EARLY SURVIVAL AND GROWTH OF PLANTED SHORTLEAF PINE SEEDLINGS AS A FUNCTION OF INITIAL SIZE AND OVERSTORY STOCKING

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Abstract.—Shortleaf pine was once abundant throughout the Missouri Ozarks and there is renewed interest in its restoration. Past research suggested that the greatest survival and growth of shortleaf pine seedlings occurred where there was little competition for sunlight. This study, in the oak and oak-pine forests of the Sinkin Experimental Forest in southeastern Missouri, quantified the effects of residual overstory density on the early survival and growth of planted shortleaf pine seedlings. We established 48 one-acre experimental units and thinned each from below to establish a uniform stocking level in the range of 0 to 80 percent. In the center of each experimental unit we established 30 1-0 shortleaf pine seedlings on a 12- by 24-foot spacing. One growing season after planting we used regression to analyze seedling (1) survival, (2) basal diameter growth, and (3) shoot growth as functions of initial seedling size and overstory stocking. Increasing overstory stocking nominally decreased seedling survival, but the effect was small and not significant. However, each 20-percent increase in overstory stocking significantly ($P < 0.001$) decreased diameter growth by about 0.01 inches and shoot growth by 0.7 inches. Seedlings with larger initial size had a significantly greater ($P < 0.02$) survival rate.

INTRODUCTION

Shortleaf pines (*Pinus echinata* Mill.) were once dominant on about 4.2 million acres of the Missouri Ozarks and were prominent on an additional 2.4 million acres (Liming 1946). They were most abundant on rolling to steep terrain on soils derived from sandstone or cherty dolomite that were excessively well drained and acidic (Fletcher and McDermott 1957).

Today, shortleaf pine in its native range often accounts for less than 10 percent of stocking (Kabrick and others 2002), having been displaced by black oaks (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Muenchh.) following extensive timber harvesting and subsequent land clearing and frequent burning during the early 1900s. These two species of oaks are particularly susceptible to oak decline as they mature. Consequently, hundreds of thousands of acres of declining oak forests throughout the Missouri Ozarks are now found on sites where shortleaf pine or pine-oak mixtures were formerly prominent.

There is renewed interest in restoring shortleaf pine throughout its native range in the Ozark Highlands. Restoring shortleaf pine on former pine and oak-pine sites is viewed as a long-term strategy for mitigating

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chronic oak decline (Law and others 2004). There also is an increasing interest in restoring the native oak-pine woodland communities where they once were abundant.

In the Missouri Ozarks, methods for establishing and recruiting shortleaf pine in plantations and natural stands were evaluated from the 1930s through the 1960s. U.S. Forest Service scientists conducted considerable research in the former Clark National Forest, in the Mark Twain National Forest, and on the Sinkin Experimental Forest in southeastern Missouri. This research included studies of natural and artificial regeneration (Phares and Liming 1960, Seidel and Rogers 1965), an examination of the effects of stand density on growth and tree quality (Brinkman and Liming 1961, Brinkman and Rogers 1965), and the development of yield and volume tables for shortleaf pine stands (Brinkman and Rogers 1965, Brinkman 1967). Most of the findings were summarized in two pivotal management publications, *Timber Management Guide for Shortleaf Pine and Oak-Pine Types in Missouri* (Brinkman and Rogers 1967) and *Managing Shortleaf Pine in Missouri* (Brinkman and Smith 1968). These guides emphasized establishing and managing even-aged shortleaf pine-dominated stands. Consequently, guidelines recommended controlling or removing all undesirable hardwoods, particularly in the overstory, using a combination of prescribed fire, herbicides, and mechanical removal with a bulldozer (Brinkman and Smith 1968).

However, foresters are increasingly seeking or are required to select methods for regenerating or re-establishing shortleaf pine other than the ones recommended by Brinkman and Rogers (1967) and Brinkman and Smith (1968). These alternative methods often include leaving moderate to high densities of residual oaks and pines in the overstory of harvested stands either for aesthetic reasons or to meet other natural community or habitat goals.

Past research (Brinkman and Liming 1961) indicates that leaving a residual overstory is likely to reduce the survival or growth of shortleaf pine seedlings. However, there are few quantitative estimates of the magnitude of these survival and growth reductions. The objective of this study was to quantify the survival and growth reductions of shortleaf pine seedlings due to overstory stocking compared to stands having no residual overstory. Findings from this study will allow foresters to anticipate the survival and growth of shortleaf pine seedlings under various levels of overstory stocking to meet desired stocking goals for pine reproduction.

METHODS

STUDY AREA

The study was conducted in the Sinkin Experimental Forest in southeastern Missouri on sites suited for managing shortleaf pine or pine-oak mixes. Study sites were located on summit and shoulder slope positions on soils derived from sandstones (Roubidoux formation) or cherty dolomites (Gasconade formation) and were deep (> 4.9 ft), were moderately-well to excessively-well drained, and had low cation supply. Soil series included Nixa (Loamy-skeletal, siliceous, active, mesic, Glossic Fragiudults) and Coulstone and Clarksville (each Loamy-skeletal, siliceous, semiactive, mesic, Typic Paleudults).

Before the study began, forests were mature and fully stocked. Species in the overstory by proportion of basal area were as follows: black oak (34 percent), white oak (*Q. alba* L., 27 percent), shortleaf pine (17 percent), scarlet oak (6 percent), post oak (*Q. stellata* Wangenh., 5 percent), hickories (*Carya* spp. Nutt., 5 percent), and other hardwoods (6 percent).

EXPERIMENTAL UNITS AND TREATMENTS

We established 48 one-acre experimental units. In the center of each experimental unit we placed a circular 0.2-acre plot for the inventory of all trees ≥ 2 inches in diameter at breast height (d.b.h.) and a circular 0.001-acre plot for the inventory of all trees < 2 inches d.b.h. After pretreatment inventories were completed, the density of each of the 48 experimental units was adjusted to a single stocking level (*sensu* Gingrich 1967, Rogers 1983) ranging from 0 to 80 percent. To achieve the target stocking levels, stems were removed "from below," creating a shelterwood structure. To facilitate marking to a specified stocking level, a marking guide was created that expressed the target stocking level in units of basal area that could be verified with a 10-BAF prism. Once the experimental units were marked, the merchantable timber was harvested commercially and all other stems marked for removal were felled.

After harvesting, trees ≥ 2 inches d.b.h. were re-inventoried on all experimental units. In the 0.2-acre circular vegetation plots 30 1-0 bareroot shortleaf pine seedlings were hand-planted on a 12-foot by 24-foot spacing during the first week of April. Seedlings were produced by the George O. White State Tree Nursery in Licking, MO. Planting within the 0.2-acre plot ensured a buffer of at least 52 feet from the experimental unit boundary to the nearest planted seedling. After planting, a numbered metal tag attached to a wire was placed next to each seedling so that they each could be relocated for subsequent determination of survival and growth. The initial basal diameter (measured one-half inch above the root collar) and shoot length of each seedling were recorded after planting. The 1,440 seedlings that were planted initially had an average basal diameter of 0.13 inches and an average shoot length of 8.5 inches. One growing season later, the shoot length and basal diameter of all living seedlings were re-measured. We also recorded the condition of each seedling and noted browse or other forms of animal and insect damage.

ANALYSIS

We used logistic regression (LOGISTIC procedure, SAS version 9.1, SAS Institute, Inc., Cary, NC) to analyze the survival probability and the probability of browse occurring as a function of initial basal diameter (and initial height for browse) and overstory stocking. We then used linear regression (REG procedure, SAS version 9.1) to examine the change in basal diameter or shoot length as a function of overstory stocking and the initial basal diameter or initial shoot length. These models included both browsed and non-browsed seedlings. The significant parameters of these models were used to estimate survival probabilities and growth rates for the range of initial basal diameters and shoot lengths of seedlings planted in our study.

RESULTS

The first-year survival rate was 76 percent and the survival probability largely was a function of initial basal diameter (Table 1, Fig. 1). Seedlings with a basal diameter > 0.4 inches had survival probabilities that exceeded 0.90, and those seedlings were 1.2 times more likely to survive than those that had basal diameters < 0.2 inches. On average, seedlings on plots beneath greater residual overstory stocking had slightly higher survival rates, but the effect was small in magnitude and not significant (Table 1).

Increasing the residual stocking of the overstory significantly decreased both the basal diameter growth and the shoot growth of underplanted shortleaf pine seedlings (Table 1, Figs. 2 and 3). Each additional 20-percent increase in overstory stocking decreased the shortleaf pine basal diameter growth by 0.01 inches and the shoot growth by 0.7 inches compared to seedlings grown under no overstory canopy. Seedlings grown under stocking levels greater than 50 percent had decreased basal diameters because of shoot dieback and resprouting. Initial seedling size did not significantly alter the growth response to overstory density (Table 1).

Table 1.—Model parameters[a] for estimating survival probability, basal diameter growth (in inches), and height growth (in inches).

Parameter	df	Estimate	Standard error	P-value
Survival probability				
Full model (Hosmer and Lemeshow goodness of fit = 0.10)				
Intercept	1	0.410	0.279	0.142
Initial basal diameter	1	4.851	2.032	0.017
Percent stocking	1	0.003	0.002	0.184
Partial model[b] (Hosmer and Lemeshow goodness of fit = 0.57)				
Intercept	1	0.536	0.262	0.040
Initial basal diameter	1	4.854	2.028	0.017
Diameter growth				
Full model (Adjusted R-square = 0.26)				
Intercept	1	0.063	0.048	0.192
Initial basal diameter	1	-0.080	0.371	0.830
Percent stocking	1	-0.0006	0.001	<0.001
Partial model[b] (Adjusted R-square = 0.28)				
Intercept	1	0.053	0.006	<0.001
Percent stocking	1	-0.0006	0.001	<0.001
Shoot growth				
Full model (Adjusted R-square = 0.38)				
Intercept	1	4.759	1.647	0.006
Initial shoot length	1	-0.076	0.185	0.683
Percent stocking	1	-0.033	0.006	<0.001
Partial model[b] (Adjusted R-square = 0.39)				
Intercept	1	4.093	0.283	<0.001
Percent Stocking	1	-0.033	0.006	<0.001

[a]Model form: $Y=\beta_0+\beta_1X_1 + \beta_2X_2$, where Y is the logit of survival probability, diameter growth, or shoot growth, β_0 is the intercept, β_1 is the parameter for initial diameter or shoot length, and β_2 is the parameter for percent stocking.

[b]Partial models contain the intercept and significant parameters of the full model and are to be applied by foresters for predicting survival probability, diameter growth, or shoot growth of planted shortleaf pine seedlings.

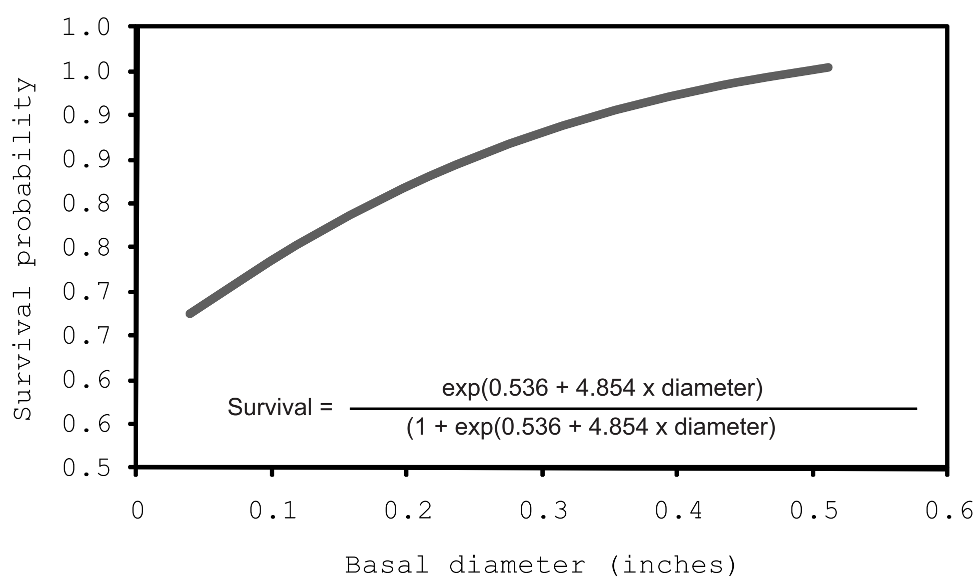

Figure 1.—First-year survival probability of shortleaf pine seedlings as a function of initial basal diameter and overstory stocking.

About 11 percent of the seedlings exhibited some degree of browse damage by animals. The browsing partially removed some of the leader or the ends of the branches. The shoot length of seedlings that were browsed was, on average, about 2 inches shorter than those that were not browsed. Browsed seedlings had significantly ($P < 0.01$) reduced shoot growth compared to those that were not browsed, but the diameter growth of browsed seedlings was unaffected. According to the analysis, browsing was not related to the initial basal diameter or shoot length, or the amount of harvesting (i.e., the residual overstory stocking).

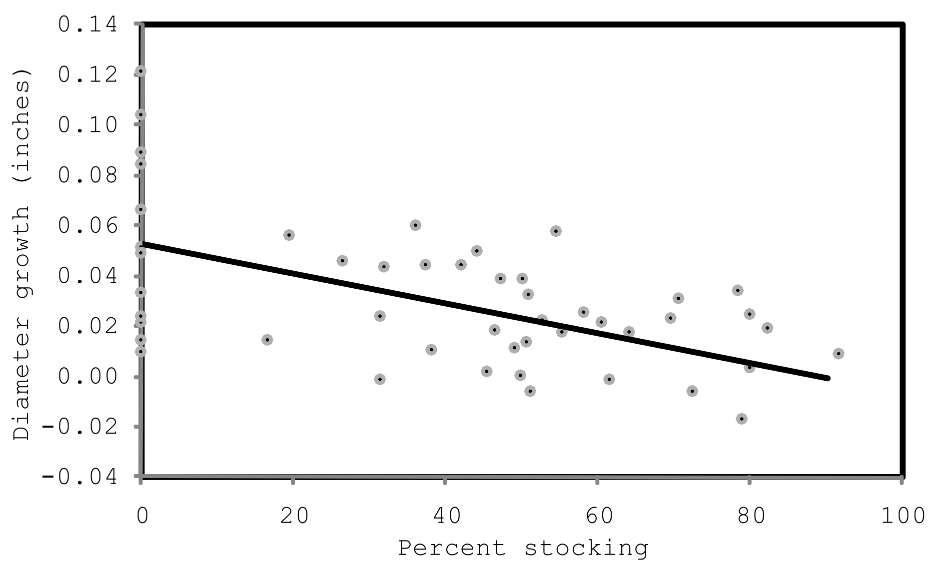

Figure 2.—First-year basal diameter growth as a function of overstory stocking.

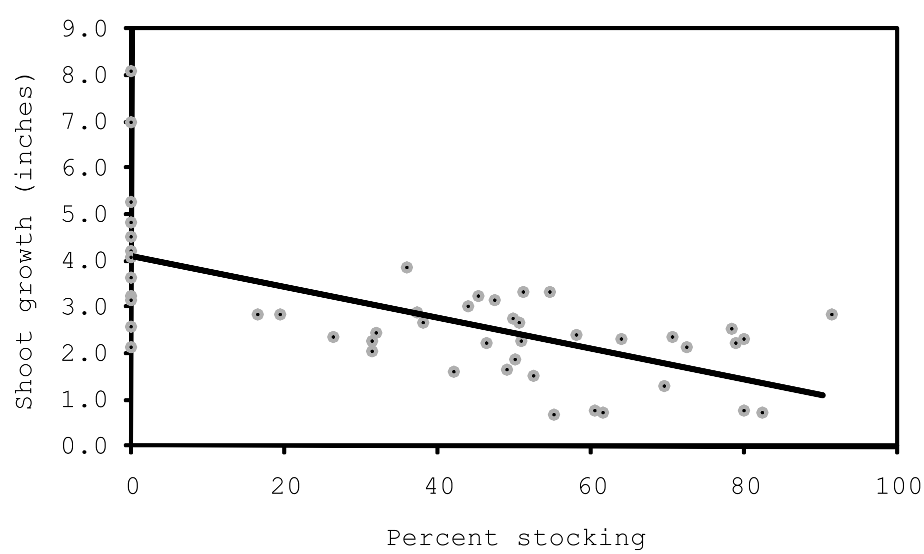

Figure 3.—First-year shoot growth as a function of overstory stocking.

DISCUSSION

The first-year survival rates of shortleaf pine seedlings were consistent with survival rates reported for bareroot seedlings planted elsewhere in the Missouri Ozarks (Gwaze and others 2006) and in the southern United States (Barnett and Brissette 2004). Seedlings with larger basal diameters had significantly greater survival than smaller ones, much like has been reported for oak seedlings (Johnson and others 2009). Larger shortleaf pine seedlings generally have a more balanced root:shoot ratio (Barnett and Brissette 2007), which was reported to increase shortleaf pine seedling survival (Mexal 1992).

We found no significant relationship between overstory stocking and seedling survival. Because of shortleaf pine's shade intolerance, we hypothesized that the increased light levels resulting from a lower overstory stocking (Fig. 4) would increase the seedling survival probability. Shelton (1995) noted that overstory density did not appear to be limiting to the establishment of natural shortleaf pine seedlings and suggested that newly-established pine seedlings may be moderately shade-tolerant and become less tolerant with age. Moreover, the canopy growing space requirement of a 1-0 pine seedling is less than a square foot and initially can be accommodated by a small canopy gap. This adaptability may explain why shortleaf pine seedlings can persist under a partial or full overstory for a short time (Shelton and Cain 2000). Blizzard and others (2007a) reported that overstory density had little effect on the establishment of natural shortleaf pine seedlings elsewhere in the Missouri Ozarks. As seedlings grow, we anticipate a significant effect from overstory density on growth and competitive status (see below), which will eventually manifest itself in reduced long-term pine seedling survival with increasing overstory density, other factors being equal.

Maintaining a residual overstory had an immediate negative effect on basal diameter growth and on shoot growth. For an average-size seedling, both diameter growth and shoot growth were reduced by 8 percent. Our

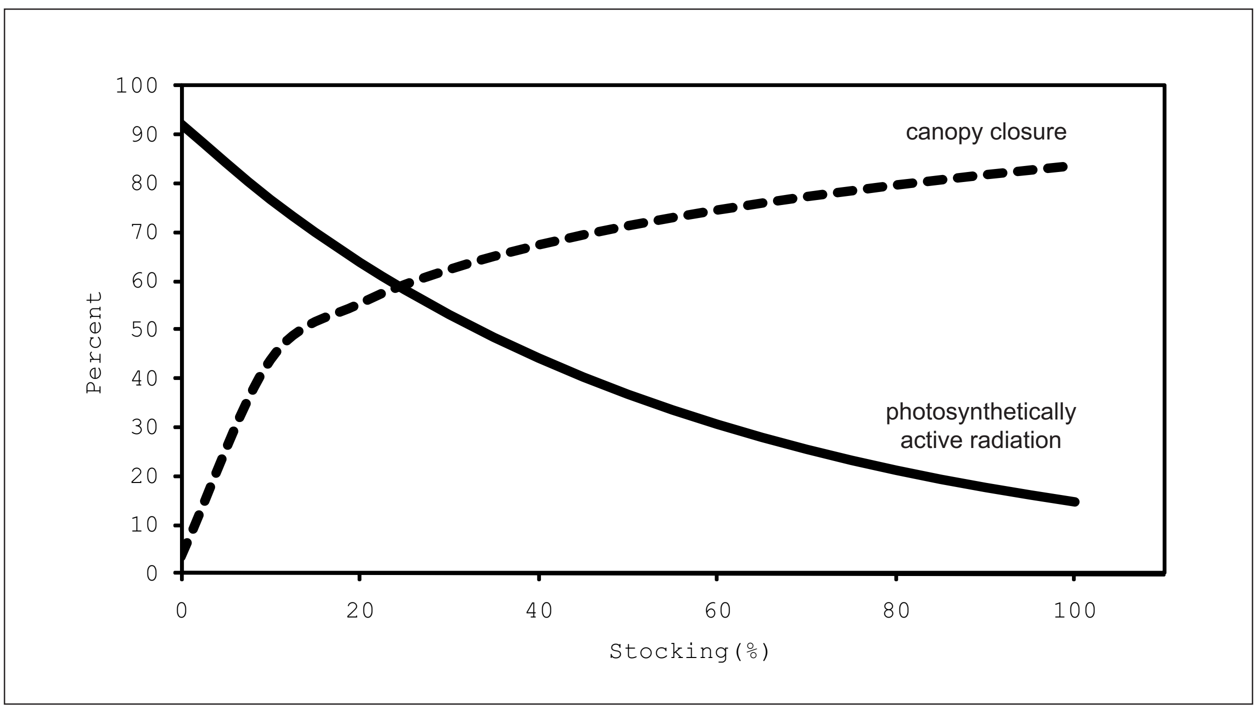

Figure 4.—Relationship between overstory stocking, canopy closure (dashed line), and photosynthetically active radiation (solid line) expressed as percent of full sunlight, and canopy closure for the study area. Adapted from Blizzard and others (in press).

findings were consistent with those of Liming (1946), who reported that the height growth rate of shortleaf pine increased significantly when the overstory density was reduced to or below 27 square feet per acre, which is about 20-percent stocking in our study region. Shelton (1995) also reported growth reductions in 1-year-old shortleaf pine seedlings with increasing overstory density in the Ouachita Mountains of western Arkansas and southeastern Oklahoma although direct comparisons cannot be made to our data because of differences in the respective studies. These shortleaf pine seedling growth reductions are likely to persist and eventually favor the hardwoods as Blizzard and others (2007a) noted that increasing the residual overstory density decreased the probability of producing dominant or codominant pine reproduction 5 years after harvesting. These growth reductions are attributed to the reduction in light levels in plots retaining a residual overstory (Tappe and others 1993). Blizzard and others (in press) demonstrated that even minor increases in residual stocking such as from 0 to 30 percent decreases the photosynthetically-active radiation from 92 to 50 percent of full sunlight in our study area (Fig. 4).

Collectively, our findings and those of others examining the growth of shortleaf pine seedlings are compatible with many of the methods recommended for regenerating shortleaf pine in the Missouri Ozarks. Because of the noted growth reductions under residual overstories, shortleaf pine guidelines recommended managing pines in even-aged stands using clearcutting with hardwood competition control as the preferred regeneration method (Brinkman and Rogers 1967, Brinkman and Smith 1968). These recommendations were intended to minimize the rotation length by maximizing the survival and growth rate of the desired pine reproduction and thereby maximizing the economic return (Brinkman and Rogers 1967).

However, maximizing the economic return is seldom the primary management goal for much of the publicly and privately owned land in the Ozark Highlands (Butler 2008) and there are many situations in which foresters elect to retain some residual overstory when managing or regenerating shortleaf pine or pine-oak mixes. For example, retaining some pines and oaks in the overstory may help promote a healthy ground flora community comprising legumes, forbs, and grasses that otherwise would be lost to competition by hardwood seedlings and seedling sprouts should the entire overstory be removed (Nelson 2005). Public land management agencies are increasingly retaining partial overstories during harvesting for aesthetic reasons (Blizzard and others 2007b). Uneven-age management of shortleaf-loblolly pine mixtures has been practiced successfully for many decades in the southern United States (Shelton and Cain 2000), suggesting that with attentive management, pines can successfully be regenerated and recruited under partial overstories. Although significant, the small growth reductions in shortleaf pine seedlings caused by retaining a residual overstory may be overcome by other management interventions to control hardwood competition. Forest managers are increasingly interested in the application of prescribed fire and periodic release of understory trees to favor shortleaf pine seedlings when hardwoods appear to be gaining dominance (Blizzard and others 2007a). The application of these management interventions will be examined in future years during this study.

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