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Long-Term Development of Regeneration Under Longleaf Pine Seedtree and Shelterwood Stands

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ABSTRACT. *Well-stocked mature longleaf pine (Pinus palustris Mill.) stands were cut to five residual basal areas in 1957, namely 9, 18, 27, 36, and 45 ft² per ac, to observe the effect of stand density on seed production and seedling establishment. Seedlings, mainly from the 1955 or 1961 seed crops, were established in treated stands. All pines on net 0.9 ac plots were remeasured in 1991 to determine the effect of residual pine density on development of the regeneration. Even the lightest residual overstory converted the structure of 29- to 35-yr-old ingrowth into the reverse-J diameter class distribution characteristic of uneven-aged stands. Four or six residual trees, now comprising 7 to 10 ft² basal area (ba)/ac, reduced ingrowth basal area to about half that of same-aged stands released from overstory competition. Merchantable volume of ingrowth under these low residual densities averaged 40% of that in released stands. Mean annual per ac volume increment of ingrowth averaged 21 to 22 ft³ under the 9 ft² density but did not exceed 7 ft³ under any residual density above this. The potential impact of significant growth reductions should be taken into account when considering uneven-aged management methods for longleaf pine. South. J. Appl. For. 17(1):10–15.*

Longleaf pine (*Pinus palustris* Mill.) is generally considered the most intolerant of the southern pines (Baker 1949). It is notoriously intolerant of competition from any source, especially overtopping trees including parent pines. Longleaf pine regeneration in old-growth forests was largely confined to openings where it was free to develop (Wahlenberg 1946), and some seedlings could reach a fire-resistant size in a relatively short time. The early growth of seedlings under a pine canopy, if they survive, is very slow (Boyer 1975, Maple 1977), even under a light overstory. Growth rapidly declines as overstory density increases. About 70% of the growth reduction observed under an overstory of 90 ft² ba/ac was reached under 30 ft² (Boyer 1963).

The competitive influence of individual seed trees or forest walls on longleaf pine seedlings decreases with distance, but may extend 50 ft or more from the base of parent trees into an opening, well beyond the influence of the crown (Smith 1955, Walker and Davis 1956, Boyer 1963). This suggests competition for moisture and nutrients. The competition zone seems to extend farther from the parent tree on poor than on good sites.

As an early successional species, maintained through periodic fire, longleaf pine has appeared best adapted to management in even-aged stands. Alternatives to traditional even-aged management are now being promoted for this species. They include uneven-aged management, such as group selection, and also variations on even-aged management that include retention of a few or many residual trees through all or most of a second rotation, resulting in a stand comprised of two distinct age classes. Such alternatives to conventional even-aged management will maintain a relatively continuous cover of mature trees and are expected to improve and extend habitat for the red-cockaded woodpecker and other fauna and flora associated with these conditions.

The potential impact of residual trees on the development, structure, and yield of the replacement stand is not known due to the lack of information on the long-term growth response of longleaf pine regeneration retained under a parent overstory. Such information is needed in order to adequately evaluate the consequences of management systems that lead to stands consisting of two or more age classes.

An opportunity to gain some timely information on the question of stand development under residual longleaf pines was available on the Escambia Experimental Forest[1] in southwest Alabama. There, a study was begun in 1957 to determine the effect of longleaf pine stand density on seed production and seedling establishment. Longleaf pine regeneration was established shortly before or soon after parent stands were thinned to prescribed densities. Two additional studies, superimposed on parts of the original study, provided some information on development of the regeneration.

[1] Maintained by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the T. R. Miller Mill Company.

The Studies

Seed Production Study

The initial study, established in the spring of 1957, was designed to determine the effect of stand density on longleaf pine seed production and seedling establishment. Two blocks (A and B) were selected in longleaf pine stands with the highest and most uniform densities then available. Within each block, 5 square 2.5 ac plots were established, each comprised of a square 0.9 ac net plot surrounded by a l-chain isolation border. At the time of establishment, plots in Block A averaged 62 ft^2 ba/ac. Dominant pines averaged 49 yr old, with a site index (age 50) of 76 ft. Plots in Block B averaged 58 ft^2 ba/ac, the dominant pines 55 yr, and site index 70 ft.

Residual stand densities of 9, 18, 27, 36, and 45 ft^2 ba/ac were randomly assigned among the 5 plots in each block. Net plots and isolation borders were all cut to within 0.3 ft^2 ba/ac of their prescribed densities. All residual pines were in the 9 in. diameter at breast height (dbh) class (>8.5-in. dbh) or larger. All other pines on study plots, including any height-growth seedlings, were cut, and all hardwoods injected with a herbicide.

The relatively high initial stand density, combined with periodic burning, resulted in the general absence of longleaf seedlings on the forest floor. Block A, however, had 12,600 1-yr-old seedlings/ac from a good seed crop in 1955. Block A was last burned in February 1955; Block B in December 1953.

Both seedfall and seedling establishment were monitored annually from 1957 through 1964. During this time 7,000 additional seedlings/ac were established in Block A, with 79% from the 196 1 seed crop and 9% from the 1958 seed crop. At the same time, 5,400 seedlings/ac were established in Block B, with 74% from the 196 1 seed crop and 10% from the 1958 seed crop. All plots were subsequently burned in January 1964, October 1965, and February 1968. Surviving hardwoods were injected with a herbicide in 1963.

A tornado passed through part of Block A in April of 1964, destroying about half the residual pines on the 18 ft^2 plot and nearly all on the 27 ft^2 plot. The downed timber was salvaged. Replacement plots were established in May 1964 in adjacent stands. The re Iacement for the 27 ft^2 plot had an initial density of 53 ft^4 ba/ac and was cut to a residual density of 29.9 ft^2. The replacement for the 18 ft^2 plot had an initial density of only 30 ft^2 ba/ac and was cut to a residual density of 20.2 ft^2. Residual densities for the two replacement plots approximated densities recorded on replaced plots in 1962. Residual trees were all in the 9 in. or larger dbh classes. Hardwoods on replacement plots were injected with a herbicide in September 1964.

Seedling Growth Study

This study observed the development of seedlings from the 1955 seed crop under a range of overstory densities. Small plots were established in the spring of 1957 under the 9, 27, and 45 ft^2 density classes in Block A and also within a nearby 45 ac stand where the shelterwood overstory was removed in January 1957, when seedlings were 1 yr old.

In April 1957, there were 12,600 I-yr-old longleaf seedlings/ac within plots of the seed productionstudy, and 10,600/ac where the overstory had been removed. Seedling status was recorded annually through the winter of 1966. The released area was first burned in the winter of 1960, three years after overstory removal, for control of the brown-spot needle blight. Other plots were not burned until January 1964.

Season of Burn Study

In 1970, a season of bum study was superimposed on the seed production study, utilizing all but the 9 ft^2 density plots. Each of the 8 2.5 ac plots was quartered and biennial winter, spring, summer, plus no bum treatments randomly assigned among the four 0.625 ac treatment plots. The purpose of this study was to determine the composition and structure of understory plant communities that stabilized under each of these burning regimes.

The study included repeat measurements of all woody stems in the 2 in. and larger diameter classes (>1.5 in. dbh) identified as to species. The initial measurement in the winter of 1971-1972 also included a complete count of all woody stems in the 1 in. diameter class (0.6-1.5 in. dbh). Remeasurements were made in the 1974-1975, 1977-1978, and 1981-1982 dormant seasons.

This study ended in 1982. A 3-yr winter bum schedule was resumed on Block A. Biennial burning treatments continued on Block B for demonstration purposes. The 9 ft^2 plots, excluded from this study, have been on a 3-yr winter burn schedule since 197 1.

The 1991 Remeasurement

All 0.9 ac net plots in the seed production study were remeasured in the winter of 1990–1991 to determine the present status of pine ingrowth retained under a range of pine overstory densities. The remeasurement included a total inventory of all pines and hardwoods in the 2 in. and larger dbh classes. The original 18 ft^2 plot in Block A was added, since the storm in 1964 had left 7 trees and 8.4 ft^2 ba/ac in the net plot. Merchantable pine volumes (trees >3.5 in. dbh) to a 3 in. inside bark (ib) top were obtained from dbh using a local volume table. Standing merchantable volume and also average annual net (mortality excluded) volume growth of both residual and ingrowth longleaf pine were determined for each plot. Net annual growth of residual pine was the difference between standing volume after thinning i,n 1957 (or 1964 for the two replacement plots) and standing volume recorded in 1991 divided by years between measurements. Net annual growth of ingrowth pine was standing merchantable volume in 1991 divided by years since the principal seed crop, which was 1955 in Block A and 1961 in Block B.

Longleaf pine stands completely released from the parent overstory at an early age were also sampled to compare with stand development where overstories were retained. Two 0.9 ac check plots were established within the stand where seedlings from the 1955 seedcrop were released from ashelterwood overstory at age 1, and development followed in the seedling growth study. This stand had a commercial thinning from below in 1980, at age 24, removing an average volume of 169 ft^3 per ac. Two additional 0.9 ac check plots were established within a nearby stand where seedlings from the 1955 seed crop were released from a seedtree overstory in 1960, at age 4. This stand was thinned in 1985, at age 29, removing an average volume of 124 ft^3 per ac. Thinnings were included in determination of net annual volume growth for these stands.

A study where longleaf seedlings from the 1958 seed crop were released from a seedtree overstory at age 2 provided a check for Block B. Data were obtained from twelve 0.1 ac net plots, representing biennial bums in winter, spring, summer, plus no bum, with three plots for each of the four treatments. These plots were precommercially thinned to 500 well-distributed dominant longleaf pines/ac in 1973, when trees were 14 yr old. Measurements were made in 1989, when trees were 30 yr old.

Development of Longleaf Regeneration

Longleaf pine seedlings from the 1955 seed crop were followed on three plots in Block A plus the released area through the winter of 1966. Seedling counts in January 1964 indicated an average of 7,500 surviving seedlings/ac. Stocking further declined to 5,300 seedlings/ac in January 1965, reflecting some losses to the prescribed fire in January 1964 and salvage logging on one plot following the storm in April 1964.

Seedling development through age 7 has been reported (Boyer 1963). Seedling root-collar diameter declined rapidly with increasing overstory density. At age 4, most seedlings under overstory densities of 27 ft^2 ba/ac and greater were still too small to survive a fire. At age 8, average seedling root-collar diameter under the 45 ft^2 density was only slightly over half that in the released area (Figure 1). Normally, longleaf pine seedlings do not initiate height growth until root-collar diameter reaches 1 in. By age 8.29% of the seedlings in the released area were in active height growth compared to 7% under the 9 ft^2 density. Higher stand densities had no height-growth seedlings.

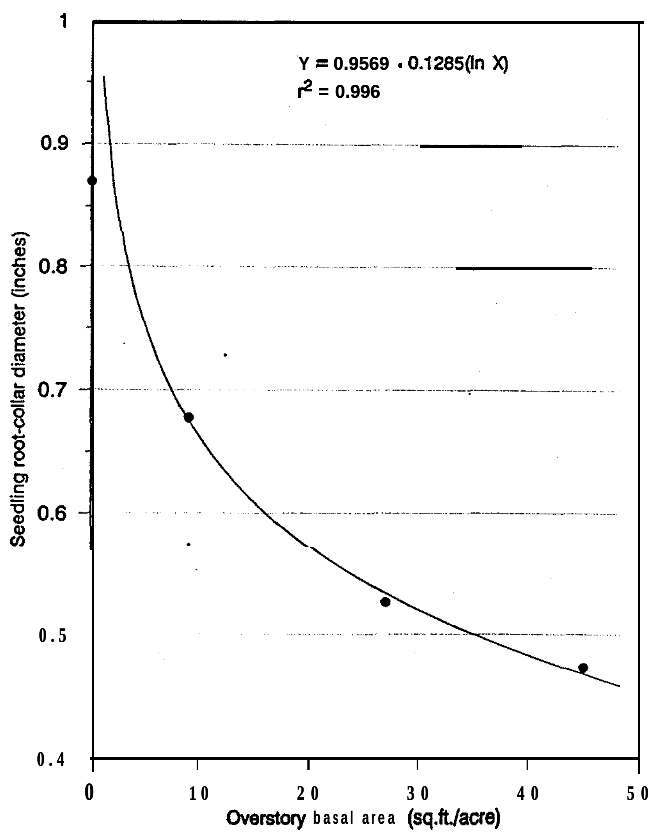

Figure 1. Longleaf pine seedling size at age 8 in relation to overstory density.

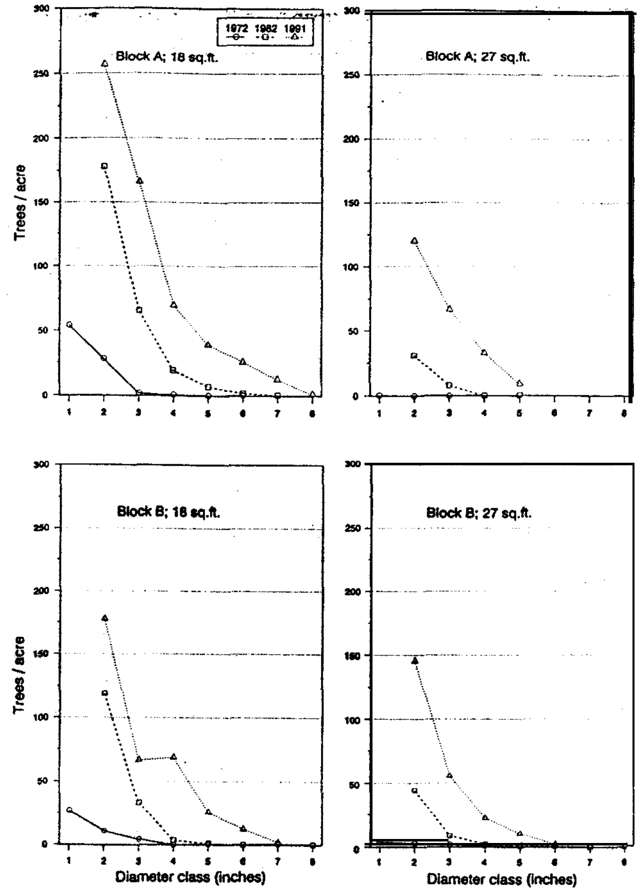

Figure 2. Development of ingrowth pines under residual densities of 18 and 27 ft^2.

Measurement of all ingrowth pines greater than 0.5 in. dbh in 1972 and all greater than 1.5 in. in 1982 and 199 1 illustrate development of the pine midstory under the 18 ft^2 and 27 ft^2 density classes, which were well stocked with ingrowth pines (Figure 2). The 1972 and 1882 measurements included entire 2.5 ac gross plots. The 199 1 measurement included only 0.9 ac net plots.

Residual Stands and Ingrowth in 1991

Stand Structure

The 199 1 remeasurement revealed the comparative development of ingrowth over the 34 yr since stands were cut to their prescribed densities. Except for periodic burning, pine ingrowth has had unrestricted development, as have hardwoods since the last herbicide treatment in 1963 or 1964. For each residual density class, including released stands, the basal area, trees per ac, and average dbh for residual pine, ingrowth pine, and ingrowth hardwood are shown in Table 1. Reasonable numbers of ingrowth pines are present in plots

Table 1. Basal area and trees per act-e and average dbh for residual and ingrowth pine and hardwood in 1991, by initial stand density and block (all trees >1.5 in. dbh).

Initial density (1957) BA	Residual pine			Ingrowth pine			Hardwood		
	BA (ft^2)	Trees (no.)	Dbh (in.)	BA (ft^2)	Trees (no.)	Dbh (in.)	BA (ft^2)	Trees (no.)	Dbh (in.)
Block A									
0*	—	—	—	82.3	353	5.9	14.6	258	2.9
9	9.1	4	19.3	46.5	364	4.2	18.1	193	3.7
18**	7.2	4	17.1	47.3	338	4.4	X.0	113	3.1
18	31.5	19	17.3	34.4	571	3.0	5.0	107	2.8
27"	36.3	23	16.8	9.9	228	2.7	7.0	157	2.7
36	53.8	32	17.4	3.3	31	3.8	7.2	149	2.7
45	63.5	43	16.8	0.9	17	2.8	1.3	28	2.7
Block B									
0*	—	—	—	95.2	467	5.9	6.4	120	3.0
9	10.4	6	18.5	46.5	507	3.5	6.2	77	3.3
18	26.0	13	18.8	19.6	353	3.0	9.3	167	2.8
27	38.8	22	17.8	9.6	236	2.6	2.7	80	2.4
36	53.0	32	17.2	2.4	47	2.8	3.5	78	2.6
45	66.8	41	17.2	0.7	19	2.5	6.4	131	2.7

* Stands released from parent overstory.
** Replacement plots, 1964.

with initial densities of 9 to 27 ft^2. Ingrowth is scarce in stands with higher initial densities.

The lowest residual density class (9 f?) has changed little over time, with overstory growth and mortality more or less in balance. Initially, there were eight residual pines per net plot in each block. By 1991, there were four surviving pines in Block A and five in Block B. After the 1964 storm, the original 18 ft^2 plot in Block A, had seven surviving trees on the net plot. By 199 1, four of these trees were still present. Mortality among residual trees over the 25 yr from 1963 to 1988 averaged 3.7 trees per net plot. Lightning was the greatest single cause of mortality.

The stand structure that has developed under the 9 ft^2 density class contrasts sharply with development in released stands (Figure 3). Although essentially a single age class, ingrowth under just a few residual trees is acquiring the reverse-J diameter class distribution characteristic of uneven-aged stands. This pattern is also exhibited by ingrowth under higher residual densities (Figure 2). After 29 to 35 yr under the lowest residual density, only 2 to 4 in. dbh now separate the largest ingrowth from the smallest residual trees. Even so, relatively few trees have reached the larger size classes by age 35. Ingrowth in Block A, for the two plots with 4 residual trees, averages 24 trees/ac in the 8 and 9 in. dbh classes, and 15 trees/ac in the 10 in. and larger dbh classes. Released stands average 85 trees/ac in the 8 and 9 in. dbh classes, and 40 trees/ac in the 10 in. and larger dbh classes.

Diameter class distribution in the released stand for Block A has two peaks, one in the 2 in. and one in the 8 in. dbh class. Despite the fact that trees in this stand are now 35 yr from seed, the largest number of stems are intermediate and suppressed trees in the 2 and 3 in. dbh classes. This distribution can be attributed to the commercial thinning that left marked dominant trees plus all stems below merchantability limits. Diameter class distribution in the released stands for Block B has a single peak at the 6 in. dbh class. The early precommercial thinning contributed to this result.

The effect of residual pines on the development of longleaf

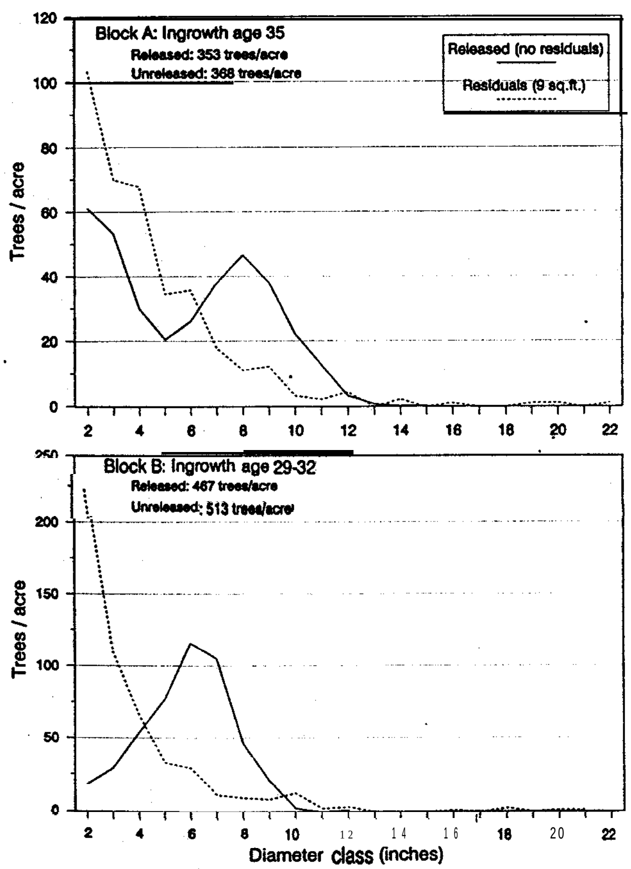

Figure 3. Diameter class distribution of pines in released compared to unreleased stands with a residual overstory of 9 ft^2

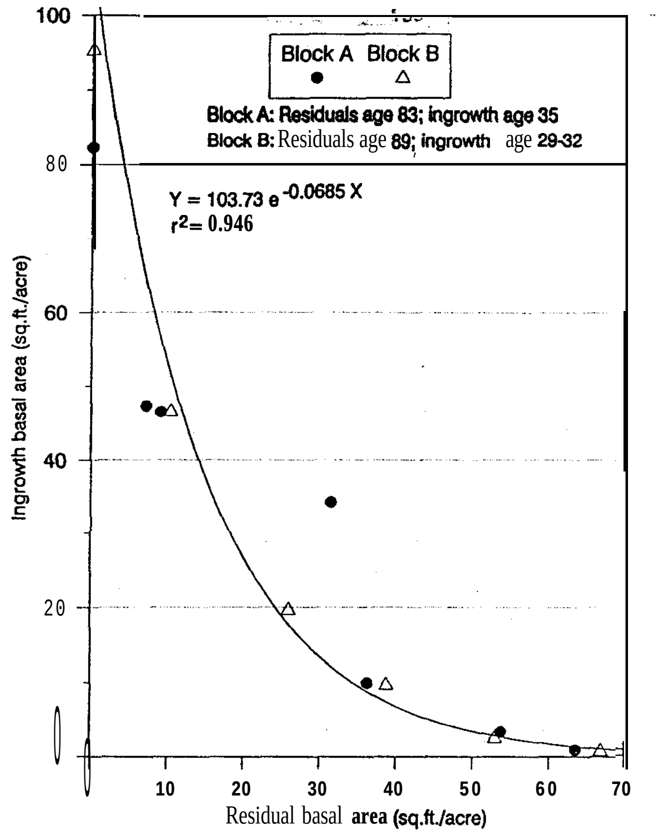

Figure 4. Density of ingrowth pine in relation to density of residuals in 1991.

pine regeneration is illustrated by the negative exponential relationship of ingrowth to residual pine basal areas (Figure 4). Even a few residual trees sharply reduced the basal areas of ingrowth stands compared to stands free from overstory competition. This is reminiscent of the impact of the parent overstory on early seedling growth (Figure 1). The replacement 18 ft^2 density plot deviates from the curve. This plot had a pre-establishment density of 30 ft^2 ba/ac, the optimum density for longleaf pine seed production. All other plots were established in stands with densities above 52 ft^2 ba/ac. As a result, this plot had the largest number of seedlings from the 1955 seed crop, with 571 ingrowth trees/ac in 1991, compared to a maximum of 364 trees/ac among all other plots in Block A.

Volume Growth

The presence of residual trees has had its greatest impact on the volume growth of the new longleaf pine stand. The status of the merchantable stand (>3.5 in. dbh), in terms of basal area and merchantable volumes, is given in Table 2. Standing volume of ingrowth under the lightest residual density in Block A (7.2 ft^2) was 46% of the standing volume in released stands, or only 42% if the average volume removed in the commercial thinning (146 ft^3/ac) is included. In Block B, ingrowth volume under the lowest residual density was 38% of that in the released stands.

The total standing merchantable volume of pine on each plot in 1991, allocated to residual and ingrowth pines, is shown in Figure 5 along with merchantable volume on associated check plots. Ingrowth volume declined precipitously with increasing density of the residual stand. At residual densities above 9 ft^2, 78 to 100% of the standing merchantable volume is in residual rather than ingrowth trees.

Net annual merchantable volume growth of released stands averaged 53.8 ft^3 per ac for Block A (including volume removed), and 56.4 ft^3 per ac for Block B (Table 3). Net annual merchantable volume growth of residual and ingrowth trees combined ranged from only 16 to 42% of the growth in released stands. For both blocks combined, growth ranged from a high of 23 ft^{23} under the 9 ft^2 density class to a low of 11 ft^3 under the 27 ft^2 density class. Annual merchantable volume increment of ingrowth pine alone did not exceed 7 ft^3 under any residual density above 9 ft^2.

Conclusions

The presence of even a few residual longleaf pine trees restricts the development of regeneration. The variable suppression imposed on a young longleaf stand by scattered residual seedtrees rapidly converts the structure of an essentially even-aged ingrowth stand into the reverse-J diameter class distribution characteristic of uneven-aged stands. The growth of such a two-aged stand should approximate that of an uneven-aged stand.

Average annual per ac merchantable volume growth of

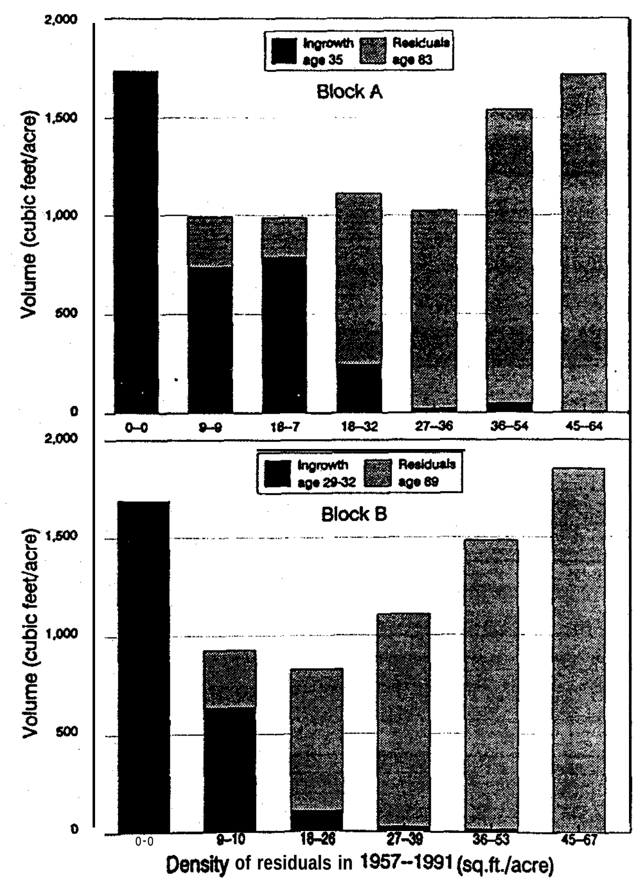

Figure 5. Standing merchantable volumes of ingrowth and residual pines on each plot in 1991.

Table 2. Basal area and merchantable volume per acre of residual and ingrowth pine in 1991, by initial stand density and block (all trees >3.5 in. dbh).

Initial density (1957) BA	Residual pine		Ingrowth pine		Total pine	
	BA (ft^2)	Volume (ft^3 ib)	BA (ft^2)	Volume (ft^3 ib)	BA (ft^2)	Volume (ft^3 ib)
			Block A			
0*	—	—	78.3	1737	78.3	1737
9	9.1	255	41.0	738	50.1	993
18	7.2	199	41.8	791	49.0	990
18**	31.5	872	20.7	244	52.2	1116
27**	36.3	1004	4.0	22	40.3	1026
36	53.8	1493	2.8	50	56.6	1543
45	63.5	1712	0.6	8	64.1	1720
			Block B			
0*	—	—	93.3	1691	93.3	1691
9	10.4	291	36.2	637	46.6	928
18	26.0	725	12.5	106	38.5	831
27	38.8	1079	3.7	28	42.5	1107
36	53.0	1467	1.1	17	54.1	1484
45	66.8	1852	0.2	1	67.0	1853

* Stands released from parent overstory.
** Replacement plots, 1964.

two-aged stands, both residuals and ingrowth combined, falls far short of that in even-aged stands. Growth of two-aged stands reached a high of 23 ft^3 per ac annually in the 9 ft^2 density class. This was only 41% of the growth recorded in released stands over the same period of time. Retention of a light (18 ft^2 ba/ac) or standard (27 ft^2 ba/ac) shelterwood overstory resulted in total stand growth averaging only 28 and 19%, respectively, of growth in released stands. Most of this growth was supplied by residual trees. The standard shelterwood appears to provide the poorest environment for stand growth with too few residuals to occupy the growing space and too many to permit development of the replacement stand.

Table 3. Annual net merchantable volume growth (ft^3 ib) per acre of residual and ingrowth longleaf pines, by initial density and block.[1]

Initial density (1957) BA	Residual pine	Ingrowth pine	All pine
		Block A	
0*	—	53.8	53.8
9	0.4	21.1	21.5
18**	13.0	7.0	20.0
27**	7.8	0.6	8.4
36	16.6	1.4	18.0
45	15.4	0.2	15.6
		Block B	
0*	—	56.4	56.4
9	1.8	22.0	23.8
18	7.1	3.7	10.8
27	11.7	1.0	12.7
36	14.7	0.6	15.3
45	21.5	0.0	21.5

[1] Beginning 1957 (** or 1964) for residual pines; with principal seed year for ingrowth.
* Stands released from parent overstory.
** Replacement plots, 1964.

Adequate longleaf pine regeneration was not retained where the initial density of overstory pine exceeded 27 ft^2 ba/ac. Suppression combined with periodic fires at 2- or 3-yr intervals in predominantly needle-litter fuels will eliminate most established seedlings. Apparently, an initial residual density of about 30 ft^2 ba/ac approaches the upper limit under which longleaf regeneration can be maintained along with surface fires frequent enough to retard hardwood encroachment.

The results reported here suggest that longleaf pine stands comprised of two or more age classes will fall far short of fully utilizing the productive capacity of the site for a long period of time. More research on competitive interactions among longleaf pines of different sizes will be needed to determine why this is so. Until further information is available, managers should be prepared to accept growth reductions exceeding 50% when a parent overstory is retained over the replacement stand.

Future remeasurements can reveal whether or not the growth performance of these two-aged stands will change as ingrowth pines mature further and continuing attrition reduces the number of residual trees.

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