Rehabilitation of Understocked Loblolly-Shortleaf Pine Stands—IV. Natural and Planted Seedling/Sapling Stands

James B. Baker *and* **Michael G. Shelton,** *USDA Forest Service, Southern Research, Station, Monticello, AR 71656.*

ABSTRACT. *A 3- to 6-yr-old naturally regenerated, even-aged loblollypine* (Pinus taeda *L.) stand and a 5-yr-old loblolly pine plantation on good sites (SI_{Lob} = 85 to 90 ft at 50 yr) were cut to density levels of 50, 90, 180,270, and 360 seedlings and/or saplings/ac. Two pine release treatments (none and individual tree release with a herbicide) were applied to the natural stand, but were not imposed in the plantation because site preparation treatments were appliedbeforeplanting. At 2, 5, and 10 yrafter installation, plots were inventoried to determine: (I) the lowest threshold of seedling/sapling density that was feasible to manage, (2) the time required for poorly stocked seedling/sapling stands to reach an acceptable stocking level, and (3) whether release treatments would improve survival and growth of understocked, natural seedling/sapling stands.*

Results indicated that loblolly pine plantations on good sites having at least 180 trees/ac (30% stocking) reached an acceptable stocking level of 60% by age 10 and produced up to 1,500 ft^3/ac (19 cd/ac) of merchantable volume by age 15. By this age, trees inplantations with 270 and 360 trees/ac displayed good form, but at densities of 180, 90, and 50 trees/ac the trees still retained large branches nearly to the ground.

Natural stands having at least 180 trees/ac that were released from overtopping by hardwood at age 5 reached 60% stocking by age 15 but produced only 627 ft^3/ac (8 cd/ac) of merchantable volume. When pines in the natural stand were not released, only plots with 360 trees/ac reached an acceptable 60% stocking level by age 15 but only produced 539 ft^3/ac (7 cd/ac) of merchantable volume. The observed differences in recovery rates in the understocked pine stands principally reflected the levels of competing hardwoods.

Results suggest that understocked, natural stands or plantations of pine seedlings/saplings withfewer than 180 trees/ac (less than 30% stocking), at age 5, should probably be liquidated and a new stand established unless the landowner is willing to sacrifice significant reductions in early volume production. South. J. Appl. For. 22(1)53–59.

Thousands of acres of southern pine timberlands are not adequately regenerated with pine following reproduction cutting (USDA Forest Service 1972). Understocked seedling and sapling stands are sometimes the result of failures to adequately regenerate areas either naturally or artificially.

When foresters encounter understocked seedling and sapling stands, they have to decide whether to manage them, with a possible sacrifice in production, or to replant at an additional expense to the landowner. Before a prudent decision can be made, foresters need answers to several important questions: (1) What is the threshold of seedling and sapling density that is feasible to manage, below which the best alternative would be to start over with an artificially regenerated fully stocked seedling stand? (2) How long will it take an understocked seedling/sapling stand to approach an acceptable stocking level? (3) Does release from overtopping hardwoods enhance survival and growth of understocked natural pine seedling/sapling stands? This study was established in understocked, natural, and planted stands in an attempt to answer some of these questions.

NOTE: Manuscript received July 1, 1996, accepted March 3, 1997. James Baker is the corresponding author and can be reached at (870) 367-3464; Fax (870) 367-l 164. This research was done in cooperation with the Mid-Continent Division of Georgia-Pacific Corporation, which provided the study sites Use of trade names is for reader information and does not imply endorsement by the U.S. Department of Agriculture to the exclusion of any suitable product orprocess. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

Methods

Study Areas

The study was installed in two loblolly pine (*Pinus taeda* L.) seedling/sapling stands. One stand developed following a seed-tree reproduction cut and was of natural seedling origin; the other was a 5-yr-old plantation. The stands were about 8 miles apart in Ashley County, AR. Soils on the study areas are Bude (Glossaquic Fragiudalf) and Grenada (Glossic Fragiudalf) silt loams, having a site index (SI) for loblolly pine of 85 to 90 ft at 50 yr.

Natural Stand.-The natural stand was comprised of 3- to 6-yr-old loblolly pine seedlings (dbh less than 0.6 in.) and saplings (dbh 0.6 to 3.5 in.) that became established following a seed-tree reproduction cut in 1978. No site preparation, other than the logging operation, was done. The seed trees were removed in 1983. At study installation (January 1985), the stand averaged 375 pines/ac that ranged from 1 to 14 ft in height and averaged 7 ft. Fifty-six percent of the pines were seedlings and 44% were saplings.

The natural stand also contained about 10,000 hardwood stems/ac that ranged from 4 to 20 ft in height and averaged 10 ft. The most prevalent species were sweetgum (*Liquidambar styraciflua* L.), dogwood (*Cornus jlorida* L.), red maple (*Acer rubrum* L.), red oaks (***Quercus nigra*** L., Q. *phellos* L., Q. ***falcata*** Michx., and Q. *falcata* var. *pagodifolia* Ell.), and white oaks (Q. *stellata* Wangenh. and Q. *alba* L.). No attempt had been made to control the hardwoods since the reproduction cut in 1978.

Plantation.-The pine plantation was established on an area that was clearcut, site prepared, and planted in the fall and winter of 1978-1979. Site preparation consisted of shearing, rootraking and piling logging debris in windrows. Approximately 600 genetically improved 1-O loblolly pine seedlings/ac were planted at a 8 x 9 ft spacing in January 1979. At study installation (January 1985), the plantation averaged 440 trees/ac that ranged from 5 to 13 ft in height and averaged 9 ft. Seven percent of the pines were seedlings and 93% were saplings. The stand contained about 900 hardwood stems/ac that ranged from 2 to 8 ft in height and averaged 4 ft. Hardwoods were predominately sweetgum and red oaks that sprouted following site preparation.

Treatments

Treatments included five pine density levels: 50, 90, 180, 270, and 360 seedlings/saplings per acre, and two levels of pine release: none and individual tree release. All of the stocking levels, except the highest (360 stems/ac) fall below the 60% minimum acceptable stocking level for seedling/sapling stands stated in Forest Inventory and Analysis (FIA) standards (USDA Forest Service 1972).

All treatments were implemented in the natural stand. However, since it was difficult to locate a pine plantation that had not been previously site prepared, and thus in need of pine release, the pine release treatment was not included in the plantation phase of the study. For the pine plantation, treatments included only the five pine density levels. Treatments in both stands were randomly assigned in a 3-replicate, randomized blockdesign. A plot consisted of a square 0.25 ac treatment plot (104 ft on the side) and a 0.10 ac interior measurement plot (66 ft on the side).

The prescribed density levels for treatments in both stands were accomplished by hand-thinning. Retained pines were selected at random to simulate the natural distribution of trees within a poorly stocked stand.

The pine release treatment was applied in mid-May 1985. It consisted of treating all hardwoods that were overtopping pine seedlings/saplings on a plot with Roundup@ (glyphosate) herbicide (50% solution in water) using the hatchet and squirt-bottle technique. A pine was considered overtopped if the branches of a neighboring hardwood extended over its terminal bud. Thus, the pine release treatment only assured that released pines received full sunlight during midday and did not necessarily free them of other competition from neighboring trees. Hardwoods were not treated on plots designated for no release.

Measurements and Analyses

Immediately after thinning to prescribed density levels, residual pines on each net plot were numbered and their location plotted in relation to plot center. Each numbered pine was then measured for total height (0.1 ft) and dbh (0.1 in.) and categorized as either overtopped (the branches of a neighboring hardwood extended over its terminal bud) or not overtopped. All hardwoods, within a 2-ft-wide strip that transected the gross plots from the northwest to the southeast corner, were also inventoried for size (total height and dbh), species composition, and number per acre.

Total basal area of all pines with dbh of at least 0.1 in. was calculated. Pine volumes were calculated from equations of Clark and Saucier (1990), where merchantable cubic ft volume, inside bark, was from a 0.5 ft stump to a 3.0 in., outside bark, top for trees with dbh 3.6 in. or larger. In addition, pine stocking percent was calculated using the following equation:

$$\%\ \text{stocking} = 0.16667(N) + 0.00404(\Sigma D) + 0.00434(\Sigma D^2) \tag{1}$$

where N = number of pines/ac at least 1 ft in height, and ***D*** = dbh (in.) of pines more than 4.5 ft in height. The equation was derived by fitting FIA stocking guides (USDA Forest Service 1972) to Chisman and Schumacher's (1940) tree-area ratio equation, and thus provided an expression of stocking based on both number and tree size. This measure of stocking is useful in stands that have seedlings and/or saplings which make little or no contribution to basal area or volume stocking levels.

Analyses of variance were used to test for differences in initial pine seedling sizes (height and dbh) and numbers, and sizes of hardwood stems by treatment. These analyses indicated that no significant (0.05 probability level) differences existed by treatments or blocks at time of study establishment.

At 2 and 5 yr after study installation, surviving (numbered) pines on each plot were remeasured for dbh and total height. Hardwood overtopping was also recorded for each pine. Ten years after study initiation (in 1995 at stand age 15), surviving pines were remeasured for dbh, but total height was measured for a sample of trees across the range of dbh classes (a minimum of six trees per plot if available). For each inventory, percent mortality, total basal area, merchantable cubic ft volume, and stocking percent were calculated. For trees that were not measured for height in 1995, height was predicted from their dbh using height–dbh prediction equations developed from trees on all plots having the same treatment.

The concept of a potential and modifier function, which has widespread application in growth modeling, was used to predict stocking, basal area, and volume. Following the procedure of Murphy and Shelton (1996), several potential functions were examined. In some situations, the potential function displayed an inflection point, and the Chapman-Richards function (Pienaar and Turnbull 1973) was used. At other times, no inflection point was displayed for the observation period, and a simple power function was used. The logistic function, which was constrained between the interval 0 and 1, was used as a modifier function. The resulting functions were:

$$G_i = b_0\{1 - \exp(b_1 A_i)\}^{b2} / \{1 + \exp(c_1 + c_2 D + c_3 R)\} \quad (2)$$

$$G_i = b_0 A_i^{b1} / \{1 + \exp(c_1 + c_2 D + c_3 R)\} \quad (3)$$

where G_i is pine stocking level, basal area, or volume at i yr, A_i is stand age in years, D is initial pine density in trees per acre, R is an indicator variable (natural stand only) with a value of 0 when trees were not released and 1 when trees were released, and b_i's and c_i's are coefficients to be estimated. The choice between Equation (2) and (3) was based on the significance of coefficients for the Chapman-Richards portion of Equation (2).

Data for fitting the equations were calculated from the inventories conducted at stand ages 5, 7, 10, and 15 yr; there were 60 observations for the plantation and 120 observations for the natural stand. Equations (2) and (3) were fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Variables were eliminated from the full model if their coefficient did not significantly differ from zero at a probability level of 10.05. The reported fit index is analogous to the coefficient of determination for linear regression.

Results and Discussion

Stand Development

Suppression and Mortality.-The percentage of pines that died or were overtopped by hardwoods are summarized in Table 1. During 10 yr of development in the understocked plantation, virtually no mortality occurred and none of the trees were ever overtopped by hardwoods. In the natural stand, mortality during the 10 yr period ranged from 0 to 33% and averaged 16% across all stand density levels. On average, only 8% of the released pines died, while 25% of the pines that were not released died

Table 1. Percentage of released and unreleased loblolly pine seedlings/saplings that died or were overtopped by hardwoods in the understocked plantation and natural stand.

Stand density/	Mortality			Pines overtopped by hardwoods		
release (trees/ac)	1985-1990	1990–1995	Total	1985	1990	1995
	(%)					
Plantation						
50/NR[1]	0	0	0	0	0	0
90/NR	0	0	0	0	0	0
180/NR	0	0	0	0	0	0
270/NR	0	0	0	0	0	0
360/NR	0	1	1	0	0	0
Mean	0	<1	<1	0	0	0
Natural stand						
50/NR	7	13	20	80	35	0
50/Rel[2]	7	13	20	67	0	0
90/NR	22	11	33	82	39	11
90/Rel	0	0	0	82	0	0
180/NR	4	20	24	76	25	0
180/Rel	2	0	2	69	0	0
270/NR	15	17	32	72	34	7
270/Rel	5	7	12	78	0	0
360/NR	6	11	18	71	33	13
360/Rel	3	5	7	65	0	0
Mean NR	11	14	25	76	33	6
Mean Rel	3	5	8	72	0	0

[1] NR = Not released from overtopping hardwoods. Release was not needed in the plantation.
[2] Rel = Released from overtopping hardwoods.

within 10 yr (Table I). This difference in mortality between release treatments was significant (P = 0.0001).

In 1985, before the release treatment was applied in the natural stand, about 75% of the pines were overtopped by hardwoods (Table 1). Five and ten years later, all pines that were released were still not overtopped by hardwoods. However, for the treatment with no release, only 33% of the pines were overtopped by hardwoods in 1990 and still fewer (6%) were overtopped in 1995. Some of the overtopped pines obviously died, as indicated in the mortality data, but many pines outgrew the overtopping hardwoods by 1995.

Tree Growth and Stocking Increases.-At study installation, the 5-yr-old pines in the plantation averaged 1.2 in. in dbh and 8.7 ft in height (Table 2). By 1995, the 15-yr-old trees averaged 9.4 in. in dbh (ranging from 8.2 in. for 360 trees/ac to 10.5 in. for 50 trees/ac) and 43.2 ft in height (ranging from 41.6 ft with 50 trees/ac to 44.2 ft with 360 trees/ac). Initial stocking percentages in the 5-yr-old plantation ranged from 9 to 64% for 50 and 360 trees/ac, respectively (averaging 34% across all density levels). By age 10, stocking percentages had doubled for most tree density levels, ranging from 18 to 112% and averaging 63% across all density levels. Thus by age 10, plots with at least 180 trees/ac had reached an acceptable stocking level of 60% or more. At 15 yr, stocking percent increased to 34% for 50 trees/ac and to 177% for 360 treeslac and averaged 105%.

At study installation, pines in the natural stand averaged 0.5 in. in dbh and 6.8 ft in height (Table 2). Ten years later, they averaged 5.9 in. in dbh and 34.1 ft in height. Average height of dominant and codominant pines was 39 ft. Trees that were released in 1985 averaged 1.4 in. (27%) larger in dbh and 1.8 ft (5%) taller in height than trees not released. Stocking levels in the natural stand in 1985 ranged from 9% for 50 trees/ac to 62% for 360 trees/ac and averaged 32% across all density levels. In 1995, stocking levels in the natural stands increased to 14 and 126% for 50 and 360 trees/ac, respectively, and averaged 56%.

On average, stocking levels increased only 13 percentage points where pines were not released. The small increase in stocking levels for the unreleased pines was due, in part, to the 25% mortality rate occurring from 1985 to 1995 (Table 1). On plots where pines were released, stocking increased 36 percentage points from 1985 to 1995, due to both increased growth and lower mortality rates.

Basal Area and Volume.-By stand age 15, basal areas in the plantation ranged from 30 ft^2/ac on plots having only 50 trees/ac to over 130 ft^2/ac on plots having 360 trees/ac (Table 2). Between 1985 and 1995, this amounted to average annual basal area increments of 3 to 13 ft^2/ac.

By stand age 15, basal areas in the natural stand ranged from about 8 ft^2/ac on plots having 50 trees/ac that were not released to about 80 ft^2/ac on plots having 360 trees/ac that were released (Table 2). Basal area increases were influenced by both stand density and release treatment. On average, plots

Table 2. Development of released and unreleased loblolly pine seedlings/saplings in the understocked plantation and natural stand.

Stand density/ release	Dbh			Height			Stocking			Basal area			Merch. volume		
(trees/ac)	1985	1990	1995	1985	1990	1995	1985	1990	1995	1985	1990	1995	1985	1990	1995
		(in.)			(ft)			(%)			(ft^2/ac)			(ft^3/ac)	
Plantation															
50/NR[1]	1.2	6.2	10.5	8.8	25.3	41.6	9	18	34	0.5	10.6	30.0	0	95	482
90/NR	1.3	6.0	10.0	8.9	25.8	43.0	16	32	58	0.9	18.4	49.8	0	169	825
180/NR	1.3	5.9	9.5	9.2	26.2	43.4	32	62	108	1.8	34.9	89.9	0	320	1,492
270/NR	1.2	5.7	8.9	8.7	27.4	44.1	48	90	149	2.3	49.0	117.9	0	464	2,014
360/NR	1.1	5.3	8.2	8.1	26.7	44.2	64	112	177	2.5	55.4	132.9	0	485	2,243
Mean	1.2	5.8	9.4	8.7	26.3	43.2	34	63	105	1.6	33.7	84.1	0	‘307	1,411
Natural stand															
50/NR	0.7	2.6	5.7	7.8	18.0	33.2	9	10	14	0.2	1.9	7.6	0	3	91
50/Rel[2]	0.4	3.3	7.4	6.3	18.9	35.6	9	11	18	0.1	3.2	12.5	0	14	170
90/NR	0.5	2.5	5.4	6.9	17.8	32.1	15	15	20	0.2	3.0	11.2	0	8	130
90/Rel	0.5	3.5	6.9	7.0	20.1	35.2	15	22	38	0.2	6.7	25.9	0	33	351
180/NR	0.5	2.4	5.6	6.4	17.0	33.4	31	36	46	0.4	6.7	25.6	0	16	310
180/Rel	0.5	3.6	6.7	6.6	20.1	36.3	31	43	71	0.4	13.3	46.2	0	62	627
270/NR	0.6	2.2	4.5	6.9	17.0	32.4	46	47	54	0.8	8.0	25.3	0	24	281
270/Rel	0.5	3.1	5.9	7.1	19.0	33.4	46	59	88	0.7	16.2	52.9	0	73	683
360/NR	0.4	2.4	4.8	6.2	17.2	34.9	61	70	91	0.8	13.2	44.8	0	36	539
360/Rel	0.5	3.3	6.3	6.6	18.8	34.3	62	82	126	1.0	23.4	78.4	0	103	1,030
Mean NR	0.5	2.4	5.2	6.8	17.4	33.2	32	36	45	0.5	6.6	22.9	0	17	270
Mean Rel	0.5	3.4	6.6	6.7	19.4	35.0	32	43	68	0.5	12.6	43.2	0	57	572

[1] NR = Not released from overtopping hardwoods. Release was not needed in the plantation.
[2] Rel = Released from overtopping hardwoods.

where pines were released produced almost twice as much basal area growth by age 15 as plots where pines were not released.

Merchantable volume in the plantation was also strongly influenced by initial stand density levels, ranging at 15 yr from 482 ft^3/ac on plots with 50 trees/ac to 2,243 ft^3/ac on plots with 360 trees/ac. Assuming a cord of pulpwood is equivalent to 80 ft^3 of merchantable volume, plots with only 50 trees/ac averaged 0.6 cd/yr of pulpwood from plantation age 5 to 15. Plots with 360 trees/ac produced 2.8 cd/yr of pulpwood during this 10 yr period.

Merchantable volume in the natural stand, at age 15, ranged from 91 ft^3/ac for 50 trees/ac that were not released to 1,030 ft^3/ac for 360 trees/ac that were released. On average, plots on which pines were released produced 112% more volume in 15 yr than plots on which pines were not released. For plots with initial density levels of 180,270, and 360 trees/ac, the release treatment resulted in an additional 4.0, 5.0, and 6.1 cd/ac, respectively, of pulpwood at age 15.

Prediction Models

Regression equations and associated statistics for predicting stocking level, basal area, and volume from stand age, initial pine density, and the release treatment are presented in Table 3. The equations can be used to estimate growth trends of understocked seedling/sapling stands having similar stand and site conditions as those of this study. As with any prediction equation, users should not apply these equations beyond the bounds of the data (initial density of 50 to 360 trees/ac and a period of time of 5 to 15 yr) and should recognize that data were collected from a single location.

The fit index was 0.99 for all equations developed for the plantation. Data from the natural stand were somewhat more variable than that of the plantation, which resulted in a slightly lower fit indices (0.92 or 0.93 for all equations). For the natural stand, the release treatment significantly affected stocking level, basal area, and volume (P = 0.0001 in all cases).

Equations were solved for stand ages ranging from 5 to 15 yr and stand densities of 50 to 360 pines/ac, and values were plotted in Figures 1-3. The equations behaved in a logical manner-values increased as the stands aged and when more trees occupied the site. At 15 yr, the plantation had about twice as much stocking, basal area, and volume as the natural stand with pine release. The release treatment in the natural stand increased basal area and volume by about twofold through age 15; stocking levels increased about 1.5 fold. The basal area in the plantation with 360 pines/ac was beginning to approach the carrying capacity of this site (about 170 ft^2/ac), based on a mature, undisturbed stand described by Cain and Shelton (1994). This was also suggested by a slight decline in rate of basal area growth for this treatment.

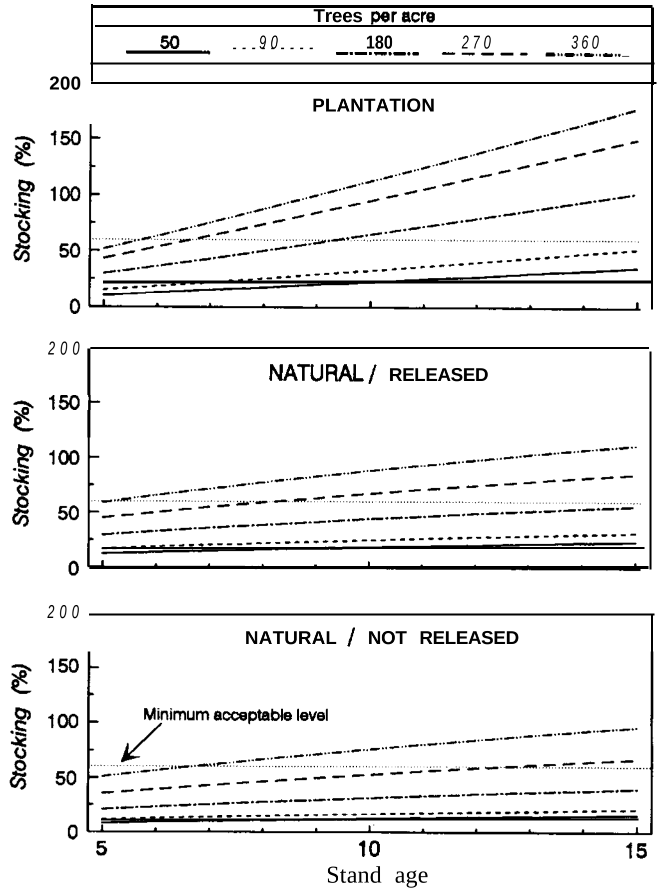

Figure 1. Predicted increases in stocking level in understocked pine seedling/sapling stands on a good site (SI_{Lob} = 85 to 90 ft at 50 yr) calculated from equations presented in Table 3. The dotted, horizonal line represents the minimum acceptable level of stocking.

Summary and Conclusions

Understocked Natural Stands

Understocked natural seedling/sapling stands on a good site (SI_{Lob} = 85 to 90 ft at 50 yr) having at least 180 trees/ac

Table 3. Regression equations and associated statistics for predicting the development of understocked pine plantations and natural stands from age, stocking, and release treatment.

Equation [1]	RMSE	Fit index
Plantation		
$BA = 210.5\{1-\exp(-0.2218A)\}^{11.45}/\{1+\exp(1.919-0.01393D)\}$	3.7	0.99
$ST = (9.404A^{1.119})/\{1+\exp(2.112-0.01226D)\}$	5.5	0.99
$VM = (0.04543\ A^{4.006})/\{1+\exp(1.967-0.01422D)\}$	69.8	0.99
Natural stand		
$BA = (0.02729A^{3.172})/\{1+\exp(3.088-0.006344D-0.9225R)\}$	4.6	0.93
$ST = (31.08A^{0.5797})/\{1+\exp(2.608-0.008888D-0.4952R)\}$	8.2	0.92
$VM = (0.0002269A^{5.892})/\{1+\exp(3.189-0.006179D-1.068R)\}$	62.8	0.93

[1] Abbreviations and units are: BA= basal area (ft^2/ac); ST= stocking level (%); VM = merchantable inside bark volume (ft^3/ac); A = stand age (yr); D = initial density (trees/ac); R = release treatment in natural stand only (0 if not released, 1 if released); exp = exponential function; RMSE = root mean square error.

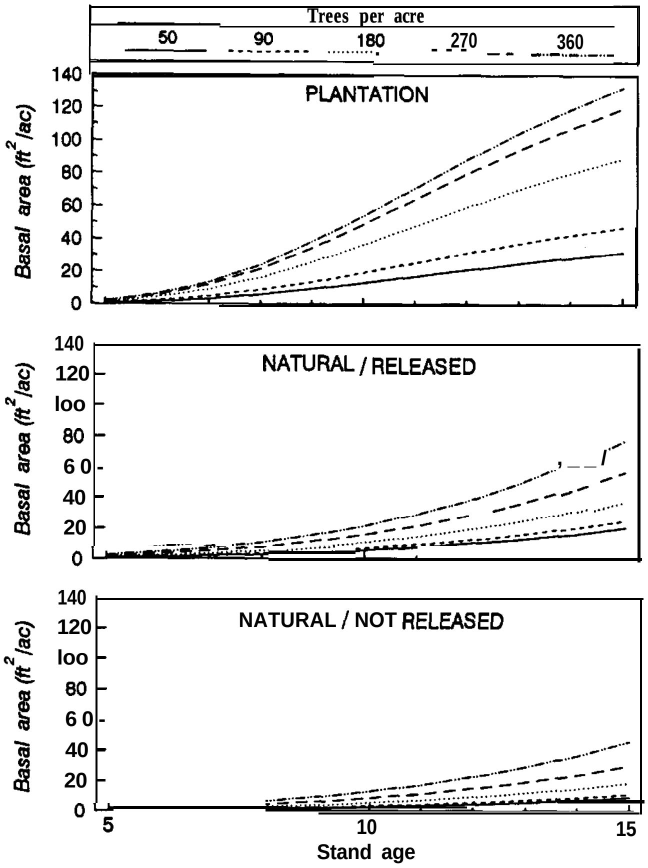

Figure 2. Predicted basal area development in understocked pine seedling/sapling stands on a good site (SI_{Lob} = 85 to 90 ft at 50 yr) calculated from equations presented in Table 3.

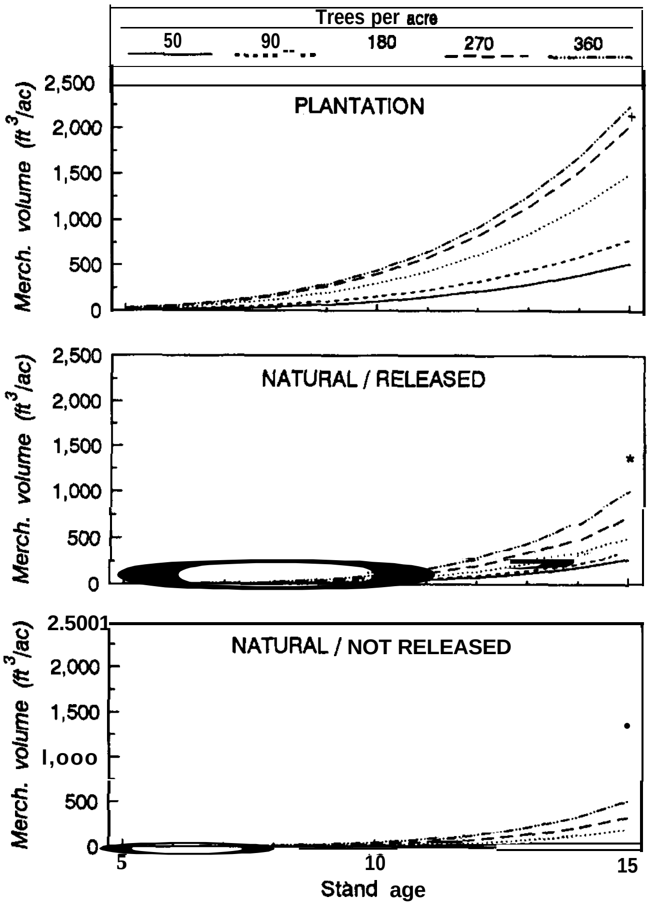

Figure 3. Predicted merchantable volume development in understocked pine seedling/sapling stands on a good site (SI_{Lob} = 85 to 90 ft at 50 yr) calculated from equations presented in Table 3. The + and • at stand age 15 represent normal yields for fully stocked plantations and natural stands, respectively (Baker and Langdon 1990).

(30% stocking) that were released from overtopping hardwoods at age 5, reached an acceptable stocking level of 60% by age 15. However, plots with only 50 and 90 released trees/ac (9% and 15% stocking, respectively) achieved only 18% and 38% stocking by age 15. When trees were not released at age 5, about 25% of the residual trees died, and only plots with initial densities of 360 trees/ac were at an acceptable stocking level by age 15. This was attributed to the higher mortality and reduced diameter growth of the unreleased trees.

Natural seedling/sapling stands with 180, 270, and 360 released trees/ac, at age 5, produced 627,683, and 1,030 ft^3/ac of merchantable volume or 7.8, 8.5, and 12.9 cd/ac of pulpwood, respectively, by age 15. Normal merchantable volume yield for fully stocked natural loblolly pine stands on good sites across the South is 1,325 ft^3/ac or 16.6 cdlac at age 15 (Baker and Langdon 1990). Thus, natural stands having 180, 270, and 360 trees/ac that were not overtopped by hardwoods, at age 5, produced from 47 to 78% of the merchantable volume of a fully stocked stand.

The release treatment at age 5 significantly improved both survival and growth of trees in the natural stand-increasing survival by 17% and basal area and merchantable volume growth by 89 and 112%, respectively. However, more time will be needed to fully assess the importance of the release treatment because the greatest gains will undoubtedly be realized when the trees reach sawtimber size.

Understocked Plantations

The loblolly pine plantation on a good site (SI = 85 to 90 ft at 50 yr) having at least 180 trees/ac (30% stocking) at age 5 exceeded an acceptable stocking level of 60% by age 15, and plots with only 90 trees/ac (16% stocking) were approaching 60% stocking by age 15.

Plantations with 180, 270, and 360 trees/ac, at age 5, produced 1,492, 2,014, and 2,243 ft^3/ac of merchantable volume or 18.6, 25.2, and 28.0 cdlac of pulpwood, respectively, by age 15. Average merchantable volume yield for loblolly pine planted at 700 trees/ac on good sites across the South is reported as 2,200 ft^3/ac or 27.5 cdlac at age 15 (Baker and Langdon 1990). Thus, planted stands having at least 180 trees/ac at age 5 produced from 70 to 100% of the volume expected for a fully stocked stand by age 15.

Sawtimber volume production of these understocked plantations will likely accelerate over the next 15 yr. Williston (1978) reported a 30 yr sawtimber yield of nearly 16,600 bd ft/ac (International l/4-in.) in a loblolly pine plantation on a good site in southern Arkansas that was precommercially thinned to 100 crop trees/ac at age 9.

It must be noted, however, that many of the trees in stands having 180 trees/ac or less still displayed open-grown character at age 15, with many large branches retained nearly to the ground. If plantations with initial densities of 180 trees/ac or less are to be managed for sawtimber, final crop trees should probably be pruned to a height of 17 ft by age 10 (Williston 1978). Pruning the understocked stand would increase tree quality and value for sawtimber and/or veneer and may be more economical than establishing a new plantation.

Minumum Stocking Thresholds

This study suggests that understocked, natural stands or plantations of pine seedlings/saplings with fewer than 180 trees/ac (less than 30% stocking), at age 5, should probably be liquidated and a new stand established unless the landowner is willing to sacrifice significant reductions in early volume production. Even though fewer than 180 trees/ac at age 5 may achieve an acceptable stocking level of 60% by age 15, merchantable volume yields by that time would likely be only 2.5 to 35% of yields of fully stocked stands.

Natural stands with 180 or more trees/ac that were released from overtopping hardwoods, at age 5, could produce 50 to 75% of the merchantable volume as fully stocked natural stands by age 15. Plantations with 180 or more trees/ac, at age 5, could produce 70 to 100% of the expected merchantable volume of fully stocked plantations by age 15.

Literature Cited

BAKER, J.B., AND O.G. LANGDON. 1990. Loblolly pine. P. 497-512 in Silvics of North America: 1. Conifers. Agric. Handb. 654. USDA For. Serv., Washington, DC.

CAIN, M.D., AND M.G. SHELTON. 1994. Indigenous vegetation in a southern Arkansas pine-hardwood forest after a half century without catastrophic disturbance. Natur. Areas J. 14(3):165–174.

CHISMAN, H.H., AND F.X. SCHUMACHER. 1940. On the tree-area ratio and certain of its implications. J. For. 38:311-317.

CLARK III, A., AND J.R. SAUCIER. 1990. Tables for estimating total-tree weights, stem weights, and volumes of planted and natural pines in the Southeast. Georgia For. Res. Pap. 79. Georgia For. Comm., Macon, GA. 23 p.

MURPHY, P.A., AND M.G. SHELTON. 1996. An individual-tree basal area growth model for loblolly pine stands. Can. J. For. Res. 26:327–331.

PIENAAR, L.V., AND K.J. TURNBULL. 1973. The Chapman-Richards generalization of von Bertalanffy's model for basal area growth and yield in even-aged stands. For. Sci. 19:2–22.

SAS INSTITUTE, INC. 1988. SAS/ETS user's guide. Version 6, first edition. SAS Institute, Inc., Cary, NC. 560 p.

USDA FOREST SERVICE. 1972. Forest survey handbook FSH 48 13.1. USDA For. Serv., Washington, DC. 254 p.

WILLISTON, H.L. 1978. Growth of understocked southern pine stands. USDA For. Serv., S&PF For. Manage. Bull. (February 1978). Southeastern Area, State and Private Forestry, Atlanta, GA. 4 p.