Effects of Seasonal Prescribed Fires on Residual Overstory Trees in Oak-Dominated Shelterwood Stands

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ABSTRACT: *A study was initiated in 1994 to evaluate the degree of bole damage and crown decline residual overstory trees would experience because of prescribed burning of shelterwood stands. Three oak-dominated shelterwood stands, partially harvested 2 to 4 yr earlier, were divided into four treatments (unburned control, spring burn, summer burn, and winter burn). Fifteen permanent sampling points were systematically located in each 5 to 12 ac treatment area, and overstory trees were selected from these points with a 10 BAF prism. Before burning, each tree was evaluated for lower bole and crown condition and reevaluated two growing seasons after the fires. Hickory, oak, and yellow-poplar were largely unaffected by the winter and summer prescribed fires but displayed bole damage and crown decline following spring burning. American beech and red maple declined after all fire treatments. Fire damage to oak, hickory, and yellow-poplar was strongly associated to presence of logging slash near a tree's base. Directional felling or moving slash should minimize injury to these trees. This research will aid resource managers wishing to use prescribed fire in shelterwood stands to favor oak regeneration while minimizing damage to residual overstory oaks. South. J. Appl. For. 23(2):88–93.*

Prescribed fire has until recently been dismissed as a viable tool in the hardwood forest because of wildfire history, multiple intermixed ownerships, complex species composition, and lack of knowledge about fire effects (Pyne 1982, Bowersox 1983, Simard 1983). Research into the role of fire in perpetuating oak stands on productive sites has previously yielded little or no benefit to oak regeneration (McGee 1979, Teuke and Van Lear 1982, Wendel and Smith 1986, Loftis 1990, Merritt and Pope 1991). However, these studies generally addressed fire as a single, usually preharvest, treatment and did not distinguish among different levels of fire intensity. Historically, fire occurred in conjunction with other disturbances, creating many oak stands (Pyne 1982, Van Lear and Waldrop 1989, Abrams 1992). Recent research indicates that prescribed burning of shelterwood stands a few years after initial harvest favors oak reproduction in the advance regeneration pool if the fire occurs during the growing season and at moderate to high intensities (i.e., flame lengths about 3 ft) (Keyser et al. 1996, Brose and Van Lear 1998).

An obvious concern of prescribed burning after an initial shelterwood harvest in oak-dominated stands is the potential damage to residual overstory trees, which leads to fungal infection and bole degradation (Nelson et al. 1933, Roth and Hepting 1943). Two scenarios are possible. First, fire may be intense due to the presence of slash and increased exposure to sunlight and wind, making levels of damage and mortality of residual oaks unacceptably high. Conversely, the open nature of a shelterwood stand coupled with the thick bark of a mature oak may limit damage and mortality to just those trees with slash near their bases.

Beginning in 1994, a multifaceted prescribed fire study in oak-dominated shelterwood stands was initiated to address fire effects in these systems. One aspect of this study was to document how much bole damage, crown decline, and mortality of residual overstory trees occurred due to seasonal prescribed fires. We also wanted to identify potential measures to reduce or eliminate these losses. This information will aid resource managers wishing to use prescribed fire in conjunction with shelterwood harvesting to enhance oak regeneration while minimizing damage and mortality to residual overstory trees.

Methods

Study Area

This study was conducted at the Horsepen Wildlife Management Area in the Piedmont of central Virginia Topography consists of broad gently rolling hills between 500 and 600 ft elevation. Mean annual precipitation is 43 in. distributed evenly throughout the year. The average growing season is 190 days. Mean annual temperature is 57°F with a January mean of 39°F and a July mean of 75°F

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Table 1. Site and stand characteristics of three hardwood stands before the initial shelterwood harvest.

Characteristic	Stand		
	Dunnavant	Lake Road	Ward Farm
Size (ac)	42	50	35
Forest type*	WO/NRO/BO	WO/NRO/BO	WO/NRO/BO
Basal area (ft^2/ac)	120	120	120
Site index†	75	80	75
Soil texture	Sandy loam	Sandy loam	Sandy loam
Age (dominant oak)	100	90	90
Slope position	Upper half	Upper half	Upper half
Aspect	NE	E, SE	E
Mean slope (%)	7	7	5
Slope range (%)	0–20	0–20	0–5

* WO = white oak, NRO = northern red oak, BO = black oak (Eyre 1980).
† Feet at 50 yr for white oak.

(Reber 1988). The area is presently owned and managed by the Virginia Department of Game and Inland Fisheries (VDGIF).

Three hardwood stands (Dunnavant, Lake Road, and Ward Farm), cut to shelterwood densities 2 to 4 yr earlier, were selected in 1994 for the study. According to VDGIF records, stands were similar in site and stand characteristics before the initial harvest (Table 1). Soils were of the Cecil series, which are deep, well-drained sandy loams (Typic Hapludult) derived from gneiss, granite, and schist parent material (Reber 1988). Common overstory trees were white oak (*Quercus alba*), northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), black oak (*Q. velutina*), chestnut oak (*Q. prinus*), yellow-poplar (*Liriodendron tulipifera*), pignut hickory (*Carya glabra*), and mockernut hickory (*C. tomentosa*). Ages of dominant oaks were determined by coring five trees at breast height (4.5 ft) per stand. Common midstory hardwoods included red maple (*Acer rubrum*), flowering dogwood (*Cornus florida*), blackgum (*Nyssa sylvatica*), American beech (*Fagus grandifolia*), American hornbeam (*Carpinus caroliniana*), and sourwood (*Oxydendrum arboreum*).

Table 2. Basal areas (ft^2/ac) of major tree species groups in oak-dominated stands before and after the initial shelterwood harvest.

Stand	Species	Before	Removed	After
Dunnavant	Beech/maple	26.0	25.0	1.0
	Hickory/poplar	15.2	3.5	11.7
	Upland oak	78.8	42.2	36.6
	Total	120.0	70.7	49.3
Lake Road	Beech/maple	14.4	12.2	2.2
	Hickory/poplar	14.0	6.5	7.5
	Upland oak	91.6	40.1	51.5
	Total	120.0	58.8	61.2
Ward Farm	Beech/maple	30.9	26.6	4.3
	Hickory/poplar	11.4	3.4	8.0
	Upland oak	77.7	30.0	47.7
	Total	120.0	60.0	60.0

Harvesting removed most of the codominant oaks and low-value species, leaving 20 to 25 dominant oaks per acre and fewer numbers of other species. Hickory and oak were retained for mast production while American beech, red maple, and yellow-poplar were left for esthetics, spacing, or by logger oversight. Two stands were harvested in summer 1990 and the third in winter 1992. Slash was left in place. Volumes removed averaged 6 mbf/ac (International log rule) and residual basal areas averaged 57 ft^2/ac (Table 2).

Study Design and Measurements

A randomized complete block design was used to evaluate season-of-burn effects on bole and crown condition of residual overstory trees. Each stand, i.e., replicate, was divided into four 5 to 12 ac treatment areas (winter burn, spring burn, summer burn, and an unburned control). Treatment areas served as experimental units. Within each treatment, 15 sampling points (subsamples) were systematically located and permanently marked with a 4.5 ft metal post. From each post, trees greater than 6.0 in. dbh were selected using a 10 BAF prism and permanently marked.

Each tree was placed into one of three species groups based on canopy position and bark thickness as measured 1 ft above the ground with a bark gauge. Species groups, in order of decreasing canopy position and decreasing bark thickness, were: oak, hickory/poplar, and beech/maple.

In late summer 1994 (before burning), diameter of each tree was measured at breast height. Below that height, the bole of each tree was examined for visible defects and evidence of rot and classified as undamaged, slightly damaged, moderately damaged, severely damaged, or dead. Undamaged trees had no defects, and slightly damaged trees had defects limited to one face (< 25% of bole circumference). Moderately damaged trees had defects on two faces (25 to 50% of bole circumference), while severely damaged trees had defects on three faces (50 to 75% of bole circumference). Trees with defects on all faces (> 75% of bole circumference) were considered dead. In winter 1996 (after burning), each bole and butt was reevaluated using the same procedure.

The amount of logging slash within 3 ft of each tree's base was visually estimated and categorized as absent, moderate, or plentiful *Absent* was defined as typical fuel loadings for a mature oak forest with no recent disturbance. *Moderate* slash included typical fuel loading plus up to five 3 in. diameter branches of obvious harvesting origin. *Plentiful* slash contained more than five 3 in. diameter branches in addition to typical fuel loadings.

Before prescribed burning (late summer 1994), each tree was rated for crown condition using the Gottschalk and MacFarlane (1993) method. Healthy trees had full crowns with less than 25% dieback, dense foliage, and little or no epicormic sprouting. Fair-crowned trees had dieback ranging from 25 to 50%, subnormal foliage, and some epicormic sprouting. Trees with crowns exhibiting more than 50% dieback, thin foliage, and abundant epicormic sprouting were rated as poor. Snags were classified as dead. In late summer 1996 (after burning), each tree was reevaluated for crown condition using the same procedure.

Prescribed Fires

Prescribed fires were conducted in 1995 on February 25 and 27 (winter burn), April 26 (spring burn), and August 24 (summer burn), by VDGIF personnel in accordance with department policy and state law. Spring fires occurred when leaves were 50 to 75% expanded and were commenced after 4:00 PM due to Virginia's outdoor burning law. Fuel and weather conditions were monitored with a belt weather kit and varied among and within seasons (Table 3). All prescribed fires were ignited by hand with drip torches in a strip-head fire pattern commencing at the downwind side of the treatment. Ignition strips were initially spaced 10 ft apart and gradually widened to 50 ft once firelines were secured.

Behavior of prescribed fires was measured in each treatment area. Flame length (FL) was estimated by using height reference markers placed at 1 ft intervals to a height of 6 ft on five residual trees (Rothermel and Deeming 1980). Rate of spread (ROS) was calculated by marking, timing, and measuring five 2 min. runs per plot with a stopwatch. Spring fires produced the most intense fire behavior with flame lengths and rates of spread averaging 3 ft and 5 ft/min., respectively. Winter and summer fires behaved similarly to spring fires when weather conditions permitted, but increases in relative humidity and decreases in wind generally resulted in about a 50% reduction in flame length and rate of spread.

Statistical Analysis

For each treatment, chi-square analysis was used to evaluate differences between preburn and postburn proportions of each species group in each bole damage category with the preburn percentage serving as the expected value (Ott 1993). Preburn and postburn differences in crown condition were similarly tested. For these tests, the rejection region was $P \leq 0.05$.

For each treatment, slash data were used in conjunction with bole damage categories to create a contingency table containing the proportions of each species group. Chi-square test for independence was used to determine if amount of slash influenced the proportion of each species group within each bole damage category. An adjusted contingency coefficient (Cramer's V) was used to measure the strength of the slash/bole damage relationship on a 0 to 1 scale (i.e., 0 is no association and 1 is a perfect association), for each species group in each fire treatment (Ott 1993). For these tests, the rejection region was $P \leq 0.05$.

Table 3 Environmental conditions of seasonal prescribed fires in oak-dominated shelterwood stands at time of burning.

	Stand		
Conditions	Dunnavant	Lake Road	Ward Farm
Spring burn			
Burn date	4/26/95	4/26/95	4/26/95
Time-of-burn	2000	1630	1830
Air temperature (°F)	68	73	70
Relative humidity (%)	28	20	20
Wind direction	SW	SW	SW
Wind Speed* (mi/hr)	2	13	8
Cloud cover (%)	0	0	0
Fuel† moisture (%)	10	10	10
Summer burn			
Burn date	8/24/95	8/24/95	8/24/95
Time-of-burn	1630	1430	1230
Air temperature (°F)	91	95	95
Relative humidity (%)	56	44	46
Wind direction	SW	SW	SW
Wind Speed* (mi/hr)	1	13	10
Cloud cover (%)	0	0	0
Fuel† moisture (%)	14	14	14
Winter burn			
Burn date	2/25/95	2/27/95	2/27/95
Time-of-burn	1300	1100	1430
Air temperature (°F)	46	43	48
Relative humidity (%)	26	62	54
Wind direction	NW	E	E
Wind Speed* (mi/hr)	10	3	5
Cloud cover (%)	0	100	100
Fuel† moisture (%)	10	15	15

* Eye-level, in stand at ignition of the fires.
† Dead woody debris between 0.25 and 1.00 in. diameter.

Results

Preburn Conditions

A total of 733 trees were selected from the 180 sampling points with oaks comprising 67% of the total. The hickory/poplar group, primarily hickory, accounted for another 22%, while beech/maple made up the remainder (11%) of the sampling pool.

Oaks were the largest trees in the sampling pool with an average diameter of 19 in., average bark thickness of 0.75 in., and usually occupying dominant canopy positions. Average diameter and bark thickness of the hickories and yellow-poplars were 13 in. and 0.50 in., respectively. These trees were generally codominant in the canopy. Trees in the beech/maple group averaged 9 in. diameter, 0.10 in. bark thickness, and were typically confined to intermediate canopy positions.

Prior to prescribed burning, no differences in bole condition were detected among stands or among treatments, allowing data to be pooled. The vast majority (≈ 95%) of all residual trees had undamaged or slightly damaged boles (Figures 1–3). Wounds on trees with slight butt damage (confined to one face) were usually within 1 ft of the ground, not high enough to degrade the bottom log (Hanks 1976). Moderately and severely damaged trees were extremely rare prior to burning.

When slash was present, it almost always consisted of five or more 3 in. diameter limbs with accompanying smaller branches. For this reason, slash was classified as either present or absent. Slash was present near about 20% of the trees in the control and spring burn treatments and about 10% of the trees in the other two treatments. No differences in slash presence were found among species groups except in the summer burn treatment, where more oaks had slash near them than the hickory/poplar group.

Preburn crown conditions were uniform, with no differences detected among stands or among treatments. Approximately 93% of all trees had fair or full crowns (Figures 1–3). More crowns of oaks were rated fair than those of the other two groups. Trees with poor crowns and snags were rare.

Postburn Conditions

Winter burning decreased the proportion of oaks with undamaged boles from 73 to 57%, but this loss was not statistically detectable (Figure 1). The number of slightly damaged oaks did not change, resulting in 80% of all oaks having either undamaged or slightly damaged boles. Those oaks damaged by fire have survived for two growing seasons and were recorded as increases in the moderate and heavy damage categories. Summer fires produced similar results to winter burning. Spring prescribed fires significantly reduced the proportion of undamaged oaks from 73 to 50% and increased the percentage of dead oaks from 1 to 19%. Oaks in the control treatment did not change in any bole damage class.

Winter burning did not reduce the proportion of oaks in any of the crown condition categories, but spring and summer fires decreased the proportion of oaks with healthy crowns from 47 to 33 and 26%, respectively (Figure 1). The proportion of fair-crowned oaks increased after summer burning as previously healthy trees dropped one crown classification. The proportion of dead overstory oaks increased only in the spring burn treatment, rising from 1 to 19%. Oaks in the control treatment did not change in any crown class.

Overstory hickories and yellow-poplars exhibited the same trends in bole conditions as oaks (Figures 1 and 2). Control, winter burn, and summer burn treatments did not affect the proportion of these species in any bole condition category. Spring fires reduced the percentage of hickories and yellow-poplars with undamaged boles, and these losses became increases in the heavy damage and dead categories.

Control and winter burn treatments did not change the distribution of hickories and yellow-poplars among crown condition categories (Figure 2). Summer fires reduced the proportion of hickories and yellow-poplars with healthy crowns from 86 to 64%, causing an increase in the proportion of fair-crowned trees. Spring burning also reduced the number of healthy crowned trees from 86 to 67%, with this loss causing increases in the fair and dead categories.

All fire treatments reduced the proportion of beech and red maple with undamaged boles (Figure 3). Before burning, 63% of these trees had undamaged boles, but following seasonal fires, only 17 to 21% remained undamaged. This fire damage was often lethal, with all fire treatments increasing

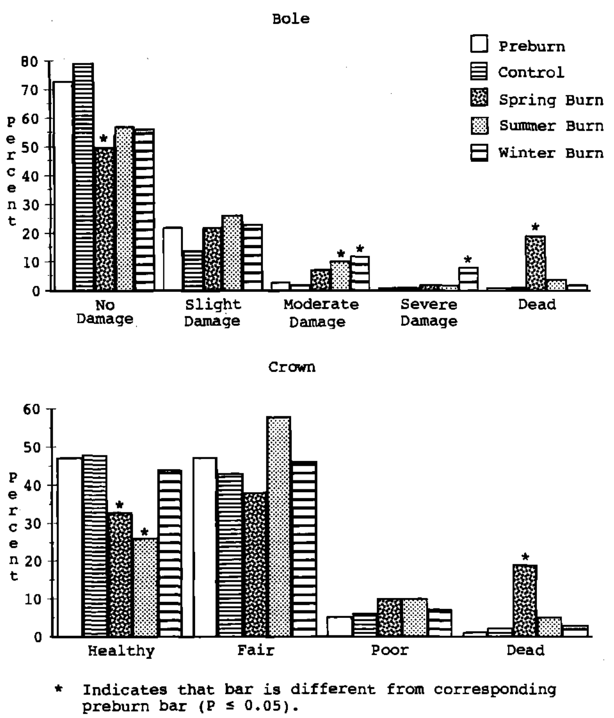

Figure 1. Effect of seasonal prescribed fires on bole and crown condition of oak overstory trees in shelterwood stands.

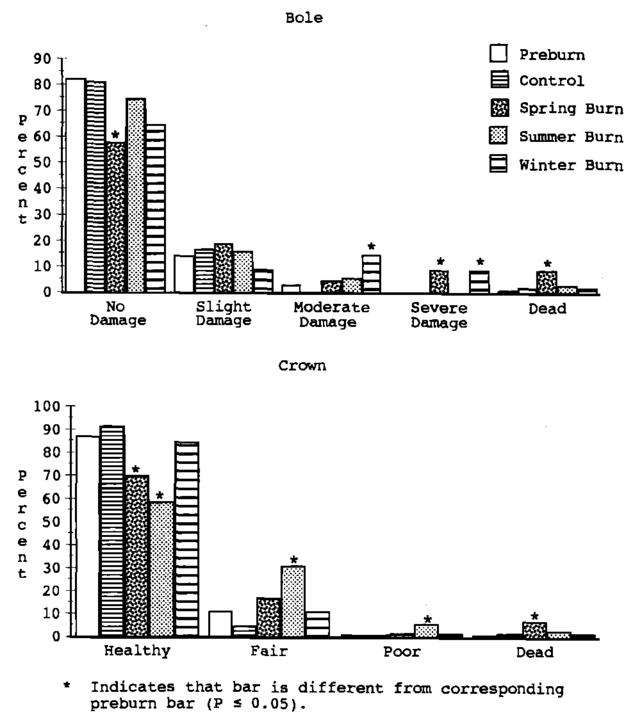

Figure 2. Effect of seasonal prescribed fires on bole and crown condition of hickory/poplar overstory trees in shelterwood stands.

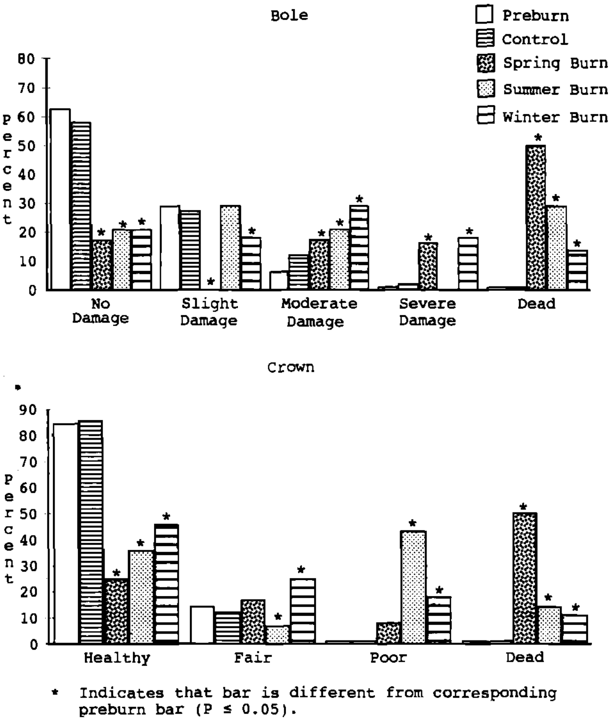

Figure 3. Effect of seasonal prescribed fires on bole and crown condition of beech/maple overstory trees in shelterwood stands.

the percentage of dead beech and red maple from 1% (preburn) to 17% (winter burn), 31% (summer burn), and 50% (spring burn). Those trees surviving the fires were often moderately or severely damaged as the proportions in these categories usually increased regardless of fire treatment.

Fire damage to the boles of beech and red maple manifested itself in declines in crown condition (Figure 3). All fire treatments decreased the proportion of healthy crowned beech and red maple from 84% (preburn) to 45% for the winter burn treatment, 34% for the summer burn treatment, and 25% for the spring burn treatment. Corresponding increases in the poorly crowned and dead categories occurred for all fire treatments with spring burning causing 50% mortality.

Influence of Slash

Regardless of fire treatment, presence of slash near the bases of residual trees was strongly associated (Cramer's V > 0.81) with bole damage of oaks, hickories, and yellow-poplars (Table 4). From 94 to 100% of all oaks, hickories, and yellow-poplars killed or severely damaged by the fires had slash present at their bases. Presence of preburn slash was moderately associated (Cramer's V ranged from 0.48 to 0.54) with the distribution of beech and red maple in the bole damage categories. In all cases, $P \leq 0.05$; indicating that presence of slash was a major contributing factor to bole damage. Conversely, there was little or no damage to any trees when slash was absent before burning. For example, over 90% of undamaged or slightly damaged oaks, hickories, and yellow-poplars had no slash within 3 ft of their bases.

Discussion

This study provides two important insights for practicing foresters. First, it is possible to prescribe burn oak-dominated shelterwood stands with moderate to high intensity fires (i.e., flame lengths of 2 to 4 ft), without killing a large portion of the residual crop trees. The majority of oaks (50 to 60%) were undamaged by any seasonal fire. Slightly damaged oaks accounted for another 20 to 25% of sampled trees, and their fire scars were usually confined to one face and below the merchantable portion of the bole. Thus, 70 to 85% of overstory oaks were essentially unaffected by prescribed burning.

Another insight is the importance of preventing and/or removing slash accumulation near residual crop trees before burning. Of the oaks, hickories, and yellow-poplars (5 to 20%) killed or severely damaged by prescribed burning, nearly all had logging slash within 3 ft of their bases. This slash contributed to and prolonged intense fire against the tree. Conversely, undamaged and slightly damaged oaks, hickories, and yellow-poplars were strongly associated with absence of slash at their bases.

Table 4. Proportion (%) of trees in each bole damage class with slash at their bases before the prescribed fires.

	Bole damage classes					Cramer's
Species group	Undamaged	Slight	Mod.	Severe	Dead	V*
Spring burn						
Beech/maple	0	0	57	66	64	0.51
Hickory/poplar	2	5	38	97	94	0.82
Oak	2	3	36	94	97	0.81
Summer burn						
Beech/maple	0	0	62	63	57	0.48
Hickory/poplar	2	2	39	96	94	0.81
Oak	3	1	41	95	98	0.83
Winter burn						
Beech/maple	0	0	50	76	74	0.54
Hickory/poplar	5	5	44	97	97	0.87
Oak	4	8	39	100	100	0.88

* Indicates the strength of the slash/bole damage relationship: 0 indicates no association; 1 a perfect relationship. All Cramer's V tests were significant at $P \leq 0.05$.

This slash/fire intensity problem is easily prevented by directional felling during harvesting. Residual densities of 20 to 25 overstory oaks per acre leave about 40 ft spacing between trees, ample area to avoid slash accumulation near bases of crop trees. When directional felling is not possible, removing slash from tree bases before burning is essential. Foresters will need to work closely with loggers during the initial harvest to ensure understanding of the need for directional felling and its proper implementation. Close supervision is essential to reduce or eliminate damage to residual trees by the prescribed fires.

This study also illustrates three well-known facts about fire. First, bark thickness is an important plant defense structure that is strongly correlated to fire resistance (Stickel 1935, Hare 1965). When slash was absent near hickory, oak, and yellow-poplar, they withstood fire with little to no damage while American beech and red maple suffered considerable damage because their thin bark was insufficient protection against the heat of a passing fire. Fire suppression efforts during this century have allowed beech and red maple to invade uplands from their traditional cool moist environments (Hodgkins 1958, Pyne 1982, Harmon 1984, Van Lear and Waldrop 1989).

Second, spring fire caused the greatest damage to residual overstory trees of all burning treatments. Spring fires easily damage hardwood trees because warm air temperatures, direct sunlight on boles, and fully hydrated vascular tissues help raise cambial temperatures to over 140°F, causing cell death. Summer burning was slightly less damaging, probably due to lower intensity fires and some shading of trees' boles. Winter fires caused the least damage due to cooler ambient conditions, low insolation levels, and the dormant state of the trees (Hare 1961, Greulach 1973).

Finally, prescribed fires must be carefully planned and executed in shelterwood stands because of the logging slash. These fuels coupled with favorable burning conditions can quickly create extreme fire behavior, causing worker safety problems, excessive crop tree damage, and possible fire escape. In this study, one of the spring burns killed all overstory trees in a 1 ac area adjacent to treatment plots when wind gusts combined with high fuel loadings to create 10 to 15 ft flames.

Given the abundance and maturity of the oak resource in the Southeast, there is strong interest in oak regeneration techniques. Shelterwood harvesting followed by prescribed fire has potential to help fill this need (Keyser et al. 1996, Brose and Van Lear 1998). This paper will help foresters make use of fire in shelterwood stands while avoiding damage to residual trees.

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