Rehabilitation of Understocked Loblolly-Shortleaf Pine Stands— I. Recently Cutover Natural Stands

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

ABSTRACT. *Two loblolly-shortleafpine* (Pinus taeda L.-P. echinata *Mill.) stands were cut to stocking levels of 10, 20, 30, 40, and 50% to simulate recently cutover, understocked, uneven-aged stands. Number of trees rangedfrom 38peracrefor 10% stocking to 213 per acre for 50% stocking; comparable total basal areas were 4 and 16 ft²/ac, respectively. One stand was on a good site (site index = 90 ft at age 50), the other on a medium site (site index = 75 ft at age 50). As a rehabilitation treatment, all hardwoods 1 in. groundline diameter and larger were injected with a herbicide. At 2, 5, 10, and 15 yr after treatment, the stands were inventoried to determine: (1) rate at which the understocked stands recovered, and (2) minimum stocking levels requiredfor successful rehabilitation.*

During 15 yr of rehabilitation, the understocked stands changed dramatically, and because of rapidgrowth of residualpines, stocking levels, basal areas, and tree volumes increasedmarkedly. Stands having at least 20% residual stocking and 5 ft²/ac of pine basal area reachedan acceptable stocking level of 60% (based on number and size of trees), or 45 ft²/ac of basal area within 15 yr. Stands at this minimum stocking thresholdproduced 4,600 bd ft(Doyle)/ac of sawtimber volume on the good site and 3,000 bd ft/ac of sawtimber volume on the medium site during the 15 yrperiod.

The study indicates that recently cutover, or damaged, understocked stands with at least 20% to 30% stocking or 5 to 10 ft²/ac of pine basal area can be rehabilitated to produce respectable sawtimber volumes. This management strategy provides a low-cost alternative to establishing a new stand at considerable cost to the landowner. South. J. Appl. For. 22(1):35–40.

A 1988 USDA Forest Service report indicated that 22% (40 million ac) of the commercial timberland in the South was understocked (less than 60% stocking) with desirable tree species for timber production (USDA Forest Service 1988). The understocked stands are usually the result of past harvesting practices, natural catastrophes, or regeneration failures. Understocked conditions can occur in three stand types: (1) recently cutover or damaged stands, (2) stands cutover or damaged some years ago, but left unmanaged, and (3) seedling or sapling stands following a regeneration failure or damage.

A forester encountering an understocked stand must decide whether to manage the existing stand, with a possible sacrifice in production, or to prepare the site and regenerate the area to obtain better stocking, at an additional cost to the landowner. Before a prudent decision can be made, the forester must have answers to the following questions: (1) How long will it take the understocked stand to approach an acceptable 60% stocking level? (2) What is the threshold of stocking that is feasible to manage? During the early to mid-1980s, a series of studies was established in southern Arkansas and northern Louisiana to help answer these questions for several understocked stand conditions. Results of these studies are given in a series of papers, beginning with this one. The study described here was conducted in recently cutover, uneven-aged loblolly-shortleaf pine (*Pinus taeda* L.-P. *echinata* Mill.) stands on two sites. Recovery and development of the stands are reported for a 15 yr rehabilitation period. An earlier paper reported 5 yr results (Baker 1989).

Methods

During the fall of 1979, three replications (blocks) of five 1 ac treatment plots were installed in loblolly-shortleaf pine stands on two sites in southern Arkansas. Three blocks were on good sites [site index (SI) = 90 ft at age 50 for loblolly pine]

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 and the Arkansas Forestry Commission, both of which provided the study sites and assisted in timber harvesting operations, 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 or process. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

in Ashley County; the other three blocks were on medium sites (SI = 75 ft at age 50 for loblolly pine) in Nevada County. Soils at the Ashley County site were Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loams. Soils at the Nevada County site were Alaga (Typic Quartzipsamment) and Norfolk (Typic Paleudult) loamy sands.

Stands on both sites were uneven-aged in character having pines ranging from saplings to sawtimber-a reflection of past uneven-aged management. The understory also contained numerous mixed upland hardwoods, most of which ranged from 2 to 12 ft tall. About 90% of the pines in the stands were loblolly pine and 10% were shortleaf pine.

Treatments (initial stocking levels) were assigned to plots according to a randomized, complete block design. Blocking was based on study plot location and/or changes in soil series. Initial stocking levels were 10, 20, 30, 40, and 50%, based on the following stocking equation:

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

where N = number of pines/ac at least 1 ft in height and D = dbh (in.) of pines at least 4.5 ft in height.

Equation (1) was derived by fitting Forest Inventory and Analysis (FIA) stocking guides (USDA Forest Service 1972) to Chisman and Schumacher's (1940) tree-area ratio equation. Thus, the stocking equation provides a measure of stocking based on number of stems per acre and basal area of stems more than 4.5 ft tall. In uneven-aged stands, where trees of all sizes are generally present, an expression of stocking must be able to include the contribution of all trees (saplings through sawtimber). This stocking equation has this attribute.

Table 1 provides the solution of Equation (1) for seedlings, saplings, and merchantable trees by 1 in. dbh classes giving their contribution toward stocking. Each seedling contributes 0.167% stocking/ac, while each tree in the 20 in. diameter class contributes 1.983% stocking/ac, for example.

Table 1. Contribution to stocking for seedlings, saplings, and merchantable trees by 1 in. dbh classes as determined by a stocking equation.'

Diameter class (in.)	Stocking/ac %	Diameter class (in.)	Stockinglac %
Seedling[2]	0.167	13	0.953
1	0.175	14	1.074
2	0.192	15	1.204
3	0.218	16	1.342
4	0.252	17	1.492
5	0.295	18	1.646
6	0.347	19	1.810
7	0.408	20	1.983
8	0.477	21	2.165
9	0.555	22	2.356
10	0.641	23	2.555
11	0.736	24	2.763
12	0.840	25	2.980

[1] The stocking equation is:
% stocking = $0.16667(N) + 0.00404(\Sigma D) + 0.00434(\Sigma D^2)$
[2] Less than 0.6 in. dbh.

In October 1979, the pine stands were cut to prescribed stocking levels. All pines more than 12 in. dbh were cut; then an appropriate number of trees, across all diameter classes, were cut to provide prescribed residual stocking levels and to maintain the current stand structure. The dbh of residual trees on each plot was measured, and each tree was marked with a numbered metal tag for future identification and measurement. Stocking level and basal area were calculated from the initial measurements of residual trees. Sawtimber volumes were determined from a local volume table (Farrar et al. 1984). In May 1980, hardwoods 1 in. dbh and larger were injected with Tordon® 101. At 2, 5, 10, and 15 yr after harvest, all marked pines on the plots were remeasured, and stocking level, total basal area (trees at least 0.6 in. dbh), and sawtimber volumes were calculated. No new pine seedlings or saplings that became established on the plots after the harvest were measured; thus growth and rehabilitation was attributed only to pines existing in the residual stand. This resulted in conservative estimates of reported recovery rates and assumed that there was either inadequate seed production or unfavorable conditions for seedling establishment.

After evaluating several candidate functions, the following equations were selected for regression analysis of data:

$$Y = b_0 + b_1 S + b_2 T + b_3 S*T \quad (2)$$

$$Y = \exp\,(b_0 + b_1 S + b_2 T + b_3 S*T) \quad (3)$$

where Y is the response variable; S is the percent stocking after harvesting in 1980; T is the number of years after harvesting; and the b_i's are coefficients to be determined.

Response variables were stocking, basal area, and sawtimber volume at 2, 5, 10, and 15 yr after harvesting. Equation (2) was fitted by linear least squares regression using the SAS procedure REG (SAS Institute 1989). Equation (3) was fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). The best equation form for each response variable was based on an examination of the residual plot, initially, and then on the lowest root mean square error (RMSE). Equation (2) generally provided best results for stocking and basal area, while Equation (3) was generally superior for sawtimber volume. Variables were eliminated from the full model if their coefficient did not significantly differ from zero at a probability level of 0.05 or less. Equations (2) and (3) were also fitted by substituting residual basal area (B) for stocking.

Results and Discussion

Initial Stand Conditions

Characteristics of the stands immediately after cutting to prescribed stocking levels of 10 to 50% are given in Table 2. Total number of pines ranged from 38 trees/ac on plots with 10% stocking to 213 trees/ac on plots with 50% stocking. However, number of merchantable-size pines (dbh 3.6 in. and larger) ranged from only 11 to 53 trees/ac. Comparable

Table 2. Characteristics of loblolly-shortleaf pine stands following cutting to prescribed stocking levels.[1]

Stocking level (%)	Density by dbh class (in.) <1	1-3	4-9	≥10	Total	Basal area (ft^2/ac)	Volume: Pulpwood [2] (cd/ac)	Sawtimber (Doyle) (bd ft/ac)
	(trees/ac)							
10	9	18	8	3	38	4	0.6	161
20	18	41	17	5	81	7	1.1	201
30	29	51	34	6	120	11	1.8	238
40	38	92	34	7	171	12	1.9	293
50	38	122	47	6	213	16	2.5	238

[1] Values are the average of the six plots from both stands.
[2] Pulpwood volume includes trees 3.6-9.5 in. dbh plus topwood of trees 9.6 in. dbh and larger. One cord is equivalent to 80 ft^3.

total pine basal areas ranged from 4 to 16 ft^2/ac, with merchantable-size trees accounting for 90% of the total.

Immediately after logging, the stands also contained approximately 1,100 hardwood stems/ac that were 1 in. dbh or larger. The most prevalent species were red maple (*Acer rubrum* L.) and dogwood (*Cornus florida* L.), but other species included post, southern red, white, water, and willow oaks *(Quercus stellata* Wangenh., Q. *falcata* Michx., Q. *alba* L., Q. *nigra* L., and Q. *phellos* L.), blackgum *(Nyssa sylvatica* Marsh.), sweetgum *(Liquidambar styraciflua* L.), persimmon *(Diospyros virginiana* L.), and hickories (*Carya* spp.).

Stand Development

During the 15 yr following logging and hardwood control, the understocked stands changed dramatically. Because of the rapid growth of pines left in the residual stand (Baker and Shelton 1998), stocking levels, basal areas, and volumes increased markedly (Table 3). As would be expected, stand rehabilitation was generally faster on the good site than the medium site and on plots with higher initial stocking.

Stocking.-During the first 15 yr of rehabilitation, stocking levels increased about 9 percentage points more in stands on the good site than in stands on the medium site (Table 3). A stocking level of 60% is considered as the lower limit for acceptable stocking (USDA Forest Service 1972). Plots with initial stocking of 30% or greater were approaching the acceptable level within 10 yr after logging, while plots having 20% initial stocking had not quite achieved 60% stocking after 15 yr. Plots with 10% initial stocking were still severely understocked (averaging 24% to 33% stocking) after 15 yr.

Basal area.-The understocked stands also showed dramatic increases in basal area during the 15 yr rehabilitation period, increasing 7 to 8 fold on the good site and 4 to 6 fold on the medium site (Table 3). The lower limit for acceptable basal area in managed, uneven-aged stands is considered to be 45 ft^2/ac (Baker et al. 1996). On the good site, basal area growth for stands that were initially 30% to 50% stocked averaged 4.5 ft^2/ac/yr and had achieved acceptable levels within 10 yr after logging. Comparable growth for stands with 30% to 50% stocking on the medium site was 3.2 ft^2/ac/yr, and acceptable levels were achieved between 10 and 15 yr after logging. On both sites, stands with 20% initial stocking reached acceptable basal areas within 15 yr. For stands with at least 30% stocking or at least 5 ft^2/ac of basal area, basal areas doubled every 5 yr for the first 10 yr of rehabilitation.

Volume.-Even though the understocked stands only had about 200 bd ft(Doyle)/ac of sawtimber volume at the beginning of the study, respectable volumes were achieved after 15 yr of rehabilitation (Table 3). On the good site, sawtimber volumes increased to about 3,200 and 7,000 bd ft/ac for 10% and 50% stocked plots, respectively, repre-

Table 3. Growth responses of understocked loblolly-shortleaf pine stands over 15 yr (1980-1995) following cutting to prescribed stocking levels.

Stocking level (%) Initial	after 10 yr	after 15 yr	Basal area (ft^2/ac) Initial	after 10 yr	after 15 yr	Sawtimber volume (bd ft [Doyle]/ac) Initial	after 10 yr	after 15 yr
Good site (SI_{Lob} = 90 ft at 50 yr)								
IO	23	33	4	19	32	184	1,304	3,178
20	40	53	7	32	49	210	2,047	4,640
30	57	74	IO	44	65	274	2,772	5,745
40	74	92	11	53	79	263	3,027	6,247
50	92	108	13	65	92	203	3,315	7,052
Mean	57	72	9	43	63	227	2,493	5,372
Medium site (SI_{Lob} = 75 ft at 50 yr)								
10	18	24	4	14	21	138	757	1,448
20	40	51	7	31	44	192	1,529	3,054
30	52	64	12	38	53	203	1,680	3,075
40	66	81	14	45	62	323	1,840	3,106
50	81	97	18	54	73	274	2,178	3,871
Mean	51	63	11	36	51	226	1,597	2,911

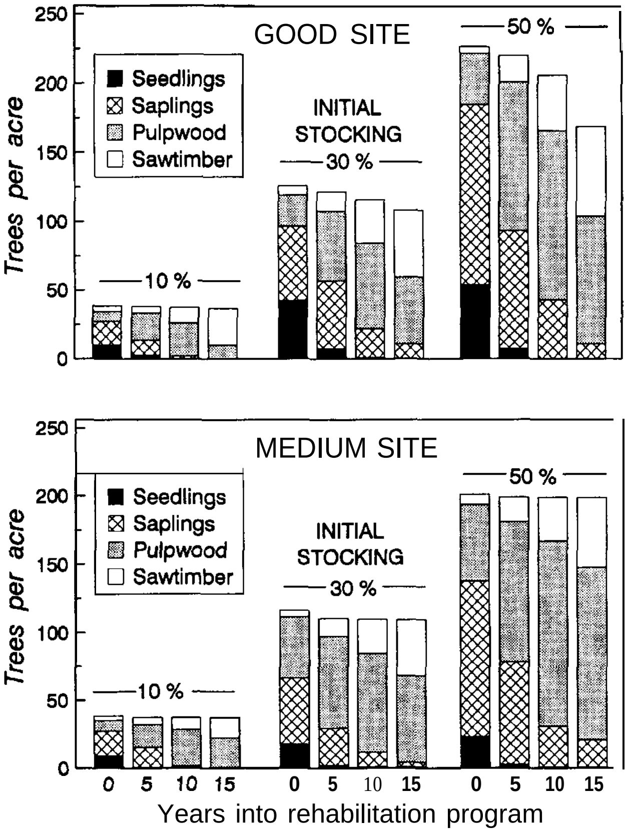

Figure 1. Progression of trees through size classes over time on good (SI_{Lob} = 90 ft at 50 yr) and medium (SI_{Lob} = 75 ft at 50 yr) sites following cutting to prescribed levels.

senting 17 to 35 fold increases. On the medium site, sawtimber volumes increased to about 1,500 and 3,900 bd ft/ac for the 10% and 50% stocked plots, respectively, representing 10 to 16 fold increases in volume.

Sawtimber volumes on the good site increased considerably more than volumes on the medium site (respective means of 5,372 vs. 2,911 bd ft/ac). A sawtimber volume of 2,500 bd ft/ac is considered to be the lower acceptable limit in managed, uneven-aged stands (Baker et al. 1996). On the good site, stands having an initial stocking of at least 10% achieved acceptable levels by the end of the 15 yr rehabilitation period. Stands on the good site with at least 30% initial stocking reached acceptable sawtimber stocking within 10 yr. On the medium site, only stands with at least 20% initial stocking reached acceptable levels within 15 yr.

Increases in sawtimber volumes were partly due to growth of residual sawtimber trees in the initial stands. However, a large portion of the volume increase was the result of ingrowth from original stems in the stand, as trees grew from smaller to larger size classes during the 15 yr management period (Figure 1). No new stems that became established after study installation were included in growth determinations. Figure 1 also shows that considerable mortality (22%) occurred on the good site for plots having an initial stocking of 50%. During the 15 yr management period, number of trees decreased from about 225 to about 175 per acre. Mortality was due primarily to suppression from neighboring pines that occurred during years 6 through 15 and to an ice storm that occurred during year 14. Mortality on all other plots was minimal, ranging from 2% to 5% over the 15 yr period.

Prediction Models

Regression coefficients and associated statistics for two sets of equations for predicting recovery rates in the understocked stands are given in Tables 4 and 5. The equations can be used to predict stand responses for a specific stocking percentage or basal area, and for a specific year of the rehabilitation period. As with any prediction equation, users should not apply these equations beyond the bounds of the data (initial stocking levels of 10 to 50%, initial basal areas of 5 to 15 ft^2/ac, and growth periods of 0 to 15 yr). Until growth equations for understocked stands are developed from regional studies, however, these may be useful for expressing trends in understocked stands. For the good site, stocking percentage (Table 4) tended to be a slightly better predictor of stand responses than basal area (Table 5), but the two predictors were about equal for the medium site.

Figures 2 and 3 present solution of the equations, in terms of predicted stocking, basal area, and sawtimber volumes at 5, 10, and 15 yr into a rehabilitation program. Each illustration shows when an understocked stand will reach a stocking level that is considered acceptable for uneven-aged stands.

Table 4. Regression coefficients and associated statistics for predicting development of understocked pine stands on good and medium sites from residual stocking percentage after harvesting.

	Regression coefficients					R^2 or
Property	b_0	b_1	b_2	b_3	RMSE	fit index
Good site (SI_{Lob} = 90 ft at 50 yr)						
Stocking[1]	-5.345	1.080	1.291	0.057	4.43	0.97
Basal area[1]	-2.929	0.237	1.329	0.086	4.06	0.97
Sawtimber[2]	5.523	0.017	0.169	ns[3]	514	0.94
Medium site (SI_{Lob} = 75 ft at 50 yr)						
Stocking[1]	-1.390	0.992	0.751	0.052	4.44	0.97
Basal area[1]	-0.669	0.324	0.908	0.062	5.45	0.92
Sawtimber[2]	5.400	0.017	0.137	ns	544	0.80

[1] The equation is: $Y = b_0 + b_1 S + b_2 T + b_3 ST$
where Y is the specified response variable [stocking (%) and basal area (ft^2/ac)], T is the time after harvest in years, S is the residual stocking in % after harvesting, and ST is the product of S and T.
[2] The equation is: $Y = \exp(b_0 + b_1 S + b_2 T + b_3 ST)$
where Y is the sawtimber volume (bd ft [Doyle]/ac) and the other symbols are as previously defined.
[3] Regression coefficient was not significantly (ns) different from zero at a probability level of 0.05.

Table5. Regression coefficients and associated statistics for predicting development of understocked pine stands on good and medium sites from residual basal area after harvesting.

Property	Regression coefficients				RMSE	R^2 *or* fit index
	b_0	*b,*	*b,*	b_3		
Good site (SI $_{Lob}$ = 90 ft at 50 yr)						
Stocking'	-15.200	4.729	3.001	ns[3]	14.90	0.71
Basal area[2]	1.903	0.079	0.102	ns	10.50	0.83
Sawtimber[2]	4.653	0.144	0.221	–0.005	433	0.96
Medium site (SI_{Lob} = 75 ft at 50 yr)						
Stocking'	1.604	2.473	ns	0.200	5.79	0.94
Basal area[1]	-1.819	0.976	0.760	0.179	5.29	0.93
Sawtimber[2]	5.334	0.051	0.137	ns	527	0.81

[1] The equation is: $Y = b_0 + b, B + b_2 T + b_3 BT$
where Yis the specified response variable [stocking (%) and basal area (ft^2/ac)], *B* is the residual basal area (in trees with 4 in. dbh or larger) after harvesting, Tis the time after harvest in years, and *BT* is the product of *B* and *T*.
[2] The equation is: $Y = \exp(b_0 + b, B + b_2 T + b_3 BT)$
where Yis the specified response variable [basal area (ft^2/ac) and sawtimber volume (bd ft [Doyle]/ac)] and the other symbols are as previously defined.
[3] Regression coefficient was not significantly (ns) different from. zero at a probability level of 0.05.

Application

To determine if an understocked stand is a candidate for rehabilitation, the stand must first be inventoried using acceptable techniques (Baker et al. 1996). Fixed-radius plots (e.g., 0.1 or 0.2 ac) or prism techniques are suitable for merchantable-size trees, while smaller plots are effective for saplings (e.g., 0.01 ac) and seedlings (e.g., 0.001 ac). It is also useful to collect information on potential quality of merchantable trees as future crop trees, and level of hardwood competition for both merchantable and submerchantable trees (Baker and Shelton 1998).

Stocking percentage can be calculated from the developed stand table and the stocking equation [Equation (1)] or the values presented in Table 1. If site and stand conditions are similar to those of this study, recovery rates can now be projected for the appropriate site quality and initial stocking level (equations in Tables 4 and 5 or trends in Figures 2 and 3). Lastly, existing stand conditions and projected recovery rates can be coupled with landowner

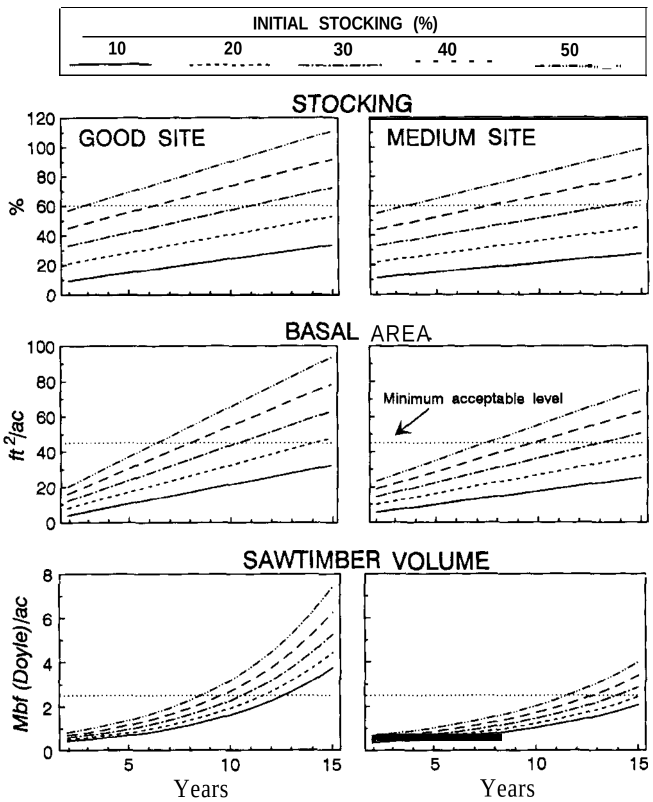

Figure 2. Changes in stocking, basal area, and sawtimbervolume on good (SI_{Lob} = 90 ft at 50 yr) and medium (SI_{Lob} = 75 ft at 50 yr) sites during 2 to 15 yr of rehabilitation, as predicted from initial stocking. The dotted, horizonal line represents the minimum acceptable level of stocking, basal area, or sawtimber volume.

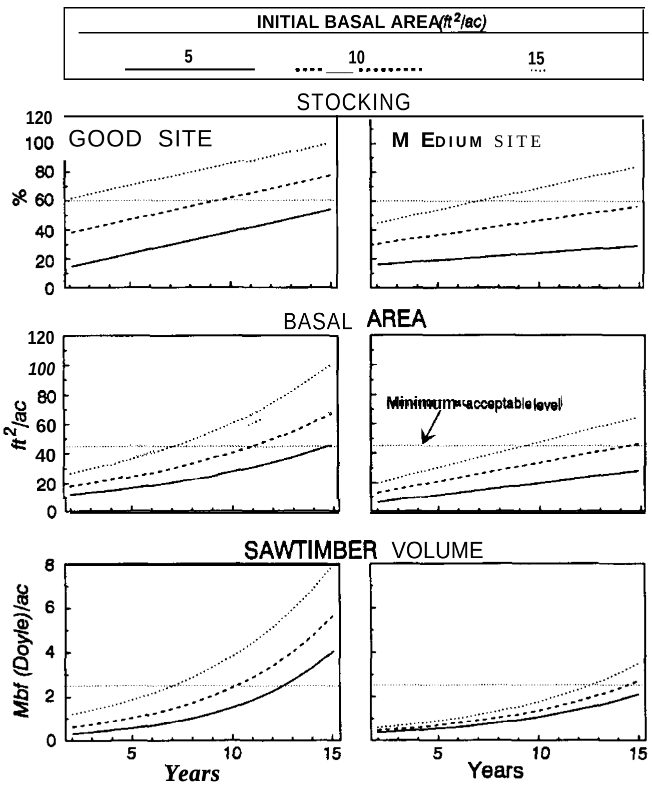

Figure 3. Changes in stocking, basal area, and sawtimbervolume on good (SI_{Lob} = 90 ft at 50 yr) and medium (SI_{Lob} = 75 ft at 50 yr) sites during 2 to 15 yr of rehabilitation, as predicted from initial basal area. The dotted, horizonal line represents the minimum acceptable level of stocking, basal area, or sawtimber volume.

characteristics (goals, capital, and expectations) and economic considerations (local timber markets and stand rehabilitation or establishment costs) to make a prudent choice between management alternatives, such as rehabilitation or liquidation of the existing stand.

Summary and Conclusions

Uneven-aged loblolly-shortleaf pine stands on good and medium sites that had been severely cut to stocking levels ranging from 10 to 50%, or 4 to 16 ft^2/ac of basal area, recovered rapidly during 15 yr of rehabilitation. Management consisted only of controlling hardwoods 1 in. dbh and larger with herbicide at time of study installation. Stand rehabilitation was faster on the good site than the medium site and on plots with higher initial stocking. During the 15 yr rehabilitation period, pine sawtimber volumes in stands with at least 20% initial stocking increased from about 200 to about 4,600 bd ft(Doyle)/ac on the good site and to about 3,000 bd ft/ac on the medium site. Stands that were initially 30% stocked had produced enough basal area (53 and 65 ft^2/ac) and sawtimber volume (3,075 and 5,745 bd ft/ac) to sustain an operable harvest of 1,200 to 1,500 bd ft/ac of good quality sawtimber in 15 yr.

The study suggests that a feasible stocking threshold for cutover, understocked, uneven-aged stands is in the range of 20 to 30% stocking, or 5 to 10 ft^2/ac of basal area. Stands with an initial stocking of at least 25%, or even lower if there is at least 5 ft^2/ac of basal area, could be rehabilitated to an acceptable stocking level of 60% in 15 yr or less. Stands with an initial stocking of 10% or less would require 20 to 30 yr before acceptable stocking was achieved.

The minimum stocking threshold suggested here is lower than the current standard of 60% for acceptable stocking in pine stands. However, stands should be evaluated on their own merit to determine if management would be feasible. If trees are uniformly distributed, of good form, and vigorous, then the stand could probably be rehabilitated and managed at a lower initial cost than starting over with a pine plantation. Rehabilitation is a management option that could be considered in lieu of site preparation and artificial regeneration on many properties throughout the South.

Literature Cited

BAKER, J.B. 1989. Recovery and development of understocked loblolly-shortleaf pine stands. South. J. Appl. For. 13:132–139.

BAKER, J.B., AND M.G. SHELTON. 1998. Rehabilitation of understocked loblolly-shortleaf pine stands-II. Development of intermediate and suppressed trees following release in natural stands. South. J. Appl. For. 22(1):41–46.

BAKER, J.B., M.D. CAIN, J.M. GULDIN, P.A. MURPHY, AND M.G. SHELTON. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. USDA For. Serv. Gen. Tech. Rep. SO- 118.65 p.

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

FARRAR, R.M., JR., P.A. MURPHY, AND R.L. WILLETT. 1984. Tables for estimating growth and yield of uneven-aged stands of loblolly-shortleaf pine on average sites in the West Gulf area. Ark. Agric. Exp. Sta. Bull. 874. Div. of Agric., Univ. of Arkansas, Fayetteville. 21 p.

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

SAS INSTITUTE. 1989. SAS/STAT user's guide. Version 6, fourth edition, volume 2. SAS Institute, Inc., Cary, NC. 956 p.

USDA FOREST SERVICE. 1972. Forest survey handbook FSH 4813.1. USDA For. Serv., Washington, DC. 254 p.

USDA FOREST SERVICE. 1988. The South's fourth forest: Alternatives for the future. USDA For. Serv., For. Resour. Rep. No. 24. 5 12 p.