

A 10-Year Evaluation of Prescribed Winter Burns in Uneven-Aged Stands of *Pinus taeda* L. and *P. echinata* Mill.: Woody Understorey Vegetation Response

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Abstract. The effects of burning cycles and pine basal area levels were assessed on natural pine regeneration and hardwood development in uneven-aged stands of loblolly and shortleaf pines (*Pinus taeda* L. and *P. echinata* Mill.). The treatments included an unburned control and prescribed winter burns at 3-, 6-, and 9-yr intervals. Basal area treatments were 9, 14, 18, and 23 m² ha⁻¹ for the merchantable-pine component and were maintained on a 6-yr cutting cycle using single-tree selection. Ten years after the study was initiated, density and quadrat stocking of pine regeneration were negatively correlated with overstorey basal area. The 6-yr burning cycle had higher pine density and better quadrat stocking of pine regeneration compared with any other burn treatment mainly because the 6-yr burning cycle coincided with a bumper pine seedcrop and the 6-yr cutting cycle. Recurring fires tended to result in reduced size of hardwood competition but had less impact on hardwood density. When considering a prescribed burning program in uneven-aged stands of loblolly and shortleaf pines, more attention should be given to density, quadrat stocking, and size of established pine regeneration and to expected seedcrops rather than to the prosecution of rigid burning schedules.

Keywords: Basal area; Burning cycles; Cutting cycles; Fireline intensity; Loblolly pine; Shortleaf pine; Selection management; Southern Arkansas.

Introduction

Prescribed burning has a long history in the loblolly and shortleaf pine (*Pinus taeda* L. and *P. echinata* Mill.) vegetation types of the southeastern United States (Crow 1982, Waldrop et al. 1987, Van Lear and Waldrop 1990, Wade and Lunsford 1989). In even-aged forest management, prescribed burning has been used for fuel hazard reduction, control of undesirable vegetation, seedbed preparation, and improvement of wildlife habitat (Davis 1959). In uneven-aged (selection) manage-

ment, however, prescribed fire has been rigorously excluded because of the perception that fires cause too much destruction to the submerchantable pine component (Farrar 1984).

Under the selection system, some trees are harvested regularly as individuals or in groups, with total volume cut at any one time being roughly equal to the growth that has occurred since the last harvest (Reynolds et al. 1984). In order to achieve that objective, there must be a progression of trees from the smaller to the larger and more valuable size classes, based on diameter at breast height (dbh), taken 1.37 m above ground. Since fire is not selective, young pines can be destroyed during prescribed burning, thereby creating gaps in the progression of size classes from regeneration to merchantable trees in uneven-aged stands.

Although the disadvantages of prescribed burning in uneven-aged stands seem intuitively obvious, there have been no formal research investigations to address this subject. The purpose of the present study was to determine the effect of four overstorey pine basal area levels and three prescribed burning intervals on the establishment and growth of natural pine regeneration and on understorey hardwood development in uneven-aged loblolly-shortleaf pine stands that are managed using single-tree selection. This paper contains results that were obtained during the first 10 yrs of the experiment.

Methods

Study area

The study is located on the Crossett Experimental Forest in southern Arkansas, USA, at 33°02'N mean latitude and 91°56'W mean longitude. Elevation of the forest is about 53 m with nearly level topography. Soils are predominantly Bude and Providence silt loam (Glossaquic and Typic Fragiudalfs, respectively) with

an impervious layer at 46-102 cm that impedes internal drainage (USDA 1979). These soils have a site index of 27 m for loblolly pine at base age 50 yrs. Annual precipitation averages 1400 mm, with extremes being wet winters and dry autumns.

Experimentation

Beginning in 1980, pine seed crops were monitored annually for 10 yrs, between 1 October and 1 March, by taking weekly seed counts from 0.2 m² seed collection traps. An average of 24 seed traps were used each year. Collected pine seeds were cut open and those containing fully developed gametophyte tissue were judged as potentially viable (Bonner 1974).

The study encompasses three 16 ha compartments that had been managed using single-tree selection from the late 1930's to the late 1960's, with complete exclusion of fire. Hardwoods were periodically controlled by girdling in early years of selection management and later by stem injection and mist-blowing with herbicides. From 1970 until 1980, there was no harvesting of pines, nor control of competing vegetation. Consequently, at the time of study installation in 1980, basal area of merchantable-sized pines (>8.9 cm dbh) ranged from 18 to 29 m² ha⁻¹. Basal area is the area of ground surface occupied by tree stems and was calculated from tree diameters taken at breast height (dbh), 1.37 m above ground. Density of the submerchantable component (≤8.9 cm dbh) averaged 77 stems ha⁻¹ for pines and 12,355 rootstocks ha⁻¹ for hardwoods.

Individual compartments were divided into 16 plots of 1.0 ha (100 m by 100 m). Interior measurement plots of 0.65 ha (80 m by 80 m) were surrounded by 10-m-wide isolation strips. After plot establishment in the fall of 1980, all pines of merchantable size were inventoried on a plot-by-plot basis by 2.54-cm dbh classes for computation of basal area.

Treatments

Four contiguous 1.0-ha plots constituted a 4-ha burn treatment (Figure 1). Three burning intervals of 3, 6, and 9 yrs and an unburned control were randomly assigned to the 4-ha burn treatments within each compartment (replication). Prescribed burning was done during the dormant season at these specified intervals to control hardwoods, as well as, to encourage the development of natural pine regeneration. Within each burn treatment, residual merchantable pine basal areas of 9, 14, 18, and 23 m² ha⁻¹ were assigned to the 1.0-ha plots at random.

The four basal area levels used in this investigation were achieved by cutting and removing merchantable pines and were thought to include the practical range of residual density suitable for selection management of loblolly-shortleaf pine stands. Historically, a residual pine basal area of from 10 to 15 m² ha⁻¹ is used to permit the establishment and growth of natural pine regeneration while insuring that basal area does not exceed a maximum of 17 m² ha⁻¹ between periodic cuts on cycles of 5 to 10 yrs (Murphy et al. 1991).

All plots, except those in the unburned controls, were initially prescribed burned in mid-January 1981 (Table 1). In the spring of 1981, all surviving hardwoods that were ≥2.5 cm in groundline diameter (gld), including those on unburned control plots, were stem injected with Tordon® 101R (0.03 kg/l picloram [4-amino-3,5,6-trichloropicolinic acid] and 0.12 kg/l 2,4-D [2,4-dichlorophenoxyacetic acid])¹. For this study, tree groundline diameters were specified as being in the transition zone between stem and root, just above a recognizable swelling. Dosage rates for stem injection were 1 cc of undiluted herbicide per 2.5 cm of gld.

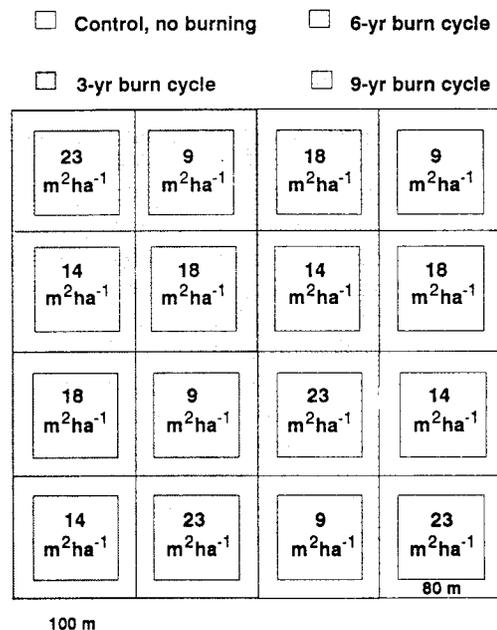


Figure 1. Schematic diagram of the experimental design on a 16 ha compartment. An unburned control and three burn treatments were randomly assigned to areas containing 4 ha each. Four basal area levels (9, 14, 18, and 23 m² ha⁻¹) were randomly assigned within the unburned control and the three burn treatments.

¹Treatments involved the use of herbicides, but their discussion in this paper is not a recommendation for their use and does not imply that uses discussed here are registered by appropriate State and/or Federal agencies.

Table 1. Fuel and weather conditions during the prescribed winter burns in southern Arkansas, USA.

Fuel and Weather Variables	Burning Cycles						
	Initial Burn	3-Year Cycle	3- and 6-Year Cycle			3- and 9-Year Cycle	
Date of burn (month/day/yr)	01/14-15/81	01/31/84	01/28/87	02/05/87	02/12/87	12/04/89	12/05/89
Days since last precipitation	8	8	4	6	4	11	12
Time of burning (hrs. CST)	1000-1700	1000-1600	-----1200-1800-----			1100-1900	1000-1500
Air temperature (°C)	4-16	1-10	11-17	21-24	11-17	11-14	13-21
Relative humidity (%)	60-32	70-24	71-44	48-35	45-22	22-12	38-26
Wind direction	SW-NW	S	NE	variable	ESE	SW	W
Wind Speed (km h ⁻¹)	8	4.8	8.0	16.0	8.0	21	16
Fine fuel moisture ¹ (%)	10	12	15	11	13	6	10
Mean fireline intensity ² (kWm ⁻¹)	not available	318	315	419	315	268	208
Range in fireline intensity (kWm ⁻¹)	not available	163-439	----- 315-419 -----			214-336	55-464
Type of burn	----- back and flank fires -----						

¹ Determined from fuel-moisture sticks at midday (Phillips and Abercrombie 1987).
² $I = 5.67L_f^{2.17}$, where L_f = Ocular estimates of flame length (Byram 1959).

Residual pine basal areas were maintained by thinning the merchantable component on a 6-yr cycle. The initial cut was made during the summer of 1982. The stands were marked for harvest in accordance with the basal area — maximum diameter — quotient (BDQ) technique (Farrar 1984). During cutting, priority was given to achieving the assigned basal area by using a maximum dbh class of 56 cm and a “q” of 1.2. The “q” is defined as the constant ratio of the number of trees in a given 2.5-cm dbh class to the number in the adjacent larger 2.5-cm class for balanced uneven-aged stands. A second cycle cut was completed during the winter of 1987, using the same marking criteria developed for the initial harvest.

In addition to the initial prescribed burn, subsequent burn treatments were as follows: three prescribed fires on the 3-yr cycle, one prescribed fire on the 6-yr cycle, and one prescribed fire on the 9-yr cycle (Table 1). While the cycle burns were in progress, flame lengths were ocularly estimated to the nearest 0.3 m by fireline personnel and recorded. Weather information was recorded at the Experimental Forest headquarters, within 1.6 km of the study sites.

Measurement of understorey vegetation and data analysis

For this 10-yr assessment, density and quadrat stocking data for pine regeneration and hardwood rootstocks, were collected from 100 nonpermanent 4-m² quadrats that were systematically spaced across each 0.65-ha interior measurement plot. The 4-m² quadrats were assessed as being overtopped by competing vegetation in accordance with free-to-grow criteria: not overtopped, overtopped by pine, overtopped by hardwoods, overtopped by pine/hardwood. Hardwood rootstocks were comprised of either single or multiple stems (clumps) which obviously arose from the same

root system. Within each 4-m² quadrat, the dominant hardwood seedling and sapling rootstock was identified by species. Stem counts were limited to pines and hardwoods of submerchantable size (<9.0 cm dbh). Stems were categorized into seedling (<1.5 cm dbh) and sapling (1.5 to 8.9 cm dbh) size classes.

The study employed a split-plot design with burning cycles as the major plots and basal area treatments as the minor plots. The study was installed in three replications with three burn treatments and a control comprising a single block. Analyses of variance were used to evaluate treatment differences. Data in percent were analyzed following arcsine $\sqrt{\text{proportion}}$ transformation. Scheffe’s Test was used to partition mean differences between basal-area treatments and between burning-cycle treatments. All analyses were carried out at the 0.05 level of significance.

In late January 1990, 240 submerchantable-size loblolly pines were selected for assessment of crown scorch on areas where burning occurred eight weeks earlier. During that selection process, the objective was to obtain an equal number of pines by basal area treatment (9, 14, 18, and 23 m² ha⁻¹), by each of three size classes (<0.9 m tall, 0.9 m tall to 1.4 cm dbh, and 1.5 cm to 8.9 cm dbh), and within the two burning treatments (3-yr and 9-yr cycles) that were just completed.

Percent crown scorch was ocularly estimated for each sample pine eight weeks after the 1989 burn by three individuals standing at different angles from the tree. Estimates were made to the nearest 10% between the values of 10% and 90%. Below 10% and above 90%, crown scorch was assessed to the nearest 2%. Agreement was reached between estimators, and a composite assessment of crown scorch was recorded.

Following the assessment of crown scorch, sample trees were measured to obtain crown height at the time of burning, total height, groundline diameter (gld), and

diameter at breast height (dbh). Heights were measured to 3 cm and diameters were measured to 0.25 cm. Each sample tree was assessed as free-to-grow, overtopped by merchantable-size pines, or overtopped by nonpine competition.

Linear regressions were generated with these sample pines to illustrate dbh and height growth trends, during the year after burning, relative to crown scorch for surviving pines by size class. Linear regression was also used to show the correlation between total height and gld for submerchantable pines in these uneven-aged stands.

Results

Pine seedcrops

Ten years of natural pine seedfall resulted in two bumper seedcrops in 1983 and 1986 (about 2,500,000 potentially viable seeds [pvs] ha⁻¹), three above-average seedcrops in 1981, 1984, and 1988 (371,000 to 741,000 pvs ha⁻¹), two average seedcrops in 1980 and 1987 (133,400 to 212,500 pvs ha⁻¹), one below-average seedcrop in 1989 (81,500 pvs ha⁻¹), and two seedcrop failures in 1982 and 1985 (0 to 5,000 pvs ha⁻¹). There were never two consecutive seedcrop failures nor two consecutive years with bumper seedcrops.

Prescribed burns

Average fuel and weather conditions that existed at the time of the four prescribed burns are presented in Table 1. Fireline intensity ranged from 208 to 419 kWm⁻¹ and averaged more than 299 kWm⁻¹ for the three burns where flame lengths were recorded. Fireline intensity is important because it has been shown that, in 9-yr-old even-aged stands, intensities exceeding 208 kWm⁻¹ during prescribed winter burns can kill loblolly pines that are less than 2.4 m tall or less than 5 cm in gld (Cain 1985).

Density and quadrat stocking of submerchantable pines

Not surprisingly, submerchantable pine density declined as overstorey pine basal area increased from 9 to 23 m² ha⁻¹ (Table 2). That trend generally held true regardless of the burning cycle. Submerchantable pine density on plots with 9 m² ha⁻¹ basal area averaged from 2 to almost 4 times the density recorded on plots with 14 to 23 m² ha⁻¹. There was no interaction between burning cycle and basal area treatments in the statistical analysis of submerchantable pine density.

Table 2. Density and quadrat stocking of submerchantable-size pines, 10 years after study establishment.

Treatments	Measurement variable for submerchantable pines	
	Density	Quadrat stocking ¹
	Stems ha ⁻¹	Percent
Burning cycles		
Control, no burning	1,240 b ²	18 ab
3-Yr	521 c	11 bc
6-Yr	2,612 a	28 a
9-Yr	217 c	5 c
Mean Square Error	24,049	0.0126
P>F	0.0001	0.0014
Basal area		
9 m ² ha ⁻¹	2,199 a	27 a
14 m ² ha ⁻¹	1,033 ab	15 ab
18 m ² ha ⁻¹	731 b	10 b
23 m ² ha ⁻¹	630 b	10 b
Mean Square Error	208,083	0.0159
P>F	0.0084	0.0003

¹ A 4-m² quadrat was stocked if it contained at least one pine stem of submerchantable size. (Trousdel 1963, Campbell and Mann 1973).

² Within treatments, columnar means followed by the same letter are not significantly different at the 0.05 level.

Within each basal area level, density of pine regeneration exceeded 494 stems ha⁻¹, which approaches the minimum required in uneven-aged management (Farrar 1984). Pines in the seedling size class comprised 94% of submerchantable pine density. In regulated uneven-aged pine stands, the percentage of submerchantable-size pines within the mid-range of four size classes should approach the following distribution (Reynolds 1959): seedlings—32%, 2.5 cm—27%, 5.1 cm—23%, and 7.6 cm—18%.

The prescribed burns had a more depressing effect on submerchantable pine density than did basal area (Table 2). Densities on a 3-yr burning cycle (521 stems ha⁻¹) and 9-yr burning cycle (217 stems ha⁻¹) were less than on control plots (1,240 stems ha⁻¹), which had fewer submerchantable pines than on the 6-yr cycle (2,612 stems ha⁻¹).

The highest quadrat stocking on any basal area treatment was 27% at 9 m² ha⁻¹, which is much better than the 10% to 15% stocking on the other basal area treatments (Table 2). Quadrat stocking of submerchantable pines tended to decline as overstorey pine basal area increased, which is a similar result to that obtained for density. Quadrat stocking on the 6-yr burn plots averaged 28% which was 17 to 23% more than stocking on the other burn treatments. Since unburned control plots averaged only 18% quadrat stocking, poor distribution of pine regeneration cannot be attributed solely to the use of fire. There was no basal area by burning-cycle interaction in the statistical analysis of quadrat stocking.

At the time of this 10-yr assessment and within the recommended range of basal area (9 and 14 m² ha⁻¹) for uneven-aged management of loblolly and shortleaf

pinus, only four treatments, out of a possible eight, were considered to be adequately stocked with submerchantable-size pines. These included the 6-yr burn plots with 9 m² ha⁻¹ (64% quadrat stocking [qs]), control plots with 9 m² ha⁻¹ (64% qs), 6-yr burn plots with 14 m² ha⁻¹ (43% qs), and 3-yr burn plots with 9 m² ha⁻¹ (37% qs). For the other four treatments within recommended basal area levels, quadrat stocking of submerchantable-size pines, as a percent of total pine stocking, averaged less than 25%.

Response of pine seedlings and saplings to prescribed burning

For the individual sample pines that were selected for evaluation following the 1989 prescribed burn, there was a statistically significant correlation ($r^2 = 0.86$) between total height and groundline diameter (Figure 2). Consequently, either total height or gld might be used as predictors of pine survival following prescribed winter burns in uneven-aged stands.

Pines of submerchantable-size were most likely to survive prescribed burns in the present study if crown scorch was less than 60%, and if the trees were taller than 2.4 m or larger than 3.8 cm in gld at the time of burning. Regardless of size, pines with 100% crown scorch or complete crown consumption did not survive.

Crown scorch in late January 1990, 8 weeks after prescribed burning, averaged 95% for pine seedlings <0.9 m tall, 90% for seedlings 0.9 m tall to 1.4 cm in

dbh, and 80% for saplings 1.5 to 8.9 cm in dbh. Only 15% of the 240 sample pines survived through the first growing season after burning. Of those pines that survived, 86% were in the sapling size class (1.5 cm to 8.9 cm dbh). The original postburn crown scorch for pines that survived through the next growing season averaged 50% on trees <0.9 m tall, 67% on trees 0.9 m in height to 1.4 cm in dbh, and 65% on trees 1.5 cm to 8.9 cm in dbh. For these survivors, live-crown ratio was 15% less, one year after the burn, than before the burn.

Of the 36 pine seedlings and saplings that survived for one growing season after prescribed burning, 75% were judged as free-to-grow at the time of burning. In all three size classes of submerchantable-size pines, the greatest proportion of pines that died during the year after burning were overtopped by pines.

Survival of pines that were <1.5 cm in dbh was too scant for analyzing growth response following crown scorch. During the year after burning, surviving pines that were 1.5 to 8.9 cm in dbh exhibited a statistically significant decline in both height growth (Figure 3) and gld growth (Figure 4) as crown scorch increased.

Density and quadrat stocking of woody competition

Unlike pine regeneration, density of woody competition, which averaged 11,256 rootstocks ha⁻¹, was not significantly influenced by overstorey basal area because hardwood species are generally more shade

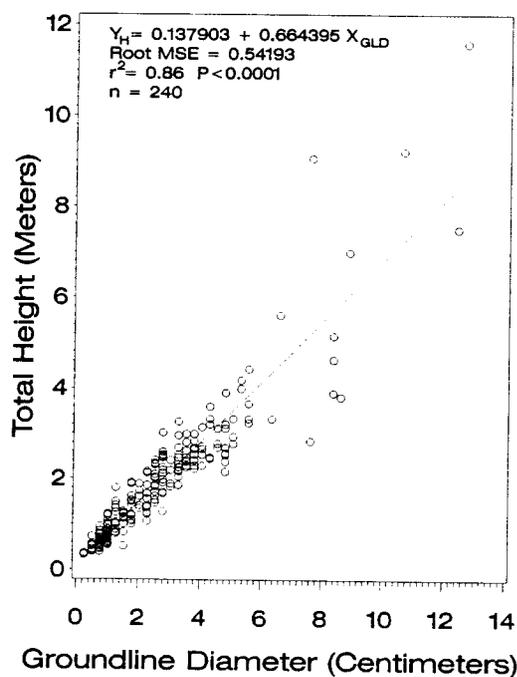


Figure 2. Relationship of total height to groundline diameter for submerchantable-size loblolly pines in uneven-aged stands.

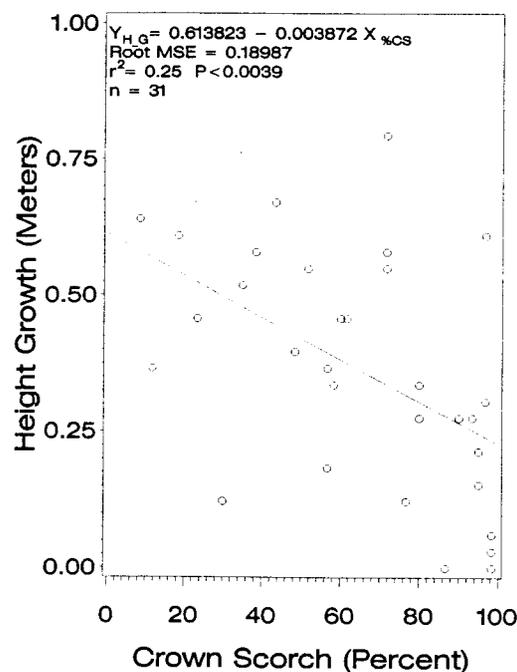


Figure 3. Impact of crown scorch on height growth of submerchantable-size loblolly pine saplings one growing season after a prescribed winter burn.

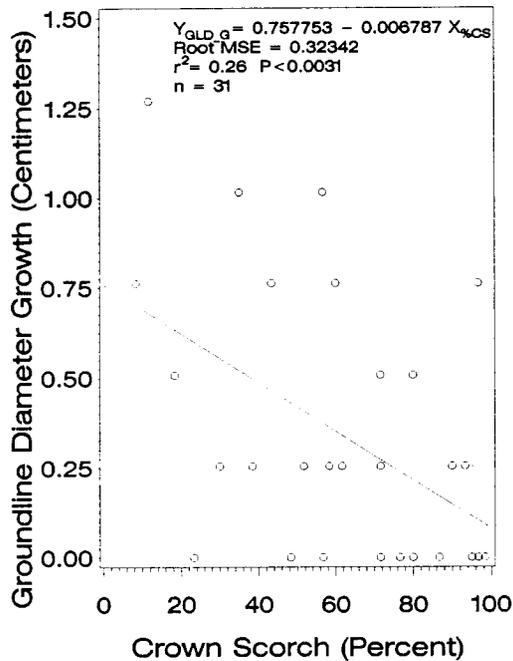


Figure 4. Impact of crown scorch on groundline diameter growth of submerchantable-size loblolly pine saplings one growing season after a prescribed winter burn.

tolerant than the southern pines. Again there was no basal-area by burning-cycle interaction (Table 3). Recurring fires on a 3-yr cycle tended to have fewer hardwood rootstocks than were recorded on control plots or on those plots in the 6-yr or 9-yr burn cycles, but differences in rootstock densities between burn treatments were not statistically significant (Table 3).

When the 10-yr assessment was made, seedling-size rootstocks were the most prevalent form of hardwood competition, accounting for 93% of all woody rootstock density. Sapling-size hardwoods averaged only 741 stems ha^{-1} . There were no differences between basal area treatments for density of sapling-size hardwoods, but unburned control plots had more ($P=0.0005$) sapling-size hardwoods (1,769 ha^{-1}) than plots in the 6-yr (660 ha^{-1}), 9-yr (420 ha^{-1}), or 3-yr (114 ha^{-1}) burning cycles.

Callicarpa americana L. (American beautyberry) was found to be the most prolific hardwood competitor during this investigation. Regardless of burning cycle or basal area treatment, 27% of dominant seedling-size woody rootstocks were American beautyberry. For sapling-size hardwoods, three species predominated in terms of density. *Aralia spinosa* L. (devils-walking-stick), *Cornus florida* L. (flowering dogwood), and *Quercus nigra* L. (water oak) accounted for 29% of

Table 3. Density and quadrat stocking of submerchantable-size hardwood rootstocks, 10 years after study establishment

Treatments	Measurement variable for submerchantable hardwoods	
	Density	Quadrat stocking ¹
	Rootstocks ha^{-1}	Percent
Burning cycles		
Control, no burning	11,898	95 ab ²
3-Yr	9,827	89 b
6-Yr	12,745	97 a
9-Yr	10,553	94 ab
Mean Square Error	820,213	0.0071
P>F	0.0661	0.0227
Basal area		
9 $\text{m}^2 \text{ha}^{-1}$	10,977	92
14 $\text{m}^2 \text{ha}^{-1}$	11,989	96
18 $\text{m}^2 \text{ha}^{-1}$	11,328	94
23 $\text{m}^2 \text{ha}^{-1}$	10,732	93
Mean Square Error	785,844	0.0098
P>F	0.5359	0.6828

¹ A 4- m^2 quadrat was stocked if it contained at least one hardwood rootstock of submerchantable size.

² Within treatments, columnar means followed by the same letter are not significantly different at the 0.05 level.

dominant sapling-size hardwoods across burning cycles and accounted for 37% across basal area treatments. Quadrat stocking of all woody rootstocks averaged 94%, with no differences between basal area levels and no interaction between basal area and burning cycles (Table 3). Plots in the 3-yr burning cycle averaged 89% quadrat stocking of woody rootstocks, and that was significantly less than on plots in the 6-yr burning cycle (97%).

Quadrat stocking of sapling-size hardwoods was strongly influenced by both burning cycles and basal area levels. All burning treatments resulted in fewer ($P=0.0001$) quadrats stocked with sapling-size hardwoods (11%) when compared to unburned control plots (42%). Plots with the most recurrent burning cycle (3 yrs) had fewer quadrats stocked with sapling-size hardwoods (3%) than plots in the 6-yr burning cycle (20%). Because of more open growing conditions, quadrat stocking of sapling-size hardwoods was highest ($P=0.003$) under merchantable basal areas of 9 and 14 $\text{m}^2 \text{ha}^{-1}$ (23%) as compared to 23 $\text{m}^2 \text{ha}^{-1}$ (15%). Since sapling-size hardwoods were eliminated by stem injection in 1981, density and quadrat stocking differences between treatments in 1991 were attributed to fire effects and basal area levels.

Discussion

Natural seedcrops and fire effects on pine establishment

Since natural seeding of loblolly-shortleaf pines is highly correlated with first-year seedling establishment

(Cain 1991), variability in seedcrops tended to confound the effects of basal area and burning-cycle treatments in this 10-yr investigation. A problem that is specific to the use of fire in association with natural pine regeneration is that fire can destroy the seed as well as kill pine regeneration. In the present study, three out of the four prescribed burns were conducted in January (Table 1) when most seed had already fallen to the ground. Even so, prescribed burning after January 1 in a bumper seedyear can still result in favorable pine regeneration because seeding is so prolific as to occupy all available microsites on the forest floor and because seedfall remains quite heavy beyond the time of burning (Cain 1986).

The higher pine density on plots in the 6-yr burning cycle is easily accounted for. The 3-yr and 6-yr cycles (Jan.-Feb. 1987) were the only burns to coincide with a bumper pine seedcrop (2,500,000 seeds ha⁻¹) and harvesting on the 6-yr cutting cycle (Nov. 1987). The third burn on plots in the 3-yr cycle (Dec. 1989) reduced submerchantable pine density to be comparable to that recorded on plots in the 9-yr burning cycle, that occurred at the same time as the 3-yr burn.

Fire induced mortality

According to Wade and Lunsford (1989), the best indicator of crop tree damage after a burn is percent foliage discoloration (crown scorch). Similarly, Cooper and Altobellis (1969) reported that mortality in young loblolly pine appears to be more closely related to crown damage than to bole damage. In the present study, pines of seedling size with more than 60% crown scorch were not likely to survive a prescribed winter burn, but pines of sapling-size had a higher probability of surviving even when crown scorch exceeded 60%.

The likelihood that submerchantable-sized pines will survive prescribed burns has been linked to tree size in other studies. For example, Cooper and Altobellis (1969) reported that loblolly pine trees larger than 10 cm in dbh are not easily killed by backfires or low-intensity headfires under moderate burning conditions. According to Crow and Shilling (1980), loblolly and shortleaf pines are completely vulnerable to winter surface fires as seedlings but become resistant when they are 3.7 to 4.6 m tall and 7.6 cm in gld. Waldrop and Lloyd (1987) found that, when prescribed fires were used for precommercial thinning, mortality of loblolly pine was highest for trees less than 3.7 m tall.

In the present study, mortality was higher for submerchantable pines that were overtopped by pines of merchantable size. This suggests that fire intensity is higher under a pine canopy, where pine litter, which carries the fire, is apt to be the greatest and where needle drape on overtopped pines may contribute

enough fuel to increase mortality. Fires of less intensity would be expected in canopy gaps due to a lack of pine litter. Open-grown pine regeneration would also be expected to have larger crown volumes than those overtopped by larger trees. Since suppressed pines have thin bark (Cain 1990) and thin crowns with small needles, buds, and branch endings, they are more easily killed by fire than vigorous, open-grown pines of the same size that have more massive crowns and thicker bark (Byram 1948, Hare 1965).

Since unburned control plots had more sapling-sized hardwoods than the three burn treatments, some other form of hardwood control—biological, chemical, or mechanical—is likely to be periodically required if pine production is the objective of management. Recurring fires were obviously effective in reducing the size of hardwood competition, but a reservoir of resprouts was in position to invade the site once burning stopped for any length of time.

Conclusions and Recommendations

In order to retain adequate density of submerchantable-size loblolly and shortleaf pines in uneven-aged stands subjected to prescribed winter burns, at least 494 stems ha⁻¹ of pine seedlings and saplings should be taller than 2.4 m in height, or greater than 3.8 cm in gld, and crown scorch must be less than 60%. If the majority of the submerchantable pines are smaller than these specified sizes, regardless of the degree of crown scorch, then density of the smaller pines should probably exceed 3,300 stems ha⁻¹ before burning, in anticipation of losing 85% of the population.

The 6-yr burning cycle resulted in higher density and better quadrat stocking of pine regeneration compared to any other burn treatment, but those results were attributed more to a bumper pine seedcrop during the winter that burning occurred, rather than to the length of the burning cycle. Consequently, the use of rigid burning cycles are not recommended in uneven-aged stands where prescribed burning is being considered. A more realistic approach is to use several annual or biennial winter burns to keep the submerchantable hardwood component in check for a longer period of time. The last burn should be timed to coincide with a better-than-average pine seedcrop, and should be completed before the majority of seed have fallen. Subsequent burns should be conducted only after the recommended density of established pine regeneration has attained a size that is resistant to prescribed fire.

Both density and quadrat stocking of pine regeneration were negatively correlated with increasing overstorey pine basal area levels. This helps explain

why basal areas of 18 and 23 m² ha⁻¹ are not recommended for managing uneven-aged stands of loblolly and shortleaf pines. The best approach is to use basal area levels that have been tested and proven to work through time. For uneven-aged loblolly-shortleaf pine stands, proven basal areas range from 10 to 17 m² ha⁻¹ (Reynolds et al. 1984).

The use of prescribed winter burns in uneven-aged stands of loblolly and shortleaf pines has not been tested long enough to conclude that fire alone is sufficient to manage competing vegetation while allowing ingrowth of submerchantable pines to merchantable size classes.

Acknowledgments. The design for this study was conceived by R. M. Farrar, Jr. (USDA Forest Service, retired), B.F. McLemore (USDA Forest Service, retired), and P.A. Murphy (USDA Forest Service, Southern Forest Experiment Station). The assistance of Bettina Pournaghsband, computer programmer, was appreciated.

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