

Prescribed Burning For Understory Control

*In loblolly pine stands
of the coastal plain*



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INTRODUCTION

THE UNDERSTORY PROBLEM

If one were to select the particular problem giving pine foresters the most concern, it probably is the natural replacement of pine by the more tolerant but often inferior hardwoods. This is especially true for loblolly pine (*Pinus taeda* L.), which is the principal commercial species of the southeastern United States. (12). Early invaders of the understory in the loblolly pine stands of the southeastern coastal plain are mainly light-seeded species such as sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and southern bayberry (*Myrica cerifera* L.). Later, the climax components, oaks (*Quercus* spp.) and hickories (*Carya* spp.), appear (14). In stands protected from all fires, the understory development is often rapid; where management also requires early and heavy thinning of the pine overwood, understories develop even faster. The problem becomes more acute where many large-scale harvest cuttings are made without adequate measures for regeneration of the pine. Hundreds of thousands of acres of former pine lands now converted to a cover of brush and hardwoods prove that past efforts to combat the ecological trend have been too few or too late (fig. 1).

Extensive programs to return these lands to pine are now under way in the coastal plain. The techniques used are far from simple or inexpensive.

For the most part, the inferior hardwoods and brush require removal by costly mechanical methods. In many instances, hand planting is necessary. Even when machine planting or direct seeding is possible, the total cost of conversion can only be justified by the establishment of fully stocked plantations of pine. Consequently, only minimum losses to plant competitors, insects or diseases can be tolerated—a Herculean objective, as many forest managers discover.

Because of all these troubles, there is definite need for low-cost cultural measures which will effectively arrest the trend toward hardwoods in the remaining natural stands of loblolly pine. Basic qualifications for any practical measure are: (1) In immature pine stands, the treatment must kill or weaken undesirable hardwoods and shrubs that would later prevent the establishment of pine seedlings and (2) in mature stands, it must remove heavy litter and any residual plant competitors which may interfere with natural reseeding at the time of timber harvest. Prescribed burning is a low-cost cultural measure which meets these requirements at least in the loblolly pine stands of the Carolina coastal plain (fig. 2). This is borne out by investigations carried on at the Charleston, S. C., Research Center since 1946. Results from comprehensive plot studies show that most broad-leaved species in the understory can be controlled or even eradicated by a few fires, without damage to the pine overwood or to the site itself.



Figure 1. --Although loblolly pine seed trees are present, this site was captured by the advance understory at time of harvest cutting. Understory control before cutting assures pine regeneration on sites like these.



Figure 2. --The cost of prescribed burning is low because it can be done with small crews using simple hand tools and low-cost plowed fire lines.

CONTROL BY FIRE

The use of prescribed fire in the silviculture of loblolly pine is not a new notion. H. H. Chapman strongly supported its use (1942) in loblolly pine stands west of the Mississippi River (4, 5). Chapman's work was given early recognition (1949) by L. E. Chaiken in relation to the problem of controlling inferior species in loblolly pine stands of the Carolina coastal plain (1).

More than a decade of study on the Santee and Westvaco Experimental Forests¹ has determined that, for understory hardwood control, the best results with prescribed fire are obtained in loblolly pine stands where the ground is covered with a continuous mantle of fuel consisting mainly of fallen pine needles and similar fine material. Furthermore, most of the understory stems should be under 2 inches d.b.h., as many larger stems can escape control by fire. Depending on the degree of control desired, a forest manager can use either winter or summer fires. The winter fires won't kill many of the hardwoods, as most resprout regardless of the frequency of burning. However, from a practical standpoint, winter burns can be spaced about 5 to 10 years apart and the understory thus held to small-size stems subject to further control by fire as needed. The best use of a short series of summer fires is for hardwood eradication and seedbed preparation about the time of the harvest cut.

Experienced personnel can prescribe burn small tracts for less than fifty cents per acre. Consequently, a full schedule of winter and summer fires for hardwood control and seedbed preparation would cost about \$5.00 per acre over a sawtimber rotation.

Furthermore, there is little to fear regarding possible damage from well planned and executed prescribed fires in coastal plain loblolly pine stands above sapling size. Damage to the pine stand from an intense summer burn is avoided by fuel reduction obtained from prior winter burns. Intensive plot studies show that prescribed burning causes no significant difference in the radial growth of dominant pine in any season, even after 10 consecutive annual fires. As a matter of fact, the evidence is that radial growth is more sensitive to amount of soil moisture available in the

early growing season than it is to any program of prescribed burning.

Of great significance is the fact that prescribed burning does no damage to the typical sandy loams of the coastal plain loblolly pine sites. No ill effects to the soil were measured over 10 years of plot studies which included annual winter and summer fires (10 each) and periodic² winter and summer fires (2 each), as compared to no fires during the period.

It becomes apparent then, that the benefits from prescribed burning overwhelmingly favor its use in the silviculture of coastal plain loblolly pine. The reasons are more fully discussed in the following pages.

THE STUDY AREAS

FIRE TREATMENTS

Formal prescribed burning tests were carried out on ¼-acre plots located in two typical South Carolina coastal plain loblolly pine stands. The treatments compared summer and winter fires, including annual versus periodic applications (table 1). One series of plots was established in 1946 followed by a partial series in 1951. Three replications of all plots were on the Santee Experimental Forest and two replications at the nearby Westvaco Forest, making a total of 35 plots.

STAND DESCRIPTION

The Pine Overstory

Both experimental forest installations were in previously unmanaged but well stocked, even-aged loblolly pine stands containing uniformly distributed, heavy understories (fig. 3). In each case the loblolly pine overstories contained some scattered shortleaf (*Pinus echinata* Mill.), an occasional longleaf pine (*Pinus palustris* Mill.), and miscellaneous hardwoods. The Santee plots, installed in a 40-year-old stand, had 3 subsequent improvement cuts, one at the beginning of the study followed by 2 cuts at 5-year intervals. The 30-year-old Westvaco stand was cut twice, at the beginning and 10 years later. All were commercial operations, thinning mainly from below with very little disturbance of the overwood or understory.

¹ The Santee Experimental Forest, operated by the Southeastern Forest Experiment Station, is on the Francis Marion National Forest in Berkeley County, S. C. The Westvaco Forest is owned by the West Virginia Pulp and Paper Company and lies in Georgetown County, S. C., about 20 miles northeast of the Santee.

² "Periodic fire" is used in this report to designate prescribed fires at irregular intervals of three or more years.

Table 1.--Schedule of prescribed burning treatments, Santee and Westvaco Experimental Forests, 1946-1957

Fire treat-ments	1947 ^{1/}	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57
<u>1946 Series</u>											
Annual Winter	X	X	X	X	X	X	X	X	X	X	X
Annual Summer	X	X	X	X	X	X	X	X	X	X	X
Periodic Winter	X	--	--	--	--	X	--	--	--	--	--
Periodic Summer	X	--	--	--	--	--	--	X	--	--	--
No fire	--	--	--	--	--	--	--	--	--	--	--
<u>1951 Series</u>											
Annual Summer	--	--	--	--	X	X	X	X	X	X	X
Biennial Summer	--	--	--	--	X	--	X	--	X	--	X

^{1/} Dates and X's designate first growing season following prescribed fire.



Figure 3.--Stand conditions at the Santee Experimental Forest location in 1947 before any prescribed burns. Small understory stems in this picture are mainly sweetgum and southern bayberry.

The Understory

Many hardwood species occupied the understories. The major ones included sweetgum, blackgum, and mixed oaks such as post oak (*Quercus stellata* Wangenh.), blackjack oak (*Q. marilandica* Muenchh.), willow oak (*Q. phellos* L.), and southern red oak (*Q. falcata* Michx.). Among the less important trees numerically were flowering dogwood (*Cornus florida* L.), red maple, American holly (*Ilex opaca* Ait.), and miscellaneous hickories. Approximate stocking by tree species-group was 60 percent gum, 30 percent oak, and 10 percent other species.

Southern bayberry, pepperbush (*Clethra tomentosa* Lam.), and gallberry (*Ilex glabra* L., A. Gray) comprised most of the shrub understory. About 60 percent of the understory stems were trees, the remainder shrubs.

A stem tally from two circular 1/100-acre subplots on each check plot at the Santee location showed that most of the understory stems were less than 1 inch d.b.h. at the beginning of the study (table 2). Even so, over 400 stems per acre were 1 inch in diameter or larger, indicating that the prescribed burning treatments were being applied none too soon.

Much of the understory at each location dated from the last wildfire, which had occurred about 15 years before the study began.

Table 2. --Estimated number of understory stems per acre before treatment

Size	Hardwoods	Shrubs	All
-- Number of stems --			
Under 4½ ft. tall	4,170	3,970	8,140
D. b. h. class			
0 in.	1,570	320	1,890
1 in.	180	50	230
2 in.	30	--	30
3 in.	50	--	50
4 in.	50	--	50
5 in.	30	--	30
5+ in.	20	--	20
Total	6,100	4,340	10,440

SOIL DESCRIPTION

The experimental forests lie within the flatwoods portion of the coastal plain at elevations of about 40 feet above sea level.

The burning experiment on both forests was installed on Coxville very fine sandy loam, which is a poorly drained soil with very slow surface runoff and medium to very slow permeability. Although of limited importance to agriculture, it produces very good stands of loblolly pine. The soil, which occurs on level to slightly undulating terrain, is also found over much of the lower coastal plain of South Carolina, both in the higher and lower flatwoods areas. Characteristically, the soil has a surface of 2 or 3 inches of dark grey, very friable, fine sandy loam which blends into a light grey, very friable, fine sandy loam with some yellowish mottles appearing at a depth of about one foot. From 12 to 20 inches there is a mottled light grey, yellow to reddish-yellow, slightly plastic, fine sandy clay loam which overlies a clay containing mottlings of red, yellow, and grey.

The whole profile is very acid, low in nutrients, and the organic matter content decreases sharply below the surface 3 or 4 inches.

EFFECTS OF PRESCRIBED FIRE

In addition to determining degree of hardwood control obtained from the various fire treatments, the study appraises their effects on overstory growth and certain soil characteristics. The most complete evaluation involves 10 years of treatment on the series of plots established in 1946. The later series (1951) covers only a 7-year period and provides supplemental information relative to understory control only.

ON CONTROL OF THE UNDERSTORY

Since much of the understory in recently burned loblolly pine stands consists of sprout clumps, a stem count may not be a good basis for an area-wise evaluation of prescribed fire as a control measure. An estimate of the area occupied by the crowns of the understory hardwoods and shrubs is better because it directly reflects the amount

of shaded ground, or the seedbed area currently unavailable for the establishment of pine seedlings. Such an evaluation of the understory was made during September 1956 by means of a 2-percent line transect survey. To do this, we divided the 1946 series of treatment plots into four quadrats, and randomly located parallel lines run across each quadrat. The vertically projected distances of the crowns of stems over 1 inch d.b.h. (high shade) and under 1 inch d.b.h. (low shade) and length of line classed as open (bareground, grass, herbs, etc.) were measured separately. The pine canopy was excluded since, at the most, only scattered seed trees would be left after a regeneration cutting.

The 10th year examination of the 1946 series of plots showed, by comparison with the unburned (check) plots, that all of the tested fire treatments had some effect on the understory shade (table 3). However, the indicated differences in understory shade between the check, annual winter, periodic winter, and periodic summer plots largely reflect the number of growing seasons (age of rough) since last fire. Few, if any hardwood rootstocks were killed by the aforementioned fire treatments. Given the same interval of recovery from fire, the understory development should be more or less similar on these plots. In contrast, the succession of annual summer fires practically eradicated the understory. The check plots had more high shade than any of the others, mainly due to understory growth uninterrupted by fire.

Each of the two fires in the periodic winter series resulted in some reduction of high shade, but the main effect was to kill back most of the low vegetation. Early in the following growing season all rootstocks would resprout, and in a short

period of years the understory regained its competitive position. Thus, in the five growing seasons since the second winter fire, low shade competition matched that on the check plots. Obviously, another fire was needed to set back the understory development here.

The two periodic summer fires had a somewhat greater impact on the understory. One reason is that summer fires effectively girdled more of the larger hardwoods than winter fires did, thereby further reducing the amount of high shade. Moreover, there was also a greater reduction in area covered by low shade. Part of this reduction was probably due to the fact that each summer fire killed both stem and roots of some hardwoods and shrubs, bringing about an actual reduction in the subsequent sprout population. However, as shown in table 3, much of the difference can be attributed to a shorter interval since the last fire, which was only about two-and-a-half growing seasons compared to five on the aforementioned winter plots. On roughs of similar age, the indicated difference in low shade competition would not be so great.

The age of the rough had an even more important bearing on the amount of low shade measured on the plots burned annually in the winter, as there was no apparent reduction of rootstocks even after 10 fires. Actually, a cessation of burning would probably lead to a buildup of understory competition equal to that of the check plot, given time. The comeback might be slower than on plots burned less frequently, as there appeared to be a very gradual decline in sprouting vigor over the 10-year period. Also noteworthy was the apparent small reduction in high shade competition on these plots. Any kill of the larger stems probably resulted from the initial fire which, because of the

Table 3. -- Effect of prescribed fire in reducing understory shade in immature loblolly pine stands during a 10-year period

Treatment	Growing seasons since last fire	Fires	High shade ^{1/}	Low shade ^{2/}	High or low shade or both ^{3/}
	Years	Number	- - Percent of total area shaded - -		
Check (no fire)	25.0	0	45	69	82
Periodic winter fire	5.0	2	28	71	79
Periodic summer fire	2.5	2	20	57	65
Annual winter fire	1.0	10	33	39	56
Annual summer fire	0.5	10	11	2	12

^{1/} Shade cast by understory hardwood or shrub stems over 1 inch d.b.h.

^{2/} Shade cast by understory hardwood or shrub stems under 1 inch d.b.h.

^{3/} These values are not the sum of high and low shade, as they overlap.

heavy fuel accumulation present, was by far the hottest of the series. Subsequent fire intensity has been low because of a light volume of fuel, but sufficient to kill back the annual growth of sprouts.

The most drastic effect came from the annual summer fires, which almost eliminated the understory (fig. 4). This was true eradication, as the majority of rootstocks, large and small, were killed. Unfortunately, annual measurements of fire effects were not made on the 1946 series of annual summer treatment plots. After about the fourth annual summer fire, however, it was obvious that there already had been a substantial reduction of the understory. Most understory survivors had extremely low vigor and would offer a minimum of competition if pine regeneration had been scheduled at that time.

A second series of plots installed in 1951 gave us a more complete evaluation of the effects of the repeated summer fires. This series compared biennial fires with annual fires, on the assumption that weather conditions might prevent burning in some years. In 1946 this had happened on the Westvaco plots when the burning was postponed due to excessive rainfall. Nevertheless, since the initiation of the 1951 series, all summer treatments have been on schedule at both Westvaco and Santee. A chief difference between years is the length of time available for burning during a growing season; by following a policy of burning at the first opportunity after June 1, advantage was taken of even the shortest period available.

The effect of repeated fires on the understory in the 1951 plot series was evaluated by major species on randomly located 1/100-acre subplots. Where possible, five single understory stems each of southern bayberry, sweetgum, blackgum, and miscellaneous oaks were identified by means of wire pins. One year after each burn the plots were checked to determine survivors. Early results have already been reported (8). These and later measurements showed that most southern bayberry and sweetgum succumbed rapidly (fig. 5). In contrast, it took about five successive annual fires to eradicate as much as half of the blackgum and oak. Regardless of species, most survivors showed some signs of reduced sprouting vigor after the first several fires. Thus, it appears that satisfactory levels of understory control, at least adequate for good pine regeneration, can be obtained with just a few successive annual summer fires. Depending on species composition of the understory, 2 to 4 fires should be enough.

The mortality rate from biennial fires was about the same as in the annual series, at least for the first 3 fires. As a matter of fact, missing a year in a sequence of annual fires would have little or

no effect on the level of control obtained with a given number of treatments. Consequently, in any large-scale program of summer prescribed burning, delays of a year due to bad weather would be unimportant on areas undergoing treatment. Furthermore, in areas of sparse fuel, prescribed burning could be purposely delayed a year to obtain a better buildup of fuel.

The reasons are not clear for the small amount of mortality following the fourth biennial fire. Only time will determine whether this is a definite trend.

ON GROWTH OF THE OVERSTORY

In an earlier evaluation, McClay concluded that a gradual reduction in understory competition brought about by summer fires, or the annual setback of the understory from winter fires, did not result in any measurable growth benefits to the pine overstory during the first 5 years of the study (13). This was also true for the first 10 years. As before, the growth measurements were based on increment borings from every pine tree on the plots; from these, mean yearly radial growth was determined by all treatments and crown classes for the 10-year periods before and after installation of the study. In sum, the data show no statistically significant increase or decrease in growth of the dominant trees attributable to prescribed burning.

The trend of annual growth was downward, which is considered normal for stands of the ages and densities sampled in this study. Much of the yearly variation in growth seems to be closely related to the amount of rainfall during the first 6 months of each year, growth dropping when rainfall during this period was short and taking a sharp turn upward when abundant. An exception is in 1948, which showed a downward trend in growth in the face of a wet first half. A cold early growing season may have been responsible. Furthermore, the possible effect of hot initial burns on growth should not be overlooked, in that the heavy 15-year accumulation of fuel causes these fires to be more intense than any of the later ones, with possible adverse but short lived effects on growth.

Over the years, mortality due to prescribed burning has been negligible. None ever resulted from the winter fires, either annual or periodic. Five trees were killed at the Santee as a consequence of the initial summer burning. Six trees died at Westvaco following the third annual summer fire. In both cases, poor technique is blamed;



Figure 4. --Annual summer fires can eradicate the understory. Above, before fire (one improvement cut). Below, 10 years later (stumps from three improvement cuts).

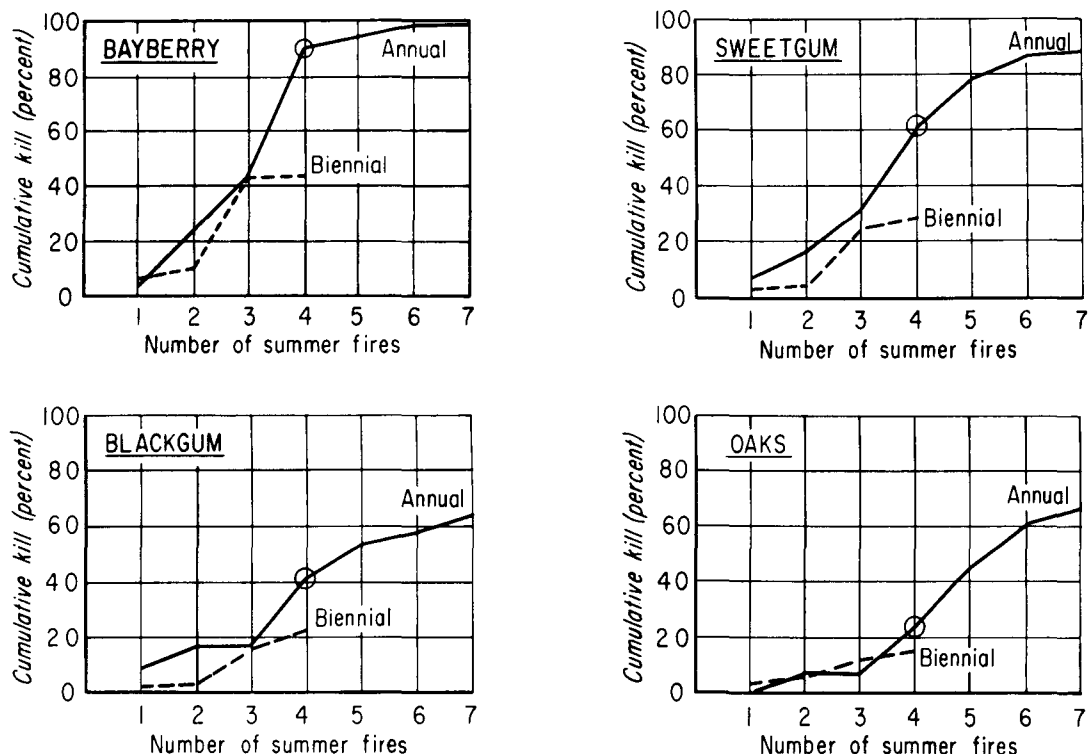


Figure 5. --Cumulative kill of certain understory species in even-aged 40- to 50-year old stands of loblolly pine prescribed burned with a series of summer fires.

the stringing of fire around all sides of the plots caused severe crown scorch from the funneling of heat up into crowns. Some of the weakened trees later succumbed to bark beetles. On most other occasions, summer burning was with backfires. Occasionally a head or flank fire was used to expedite burning light roughs or flat fuels. In each case, the heat was sufficiently dispersed by the wind to avoid any crown damage.

No butt damage to sound trees followed any of the fire treatments. Early in the experiment some trees, catfaced from earlier wildfires or cankered by fusiform rust (*Cronartium fusiforme*), caught fire. These trees were a mop-up problem. However, very few were lost and most were subsequently salvaged in one of the improvement cuts.

ON SOIL

The various soils analyses — organic matter, physical, and chemical — indicate no evidence of serious damage to soil as a consequence of any of the prescribed burning treatments; in fact over a 10-year period of treatment there is a definite increase in organic matter content of the surface 2 inches of forest soil as a consequence of annual burning (see tabulation).

Treatment	Organic matter based on oven-dry weight (Percent)
Annual summer fire	10.80
Annual winter fire	10.76
Periodic summer fire	9.49
Periodic winter fire	7.04
No fire (check)	7.79

The incorporated organic matter in the burned plots was very black and gave the appearance of being like fine bits of charcoal. Apparently it was not, as the analytical technique (wet combustion method) excludes 90 to 95 percent of the charcoal. Much of the surface litter is not converted to ash, and the material which appears to be charcoal is actually charred matter. This fine residual left after a fire can enter the mineral soil by gravity or by water if it is not washed away, which is unlikely in the flat coastal plain. This is in contrast to the unburned forest floor, where litter slowly changes to humus and while a portion of it is being incorporated into the mineral soil, much of the material volatilizes as carbon dioxide and water vapor.

Analyses of the upper 2 inches of surface soil revealed that organic matter significantly increased with all fire treatments except periodic

winter fires—in which case organic matter remained at about the same level as on the unburned areas. Furthermore, the soil nutrients, nitrogen, phosphorus, potash, calcium, and magnesium, were closely correlated with the organic matter content in the surface soil. Finally, type and frequency of fire treatments tested resulted in no detrimental effect on the physical properties of bulk density, porosity, or percolation rate, all of which are more or less related to the organic matter in the soil.³

It should be pointed out that organic matter in the soil was already of sufficient quantity so that the measured increases are not important biologically. There is now confidence that on the level sandy soils of the Carolina coastal plain no site deterioration results from a program of prescribed burning in the loblolly pine type.

A word of caution in this regard may be in order. The results of this study cannot be applied to sloping terrain or to sites on which the soil at the surface is not sandy. On the sites studied there is practically no horizontal movement of surface water. But on sloping land, water moving over the surface would tend to carry ash and charred material from the site and at the same time material in suspension would settle out and plug the surface soil pores. Sealing of the surface by moving water would be more rapid on non-sandy soils. And of course, in the Piedmont, mountains, and sandhills, where organic matter is often but 1 or 2 percent, the reaction of the site to fire could be considerably different.

PRACTICAL SIGNIFICANCE OF THE STUDY

WHERE RESULTS APPLY

As a consequence of this study, considerable information has accumulated on the use of fire in loblolly pine silviculture. The present findings apply mainly to relatively pure pine stands consisting of pole-size or larger trees. In these stands the fuel type is fairly uniform and comprised largely of pine needles and similar fine material (fig. 6). Scattered patches of flat fuels, mostly hardwood leaves, may be present but not in amounts sufficient to reduce the general effectiveness of a prescribed burn (fig. 7). In any event, primary uses of fire would be for under-

story control or seedbed preparation. This requires that for best results the majority of understory stems be under 2 inches d.b.h.

Although each fire results in some fuel reduction, this objective is more important in sapling pine stands, an age group excluded from our study. Consequently, additional investigation is needed to adequately appraise the value of prescribed burning for hazard reduction. Furthermore, our study does not cover the use of fire on former pine lands now in hardwoods or brush. A prevalence of flat and sparse fuels on these sites may require burning conditions bordering on the explosive for effective treatment, and thus mechanical or chemical treatments are likely to be more practical than fire for type conversion purposes.

Some of the fire treatments included in the present study are backed up by tests on larger areas of coastal plain loblolly pine in and out of the Santee Experimental Forest. These pilot burns ranged up to about 50 acres. Major treatments tested were periodic winter fires and annual summer fires, separately or in combination, as these gave early promise of having practical application. The possibility of serious damage precluded the use of periodic summer burns on large tracts. Furthermore, the annual winter fire treatment was not tried beyond the study plots, as no advantage over periodic winter burning was apparent. The required conditions for safe but effective burns on large areas were generally much the same as on the $\frac{1}{4}$ -acre plots. Therefore, the following information should serve as a useful guide to the treatment of immature loblolly pine stands for hardwood control and/or seedbed preparation on areas as large as several hundred acres.

PRESCRIBED BURNING TECHNIQUES

Fires were scheduled on the study plots as soon as weather permitted after December 1 (winter) and June 1 (summer). Thus, most of the experimental winter burning was done in December or January, although delayed as late as March 15 one year. The bulk of the summer burning was completed in June, but not until July 22 on one occasion. There appears to be no valid reason why a winter burning season could not extend over about a 4-month period in any large scale burning program, commencing with the first killing frost in November and ending at the beginning of the growing season in March. Likewise, the summer season could extend from early May on into September, also about 4 months. This exten-

³ A comprehensive discussion of soils on these same study plots is given in the paper, "Some Effects of Prescribed Burning on Coastal Plain Forest Soil." Publication is pending.

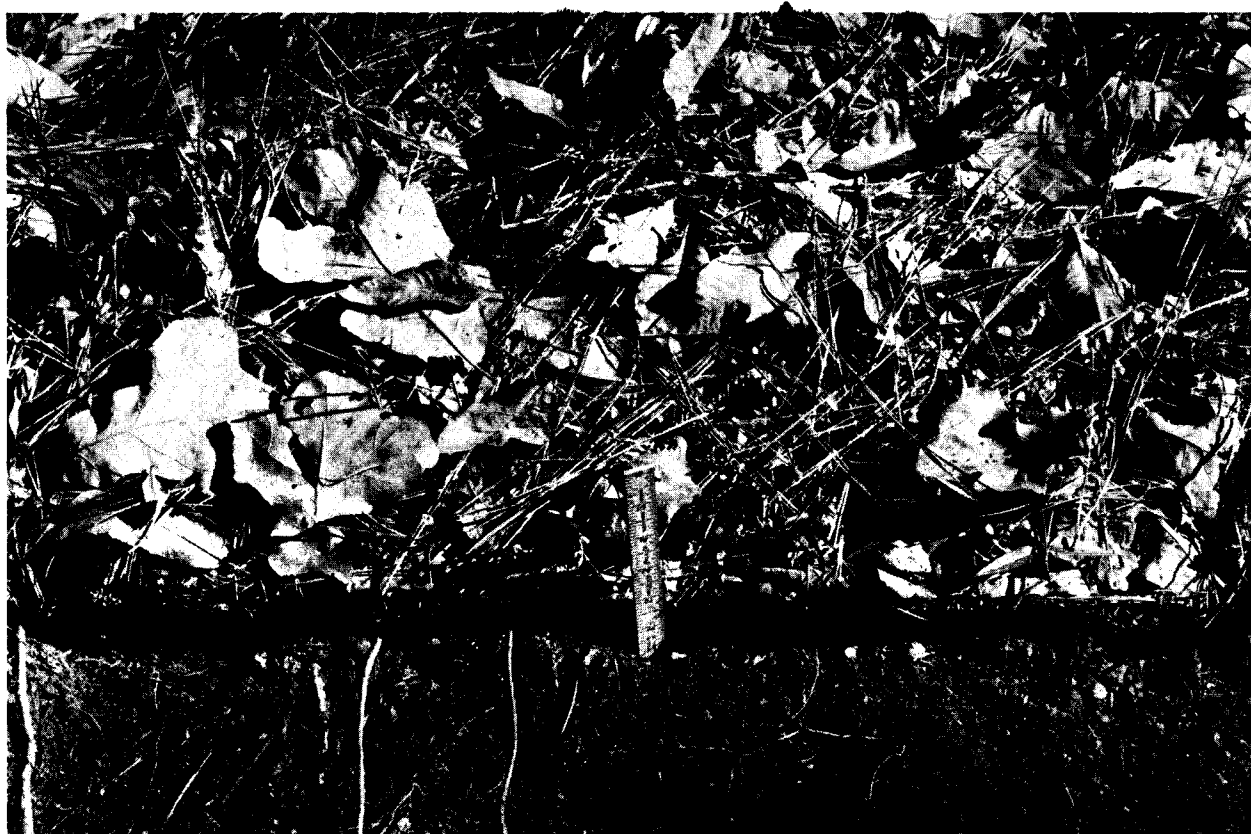


Figure 6. --Above, needles draped on understory stems, a common condition in areas infrequently burned, add to fire intensity. Below, accumulation on ground, in this case about 20 years since last wildfire. Note section cleared to mineral soil to illustrate depth of fuel.



Figure 7. --Flat fuels, mostly hardwood leaves, are less flammable than pine fuels and often do not burn when conditions are suitable for firing pine fuels.

sion was substantiated by the pilot burns, some of which were made in late summer.

In spite of best laid plans, fire treatments could not always be carried out as scheduled. Periods of heavy or frequent rains caused most delays. For example, flooding and excessive fuel moisture brought about a year's postponement in establishing the summer burn plots at Westvaco. For similar reasons, there was one less fire than scheduled in the annual summer series at that location. In addition, it was impossible to burn one of the annual winter fire plots in 1948 or 1949, and two were bypassed in 1958. In contrast, all of the Santee plots were burned as planned.

In the winter the average waiting period after a rain of $\frac{1}{2}$ inch or more was 18 days before burning conditions were right. In contrast, the average drying out period in the summer amounted to only 10 days. Conditions were seldom right in any season in less than 3 days after a soaking rain. Small areas of flat fuels composed mostly of hardwood leaves dried more slowly and were generally less flammable than the more extensive area of pine litter. Complete fuel consumption by a fire required waiting until both the litter and soil surface dried out. Generally, a dry upper layer of

litter sufficed to carry an adequate burn in pine fuels (fig. 8). Almost complete drying was needed in the flat hardwood fuels for effective results.

Favorable weather elements for burning included air temperatures of 60°F. or above in winter and 90°F. or above in summer, relative humidities under 50 percent in both seasons, and winds steady as to direction, but generally within a range of 1 to 7 miles per hour at about breast height in the stand (table 4). Such winds maintained sufficient draft to ignite fresh fuel, carried water vapor and heat at an oblique angle through the pine crowns (minimizing danger of crown scorch), and gave assurance that a fire moved in a direction and rate as planned. Fuel moisture, determined from basswood sticks, never exceeded 10 percent at the time of burning, and generally was around 5 to 8 percent.

Unfortunately, most of the foregoing factors were measured only on days scheduled for prescribed burning. This makes it difficult to estimate, as a possible guide to planning larger burning programs, how many additional days or periods might have been suitable during the 10 years. There is a clue, however, in the continuous record of relative humidity recorded on the hygrothermo-



Figure 8. --Upper third of picture shows forest floor immediately after the first winter burn, ember still smoldering. Middle third shows unburned litter. In lower third, mineral soil has been exposed to show depth of litter. Note the thick cover that remains after the burn, protecting mineral soil and fine roots.

Table 4. --Prevailing weather conditions for prescribed burning of plots at Santee Experimental Forest

ANNUAL WINTER FIRES

Date	Burning began	Maximum air temperature	Minimum relative humidity	Wind		Fuel moisture	Days since $\frac{1}{2}$ inch or more of rain
				Direction	Speed		
	Hour	Degrees F.	Percent		M. p. h.	Percent	Number
Dec. 6, 1946	1:00 p. m.	60	20	Variable N	1-3	10	8
Feb. 19, 1948	3:00 p. m.	68	44	Variable N	1-3	10	7
Jan. 17, 1949	12:30 p. m.	75	50	SW	1-3	10	18
Dec. 7, 1949	1:00 p. m.	61	32	SW	1-3	8	30
Jan. 29, 1951	1:00 p. m.	71	48	SW	1-3	7	29
Dec. 3, 1951	1:00 p. m.	72	42	Variable SE	1-4	5 $\frac{1}{2}$	30
Dec. 12, 1952	2:00 p. m.	60	30	Variable NW	1-3	5 $\frac{1}{2}$	31
Jan. 8, 1954	1:30 p. m.	60	40	SE	1-3	7	10
Jan. 5, 1955	1:30 p. m.	72	46	Variable SW	1-3	9	3
Jan. 3, 1956	1:00 p. m.	70	40	Variable SW	1-6	8	30
Dec. 28, 1956	1:00 p. m.	69	30	SW	3-6	5	4
Average	1:10 p. m.	67	38	--	1-3	8	18

ANNUAL SUMMER FIRES

June 19, 1947	1:00 p. m.	94	24	Variable	1-3	--	5
June 17, 1948	1:00 p. m.	84	46	E	1-3	--	9
July 11, 1949	12:45 p. m.	90	47	E	1-3	--	15
June 14, 1950	2:00 p. m.	87	46	SW	1-3	5 $\frac{1}{2}$	6
June 28, 1951	1:00 p. m.	99	43	Variable	1-3	--	5
June 10, 1952	1:00 p. m.	95	45	W	1-3	5	29
July 1, 1953	12:30 p. m.	96	39	SW	1-3	4 $\frac{1}{2}$	2
June 15, 1954	1:45 p. m.	90	38	NE	4-7	3	3
June 7, 1955	12:30 p. m.	92	33	SW	4-7	3 $\frac{1}{2}$	14
June 18, 1956	2:45 p. m.	95	34	SE	3-4	9	12
July 9, 1957	12:30 p. m.	97	38	Variable N	1-3	4 $\frac{1}{2}$	12
Average	1:02 p. m.	93	39	--	1-3	5	10

graph maintained at the Santee Experimental Forest Headquarters weather station. Experience has shown that on days with minimum relative humidity under 50 percent, pine fuels were sufficiently flammable to carry a prescribed fire. On this basis, an average year contained a total of 37 possible burning periods about equally divided between the winter and summer seasons, as shown in table 5. (Table 5 is based on 10 years of measurement.) For planning purposes 37 periods should be considered about maximum, especially in the absence of supplemental information on the number of days with steady but light winds. Consideration must also be given to the difficulty of mobilizing an organization within burning periods as short as 1 or 2 days, which comprise over 40 percent of the total. Even so, we find that there isn't much difference between the winter and summer season, and thus ample opportunities for prescribed burning should develop during a normal year in either season.

Frequently, a final decision to prescribe burn needed to be checked by a test fire in a typical fuel condition within a treatment area. A test fire that smoldered and did not spread uniformly from the center usually caused postponement until later in the day or another day. But if the test fire crept out uniformly and burned well, a prescribed fire followed immediately. Suitable burning conditions generally developed about mid-

day and continued until late afternoon, when rising humidity prevented a further spread of fire. For safety reasons — to minimize crown scorch or the escape of fire from plowed lines — burning conditions resulting in a flame height of less than 4 feet were preferred, especially where fuel accumulations were heavy. On the other hand, in an annual and biennial burning treatment series, light fires—resulting from the thin fuels—were the rule and sufficed to control the 1- or 2-year-old sprouts (fig. 9).

Most areas were burned against the wind, especially at the initial treatment. However, the rate of spread for the backfires seldom exceeded 2 chains per hour. On 1- or 2-year-old roughs, or light fuels, flanking fires and strip head fires helped to expedite burning; but it was bad practice to surround an area with fire. On the two occasions when fires were strung around entire plot perimeters without regard to wind direction, resultant damage to the overstory plainly indicated this was an undesirable technique for most areas.

By preparing firelines only a short time ahead, we avoided accumulations of leaves and needles and additional maintenance of the lines. On annual and biennial burns the original plowed lines required only hand raking. In contrast, a periodic series of fires, taking place at intervals of 3 years or more, always needed replowed fire

Table 5. --Average number of periods one or more days long having a minimum relative humidity under 50 percent, by months within burning seasons

Number of days in period	Summer months					Winter months					Grand total
	May	June	July	Aug.	Total	Nov.	Dec.	Jan.	Feb.	Total	
	----- Average number of periods -----										
1 or 2	2	2	2	2	8	2	3	2	1	8	16
3 to 5	2	2	1	1	6	2	2	2	1	7	13
Over 5	1	1	1	1	4	1	1	1	1	4	8
All periods	5	5	4	4	18	5	6	5	3	19	37



Figure 9. --Annual accumulation of fuel sufficed to carry a light fire on the annual summer treatment plots.

lines. A 2- or 3-man crew did most of the burning on the experimental areas. Mop-up work began with prescribed burning in progress. Occasional checks continued until the fires were considered safe, usually not more than one day after.

COST OF BURNING

The pilot burns provide some useful cost data. Fifteen areas burned for a total of 547 acres, ranging in size from 24 to 53 acres each, developed the following cost information:

<i>Item</i>	<i>Hourly cost</i>	<i>Hours per acre</i>	<i>Cost per acre</i>
TD-9 tractor	\$9.00	0.02	\$0.18
Mathis plow	2.75	.02	.06
Labor	1.00	.22	.22
Total . . .			\$0.46

The foregoing represent actual on-the-ground costs. Transportation of personnel and equipment to and from the site is not included;

neither is any overhead except that engaged in the burning operation. Very small crews were involved. In addition to tractor-plow operator there were seldom more than two or three men engaged in setting the fires or in any ensuing mop-up operation. Although full dependence was placed on the local protective organization for reinforcements in case of the escape of a prescribed fire, the reinforcements were never called out. Patrol action was held to a minimum.

Prescribed burning on small areas such as these is considered more costly than larger units burned by the local National Forest organization. A 40,000-acre program on the Francis Marion National Forest in 1958 resulted in an average expense of 45 cents per acre. This included planning and transportation of labor and equipment in addition to on-the-ground costs.

As pointed out by Klawitter (6), prescribed burning can yield some direct monetary benefits and thus help pay its way. This was determined by a comparison of extraction costs from two adjacent 50-acre areas in the same loblolly pine stand. On an area that was relatively brush free after four prescribed burns, the logging costs for an intermediate cutting operation were reduced

by \$2.29 per thousand board feet of saw logs and \$1.50 per cord of pulpwood, as compared to costs on the unburned and brushy area. This is the equivalent of \$3.95 per acre of decreased logging cost in the burned area, based on a cut of 1,300 board feet and 0.6 cords per acre—enough to pay for eight burns instead of the four that were made.

SILVICULTURAL APPLICATION

The decade of testing on small plots and larger pilot areas showed that prescribed fire is an efficient and low-cost tool for perpetuating even-aged stands of loblolly pine on coastal plain sites. In stands above sapling size, adequate understory control or seedbed preparation is obtainable with no serious damage to the pine growing stock or site. Winter or summer fires may be employed as needed to meet the requirements of the forest manager. Conditions and instructions relative to proper seasonal uses of fire were at least tentatively described in earlier reports of our research results (2, 3, 9, 7, 10, 11). With some refinements they are discussed below.

Winter Fire

As previously pointed out, little is gained from a series of annual winter fires. Most rootstocks survive, and when the treatment is stopped the understory will regain its competitive position in a few years. A comparable level of control can be obtained by burning only occasionally, thus helping to reduce costs. Frequency of reburning depends, of course, on the rate of understory development after each fire. In this respect, intermediate cuttings often result in more light reaching the understory, thus speeding up its growth. Furthermore, good sites require more frequent treatment than poor ones. Hence the interval between fires may range from several to 10 or more years. Small stems in the understory are effectively girdled by a winter fire. On those up to about 1 inch d.b.h. the kill is high but rapidly diminishes as stem size approaches 2 inches, and is negligible among larger sizes (fig. 10). For best results, this suggests reburning when most stems are still small. A recommended rule of thumb is to reburn when about 25 percent of the largest understory stems are approaching 1 inch d.b.h. Accordingly, on average



Figure 10. --All the understory stems in foreground, including the larger ones, had been killed back by a periodic winter burn. In May following the fire, sprouts were already about 2 feet high.

sites in managed stands this would mean burning at about 5-year intervals, or 8 to 10 fires in an average sawtimber rotation.

The simplest prescribed burning program is one requiring only periodic winter fires. If properly applied, the treatment holds the understory in check during the life of a loblolly pine stand. Then at the time of final harvest the seedbed is prepared with one last winter fire. As a matter of fact, such a program may be described as learning to live with the inferior hardwoods and shrubs of the understory, inasmuch as their rootstocks are not destroyed by the winter burns. A chief danger is that some growing space is invariably captured by the broad-leaved species, the extent depending upon their number, size and aggressiveness. The situation may be worsened by a poor scheduling of the terminal winter fire. If it takes place after the main seedfall, rather full dependence must be placed on the next seed crop for pine regeneration. In the meantime the site may be occupied by sprouts that have a full growing season's advantage over any pine regeneration. An alternative is to burn for seedbed preparation as early in the dormant season as feasible. If done around November 15, about half the seed is still on the trees and would fall on the freshly burned seedbed. By December 15 this proportion shrinks to about 20 percent, and by January 15 to 10 percent or less.

Summer Fire

A more progressive burning program than the foregoing is one that incorporates summer fire into the general schedule of treatments. As a minimum, one would use a summer burn in lieu of the terminal winter burn for seedbed preparation. This assumes that periodic winter fires are used to keep the understory stems small or under control during the immature stages of stand development. Then, a summer burn for regeneration is made sometime during the last growing season, but prior to the final harvest cut. The later in the season burning is done, the less chance there is for sprout development prior to pine seed germination in the following spring. Inasmuch as seedfall begins about October 15, the best timing calls for a prescribed fire during the month immediately preceding this date. For all practical purposes, however, a seedbed-preparation burn any time during the months of June, July, August, or September should do an adequate job—certainly better than any dormant season fire for the same purpose because of lesser sprout growth and no seed loss to fire.

A more intensive regeneration technique involves the use of a succession of annual summer fires, especially in stands with dense underbrush or with limited seed production. These fires can begin several years in advance of harvest to eradicate or weaken much of the understory competition in addition to preparing the seedbed. The sequence of fires can be stopped at the discretion of the forest manager following the establishment of a sufficient number of pine seedlings. Thus, reproduction can be established even before the overwood is harvested (fig. 11). In good seed years or in areas of known good seed production, an alternative is a harvest cut after seedfall following the last summer burn in the series. This utilizes seed in place and eliminates need for seed trees—a pilot test of this suggested technique resulted in 90,000 one-year-old seedlings per acre. In either case the summer fires are preceded by the usual course of periodic winter burns to keep the hardwoods small even though not reduced in number.

A possible maximum use of a succession of summer fires is for practical eradication of the broad-leaved understory about mid-rotation. This calls for a succession of three or more fires, depending on the species composition. For example, an understory with a high percentage of southern bayberry or sweetgum would require less treatment than one with a high proportion of blackgum or mixed oaks. Furthermore, a high degree of initial control would probably be easy to maintain, particularly with the removal of any hardwood seed sources within the pine stand as part of scheduled intermediate cuts. When the understory competition is once reduced to a minimum, an occasional winter fire should suffice to keep down any broad-leaved survivors or volunteer pine, and to reduce fuel. Silvicultural benefits obtained from the practical elimination of the understory often justify this burning program; in addition, one cannot overlook the possible savings in cost of field inventory, tree marking, logging, and timber sale supervision.

In the face of the evidence presented, fire has a definite place in the silviculture of coastal plain loblolly pine. Even so, fire should be considered a tool to be prescribed when and where needed. At the discretion of the forest manager, fire can be used in immature stands of loblolly pine for the control of understory hardwoods and seedbed preparation. The season and frequency of burning depend on the degree of effectiveness desired. In any event, the fires can be prescribed without fear of damage to the stand or site. Provided the burns do not get away and turn into wildfires, benefits far exceed any damage we have been able to measure.



Figure 11. --Above, 50-year-old loblolly pine stand with heavy hardwood understory. Below, one winter and three summer fires later, understory hardwoods replaced by pine even before harvest cutting.

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