Rehabilitation of Understocked Loblolly-Shortleaf Pine Stands— III. Natural Stands Cutover 15 Years Previously but Unmanaged

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ABSTRACT. *Plots in an unmanaged loblolly-shortleaf pine* (Pinus taeda *L.-P.* echinata *Mill.) stand that had been cutover 15 yrpreviously were established to representfive stocking levels: 10, 20, 30, 40, and 50%. The stand was on a good site (site* $index_{Lob}$ *= 90 ft at 50 yr) and had uneven-aged character. Two competition control treatments (none and individual tree release using herbicide) were also assigned. Three, five, and nine years later, the plots were reinventoried to determine: (1) the rate at which the understocked stands recovered, (2) the minimum stocking level requiredfor successful rehabilitation, and (3) the effects of release on pine growth.*

The pine release treatment did not enhance stand development during the 9 yr rehabilitation period, primarily because only 18% of the pines (representing 5% of total pine basal area) were overtopped by hardwoods and were thus in need of release. However, results suggest that stands having an initial stocking of 20 to 30%, or a total basal area of 10 to 15 ft^2/ac*, can reach an acceptable stocking (levels of 60% for stocking, 45* ft^2/ac *for basal area, and 2,500 bd ft(Doyle)/ac for sawlog volume) within 1.5 yr or less. South. J. Appl. For. 22(1):47–52.*

Many acres of commercial timberland in the South are understocked (less than 60% stocking) with desirable species because of opportunistic harvesting practices, natural catastrophes, or general lack of management (USDA Forest Service 1988). Sometimes, understocked stands are the result of the *recent* removal of much of the merchantable pine component. Techniques for rehabilitating and managing *recently* cutover stands have been previously discussed by Baker and Shelton (1998). Often, however, understocked stands are the result of harvest operations that occurred 10 to 15 yr previously with failure to regenerate or manage the residual stand. This type of understocked stand condition may be more difficult to rehabilitate because of the advanced development of hardwoods on the site when pines are the preferred crop trees.

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This study was installed in a cutover, understocked, uneven-aged loblolly-shortleaf pine (*Pinus taeda* L.-P. *echinata* Mill.) stand to determine (1) the rate at which the understocked stands, that were cutover 10 to 15 yr previously, recovered, (2) the minimum stocking level required for successful rehabilitation, and (3) if the release of pines from overtopping hardwoods would enhance pine growth. A stand would be considered adequately stocked orrehabilitated when itreached 45 ft^2/ac of basal area, or 2,500 bd ft(Doyle)/ac of sawtimber volume (Baker et al. 1996), or 60% stocking (USDA Forest Service 1972).

Methods

The study was installed in an understocked loblolly-shortleaf pine stand that was cut to a 12 in. diameter limit 15 yr previously and had not been managed (including hardwood control) since the harvest cut. The stand was located in Morehouse Parish in northeastern Louisiana. Soil on the study area was Bude silt loam (Glossaquic Fragiudalf) having a site index (SI) of 90 ft at 50 yr for loblolly pine. At study installation, the stand exhibited uneven-aged structure in that there were pines of several size or age classes, i.e., saplings, pulpwood, and sawtimber.

Treatments included five pine stocking levels (10, 20, 30, 40, and 50%) and two levels of pine release (none and individual tree release using a proven herbicide method). Percent stocking was based on the following 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 greater than 4.5 ft in height. The equation 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 and provided a measure of stocking based on the number and the size of trees. Three replicates of each treatment required a total of 30 treatment plots. Each plot consisted of a square, 0.25 ac measurement plot surrounded by a 2 1.6 ft isolation strip, creating a treatment plot of 0.50 ac.

In December 1985, after plot boundaries had been established, all pines were inventoried and stocking levels determined for each plot. Pine stocking ranged from 10 to 120% across the 30 plots. Based on their stocking, the plots were partitioned or stratified into three levels of initial stocking (less than 30%, 30–45%, and greater than 45%). The three replicates of each treatment were then randomly assigned to the stratified plots, i.e., 10 and 20% treatments were randomly assigned to plots with the lowest initial stocking, while 30 and 40% treatments were randomly assigned to plots with medium initial stocking, etc. This enabled installation of stocking treatments with minimal harvesting or disturbance on the plots.

Using the pretreatment inventory, a proportionate number of pines across all diameter classes was cut to achieve the designated stocking for the plot. Cutting was completed in mid-June 1986 and removed an average of four pulpwood-size trees (3.6-9.5 in. dbh) and one sawtimber-size tree (9.6 in. dbh and larger) per plot. A small, rubber-tired farm tractor was used to remove cut pines from the plots.

Immediately after cutting, all hardwoods within a 4 ft wide strip extending diagonally across each measurement plot were measured for dbh (2 in. classes). Also, all residual pines on each measurement plot were permanently numbered and mapped in relation to plot center. Each pine was then measured for dbh (0.1 in.) and evaluated as to whether it was overtopped (the branches of a neighboring hardwood extended over its terminal bud) or not overtopped. On plots designated for pine release, all hardwoods that were overtopping pines (about 30 to 50 hardwood stems per acre) were treated with Tordon® 101R using a hatchet and squirt bottle. For all treated hardwoods, except sweetgum *(Liquidambar styraciflua* L.), one incision per inch of stem diameter was made, and 1 ml of herbicide was applied per incision. For hard-to-kill sweetgum, edge-to-edge incisions were used. The release treatment, which only assured that released pines received full sunlight during midday and did not necessarily free them of other competition from neighboring hardwoods, was completed in June 1986.

At 3, 5, and 9 yr after installation (1989, 1991, and 1995, respectively), all surviving numbered pines were remeasured for dbh and evaluated for overtopping by hardwoods. No new pine seedlings or saplings that became established on plots after study installation were measured, limiting remeasurements to the original group of pines. Thus, the reported recovery rates were conservative estimates and assumed that there was either inadequate seed production or unfavorable conditions for seedling establishment.

For each inventory, pine mortality, stocking, total basal area (trees with dbh of 0.6 in. and larger), and merchantable cubic ft and bd ft volumes were calculated for each plot. Pine volumes were calculated using equations of Farrar et al. (1984) for the following expressions: merchantable volume (ft^3 inside bark for trees with dbh of 3.6 in. or larger and to a 3.5 in. inside-bark top) and sawtimber volume (ft^3 inside bark and bd ft[Doyle] for trees with dbh of 9.6 in. or larger and to a 7.5 in. inside-bark top). Increases in stocking, basal area, cubic ft and bd ft volumes were also calculated. Analysis of variance of increases in stocking, basal area, and volume by treatments were conducted for a completely random design.

Plotting the data showed that response variables for each inventory were linearly related to initial stocking percentage and basal area. However, considerable plot-to-plot variation was observed for some response variables, which largely reflected differences in the initial diameter-class distribution among plots. Thus, the increase of each response variable over initial levels was predicted. After evaluating several candidate functions, the following equation was selected for data analysis:

$$Y_t = Y_0 + T^{b_1}(b_2 + b_3 X_0 + b_4 R) \quad (2)$$

where Y_t is the response variable at t yr; Y_0 is the initial level of the response variable; T is number of years after treatment application in 1986; X_0 is either stocking percentage or basal area in 1986; R is an indicator variable for the 1986 release treatment (0 for no release and 1 for release); and b_i's [b_1, b_2, b_3, and b_4 in Equation (2)] are coefficients to be determined. Response variables were stocking, basal area, and merchantable and sawtimber volumes at 3, 5, and 9 yr after study implementation, which provided 90 observations for fitting each equation. Equation (2) was fitted by nonlinear least squares regression using the SAS procedure MODEL (SAS Institute 1988). Variables were eliminated from the full model if their coefficients did not significantly differ from zero at a probability level of 10.05. The reported fit index was analogous to the coefficient of determination for linear regression.

To determine general growth rates observed in the study, mean initial values for response variables were used in Equation (2) to calculate stand development for a stocking percentage.

Results and Discussion

Initial Stand Conditions

Characteristics of the stands immediately after they were cut to prescribed stocking levels of 10 to 50% are given in Table 1. The total number of pines ranged from 24 trees/ac on 10% stocked plots to 157 trees/ac on 50% stocked plots. However, number of merchantable-size pines (trees with dbh of 3.6 in. and larger) on these plots ranged from only 16 to 115 per acre, respectively. The wide range of tree sizes (i.e., saplings, pulpwood, and sawtimber) reflected the uneven-aged character of the stand. Pine basal areas ranged from 7 to 27 ft^2/ac, with merchantable-size trees accounting for 92% of the total. Pine pulpwood ranged from 1 .O to 4.8 cd/ac. Pine sawtimber volumes averaged 382 bd ft(Doyle)/ac across all plots, ranging from 321 to 462 bd ft/ac.

After plots were cut to prescribed stocking levels, but before the pine release treatment was imposed, the stand averaged 1,540 hardwood stems (1 in. dbh or larger) per acre and 54 ft^2/ac basal area. Eighty of the hardwoods per acre were of merchantable size (4.6 in. dbh or larger) with a basal area of 23 ft^2/ac. Merchantable-size hardwoods were primarily post, southern red, white, water, and willow oaks *(Quercus stellata* Wangenh., Q. *falcata* Michx., Q. *alba* L., Q. *nigra* L., and Q. *phellos* L., respectively), and sweetgum. The most prevalent submerchantable-size species were red maple (*Acer rubrum* L.), dogwood (*Cornus florida* L.), blackgum *(Nyssa sylvatica* Marsh.), persimmon (*Diospyros virginiana* L.), and hickories *(Carya* spp.).

Stand Development

Initial stocking significantly affected ($P < 0.01$) the 9 yr increases in stocking, basal area, and volume (Table 2). The release treatment, however, did not result in a significant ($P > 0.05$) improvement in stand growth. This was likely due to the small number, size, and proportionate basal area of pines that were overtopped by hardwoods at time of treatment. Before the 1986 release treatment was applied, only 6 to 22% (averaging about 18%) of the pines on all plots were overtopped by hardwoods (Table 3), and the overtopped trees were generally in the smaller dbh classes. For example, mean dbh of overtopped pines averaged 2.8 in., while mean dbh of trees not overtopped averaged 6.3 in. Basal area in overtopped pines averaged only 5% of the total pine basal area.

Table 2. Analysis of variance results for the 9 yr increases in specified variables for understocked loblolly-shortleaf pine stands on a good site (SI_{Lob} = 90 ft at 50 yr).

Variable and source [1]	Mean square	Probability
Stocking (%):		
Stocking (S)	8.76E2	<0.01
Release (R)	2.80E-1	0.94
S × R	7.42E1	0.22
Error	4.67E1	
Basal area (ft^2/ac):		
Stocking (S)	1.32E3	co.01
Release (R)	3.393-l	0.94
S × R	7.70E1	0.30
Error	5.8632	
Merch. vol. (ft^3/ac):		
Stocking (S)	1.25E6	<0.01
Release (R)	4.7833	0.77
S × R	5.72E4	0.40
Error	5.3434	
Sawtimber vol. [bd ft (Doyle)/ac]:		
Stocking (S)	9.49E6	<0.01
Release (R)	1.24E6	0.24
S × R	6.32E5	0.56
Error	8.3035	

[1] Degrees of freedom are: Stocking = 4, Release = 1, S×R = 4, and error = 20

Nine years later, all pines that were released in 1986 were still not overtopped by hardwoods. However, on plots that did not receive the release treatment, only 8% of the pines were still overtopped in 1995. Some of the previously overtopped pines obviously died, as indicated by the mortality data (Table 3), but many pines (particularly ones that were not overtopped by large merchantable-size hardwoods) outgrew their hardwood competitors by 1995. Of the overtopped pines on the nonreleased plots, 46% were still overtopped in 1995, while 4 1% had outgrown their hardwood competitors.

During the 9 yr observation period, mortality across all plots ranged from 0 to 13.9% and averaged 4.6% (Table 3). About 2% more pines died where they were not released than where they were released, but differences were not significant ($P > 0.05$). Of the total mortality during the 9 yr period,

Table 1. Characteristics of previously cutover, understocked loblolly-shortleaf pine stands by stocking level at time of study installation.'

Stocking level (%)	Density by dbh size class (in,) 1-3	4–9	≥10	Total	Basal area (ft^2/ac)	Volume: Pulpwood' (cd/ac)	Volume: Sawtimber (Doyle) (bd ft/ac)
	(no./ac)						
IO	...	10	6	24	7	1.0	321
20	25	31	4	60	11	1.3	410
30	44	47	6	97	16	2.2	362
40	48	70	10	128	21	3.3	462
50	42	105	IO	157	27	4.8	356
Mean	33	53	7	93	16	2.5	382

[1] Values are the average for the pine component of six plots.
[2] Pulpwood volume includes trees with dbh 3.6 to 9.5 in. plus topwood of trees with dbh of 9.6 in. and larger. A cord is equivalent to 80 ft^3.

Table 3. Percentage of released and unreleased pines that were overtopped by hardwoods or died in previously cutover, understocked natural pine stands.

Initial stocking/release	Pines overtopped by hardwoods				Mortality			
	1986[1]	1989	1991	1995	1986-1989	1989-1991	1991-1995	Total
	(%)							
10 NR[2]	22	14	6	6	0.0	0.0	5.6	5.6
10 Rel[3]	20	0	0	0	0.0	0.0	0.0	0.0
20 NR	22	17	5	7	0.0	0.0	0.0	0.0
20 Rel	16	0	0	0	0.0	0.0	2.7	2.7
30 NR	15	15	6	5	2.8	6.9	4.2	13.9
30 Rel	20	0	0	0	0.0	1.3	0.0	1.3
40 NR	21	21	13	17	0.0	2.9	2.0	4.9
40 Rel	19	0	0	0	5.5	0.0	5.5	11.0
50 NR	6	5	5	5	0.0	0.0	2.5	2.5
50 Rel	16	0	0	0	0.0	1.8	2.8	4.6
Mean NR	17	14	7	8	0.6	2.0	2.9	5.4
Mean Rel	18	0	0	0	1.1	0.6	2.2	3.9

[1] Trees classified before release.
[2] NR = Not released from overtopping hardwoods.
[3] Rel = Released from overtopping hardwoods.

less than half (about 40%) occurred in pines that were overtopped in 1986, whether they were released or not.

Since the release treatment did not have a significant effect on pine survival or subsequent increases in percent stocking, basal area, cubic ft or bd ft volume during the 9 yr rehabilitation period, data was pooled across release treatments and analyzed and reported by initial stocking levels (treatments).

Stocking.-Pine stocking percentage increased on all plots during the 9 yr rehabilitation period (Table 4). Stocking increases were the result of growth of residual trees since no new pines that became established were included in stocking determinations.

During the first 9 yr of rehabilitation, stocking percentage nearly doubled for each stocking level. A stocking level of 60% was considered the lower limit for acceptable stocking (USDA Forest Service 1972). Plots that had initial stocking levels of 30% or greater were approaching or had achieved the acceptable stocking within 9 yr (Table 4). Plots with 10 and 20% initial stocking were still severely understocked (20 to 40% stocked) after 9 yr. During this period, stocking levels increased 8 to 42 percentage points (averaging 25) across all treatments. By comparison, stocking levels increased 13 to 42 percentage points (averaging 27) over a 10 yr period in a similar study where all hardwoods with dbh larger than 1 in. were controlled (Baker and Shelton 1998).

Basal area.-The understocked stands also showed rapid increases in basal area during the 9 yr period (Table 4). A basal area of 45 ft^2/ac was considered the lower limit for acceptable stocking in managed, uneven-aged stands (Baker el al. 1996). After 9 yr, stands that were initially 30 to 50% stocked had achieved the acceptable basal area stocking. Basal areas increased 9 to 50 ft^2/ac (averaging 30 ft^2/ac) over the 9 yr period. In comparison, basal areas increased 15 to 52 ft^2/ac (averaging 34 ft^2/ac) over a 10 yr period in a similar study where all hardwoods were controlled (Baker and Shelton 1998).

Volume.-At the beginning of the study, average merchantable volumes in the understocked stands ranged from 164 to 494 ft^3/ac, and average sawtimber volumes ranged from 321 to 462 bd ft (Doyle)/ac. All stands had substantial sawtimber volumes (ranging from 1,300 to 4,600 bd ft/ac) after 9 yr (Table 4). A sawtimber volume of 2,500 bd ft/ac was considered the lower limit for acceptable stocking in managed, uneven-aged stands (Baker et al. 1996). During the 9 yr period, volumes on 10% stocked plots increased 295 ft^3 and 979 bd ft/ac, while volumes on 50% stocked plots increased 1,533 ft^3 and 4,250 bd ft/ac. This represents 2- to 3-

Table 4. Growth responses for the pine component of previously cutover, understocked loblolly-shortleaf pine stands over a 9 yr period (1986-1995).

Stocking level			Basal area			Volume: Total merchantable			Volume: Sawtimber		
Initial[1]	After 9 yr	Inc.[2]	Initial	After 9 yr	Inc.	Initial	After 9 yr	Inc.	Initial	After 9 yr	Inc.
(%)			(ft^2/ac)			(ft^3/ac)			[bd ft (Doyle)/ac]		
10	18	8	7	16	9	164	460	296	321	1,300	979
20	41	21	11	35	24	218	948	730	410	2,426	2,016
30	54	24	16	46	30	284	1,200	916	362	3,058	2,696
40	69	29	21	56	35	398	1,494	1,096	462	3,870	3,408
50	92	42	27	77	50	494	2,026	1,532	356	4,607	4,250

[1] Data were pooled for released and unreleased plots at each stocking level, thus each value is the mean of six plots
[2] Inc. = Growth increment.

fold increases in merchantable volume and 3- to 13-fold increases in sawtimber volume. In this study, sawtimber volumes increased 979 to 4,250 bd ft/ac (averaging 2,670 bd ft/ac) over the 9 yrperiod. In comparison, sawtimber volumes increased 1,120 to 3,112 bd ft/ac (averaging 2,266 bd ft/ac) over a 10 yr period in a study where all hardwoods were controlled (Baker and Shelton 1998).

Plots that had an initial stocking of 20% or more were approaching, or had reached, the acceptable level of sawtimber stocking within 9 yr. Plots with an initial stocking of 30% or more produced 3,000 bd ft/ac of sawtimber volume in only 9 yr (averaging 340 bd ft/ac/yr of sawtimber growth).

Increases in sawtimber volumes were partly due to growth of residual trees in the stands. However, a large portion of the volume increase was the result of ingrowth, as trees moved from smaller to larger size classes (Figure 1).

Prediction Models

Regression equations, with associated statistics, describing the relationships between growth and initial stocking or basal area are presented in Table 5. The fit indices ranged from 0.84 to 0.95 for all equations, indicating a good fit of the data. The release treatment was not statistically significant in all cases. The probability of the release treatment in the full model [Equation (1)] ranged from 0.20 to 0.99 for all cases except the one for sawtimber bd ft volume with initial stocking as the predictor, where the probability was 0.07.

Equations in Table 5 may be used to estimate the growth trends of the pine component of previously cutover, understocked stands with 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 stocking **levels** of 10 to 50%, initial basal areas of 4 to 35 ft^2/ac, and growth periods of 0 to 10 yr) and should recognize that data were collected from a single location. Until growth equations for understocked stands are developed from regional studies, however, these may be useful for expressing trends in understocked stands. To use the equations, the initial level of the specified response variable and the initial stocking or basal area must be determined using a

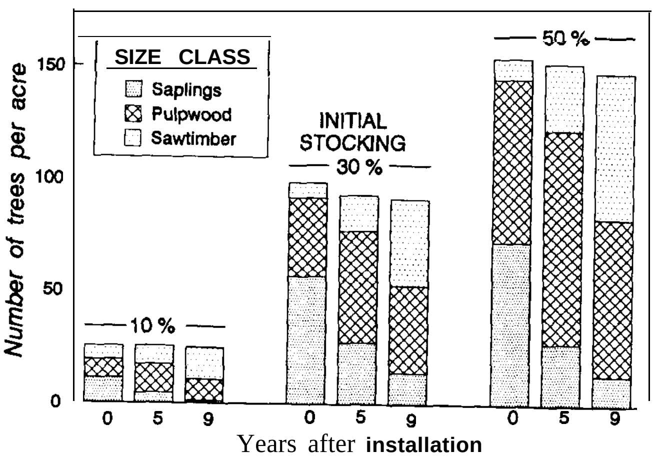

Figure 1. Progression of pines through size classes (saplings, dbh 0.6–3.5 in.; pulpwood, dbh 3.6–9.5 in.; and sawtimber, dbh 9.6 in. and larger) in previously cutover, understocked stands on a good site (SI_{Lob} = 90 ft at 50 yr). Released and no-release treatments were pooled.

Table 5. Regression equations and associated statistics for predicting development of previously cutover, understocked pine stands on a good site (SI_{Lob} = 90 ft at 50 yr) from their initial stocking percentage or basal area.

Equation [1]	RMSE [2]	Fit index
$S_t = S_0 + T^{1.215}(0.05459 S_0)$	4.8	0.95
$S_t = S_0 + T^{1.217}(0.4600 + 0.07497 B_0)$	6.4	0.92
$B_t = B_0 + T^{1.233}(0.06451 S_0)$	5.2	0.92
$B_t = B_0 + T^{1.235}(0.5209 + 0.09010 B_0)$	7.2	0.85
$MV_t = MV_0 + T^{1.318}(1.641 S_0)$	149.2	0.91
$MV_t = MV_0 + T^{1.316}(11.29 + 2.430 B_0)$	205.0	0.84
$SCF_t = SCF_0 + T^{1.885}(0.3214 S_0)$	126.4	0.86
$SCF_t = SCF_0 + T^{1.815}(0.6963 B_0)$	125.5	0.86
$DOY_t = DOY_0 + T^{1.926}(1.249 S_0)$	572.4	0.85
$DOY_t = DOY_0 + T^{1.866}(2.680 B_0)$	508.3	0.88

[1] Abbreviationsand units are as follows: S_0 is initial stocking percentage, S_t is stocking percentage at t yr, B_0 is initial basal area (ft^2/ac), B_t is basal area at t yr, MV_0 is initial merchantable volume (ft^3/ac), MV_t is merchantable volume at t yr, SCF_0 is initial sawtimber cubic-foot volume (ft^3/ac), SCF_t is sawtimber cubic-foot volume at t yr, DOY_0 is initial sawtimber bd ft volume (bd ft [Doyle]/ac), DOY_t is sawtimber bd ft volume at tyr, and T is number of years after treatment implementation (0 to 10 yr).

[2] RMSE = Root mean square error.

suitable stand inventory procedure (Baker et al. 1996). These initial values are entered into the selected equation, and then number of years in the projected time period may be varied from 1 to 10.

Selected equations in Table 5 were solved for a time period of 0 to 10 yr and for initial stocking levels of 10 to 50% (Figure 2). The equations behave in a logical manner—values increase as the stand ages and as stocking increases. The predicted values also agree well with the mean stand properties given in Table 4.

Summary and Conclusions

Loblolly-shortleaf pine stands on good sites that had been severely cut to stocking levels ranging from 10 to 50%, or 7 to 29 ft^2/ac of basal area 15 yr previously, recovered rapidly during the following 9 yr period. Rehabilitation was faster on plots with higher initial stocking than on plots with lower initial stocking.

Although these stands were poorly stocked with pines and had a substantial hardwood component, the 9 yrresults of this study indicate that release of individual pines from overtopping hardwoods did not significantly enhance stand growth. This result stresses the importance of evaluating existing stand conditions before prescribing a release treatment. Even though these poorly stocked pine stands averaged 80 merchantable-size hardwoods/ac, less than 20% ofthepines were overtopped by hardwoods at the beginning of the study and most were in the smaller dbh classes. Thus, release of only 20% of the pines in the stand that were overtopped would not be expected to appreciably increase growth in these stands. Apparently, at these low stocking levels there is little tree-to-tree competition for limited resources, such as light and water, and the elimination of a few overtopping hardwoods provided no additional resources needed for pine growth.

During the 9 yr rehabilitation period, pine sawtimber volumes on plots that were at least 30% stocked, initially, increased 7- to 12-fold. Sawtimber volumes on plots at or

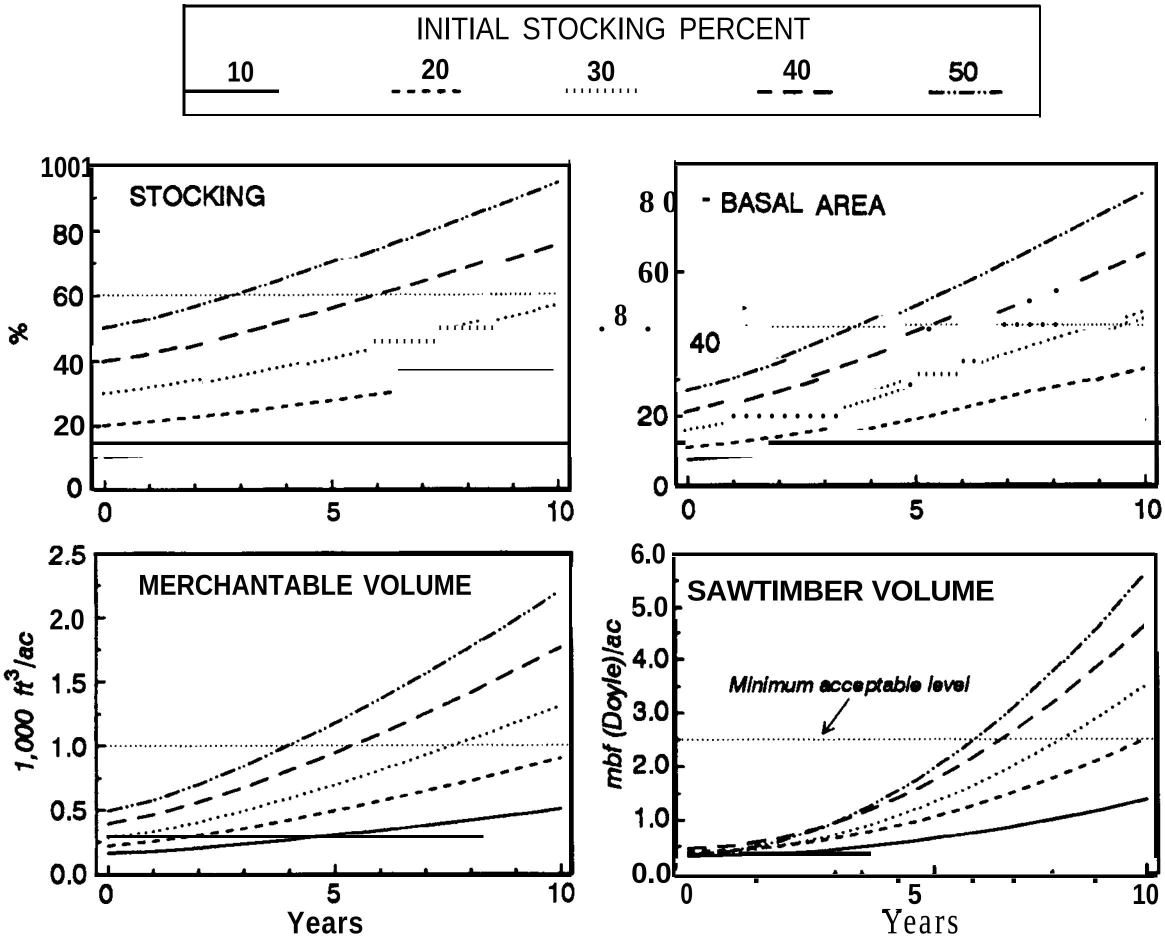

Figure 2. Predicted development of the pine component of previously cutover, understocked stands on a good site (SI_{Lob} = 90 ft at 50 yr) based on initial pine stocking. Initial values of response variables were from means in Table 4 and were projected through time using equations presented in Table 5. The dotted, horizontal line represents the minimum acceptable level of stocking, basal area, merchantable, and sawtimber volume.

above the 30% stocking level increased from an initial volume of 400 bd ft/ac to 3,450 bd ft/ac after 9 yr.

The study suggests that a feasible stocking threshold for previously cutover, understocked stands is in the range of 20 to 30% stocking or 10 to 15 ft^2/ac of pine basal area. Stands with this initial stocking could be rehabilitated (achieve an acceptable stocking level of 60%) in 15 yr or less, whereas stands with an initial stocking of 10% or less would require 20 to 30 yr before acceptable stocking was achieved.

This threshold level is considerably 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 cost than starting over with a pine plantation.

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