBA' Age Non-HwdRepro	1824	11	5	0.07
PROBABILITY OF A GIVEN PINE BEING DOM./CODOM.[4]			**Chi-Square**	
OverBA Age' TotalRepro.' Compht	298	0	73	
OverBA Age' Non-PineRepro Pine Compht	298	0	105	
OakBA PineBA HwdBA' Age' TotalRepro.' Compht	330	32	75	
OakBA PineBA HwdBA' Age' Non-PineRepro. Pine Compht	300	2	107	

[1]Abbreviations: Age = number of growing seasons since regeneration treatment; BA = Basal area (ft^2/ac); CompHt = height (ft) of the tallest competitor within the understory; Dom., Codom., Inter. = dominant, codominant, or intermediate pine within the understory, use 1 if true, 0 otherwise; Int. = y-intercept; Over. = overstory; Oth. Hwd. = other hardwood tree species; and Repro = density of reproduction (TPA).

[2]All parameters and statistics are significant except those followed by an " ' ".

[3]Model: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i$.

[4]Model: $P = (e^\wedge(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i))/(1+ e^\wedge(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i))$.

Table 4.—Winter 2006 overstory basal area (ft²/ac), understory density (TPA), height (ft) of the tallest competitors, and height (ft) of the tallest competitor relative to the pine reproduction.

	Overstory	Understory Competitors		
	Basal Area Mean (Range) (ft²/ac)	Density Mean (Range) (TPA)	Height Range (ft)	Relative Height of Tallest Competitor Range (ft)
All Species	63 (0 – 200)	4,615 (0 – 20,732)	0.0 – 18.5	-10.4 to 14.5
Pine	38 (0 – 190)	1,020 (0 – 19,251)	0.8 – 18.5	-3.0 to 11.9
Oak	23 (0 – 130)	1,228 (0 – 8,391)	2.1 – 16.6	-10.4 to 14.5
Other Hardwoods	1 (0 – 40)	2,368 (0 – 7,404)	1.4 – 15.9	-9.2 to 13.9

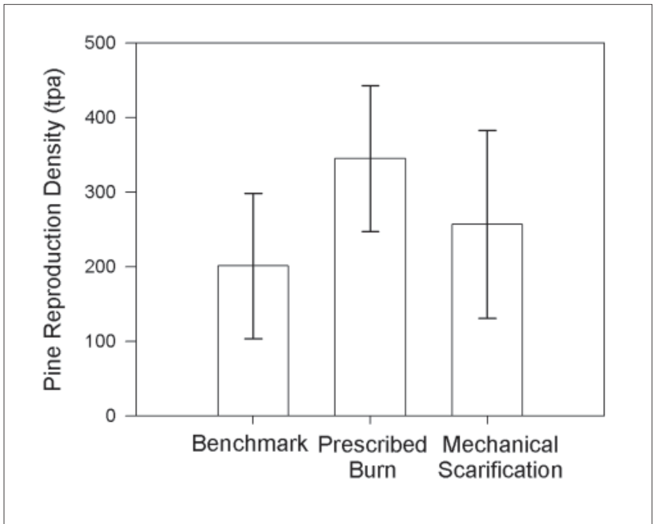

Figure 2.—Density of pine reproduction by site preparation treatment. Error bars represent 1 standard deviation. Mechanical scarification treatments were applied as needed, rather than uniformly, across the stand. There was no significant difference in pine density at the stand level by treatment.

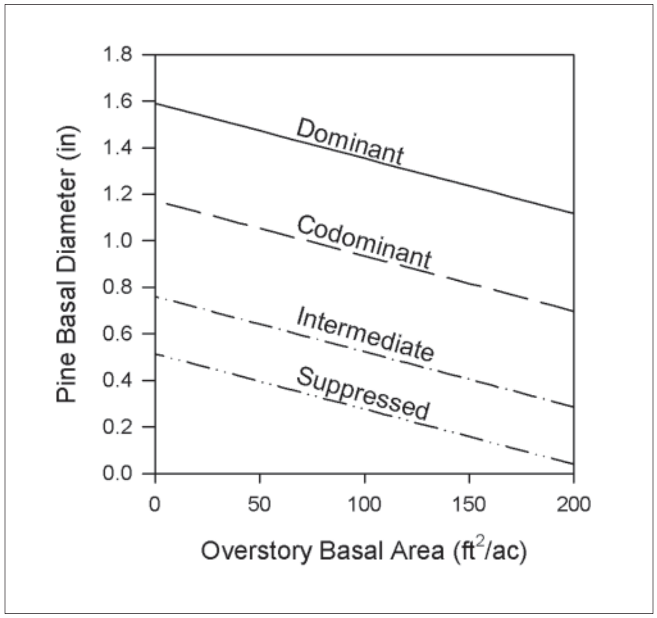

Figure 3.—Basal diameter of pine reproduction at age 10 yr based upon the pine's crown class, height (ft) of its tallest competitor and 5,000 TPA competitors (all species) by overstory basal area (ft²/ac). Dominant pine reproduction had twice the basal diameter of intermediate pine reproduction.

reproduction, density of pine reproduction, overstory basal area, and age and height of the tallest competitor; the model had a Chi-square of 105.2 (Table 5).

The probability of a given pine being dominant or codominant increased with decreasing overstory density and with decreasing reproduction density (Fig. 5). To have a greater than 50/50 chance of a given pine being dominant or codominant the overstory basal area must be less than 70 ft²/ac with 2,000 TPA or less in the understory, or less than 10 ft²/ac overstory basal area with 6,000 TPA or less in the understory.

Density of Non-Pine Competitors

We also examined factors potentially affecting the density of non-pine competition around sampled pines. Density of non-pine competitors was related to overstory oak basal area and density of non-pine understory competition (other hardwoods for oak or oaks for other hardwoods) (Table 5). However, the models failed to account for much of the variance in the data, as indicated by the low R^2 values of 0.05 and 0.10.

Table 5.—Linear models with growth of pine reproduction dependent upon crown class within the understory, overstory density, understory density, height of the tallest competitor and age; crown class within the understory dependent upon density of non-pine reproduction, pine reproduction, overstory basal area, age and height of the tallest competitor, and age; and density of understory competitors dependent upon overstory basal area and density of understory by species. There were 320 observations of each dependent variable.

	Parameter Estimates (X)[1,2]								Statistics	
Dependant variable	**Int.**	**Dom.**	**Codom.**	**Inter.**	**Over. BA**	**Age**	**Total Repro.**	**Comp. Ht**	**F-value**	**R^2**
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7		
Pine Basal Diameter[3]	-0.055’	1.078†	0.658†	0.246†	-0.002*	0.019*	-0.000’	0.052†	39†	0.46
Pine Height[3]	-0.006’	4.505†	2.957†	1.067†	-0.012†	0.091†	0.000’	0.233†	40†	0.47

	Parameter Estimates (X)[1,2]						Statistics
Dependant variable	**Int.**	**Non-Pine Repro.**	**Pine Repro.**	**Over. BA**	**Age**	**Comp. Ht**	**Chi-Square**
	β_0	β_1	β_2	β_3	β_4	β_5	
Probability of a Given Pine Being Dom./Codom.[4]	2.8228†	-0.0005†	0.0002¤	-0.0236†	0.0980’	-0.2378†	105†

	Parameter Estimates (X)[1,2]								Statistics	
Dependant Variable	**Int.**	**Oak BA**	**Age**	**Oth. Hwd. BA**	**Pine BA**	**Pine Repro.**	**Oak Repro.**	**Oth. Hwd. Repro.**	**F-value**	**R^2**
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7		
Density of Oak and Oth. Hwd.	3750.5†	-19.75‡	67.25’	0.623’	-0.575’	-0.136¤			3*	0.05
Density of Oak	2004.3†	-10.12†	-5.333’			-0.074’		-0.182†	9†	0.10
Density of Oth. Hwd.	2793.1†	-14.88¤	77.86¤			-0.101’	-0.419†		9†	0.10

[1]Abbreviations: Age = number of growing seasons since regeneration treatment; BA = Basal area (ft^2/ac); CompHt = height (ft) of the tallest competitor within the understory; Dom., Codom., Inter. = dominant, codominant, or intermediate pine within the understory, use 1 if true, 0 otherwise; Int. = y-intercept; Over. = overstory; Oth. Hwd. = other hardwood tree species; and Repro = density of reproduction (TPA).
[2]Parameter estimates differ from zero at the following alphas: † = <0.0001, ‡ = ≤0.001, * = ≤0.01, ¤ = ≤0.05, ’ = not significant (>0.05).
[3]Model: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i$.
[4]Model: $P = (e\hat{}(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i))/(1 + e\hat{}(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i))$.

DISCUSSION

Shortleaf pine-upland oak mixtures occur naturally in Missouri, but foresters would like to better understand the stand dynamics in order to more predictably achieve these mixtures. While stand-wide regeneration events are natural—the tornado near Poplar Bluff being an excellent example—widespread and chronic oak decline has provided an opportunity to study regeneration and growth of shortleaf pine under a thinned canopy. Our results show that given these stand structures, overstory retention results in slowed shortleaf pine growth.

Both mechanical scarification and prescribed burning increased pine reproduction densities to levels similar to stands that had adequately reproduction stocking without treatment. Scarification is more practical than burning in small stands or when there are smoke management issues. Scarification treatments by skilled operators may cause less damage to crop oak trees than prescribed fire, particularly in stands that have not been burned for decades. Prescribed fires can cover large areas in a day or two, and proper timing and fire techniques aid in reducing or increasing oak reproduction (Dey and Hartman 2005, Van Lear et al. 2000).

Overstory densities must be kept low to recruit seedlings, especially shortleaf pine (Larsen et al. 1997, Baker 1992, Liming 1945). Shortleaf pine seedlings are moderately shade tolerant, but become shade intolerant with age (Baker 1992). Thus, if shortleaf pine is being recruited, then the

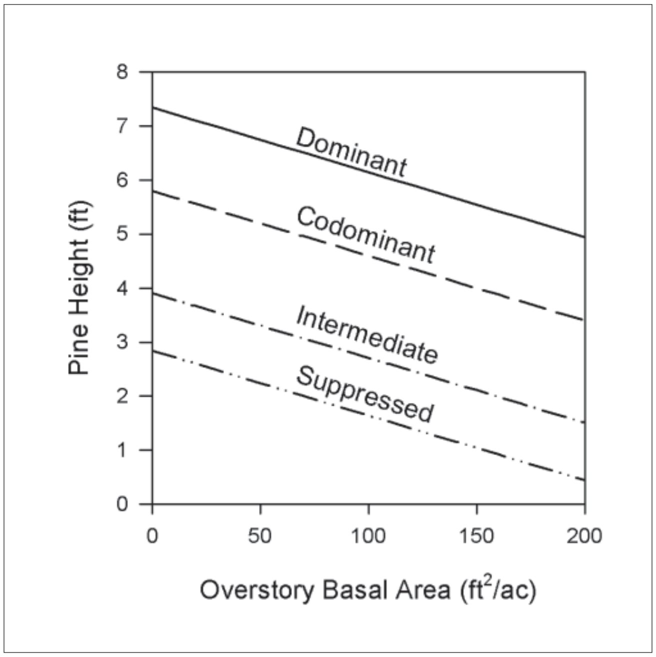

Figure 4.—Height (ft) of pine reproduction at age 10 yr based upon the pine's crown class, height (ft) of its tallest competitor, and 5,000 TPA competitors (all species) by overstory basal area (ft^2/ac).

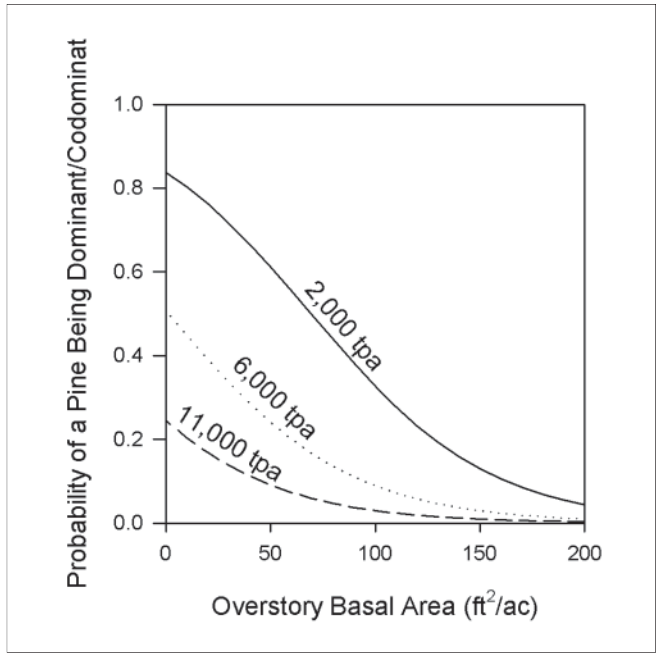

Figure 5.—Probability of a given pine being dominant/codominant for a given understory density (TPA) by overstory basal area (ft^2/ac). There is a 50 percent probability of a given pine being dominant/codominant with 2,000 TPA mixed-species reproduction at 70 ft^2/ac basal area and with 6,000 TPA mixed-species reproduction at 10 ft^2/ac basal area.

mature overstory basal area should be kept low during seedling establishment and even lower after establishment to promote maximum reproduction height growth (Fig. 5).

In addition to reductions to overstory density, periodic releases have long been recognized as key to reliably recruiting shortleaf pine among oak reproduction (Brickman and Smith 1969, Baker 1992, Liming and Seizert 1943). Our data suggest that recruiting pine under a thinned canopy requires a commitment to periodic release from oak and other hardwood reproduction, particularly where there is a high density of hardwood competition (Fig. 5). While oaks also grow best in the open, they are more shade tolerant than shortleaf pine. Even under low overstory stocking levels, a high density of oaks in the reproduction cohort can greatly reduce the likelihood that pine reproduction will successfully compete for growing space and grow into the overstory.

ACKNOWLEDGMENTS

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LITERATURE CITED

Baker, J.B. 1992. Natural regeneration of shortleaf pine. In: Brissette, John C.; Barnett, James P., comps. Proceedings of shortleaf pine regeneration workshop; 1991 October 29-31; Little Rock, AR. Gen. Tech. Rep. SO-090. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Research Station: 102-112.

Brinkman, K.A.; Smith, R.C. 1969. Managing shortleaf pine in Missouri. Station Bull. No. 875. Columbia, MO: Agricultural Experiment Station, University of Missouri. 35 p.

Burnham, K.P.; Anderson, D.R. 2003. Model selection and multimodel Inference: a practical information-theoretic approach. New York, NY: Springer. 488 p.

Dey, D.C.; Hartman, G. 2005. Returning fire to Ozark Highland forest ecosystems: Effects on advance regeneration. Forest Ecology and Management. 217: 37-53.

Dickson, J.G.; Thompson, F.R., III; Connor, R.N.; Franzreb, K.E.. 1995. Silviculture in central and southeastern oak-pine forests. In: Ecology and Management of Neotropical Migratory Birds – a synthesis and review of critical issues. New York, NY: Oxford University Press. 489 p.

Haney, G.P. 1962. Seedbed scarification aids regeneration of shortleaf pine. Journal of Forestry. 60(6): 400-402.

Larsen, D.R.; Metzger, M.A.; Johnson, P.S. 1997. Oak regeneration and overstory density in the Missouri Ozarks. Canadian Journal of Forest Research. 27: 869-875.

Liming, F.G.; Seizert, B.F. 1943. Relative height growth of planted shortleaf pine and cut-back and uncut hardwood reproduction after release. Journal of Forestry. 41(3): 214-216.

Liming, F.G. 1945. Natural regeneration of shortleaf pine in the Missouri Ozarks. Journal of Forestry. 43(5): 339-345.

Mitchell, K. 2001. [Revised June 2005]. Quantitative analysis by the point-centered quarter method. William Smith's, NY: Hobart and William Smith College, Department of Mathematics and Computer Science,. http://people.hws.edu/mitchell/PCQM.pdf.

Nelson, N.W. 2005. The Terrestrial natural communities of Missouri. Jefferson City, MO: Missouri Department of Natural Resources. 550 p.

Nigh, T.A.; Schroeder, W.A. 2002. Atlas of Missouri ecoregions. Jefferson City, MO: Missouri Department of Conservation. 212 p.

Rogers, Robert. 1982. Guides for thinning shortleaf pine. In: Jones, Earle P., Jr., ed. Proceedings of the 2nd Biennial Southern Silvicultural Research Conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Research Station: 217-225.

SAS. 2003. Getting started with SAS version 9. SAS Institute Incorporated. Cary, NC: SAS Institute.

Starkey, D.A.; Oak, S.W; Ryan, G.W.; Tainter, F.H.; Redmond, C.; Brown, H.D. 1989. Evaluation of oak decline areas in the south. Protection Rep. RB-PR 17. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region.

Van Lear, D.H; Brose, P.H.; Keyser, P.D. 2000. Using prescribed fire to regenerate oaks. In: Yaussy, D.A., ed. Proceedings: workshop on fire, people, and the central hardwoods landscape; 2000 March 12-14; Richmond, KY. Gen. Tech. Rep. NE-274. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 97-102.

Wendland, W.M.; Kunkel, K.E.; Conner, G.; Decker, W.L.; Hillaker, H. Naber-Knox, P.; Nurnberger, F.V.; Rogers, J.; Scheeringa, K.; Zandlo, J. 1992. Mean 1961-1990 temperature and precipitation over the Upper Midwest. Research Report 92-01. State Water Survey Miscellaneous Publication 136. Champaign, IL: Midwest Climate Center.

Woodward, S.; Stenlid, J.; Karjalainen, R.; Hutterman, A., eds. 1988. *Heterobasidion annosum*: Biology, ecology, impact, and control. New York, NY: CABI. 589 p.