Rehabilitation of Understocked Loblolly-Shortleaf Pine Stands—II. Development of Intermediate and Suppressed Trees Following Release in Natural Stands

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ABSTRACT. *Development of 86 intermediate and suppressed loblolly pine* (Pinus taeda *L.) trees, that had been recent!\. releusedfrorn overtopping pines and hardwoods, was monitored over a 15 yr period. The trees were growing in natural stands on good sites (site index = 90 ft at 50 yr) that had been recently cud to stocking levels ranging from 10 to 50%. At time of release, the trees averaged 26 yr in age, 4.8 in. in dhh, and 37ft in height. The trees had averaged only 0.5 in. in dhh growth the 5 yr prior to release (0. I in./yr).*

After 15 yr, the 77 surviving trees averaged 59 ft in height und 12.9 in. in dbh, increasing 21 ft in height and 8. I in. in dbh. During the 15 yr period, crown dimensions of the trees increased markedly as well. On average, crown lengths increased I I ft (from 16 to 27 ft); crown widths nearly tripled from 9 to 25 ft; and crown volumes increased 11 fold from 608 to 6,700 ft³. The majority of the trees had good form and wouldproduce high-quality sawtimber. Satisfactory response to release was best predicted by initial dbh and live-crown ratio.

Results of the study suggest that trees with at least a 20% live-crown ratio should satisfactorily respond to release even though they had developed in lower crown positions of fully stocked uneven-aged stands for 10 to 50 yr. Responding trees rupidlyexpanded their crowns and accelerated in height and diameter growth. South. J. Appl. For. 22(1):41–46.

Understocked pine stands are common in the South due to inappropriate harvesting operations or natural catastrophes. Baker and Shelton (1998) reported that such stands can often be rapidly rehabilitated into productive sawtimber stands at a lower cost than site preparation and planting. However, rehabilitation depends on the growth of the existing trees within the stand. Understocked natural stands often have many residual trees of poor form and vigor that previously developed in lower crown positions of the original stand. If understocked stands are to be successfully rehabilitated for future productivity, these previously overtopped trees must respond to release and become future crop trees.

Foresters must be aware of a tree's potential to respond to release to accurately estimate the existing stocking and growth potential of a stand. It has been observed that high quality sawtimber trees often develop from previously suppressed or oppressed trees that were released (Chapman 1923, Mattoon 1915, Reynolds 1952); however, this trait has not been adequately tested under controlled conditions.

This study was initiated to determine: (1) if intermediate and suppressed trees that had developed for 10 to 50 yr in the lower crown positions of fully stocked uneven-aged stands would respond to release, and (2) what measurable tree or stand variables could be correlated with satisfactory response to release. McLemore (1987), reporting on 5 yr results of this study, concluded that 1.5 to 40 yr old intermediate and suppressed trees with small, thin crowns can recover quickly and make rapid growth following release. This paper reports results through 15 yr.

Methods

In 1980, 86 loblolly pine (*Pinus taeda* L.) trees that had developed for 10 to 50 yr in lower crown positions of fully stocked (basal areas 70 ft²/ac or more), uneven-aged stands before release were selected for evaluation and monitoring.

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 and assisted in timber harvesting operations.

They were selected as being representative of the observed variation in size, crown dimension, and tree vigor from the stands on the good site (SI = 90 ft at 50 yr) in Ashley County, Arkansas that were harvested to prescribed residual stocking levels as described by Baker and Shelton (1998).

Before release, each sample tree was measured for dbh, total height, crown length, crown width, and stem diameter at the base of the live crown. Increment cores taken at breast height were used to determine tree age (3 yr were added to achieve 4.5 ft of height growth) and dbh growth during the last 5 yr. Live- crown ratio (100 x crown length/total height) and crown volume (from crown width and length using the formula for a paraboloid) were calculated.

The dbh of the sample trees' competitors (all trees 3.6 in. dbh and larger that fell within a 10 BAF prism radius of the sample tree) and their distance from the sample tree were measured. A competition index was then calculated for each sample tree as the sum of the following expression for all competitors: [(dbh of competitor/dbh of sample tree)/distance from sample tree to competitor] (Daniels 1976). Competition indices were calculated for competing pines before and after release, and for competing hardwoods after release. Camera points were established and photographs were taken of each sample tree immediately after release and 5 and 10 yr later. Five, 10, and 15 yr after release, the sample trees were remeasured and the data analyzed to determine growth response.

The 12 independent variables mentioned above were evaluated as predictors of the trees' recovery rate. A correlation matrix was calculated for all independent variables and between independent variables and dbh, height, and crown volume 15 yr after release.

Some independent variables were eliminated because they were either (1) highly correlated with more easily measured variables (e.g., stem diameter at base of crown and dbh), (2) difficult to determine (e.g., tree age), or (3) not highly correlated with recovery (e.g., all competition indices). Thus, the two independent variables that had merit as predictors of potential recovery of trees were dbh and live-crown ratio at time of release. These variables are easily determined or estimated, and they varied independently of each other ($r = 0.11$; $P = 0.32$). Time after release was also included in the prediction equation so rate of recovery could be calculated.

After evaluating several candidate functions, the following equation was selected for analysis of data:

$$Y_i = \exp\ (b_0 + b_1T_i + b_2D_0 + b_3C_0) \qquad (1)$$

where Y_i is the response variable at ith yr; T_i is number of yr after release; D_0 is dbh (in.) at time of release; C_0 is live-crown ratio at time of release; and the b_i's are coefficients to be determined. Response variables were dbh, total height, and crown volume. However, Equation (1) was modified in the following manner for fitting dbh so that irrational results would not occur when $T = 0$:

$$Y_i = D_0 + T_i^{b0} \exp\ (b_1 + b_2D_0 + b_3C_0) \qquad (2)$$

Data for fitting the equations were as follows: (1) dbh at 5, 10, and 15 yr after release, (2) total height at 0, 5, 10, and 15 yr, and (3) crown volume at 0, 10, and 15 yr (crowns were not measured at 5 yr). Dbh for yr 0 was not used because predicted and observed values are equal at 0 yr in Equation (2); thus, exclusion of 0 yr data provided more realistic statistics for goodness-of-fit. Equations (1) and (2) 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 R^2 for linearregression.

Results and Discussion

Tree Characteristics at Time of Release

Average age of sample trees was 26 yr, with individual tree ages ranging from 11 to 43 yr. For data summary and presentation, we grouped the sample trees into four 10 yr age classes (Table 1) because of: (1) the wide range in ages of the **86** sample trees, and (2) the perceived importance of age on a tree's ability to respond when released.

The sample trees averaged 4.8 in. in dbh and 37 ft in height (Table 1); however, individual trees ranged from 1.6 to 9.7 in. in dbh and 15 to 68 ft in height. Crown volumes of individual trees ranged from 3 1 to 2,800 ft' and averaged 608 ft^3, while live-crown ratios ranged from 17 to 80% and averaged 42%. On the average, the trees had grown only 0.5 in. in dbh during the 5 yr (0.1 in./yr) before release.

Tree Development

Nine of the 86 trees (10%) died within 5 yr of release, primarily a result of logging damage that occurred at release (Table 1). Five of the dead trees were in the 21 to 30 yr age class and four were in the 3 1 to 40 yr age class. Surviving trees averaged only 4 ft in height growth during the first 5 yr after release (0.8 ft/yr); however, they averaged 2.4 in. dbh growth (0.5 in./yr). Photographs taken at release and 5 yr later illustrate that the trees expanded their crowns significantly during this 5 yr period (Figures 1 and 2). However, major crown expansion was lateral rather than vertical. The rapid increase in dbh growth was apparently required to support the expanding crowns.

During the 15 yr after release, most of the trees made remarkable recovery and growth (Tables 1 and 2). On average, tree heights increased 21 ft or 1.4 ft/yr and diameters increased 8. 1 in. or 0.54 in./yr (Table 2). Diameter growth responded faster to release than height growth, and response was sustained over a longer period of time. For example, the dbh growth averaged 0.50, 0.52, and 0.60 in./yr for the first, second, and third 5 yr periods after release, respectively, with no significant differences occurring between the means ($P = 0.$ IO; mean square error = 0.036). In contrast, mean annual height growth of sample trees was 0.8, 2.0, and 1.6 ft for the three 5 yr periods after release; these means were significantly different (P = 0.001; mean square error = 0.62).

Tree crowns expanded rapidly following release. Fifteen years after release, average crown lengths increased 11 ft

Table l. Average characteristics, by age class, of intermediate and suppressed loblolly pines following release.

Age class	No. of trees	Mortality %	Ht. (ft)	Dbh	Dbh growth last 5 yr	Crown Length	Crown Width	Crown Volume (ft³)	Live crown (%)
					(in.)	.... (ft) ·			
Immediately after release									
1 l-20	26		29	3.7	0.6	15	8	520	50
21-30	34		40	5.2	0.4	16	9	687	40
3140	23		43	5.6	0.4	17	9	638	41
41-50	3		43	5.2	0.2	12	7	259	28
Weighted mean	—		37	4.8	0.5	16	9	608	42
5 yr after release									
11-20	26	0	35	6.3	2.6	[1]			
21-30	29	15	43	7.7	2.4		—		
31-40	19	17	47	8.2	2.6				
41-50	3	0	46	7.1	1.9	—	—	—	
Weighted mean	—	10	41	7.3	2.5			—	
IO yr after release									
1 I-20	26	0	46	9.0	2.7	24	16	2,920	51
21-30	29	0	52	10.4	2.7	28	17	3,650	54
31-40	19	0	55	11.0	2.8	29	16	3,320	52
41-50	3	0	53	9.3	2.2	25	13	1,560	48
Weighted mean	—	0	51	9.9	2.7	26	16	3,240	51
15 yr after release									
11-20	25	4	55	11.7	2.7	25	24	6,010	46
21-30	29	0	59	13.3	2.9	27	25	7,100	47
31-40	18	5	62	13.8	2.8	28	25	7,220	45
41-50	3	0	62	12.5	3.2	32	21	5,400	51
Weighted mean	—	3	59	12.9	2.8	27	25	6,700	46

[1] Crown dimensions not measured 5 yr after release.

Figure 1. Tree 7: Left: 23-yr-old loblolly pine, 3.5 in. in dbh and 31 ft in height at time of release; Right: 6.2 in. in dbh and 36ft in height 5 yr later. Note crown development and expansion. The tree was 9.1 in. in dbh and 47 ft in height 10 yr after release, and 13.1 in. in dbh and 58 ft in height 15 yr after release. In the photo taken from the same camera point 10 yr after study installation, the subject tree was obscured by dense understory vegetation.

Figure 2. Tree 23: Left: 30-yr-old loblolly pine, 3.5 in. in dbh., and 27 ft in height at time of release; Right: 7.0 in. in dbh and 32ft in height 5 yr later. Note crown development and expansion. The tree was 11.3 in. in dbh and 44 ft in height 10 yr after release, and 15.6 in. in dbh and 56ft in height 15 yr after release. In the photo taken from the same camera point 10 yr after study installation, the subject tree was obscured by dense understory vegetation.

(from 16 to 27 ft); crown widths almost tripled from 9 ft to 25 ft; and crown volumes increased 11 fold, from 608 ft^3 to 6,700 ft^3 (Tables 1 and 2). Live-crown ratios increased from 42 to 51% during the first 10 yr after release, but then declined to 46% 5 yr later (Table 1).

Prediction Models

Regression coefficients and associated statistics for predicting development of intermediate and suppressed trees from initial dbh, initial live-crown ratio, and years after release are given in Table 3. All of the variables measured for

Table 2. Periodic growth in dbh, height, and crown volume, by age class, for intermediate and suppressed loblolly pine trees during 15 yr after release.

	Dbh growth			Height growth			Crown volume growth	
Age class (yr)	0–5 yr	5–10 yr	10–15 yr	0–5 yr	5–10 yr	10–15 yr	0–10 yr	10–15 yr
	(in.)			(ft)			(ft^3)	
11-20	2.6	2.7	2.1	6	11	9	2,400	3,090
21-30	2.4	2.7	2.9	3	9	7	2,960	3,450
31–40	2.6	2.8	2.8	4	8	7	2,680	3,900
41-50	1.9	2.2	3.2	3	7	9	1,300	3,920
Weighted mean	2.5	2.1	2.8	4	10	8	2,630	3,460

Table 3. Regression coefficients and associated statistics for predicting development of intermediate and suppressed loblolly pine trees from years after release and initial dbh and live-crown ratio.

Property	Regression coefficient b_0	b_1	b_2	b_3	Root mean square error	Fit index
Dbh[1]	1.049	−1.45900	0.05790	0.009439	1.52	0.84
Total height[2]	3.156	0.02980	0.09263	ns[3]	7.17	0.14
Crown volume[2]	-1.293	0.13290	0.15720	0.008979	1.84	0.72

[1] The equation is:

$$D_i = D_0 + T_i^{b0} \exp(b_1 + b_2 D_0 + b_3 C_0)$$

where D_i is dbh (in.) at i yr after release, T_i is yr after release, D_0 is dbh (in.) at time of release, and C_0 is live-crown ratio at time of release. Number of observations = 227.

[2] The equation is:

$$Y_i = \exp(b_0 + b_1 T_i + b_2 D_0 + b_3 C_0)$$

where Y_i is total height (ft) or crown volume (1,000 ft^3) at i yr after release, and the other symbols are as previously defined. Number of observations = 304 for total height and 227 for crown volume.

[3] Regression coefficient was not significantly (ns) different from zero at a probability level of 0.05.

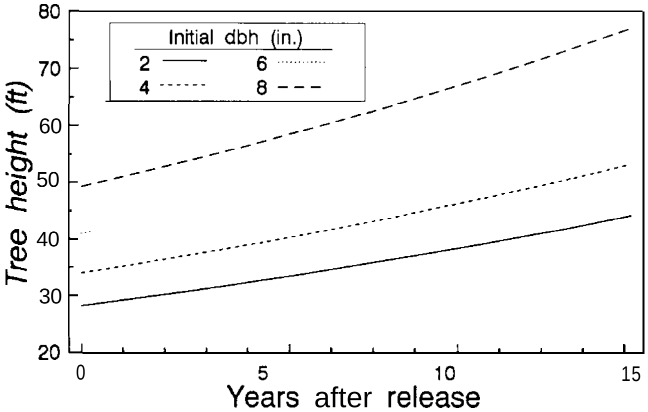

Figure 3. Changes in height of intermediate and suppressed loblolly pine trees on a good site (SI_{Lob} = 90 ft at 50 yr) as predicted from tree dbh at time of release.

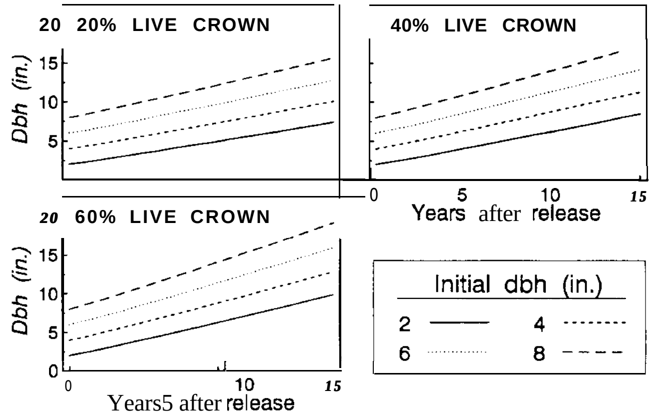

Figure 4. Changes in dbh of intermediate and suppressed loblolly pine trees on a good site (SI_{Lob} = 90 ft at 50 yr) as predicted from dbh and live-crown ratio at time of release.

sample trees were evaluated for their potential as predictors of the trees' recovery rate, but some were eliminated for various reasons. For example, stem diameter at base of crown was eliminated because it was highly correlated (r = 0.91; P = 0.0001) with the more easily measurable variable dbh. All competition indices were eliminated because they were not highly correlated with recovery (r ranged from -0.17 to 0.09 with respective P of 0.14 and 0.46).

Tree age was not found to substantially contribute to the relationships for total height and crown volume. The coefficient for tree age was significant for the relationship for dbh, but age explained less variation than other predictor variables. Thus, tree age was not included in the prediction models because it is difficult and time-consuming to determine. In addition, age was significantly correlated with other more easily determined tree parameters. For example, the correlation coefficient between tree age and dbh, total height, and live-crown ratio was +0.43, +0.51, and -0.45, respectively (P = 0.0001 in each case). Thus, older trees tended to be larger than younger trees but had smaller live-crown ratios.

Solution of equations given in Table 3, in terms of predicted tree heights. diameters, and crown volumes, are presented in Figures 3, 4, and 5, respectively. Annual height growth of an 8 in. tree was predicted to be 2.0 ft from 5 to 15 yr after release, and its predicted height increased from 57 to 77 ft over this IO yr period (Figure 3). For comparative purposes, we calculated expected height growth of dominant trees from site index equations developed by Farrar (1973). On good sites (SI = 90), loblolly pine trees ranging from 57 to 77 ft in height should have an annual height growth of 1.6 ft according to Farrar's equation. The released trees of this study appear to be growing slightly faster in height than the trees selected for site index determination, which by definition have had no periods of suppressed growth. Thus, no reduction in potential height of the intermediate or suppressed trees is expected.

Conclusions

Rehabilitation of understocked pine stands may be an alternative to site preparation and planting. However, successful rehabilitation often depends on growth of residual intermediate and suppressed trees within the existing stand. Foresters must be aware of the growth potential of such trees that develop in uneven-aged stands. Loblolly pine's ability to recover from suppression when released is a desirable characteristic for uneven-aged silviculture.

Results of this study can be used to more accurately access the rehabilitation potential of understocked, uneven-aged stands. Satisfactory response of intermediate and suppressed trees to release was best predicted by dbh and live-crown ratio at time of release. Tree age had relatively little effect on recovery rates for the range of ages (11 to 43 yr) observed in this study. Heights and diameters of released trees increased at a mean annual rate of 1.4 ft and 0.52 in., respectively, during the first 15 yr after release.

Results indicate that intermediate and suppressed trees that have at least a 20% live-crown ratio and good apical dominance, should satisfactorily respond to release. Even though these trees often develop in lower crown positions of fully stocked, uneven-aged stands for up to 40 yr, they should expand their crowns, initiate rapid height and diameter growth, and produce high-quality sawtimber.

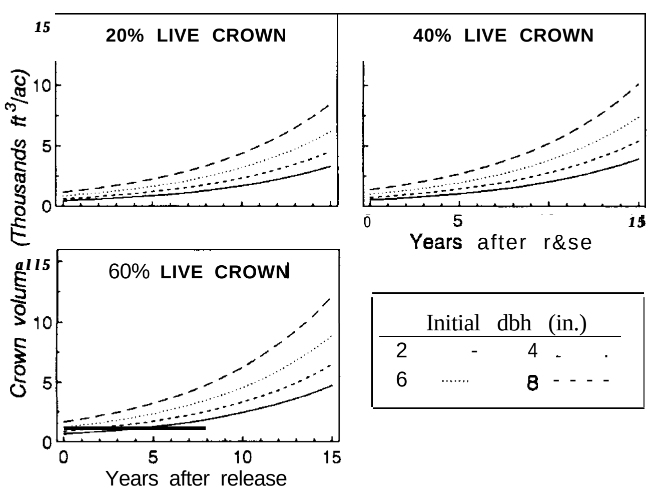

Figure 5. Changes in crown volume of intermediate and suppressed loblolly pine trees on a good site (SI_{Lob} = 90 ft at 50 yr) as predicted from dbh and live-crown ratio at time of release.

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