United States
Department of
Agriculture

Forest Service

Southeastern Forest
Experiment Station

General Technical
Report SE-41

Effects of Fire on Southern Pine: Observations and Recommendations

Dale D. Wade and R.W. Johansen

Front Cover

Damage 1 month after a 3/6/86 headfire in an 8-year-old slash pine plantation near Waycross, GA. Pines in the central foreground were completely crown scorched. The candles visible on some terminal leaders show those buds survived the fire. Dead needles in the upper crowns have already dropped, whereas branch cambium in the lower crowns was heat-killed precluding formation of an abscission layer at the needle base. Thus, the dead foliage on those branches will remain attached for long periods of time. Photo taken by Wayne Adkins, Southern Forest Fire Laboratory.

September 1986

Southeastern Forest Experiment Station
P. O. Box 2680
Asheville, North Carolina 28802

Contents

Effects of Fire on Southern Pine: Observations and Recommendations

Dale D. Wade, Project Leader

R.W. Johansen, Research Forester

Sou thern Forest Fi re Labora tory
Dry Branch, Georgia

ABSTRACT

This overview systematically discusses fire damage as it relates to al l parts of tbe tree: avai Zabl e 1 i terature is cri ti qued, apparent contra- dictions resolved, and some commonly beld misconcep- ti ons dispel l ed. Suggestions for avoiding fire damage during prescribed burns are gi veu.

Keywords: *Fire damage, fire injury, crown scorch, fire* mortality, bark char.

Introduction

In *tbe Southern Uni ted States the intenti onal use of fire bas evolved over the past three centuries into a highly sopbi sti ca ted tool, currently used on more than 4 mi 11 ion acres of southern pine forest 1 and each year. The tra-* di ti onal means of treating tbi s acreage *has been wi tb backfires. Tbese fires, if properly conducted, are of rel ati vely low intensity and cause li ttle if any need1 e scorch once tbe pines reach 20 to* 25 feet in height. Backfires are slow movi ug, however, generally spreading 1 ess than 150 feet per hour, wbi cb necessi ta tes numerous i n teri or pl owl i nes or lengthy burnout times. This slow rate of spread coup1 ed wi tb tbe 1 imi ted occurrence of days wi tb acceptable prescri bed burning condi ti ons means tba t tbe number of acres actually treated during a given year frequently fall s far *short of the number planned. Many* resource managers attempt to reach tbei r acreage goals by burning under marginal wea tber condi ti ous, extending *the* winter burning season *to* encompass early fall and 1 ate spring, or resorting to 1 i ne *beadfi res, whi cb take* much 1 ess time *to* complete but wbi cb burn wi tb increased i ntensi *ty. Inherent in al 1 tbese prac- ti ces is tbe greatly increased potenti al for fire damage. The addi ti onal acreage burned by uti 1 izing these more risky practices* is small, however, compared to the *gains realized* from emerging *aerial igni ti on tecbni ques.* Now thousands of acres can be burned during *a given day under close to ideal con-* di ti ons tba *t, incidentally, occur when litter* moisture is slightly *damper tban* desi rabl e for 1 i ne backfi res.

Aeri ally igni ted spotfi res sol ve many *of tbe problems associated wi tb* backi *ng fires, but tbey bave one poten- ti al ly maj or drawback: al though tbi s tecbni que resul ts in fires tba t burn in al 1 di recti ous,* most *of tbe area is exposed to beading or flanking flames; and the bigber fire intensi ties produced* increase tbe potential for crown scorch. *Intensi* ti es are al so magni fi ed along the merging zones as the spots burn *togetber. Tbus the resource* manager *needs to use care in sel ecti ng burning condi ti ons to prevent excessi ve beat from developing under the stand. If a* mistake i s made and i ntensi ties are bigber than desired, what del-eterious effects might a forest *manager expect?* and bow can *they* be assessed? Tbi s Report attempts to answer these ques- ti ons and, in so doing, dispel some *commonly hel d mi sconcepti ons. Al -* though the *yel* 1 ow or bard pines are empbasi zed- - *in particular, the four* major southern pines- -*much* of the i *nfor- mati* on presented pertains to other pine species as *wel* 1.

Plant Susceptibility

Plant susceptibility to fire varies among species as well as among individuals within a species. Differences between species are generally attributed to bark thickness, rooting depth, crown characteristics, and the relative density of the stand (Brown and Davis 1973). Within a species, the age of the tree, season of the year, prefire and postfire soil moisture conditions, and ambient temperature at the time of the fire are additional factors thought to be important. Rnowledge of these and other environmental, physiological, and phenological factors can be used by a resource manager to more accurately predict the fate of fire-damaged trees. Literature reviews describing some of these factors and their effects include Bare (1961), Langdon(1971), McArthur (1980), Ryan (1982), and Spalt and Reifsnyder (1962). Kulman (1971) presents an excellent review of the effects of insect defoliation which, like fire-induced crown damage, results in at least a temporary reduction in photosynthetic capacity.

The threshold temperature at which plant tissue death is instantaneous varies slightly by species but is generally considered to be 141 °F. Lower temperatures can also be lethal if sustained long enough. For example, Nelson (1952) found that the time needed to kill the needles of four southern pine species averaged less than 1 minute at 138 °F, almost 5 minutes at 131 °F, and over 11 minutes at 124 °F. Ursic (1961) found that tissue death occurred in 2 hours at 118 °F and Hare (1961) found it did not occur below 113 °F in the 20 species he reviewed. Gentile and Johansen (1956) reported 100 percent mortality of sand pine (Pinus clausa) and slash pine (P. elliottii var. elliottii) seedlings after immersion of their root systems in a 125 °F water bath for 17 minutes, whereas immersion in 116 °F water for 25 minutes had no effect on survival. When measured by heating individual plant cells, death has been shown to occur at 108 °F in eastern white pine (P. strobus) (Thimann and Kaufman 1958) and between 118 and 122 °F in longleaf pine (P. palustris) (Hare 1965b). Death of a few cells is of little consequence, but as additional amounts of live tissue are killed, the fate of a tree becomes increasingly dependent (up to a point) upon postfire environmental conditions and is much more difficult to predict correctly. Fire can damage the roots, bole, or crown of a tree; a single fire can, and often does, impact all three zones.

Root Damage

Hare (1961) stated that roots are most susceptible to heat injury because they have no specialized exterior protection. Rut root damage is generally assumed not to be a problem during prescribed burning, provided the roots are below the soil surface and the soil is moist. As the humus and upper soil dry out during periods of drought, however, less protection is provided (Beadle 1940), and shallow-rooted plants can be killed. Heyward (1934) reported that a "very hot" spring wildfire on the Georgia Coastal Plain killed all longleaf pine feeder roots within the top inch of soil, but he thought they would be quickly replaced. Geiszler and others (1984) examined the susceptibility of Sierra lodgepole pine (P. contorta var. murrayana) roots to low-intensity wildfires by comparing root mortality within a meter radius of each stem to the amount of charred bark on the stem. Retween 14 and 33 percent of the trees with no evidence of bark char and no burned fuels at their base nonetheless had fire-killed roots. When char was observed on more than 66 percent of a tree's basal circumference, the probability of associated root-kill approached 100 percent. McConkey and Gedney (1951) found the number of fire-killed or severely injured visible roots was a better indicator of future mortality in eastern white pine stands than was crown scorch.

The senior author has been involved with seemingly innocuous prescribed fires in south Florida dry prairie ecosystems. Fine fuel loads were less than 2 tons/acre and, except under the scattered clumps of South Florida slash pine

(*P. elliottii* var. *densa*), fuel continuity was such that backfires would not carry well, residence times were short, and no scorch was observed. Yet the older pines were dead 4 months later, with no outward evidence of injury or infestation. Furthermore, intermixed younger trees showed no visible signs of stress. Although the root systems were not excavated, a plausible explanation is that the fire killed the upper feeder roots of all trees, and only the younger ones were able to put out new rootlets in a timely fashion.

The reintroduction of fire into stands after long periods of exclusion can also result in root and lower bole damage. Low-intensity fires may smolder in the domelike accumulations of sloughed bark and deep needle accumulations beneath the trees, resulting in their death months later. This phenomenon has been noted in loblolly (*P. taeda*) and shortleaf (*P. echinata*) pines (Ferguson and others 1960), in ponderosa pine (*P. ponderosa*) (Herman 1954), and in sugar pine (*P. lambertiana*) (Wagener 1955). Although fire can damage existing roots, it also stimulates new root growth as evidenced by increased fine root density the year following fire, apparently in response to recycled nutrients (Kummerow and Lantz 1983).

Some investigators, for example Swaine and Craighead (1924), have reported considerable root mortality associated with crown defoliation from insect attack. We speculate that this same association would result from a heat-induced loss of foliage. Redmond (1959) found that with less than 70 percent defoliation by spruce budworm (*Choristoneura fumiferana*), young balsam firs (*Abies balsamea*) were able to produce new rootlets and survive but that mature and overmature trees could not do so.

Bole Damage

If the cambium tissue is killed completely around the bole at any height below the live crown, the stem will die back to this girdle unless it can be bridged with new tissue. Although pitch (*P. rigida*) and shortleaf pines can sprout basally when young, and pond pine (*P. serotina*) can stem-sprout as well, most other North American pines are unable to do so and thus girdling below the live crown invariably results in their death. Death, however, may take some time to manifest itself. Although the phloem is heat-killed, the xylem may not be affected, thereby allowing water to continue to reach the tree crown. It can take 1 to 2 years for the well-developed root systems of large, vigorous trees to exhaust their food reserves and die. Wyant and others (1986) state that most long-term studies show fire-related mortality peaks the second growing season following fire, but the literature does not support this contention. Instead, it shows the preponderance of fire-caused mortality occurs within the first full postfire growing season unless secondary factors such as insects are involved.

The aboveground cambium depends upon the bark for protection, and the insulating ability of this outer skin varies considerably within and between species (Ryan 1982; Spalt and Reifsnyder 1962). Of the many bark characteristics studied in the efforts to determine and rank fire resistance by tree species, two of the most important are thought to be thickness (Reifsnyder and others 1967) and the presence of an outer layer of dead bark (Vines 1968), especially in pines whose bark tends to be more corky (Stickel 1941).

Fahnestock and Hare (1964) found that bark thicker than 0.5 inch protected longleaf pine cambium during prescribed fires. Although we have not measured the relationship between bark thickness and survival in the field, we have a fairly large data base (over 1,000 trees) relating basal diameter to survival. When combined with published bark thickness to stem diameter ratios (e.g., Pederick 1970), our data show that bark considerably thinner than 0.5 inch will protect young loblolly and slash pines during low-intensity dormant-season fires. Hare (1965c) subjected 14 southern tree species to an external heat pulse. He was able to divide the species in to five fire-resistance classes based on bark thickness and its insulating efficiency. Longleaf pine and slash pine formed the most resistant class; loblolly pine and baldcypress (*Taxodium distichum*), the second most resistant class.

The bark of longleaf and slash (Martin 1963), and loblolly (Minor 1953) pines thickens with age and diameter, the latter being the more important. But at a given age or diameter, thickness can vary considerably, depending upon such factors as seed source (McMinn 1967) and crown position. Pederick (1970) showed that bark thickness of loblolly pine is a strongly inherited characteristic; as a result, bark thickness varies widely between trees of comparable size and age. He also concluded that the bark of Piedmont populations is inherently thicker than that of Coastal Plain populations. McNab (1977) found that 85 percent of the variation in survival following low-intensity wildfire in a dense loblolly pine stand was explained by differences in bark thickness. Wahlenberg (1960) found that suppressed loblolly pines were much slower to develop thick, insulating bark. This fact has direct implications when using fire as a thinning tool. Because bark thickens with age, the bark at the base of a pine is much thicker than that farther up the stem. Phillips and Schroeder (1972) found that tbe bark thickness of lo-inch d. b. h. slash and loblolly pines at the height representing 25 percent of merchantable height (about 15 feet) was 50 percent less than that at ground level. Prom this point upward the decreases continued, but at a much more gradual rate. In their study, slash pine had slightly thicker bark ($\bar{x}$ = 0.95 inch at tree base) tban loblolly pine ($\bar{x}$ = 0.85 inch at tree base). Pederick (1970) measured the bark thickness at various stem heights on young loblolly pines averaging 6 inches d. b. h. The bark at 1.5 feet was more than twice as thick as it was at 15 feet. He found the ratio of double-bark thickness to inside bark stem diameter decreased from 0.202 at 1.5 feet to 0.144 at 10 feet and then less rapidly to 0.112 at 20 feet. From a theoretical standpoint, doubling the bark thickness will increase the letbal exposure time by a factor of 4.

Intuitively, it would seem that tree girth should be an important factor in determining fire susceptibility. Because wood acts as a heat sink, the greater the volume of a section of stem, the greater its ability should be to retard temperature buildup in the cambium. Moreover, live wood has a much higher moisture content than the dead outer bark, which means these live tissues have a much higher thermal conductivity and can thus more rapidly dissipate a fire-generated heat pulse. The fact that the cross-sectional area of the stem increases as the square of the diameter means that as a tree gets larger, it becomes increasingly more difficult to girdle in a single fire. The importance of tree girth as a factor in determining cambial temperature responses is currently a topic of debate among fire researchers. Both Robert E. Martin[1] and Ralph M. Nelson, Jr.,[2] have derived equations which show stem diameter exerts a pronounced influence, but these equations have yet to be field verified.

It is often assumed that the more rapid passage of a heading fire will cause less heating of the lower stem than a slower moving backing fire. Even though peak temperatures are not as high, the longer duration of elevated temperatures along the lower stem during passage of the backing fire are thought to be more likely to produce lethal temperatures at the cambium. However, the actual situation is not so clear cut. Headfires always spread faster than backfires under the same burning conditions, but they also have a deeper (horizontal) flame zone; tbus, residence

[1]Martin, Robert E. 1985. Personal communication. University of California, Department of Forestry and Resource Management, 145 Mulford Hall, Berkeley, CA 94720.

[2]Nelson, Ralph M., Jr. 1985. Unpublished data on file, Southern Forest Fire Laboratory, Route 1, Box 182A, Dry Branch, GA 31020.

times are often about equal. Also, during backfires most of the litter fuels are consumed in the flame front, whereas residual flaming and smoldering combustion continue after passage of headfire flame fronts. The net result, according to measurements by Fahnestock and Dare (1964), is that the very base of a tree is subjected to about the same total amount of heat energy in both backfires and headfires. But this does not mean the total heat energy released is equivalent for both heading and backing fires. Assuming the caloric contents of the fuel beds are comparable, the total amount of heat energy released is simply a function of the total amount of fuel consumed. In the above study, headfires consumed 8.7 tons of fuel/acre, 2 tons/acre more than backfires. This additional released heat was distributed farther up the tree stems primarily because of the higher flames associated with headfires. However, it is widely accepted and supported by both laboratory (Beaufait 1965; Nelson 1982) and field (Hough 1968, 1978) studies that backfires usually consume more forest floor fuels. In these cases, backfires should do a better job of "cooking" the stem because their heat is concentrated at the base of a tree, as demonstrated by the results of Bruce (1951) and Lindenmuth and Byram (1948) in longleaf pine. Again, contrasting results have been reported (e.g., Davis and Martin 1960), and many questions also remain regarding the net result of differences in bark mechanical and thermal properties related to tree height and diameter.

Several methods of assessing cambial damage in tree boles have been used. These include the physical examination of the cambium (Mann and Gunter 1960; Diller and others 1961), sometimes with the help of viability test stains (Hare 1965a; Kayll 1963); the use of a moisture meter (Hare 1960); the amount of pitch bleeding (Fahnestock and Hare 1964; Mann and Gunter 1960); and the presence of bark beetles (Mann and Gunter 1960). Ferguson (1955) found basal damage as indicated by cupping of the bark, combined with crown scorch, to be useful in assessing damage to loblolly and shortleaf pines.

Although bark char height is an indicator of fire intensity, Bourgeois (1985) was unable to correlate it with the growth of young loblolly pines, nor has it been found to be highly correlated with pine mortality (Herman 1954; Villarrubia and Chambers 1978) unless it was noted within the crown (Dixon and others 1984; Storey and Merkel 1960). These results strongly imply that any correlation between high bole char ratios and mortality is simply an analog of heavy crown damage. Cooper and Altobellis (1969) conducted a study in loblolly pines less than 6 inches d.b.h. to determine whether they are killed by bole damage, crown damage, or both. Results indicated a fire intense enough to kill the stem cambium also killed the tree crown. Van Wagner (1970) stated he had yet to find large red (P. resinosa) or eastern white pines that died of stem cambial damage alone, although young trees do. Wade (1985) found that all loblolly pines at least 4 years old with less than 75 percent crown scorch were still alive the fall after dormant-season wildfires. Data in Cain (1985) show all pines more than 5 feet tall with less than 95 percent crown scorch survived the first growing season following a planned headfire in an overcrowded 9-year-old loblolly stand. Live crown consumption, if it occurred, was not specified. At the other end of the scale are pines such as lodgepole (P. contorta var. latifolia) that retain relatively thin bark throughout their lives and are thus susceptible to cambial damage even in old age (Peterson 1984). Gara and others (1986) found cambial tissue was killed whenever the bark of lodgepole pine was charred.

Crown Damage

Once southern pines reach 2 to 3 inches d.b.h., mortality resulting from fire will generally be caused by damage to the tree crown. But this does not mean, in spite of the commonly held misconception to the contrary, that needle scorch is the principal cause of pine mortality. Dormant-season fires can--and often do--completely defoliate a tree without killing it as long as enough buds and branch cambium survive. What constitutes "enough" depends upon such factors as prefire tree vigor, postfire weather, and tree species. Needle kill is a prerequisite to bud kill in those species whose buds are equal to or larger than the needles in cross section because in this case buds have a higher heat capacity (Byram 1958). Thus the larger the bud, the more heat resistant it is. Dare (1961) states that the bud scales, like bark, are insulating tissues.

But how can an observer on the ground determine whether the buds or branch cambium have been thermally killed? Perhaps the easiest method is to use needle consumption as an indicator of bud and cambium death. Temperatures of about 400 °F are required to ignite the foliage, and these are high enough to kill surrounding meristematic tissue. In fact, the data presented by many authors show little mortality in southern pine until crown scorch approaches 100 percent (Allen 1960; Ferguson 1955; Mann and Gunter 1960; Van Loon 1967; Villarrubia and Chambers 1978; Wade and Ward 1975; Waldrop and Van Lear 1984). But as crown consumption begins, dramatic increases in mortality take place (McCulley 1950; Storey and Merkel 1960; Wade 1985). This same phenomenon has been noted in the West with Jeffrey pine (*P. jeffreyi*) and ponderosa pine (Dieterich 1979; Herman 1954; Lynch 1959; Pearson and others 1972; Wagener 1955; Wyant and others 1986) and with red pine and eastern white pine in the Lake States and Ontario (Dochinger 1963; Methven 1971: Sucoff and Allison 1968; Van Wagner 1963).

Postfire damage surveys should be conducted within 2 to 3 weeks after a fire, before the scorched foliage falls. Otherwise, neither consumption nor prefire limb death and foliage loss (e.g., from insect activity) can be accurately assessed without close individual branch inspection, such as done in the study described by Wyant and others (1986).

Dead foliage retained for much longer periods indicates that the branches themselves have also been killed, precluding development of an abscission layer at the needle base.

Growth Effects

As might be expected, even when partial defoliation does not result in tree death, it can adversely affect growth. McCulley (1948, 1950) presented data showing that height growth of slash pine less than 7 inches in diameter was suppressed for 3 years following fire even when the tree crowns were not scorched. Two years after a winter prescribed burn, Johansen and Wade[3] found that the growth of 7- to 9-inch diameter slash pines with less than 10 percent crown scorch was only 85 percent of that of adjacent unburned trees. However, many of the trees on these spotfire burn plots were subjected to much higher scorch levels: perhaps some root mortality took place even under the slightly scorched trees. Landsberg and others (1984) documented reduced growth of prescribed burned 45-year-old ponderosa pine compared with adjacent unburned control trees four growing seasons after treatment. They attributed this reduced growth in part to measured reductions in crown needle mass on the burned areas, which in turn resulted in less total foliar nitrogen (although no differences in foliar N concentration were found between treatments).

Where both radial and height growth have been studied after heavy scorch, height growth has generally been found to be more severely depressed (McCulley 1948, 1950; Wahlenberg and others 1939) although Bourgeois (1985) and Johansen (1975) found the opposite to be true. It should be noted that although radial growth is traditionally measured at d.b.h., the lower stem is the zone of slowest growth and thus the least responsive to defoliation (Kulman 1971).

---

[3] Effects of crown scorch on survival and growth of pines. (Manuscript in process, Dry Branch, GA.)

Though growth losses can be substantial (Barrett 1928: Mann and Rhame 1955; Morrell 1932; Wakeley 1931; Wyman 1922), predisturbance growth rates are usually achieved again within a few years (Sickford and Curry 1943; McCulley 1948, 1950; Stone 1942) even after near-complete needle loss (Cary 1932; Wade and Ward 1975). Exceptions, however, can be found (e.g., Evenden 1940).

Some early investigators recorded a continued depression of growth in southern pine with annual fires (Mackinney 1931, 1934; Paul 1926), whereas later workers (e.g., Sackett 1975) have not. Trees surveyed by these workers were of comparable age, so the difference in results is likely due to differences in behavior or timing of the fires--neither of which were described in the earlier reports. The authors note without comment that most results of deleterious growth effects due to fire were published during the time when a sharply focused Federal effort was underway to halt the centuries-old southern tradition of "burning off the woods." The results of a fully replicated study described by Boyer (1982), however, cannot be as easily dismissed. He found that the growth of 19-year-old longleaf pines was retarded by biennial burning treatments begun when the stand was 12 years of age.

On the other hand, many studies have documented increased growth rates after light-to-moderate crown scorch (up to 60 percent in one study) when compared with unscorched controls. Early workers (e.g., McCulley 1948, 1950) often ignored such increases or attributed them to experimental error. Wyant and others (1983) give an excellent discussion of the effects of a dormant-season fire on ponderosa pine shoot growth the following growing season. Because shoot length and the number of fascicles and needles (factors determined during bud formation) did not differ between treatments, the authors concluded that the physiological processes within the dormant buds were not affected by the fire. In contrast, fascicle growth and the size of buds formed the season following fire were both significantly greater on trees in the burn. Johansen (1975) documented a first-year postfire increase in radial growth of 10-year-old slash pine if crown scorch was less than 15 percent. Height growth increased for all scorch classes below 85 percent. Even those trees with 100 percent defoliation but no consumption had shown significant (0.05 level) radial and height growth increases over the check trees within four growing seasons. Gruschow (1951, 1952) reported that the 5-year average diameter and height growth of "lightly" scorched slash pine exceeded that of the unburned controls. Morris and Mowat (1958) found a like response in ponderosa pine 6 years postfire. Somes and Moorhead (1954) noted increased diameter growth of prescribed burned shortleaf pine (they did not measure height growth) compared with trees on unburned control plots 8 years after fire.

Mechanical pruning of loblolly (Wahlenberg 1960), longleaf (Wahlenberg 1946), ponderosa (Barrett 1968), shortleaf (Walker and Wiant 1966) and slash pines (Bennett 1955) has not shown these same positive growth responses. They have, in fact, demonstrated the increased retardation of both radial and height growth with increasing increments of crown removal. Thus, tree growth increases after fire-caused lower branch mortality are not just a response to the removal of older, less-productive branches. Reduced understory competition and recycled nutrients are undoubtedly factors. Stark and Cook (1957) showed that 40 percent defoliation by insects (which was distributed throughout the whole crown rather than progressing from the bottom up) was the threshold for both height and radial growth losses in mature lodgepole pine, whereas young trees could withstand up to 50 percent defoliation without radial increment loss. Cook (1961) found that the amount of increment loss was positively correlated to the length of time defoliation (from insects) exceeded 40 percent. Ryan (1982) pointed out that young, rapidly growing trees on good sites can withstand a much greater reduction in the ratio of live crown to total height than can older, slower growing trees. Following a January fire in 10-year-old slash pine, Grissom (1985) charted monthly radial growth throughout the remainder of the year. Radial growth of the severely scorched (>40 percent) trees was much less than that of their unscorched companions during the spring but had completely recovered by fall. Midday xylem potential (sap pressure) in the scorched trees was higher although still negative, suggesting these trees were under less water stress. He postulated this reduction was due at least in part to smaller live crowns and thus reduced transpiration and subsequent water demand.

Craighead (1927) reported fire defoliation of shortleaf pine resulted in growth abnormalities such as missing rings on the lower stem the year after a burn. Missing rings after defoliation have also been reported for other pines (Dieterich and Swetnam 1984; Kulman 1965; Kulman and Hodson 1963; O'Neil 1963). Other investigators (Jemison 1943; Van Loon 1967; Waldrop and Van Lear 1984) found no reduction in postfire growth even with complete defoliation. However, when analyzing radial growth from increment cores as done by some of the above authors, missing rings will be overlooked if the cambium is used as the reference point. This oversight not only leads to erroneous results but can also lead to a complacent attitude regarding fire intensity and attendant crown scorch. Johansen and Wade[4] describe the dramatic 1-year growth loss that occurred over two growing seasons following a fire that severely scorched much of a 25-year-old slash pine plantation; 60 percent of the trees with over 95 percent crown scorch did not put on a growth ring at d.b.h. the first postburn growing season.

Minimizing Tree Damage

Tree and Stand Factors

Bark thickness and twig size, as well as bud size and the amount of foliage protecting the growing tips, influence the probability of fire-induced crown damage and provide a method to rank fire resistance. Longleaf pine with its stout terminal branches (0.5 inch or larger) and large buds, which are further protected by encompassing clusters of 10- to 18-inch-long needles, is the most fire-resistant of all pines. Chapman (1936) wrapped tissue paper around the buds of 1- to 5-foot-high longleaf pine seedlings and found it was not even scorched during the ensuing "hot" fire. The three other major southern pines have twigs that are more slender, generally between 0.125 to 0.25 inch in diameter, and much smaller buds. Needle length also differs, with shortleaf pine having the shortest, loblolly next, and slash pine approaching that of longleaf pine. That bark thickness is positively correlated with diameter means branch cambium is not as well insulated as stem cambium and is therefore more responsive to changes in ambient air temperature. Thus during the day, the preburn temperature of the branch cambium will generally be closer to the lethal plant cell temperature than will be the stem cambium, especially when the tree crown is in direct sunlight.

The higher the base of the live crown, the safer it is from lethal temperatures generated by a burning understory. As the crown becomes denser and longer, more heat is intercepted, thereby shielding the upper crown. There is little doubt that vertical flow is impeded by dense canopies, but whether this results in higher scorch heights as suggested by Ryan (1982) is debatable. Openings in dense canopies will invariably result in increased crown scorch, of the peripheral trees as the hot gasses are vented upward through these gaps.

Burning Weather

The greater the windspeed within the stand, the faster the gaseous combustion products will be mixed with cooler air and dissipated horizontally ahead of the fire instead of rising directly up into the overhead tree crowns. The greater

[4] See footnote 3.

the windspeed, the farther the flames will be bent over, thereby increasing the distance radiant beat (which cools as the square of the distance) must travel to reach the crowns. The advantage of greater windspeed, however, has to be tempered with the fact that flame length and depth, and thus fireline intensity, also increase with increasing windspeed.

According to Byram (1948, 1958), the most important parameter determining crown damage is the preburn vegetation temperature which is dependent upon the ambient air temperature. Vegetation temperature can, in fact, sometimes exceed amhient temperature by more than 40 °F because of solar radiation. For example, assuming a lethal temperature of 140 °F and a straight-line relationship, it follows that about twice the amount of heat will be needed to kill foliage with an initial temperature of 50 °F than is needed at 90 °F. When weather conditions are favorable for underburning, temperature differences in a tree crown will not approach this magnitude because of the cooling action of the wind. Ryram (1948) described a substantial increase in fire tolerance when ambient temperature dropped to 29 °F. Below this temperature, water in the foliage freezes and large quantities of heat are needed to convert it hack to a liquid.

Season of Burn

The remaining factor that resource managers can control is the time when burning takes place in relation to the physiological state of the trees (dormant or active). Meristematic tissue appears to be more heat resistant during the dormant season (Rare 1961; Jameson 1961; Kayll 1968). When a bud breaks dormancy in the spring, it pushes through the protecting bud scales and elongates beyond the protective needles, temporarily becoming much more vulnerable to heat injury. Alexandrov (1964) presented data showing the process of hardening off during the fall increased tissue heat resistance of several species of grass 5 to 6 °F during the winter. Whether this phenomenon occurs in pine and, if so, to what extent, has yet to be determined. Levitt (1972) described the mechanics of this increased thermotolerance but failed to recognize its potential significance. Although perhaps not much of a problem in the Deep South, Kulman (1971) cites several authors who show that late summer defoliation leaves twigs unlignified and thus subject to winter damage.

If the literature relating crown scorch to mortality is separated by season of burn, the results are striking. Trees with near-total foliage scorch but no crown consumption resulting from fires between October through March had a much higher likelihood of survival than those with similar damage caused by fires from April through Septemher. Craighead (1940) demonstrated that complete defoliation of 10- to 25-foot-tall jack pine (P. hanksiana) and Scotch pine (P. sylvestris) during the growing season will cause 100 percent mortality. He mechanically removed all foliage at different times of the year for up to 3 years. He found that removal of all foliage during the growing season (either about a month after new growth started in the spring or at the end of the growing season) caused tree death. On the other hand, Wilson (1966) completely defoliated Scotch pine prior to new foliage development in the spring for 3 consecutive years without any mortality.

Kramer and Wetmore (1943) found that spring defoliation of six species of evergreen shrubs in North Carolina resulted in increment loss but August defoliation resulted in death. Wilkinson and others (1966) reported 75 percent mortality in jack pine defoliated by second-generation redheaded jack pine sawflies (Neodiprion rugifrons). O'Neil (1962) found complete mechanical defoliation of jack pine in early August invariably resulted in death of the individual. Beal (1942) reported the same result in loblolly and shortleaf pines with complete late-summer defoliation by redheaded pine sawflies (N. lecontei). He further noted that trees partially to completely overtopped by hardwoods were much more susceptible to mortal i ty (33 percent of the shaded pines in *the* 26 *to* 50 percent defol i *a*-tion cl ass died, whereas none of the un-shaded pines succumbed). *Di* fferences i n survi *val* after defol i a ti on, especi al *l* y when early in the growing season, *may be primarily* due to tbe fact that *some* pines--notably loblolly, longleaf, shortleaf, and slash- -do not bave fully preformed buds and thus undergo several *successi* ve need1 e flushes during *the growing season.* *Species* such as red pine, eastern whi te pine, and ponderosa pine *wi th* fully preformed buds are, on the other hand, 1 id ted to a sing1 e growth flush per year (Kramer and Kozl owski 1979). Thus, species wi th preformed buds that are defoliated after the spring need1 e flush have to wai t until the *foll* owing spring to refol Late. A study is currently underway at the Southern Forest Fire Laboratory to *quan*-ti fy the abi 1 i ty of *the mul* tinodal southern pines to refol *i* ate after growing- season defol i a ti on.

Conclusi offs

There are times when prescribed burns are conducted at higher fire *in-tensi* ties than planned, resul ting *in* total scorch of al 1 need1 es in a tree crown. *But* the effects may not be as cal *ami tous* as they at first appear. Southern *yel* 1 ow pines *wi 11 usually not* die from even total crown scorch *pro*-vi ded tbat the buds are not *ki* 11 ed and the fire occurs wben *the trees are dor*-mant. The manager *must, however, be* ready to accept the loss of approxi - mately *1* year's diameter *growth over the next* 2 years when maximum crown scorch i s incurred. If, however, severe crown scorch occurs when conifers with pre-formed buds are *physi* 01 ogi call y ac ti ve, *the likelihood of mortal i ty is high.* Al *l* pines are more *vul* nerabl e during this period because elevated preburn ambi ent temperatures *mean the buds are* more 1 i kel y to *recei* ve a 1 *ethal* heat dose *from* the fire.

Three instances where special care should be exercised when prescribed burning under a pine overstory are: (1) during the growing season, (2) dur-*ing ini ti al burns after 1 ong fire- free* periods because of the potential for root and *l ower bol e damage beneath the* smol deri ng domel i ke duff accumul a ti ons, and (3) when using 1 ine beadfires or the flying driptorch *(which* rapidly creates 1 ine headfi res as the spots merge) because of the potential for unacceptably high fire *intensi ties.*

Nonethel ess, prescri bed burning, i ncl udi ng *aeri* al i gni ti on *techni* ques, can be used without fear of undue damage during the dormant season by adhering to es *tabl* i shed gui *del* i nes: Burn *when the ambi ent* air temperature is *bel* ow 60 "F, rel *ati* ve *humi* di ty exceeds 35 percent, wind *direction i s steady, wi ndspeed i s between 1 and 3* mi/h *at* midfl ame *height, and 1 i* tter *moisture content exceeds* moisture of extinction *(35 percent) at* the soil-litter interface. On a given day, *fire intensi ty can be regulated by* the *choice* of igni tion *tecbni que.*

Literature Cited

Alexandrov. V. YA. Cystophysiological and cytoecologi • cal investigations of heat resistance of plant cells toward the action of high and low temperature. *Quarterly Review of Biology* 39:35-77; *1964.*

Allen. Peter H. Scorch and mortality after a summer burn in loblolly piae. *Res. Notes* 144. Asbeville, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiaent Station; 1960. 2 pp.

Barrett, James W. Pruning of ponderosa pine. Res. Pap. PNW-68. Portland. OR: U.S. Deoartment of Aqricul- *ture,* Forest Service, Pacific' Northwest Forest and Range Experiment Station: 1968. 9 pp.

Barrett, L. I. Fire damage *done to a* mature 1 *oblol ly pine* stand. Naval Stores Review 38(18):11; 1928.

Beadle, N. C. W. Soil temperatures during forest fires and their effect on the survival of vegetation. *Ecology* 28:180-192;1940.

Beal, *J. A.* Mortality of reproduction defoliated *by* tbe red-beaded *pine sawfly* (Neodl rion lecontei Fi tch). Journal *of* Forestry 3 4 5 6 3 ; 1 9 4 2 .

Beaufai t. W. R. Characteristics *of* backfires and headfires *in a* pine needl e fuel *bed. Res. Note INT- 39.* Ogden, UT: U. S. Department of Agriculture, Forest *Servi ce,* Intermountain Forest *and Range* Experiment Station; 1965. 7 pp.

Bennett, *Frank A. Tbe* effect of pruning ou *the* beigbt and diameter growtb of planted slash pine. Journal of Forestry 53(9) :636-638; *1955.*

Bi ckford, C. A. ; Curry, Jobn R. The use of fire in *the* protection of longleaf and *slash* pine *forests.* Occas. Pap. 105. Ashevil 1 e. NC: U. S. Deoartnent of Agri cul ture, Forest Service, Southeastern Forest Experiment Station; 1943. 22 pp.

Bourgeois, 0. M. Growth and mortality of dominant and co- dominant trees *in* prescribed burned pine plantations--first-year results. *Rep. 6-85.* Summerville. SC: Westvaco, Southern Woodlands; Hay 1985.5 pp.

Boyer, Yilliam 0. *Growth* of young longleaf pine *as* affected by biennial burns plus chemical *or* mechanical treatments *for* competi tion control. In: Southern si 1 vi *cul tural research* conference; 1982 November 4-5: Atlanta, GA. New Orleans, LA: U. S. Department of Agri cul tare, Forest Service, Soutbern *Forest* Experiment Station; 1982:62-64. [Available *from* George W. Andrews Forestry Sciences Laboratory, Auburn, AL]

Brown, Autbur A.; Davis, Kenneth P. Forest fire control *and use.* New *York: McGraw-Hill;* 1973:46-78.

Bruce, David. Fire, *site, and* longleaf belgkt growtb. Journal of Forestry 49(1) :25-28; 1951.

By ram, George M. Some basic thermal processes controlling *the* effects of fire on living vegetation. Res. Notes 114. Asbeville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; *1958.* 2 pp.

Byram, George M. Vegetation temperature and fire *damage* in tbe *southern* pines. Fire Control Notes 9(4) :34-36; Uashington, DC: U.S. Department of Agriculture, Forest *Service; 1948.*

Cain. Michael D. Prescribed *winter* burns *can reduce the* growth of nine-year-old loblolly pines. *Res. Note SO-312.* New Orleans. LA: U.S. Department of Agriculture, Forest Service, Southern- Forest Experiment Station; 1985. 4 pp.

Cary, Austin. Some relations *of* fire to longleaf pine. Journal of Forestry 30: (5) 594-601; 1932.

Chapman, H. H. Effect of fire in preparation of seedbed *for* longleaf pine seedlings. Journal *of* Forestry 34(9) :852-854; *1936.*

Cook, *J.* A. *Growth reduction* in *l odoepol e pine defoliated by the needle miner,* Evagora (Recuvaria) starki *Freeman. Forestry* Chronicle 37:237-241; 1961.

Cooper, Robert W.; Al *tobell is, Anthony T. Fire kill in young* loblolly *pine.* Fire Control *Notes* 30(4) :14-15; Washington, DC: U. S. Department of Agriculture, Forest Servi ce; 1969.

Craighead, F.C. Abnormalities in *annual* rings resulting from fires. *Journal* of Forestry 25(7):840-842; *1927.*

Craigbead. F.C. Some effects *of* artificial defoliation on pine *and* larch. Journal of Forestry 38(11):885-888; 1940.

Oavis, Lawrence S. ; Martin, Robert E. Time- temoerature relationships *of test* bead fires and backfires. Res. Notes 148. Asbevill e, NC: U. S. Department of *Agriculture,* Forest Service, Southeastern Forest Experiment Stati on; 1960. 2 pp.

Dieteri cb, Jobn H. Recovery potential of fire- damaged southwestern ponderosa pine. *Res. Note RM-379.* Fort Col 11 ns, CO: U. S. Department of Agriculture, Forest *Service, Rocky* Mountain *Forest* and Range Experiment Station; *1979. 8* pp.

Dietericb. *John H.; Swetnam, Thomas* W. Dendrochronology of a fire- scarred ponderosa pine. Forest Science 30(1) : 238-247 ; 1984.

Dixon, Wayne N. ; Corneil, Jeffrey A. ; Wilkinson, Robert C.; Fol *tz, John* L. Using stem *char* to predict mortality and insect infestation of fire-damaged slasb pines. Southern *Journal* of Applied Forestry 8(2):85-88; 1984.

Oocbinger, L. S. Artificial defoliation of eastern *whi* te pine duplicated some effects *of cbl* orotic dwarf disease. Res. Note CS- 16. Columbus, OH: *U. S. Department* of Agriculture, Forest Service, Central States Experiment *Station; 1963. 6 pp.* [Avai 1 able from *Northeastern Forest Experiment Stati* on, *Broomal l,* PA]

Evenden, James C. Effects of defoliation by *the* pine butterfly upon ponderosa pine. Journal of Forestry 38(12) :949-955; *1940.*

Faknestock, George *R. ; Bare,* Robert C. Beating of tree trunks in surface fires. Journal of Forestry 62(11) : 799-805; 1964.

Ferguson, E. R. ; Gibbs. C. B. ; Thatcher, R. C. "Cool burns" and pine mortality. Fire Control Notes 21(1) :27-29. Washington, DC: U.S. Department of Agriculture, Forest Service; 1960.

Ferguson, Edwin R. Fire-scorched trees- • will they live or die? In: Proceedings, 4th annual forestry symposium; 1955 April 16-17; Baton Rouge, LA: Louisiana State University; 1955. (pp.102-113).

Gara, R. I. ; Agee, J. K. ; Littke, W.R. ; Geiszler, D. R. Fire wounds and beetle scars. Journal of Forestry 84(4) :47-50; 1986.

Geiszler, D.R.; Gara, R.I.; Littke, W.R. Bark beetle infestations of lodgepole pine following a fire in south central Oregon. Zeitscbrift für Angewandte Entomologie 98(4) : 389-394 ; 1984.

Gentile, A. C. ; Jobaosen. R. W. Heat tolerance of slasb and sand pine seedlings. Res. Notes 95. Ashevil Je, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1956.1~.

Grissom, Janes Edwin. Effect of crown scorch on water status and growtb of slasb pine trees. Gainesville: University of Florida; 1985. 50 pp. Thesis.

Gruscbow, George F. Effect of winter burning on growtb of slash pine In the flatwoods. Journal of Forestry 50(7) :515-517; 1952.

Gruscbow, George F. Effect of winter burning on slash pine growth. Southern Lumberman 183(2297) :260, 262, 264; 1951.

Bare, R. C. Chemical test for fire damage. Journal of Forestry 63(12) :939; 1965a.

Bare, R. C. Siwple hot stage for studying critical cell temperatures. Canadian Journal of Botany 43(6): 777- 779; 1965b.

Bare, Robert C. Contribution of bark to fire resistance. Journal of Forestry 63(4) :248-251; 1965c.

Rare, Robert C. Detecting dead cambium witb a moisture meter. Journal of Forestry 58(10) :815-817; 1960.

Bare, Robert C. Beat effects on living plants. Occas. Pap. 183. New Orleans, LA: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1961. 33 pp.

Berman, F. R. A guide for marking fire- damaged ponderosa pine in the Soutbwest. -Res. Note 13. Fort Collins. CO: U. S. Department of Agriculture, Forest Service; Rocky Mountain Forest and Range Experinent Station; 1954. 4 pp.

Heyward, Frank. Comments on tbe effect of fire on feeding roots of pine. Savannak Weekly Naval Stores Review and Journal of Trade 44(19):4; 1934.

Bough, W.A. Estimating available fuel weight consumed by prescribed fires in the South. Res. Pap. SE- 187. Ashevil l e, NC: U. S. Departaent of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1978. 12 pp.

Houoh. W.A. Fuel consumption and fire bebavior of hazard reduction burns. Res. Pap. SE- 36. Asbevi 11 e, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1968. 7 pp.

Jameson, Donald A. Meat anddesiccation resistance of important trees and grasses of tbe pinyon-juniper type. Botany Gazette 122:174-179; 1961.

Jemison. George M. Effect of single fires on the diameter growth of sbortleaf pine in tbe Southern Appalachians. Journal of Forestry 41(8) :574-576; 1943.

Jobansen. R. W. Prescribed burning way enhance growth of young slasb pine. Journal of Forestry 73(3) :148-149;1975.

Kavll. A.J. Beat tolerance of Scots pine seedling cam-&&a using tetrazolium chloride to test viability. Publ. 1006. Ottawa. Canada: Department of Forestry, Forest Research Branch; 1963. 12 pp.

Kayll, A. J. Beat tolerance of tree seedlings. In: Proceedings, 8th annual Tall Timbers fire ecology conference; 1968 March 14- 15; Tallakassee, FL: Tall Timbers Research Station; 1968; 8:89-105.

Kramer, P. J. ; Wetmore, T.H. Effects of defoliation on 01d resistance and diameter growtb of broad- leaved evergreens. American Journal of Botany 30:428-431; 1943.

Kramer, Paul J.; Kozlowski, T. J. Physiology of woody plants. New York: Academic Press; 1979. 811 pp.

Kulman, B. M. Effects of artificial defoliation of pine on subsequent shoot and needle growth. Forest Science 11:90-98; 1965.

Kulman, H. M. Effects of insect defoliation on growth and mortality of trees. Annual Review of Entomology 16:289-324; 1971.

Kulman, H.M.; Hodson, A.C. Distribution and effects of jack-pine budworm defoliation. Forest Science 9:146-157; 1963.

Kummerow, J.; Lantz, R.K. Effect of fire on fine root density in red shank (Adenostoma sparsifolium Torr.) chaparral. Plant and Soil 70(3) :347-352; 1983.

Landsberg, J.D.; Cocbmn, P.B.; Finck, M.M.; Martin, R. E. Foliar nitroeen content and tree growth after prescribed fire in ponderosa pine. Res. Note PNW-412. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 16 pp.

Langdon, O. Cordon. Effects of prescribed burnina on timber species in the southeastern coastal plain. In: Proceedings, Prescribed burnina symposium; 1971 April 14-16: Charleston. SC: 1971:34-44; [Available from Southeastern Forest Experiment Station, Asbeville, NC]

Levitt, J. Responses of plants to environmental stresses. New York: Academic Press; 1972. 697 pp.

Lindenmuth, A. W., Jr.; Byram, George M. Beadfires are cooler near the ground than backfires. Ffre Control Notes 9(4):4-g. Washington, DC: U.S. Department of Agriculture, Forest Service; 1948.

Lynch, Donald W. Effects of a wildfire on mortality and growthof young ponderosa pine trees. Res. Note 66. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1959.8 pp.

Mackinney, A.L. Some effects of three annual fires on growth of longleaf pine. Journal of Forestry 32(8):879-881; 1934.

Mackinney, A.L. Thirteen annual fires in tbe longleaf pine type. Bull. 15(37). AsbeviJJe, NC: U.S. Department of Agriculture, Forest Service, Appal acbi an Forest Experiment Station; 1931. 3 pp. [Available from Soutbeastem Forest Experiment Station, AsbeviJJe, NC]

Mann, W. F., Jr. ; Gunter, Eria R. The odds for a fire-damaged pine to die. Soutb. For. Notes 126. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 1960. 2 PP.

Mann, Y. F., Jr.; Rhame. Tommy. Prescribe-burning planted slash pine. South..For. Notes 96. New-Orleans. LA: U.S. Deoartment of Aqriculture. Forest Service; Soutbero Forest Experiment Station: 1955. 2 PP.

Martin, Robert E. A basic approach to fire injury of tree stems. Io: Proceedings, 2d annual Tall Timbers fire ecology conference: 1963 March 14-15; Tallahassee, FL: Tall Timbers Research Station; 1963; 2: 151-162.

McArthur, 6.M. Prediction of crown scorch in Pacific Northwest underbums. Seattle: University of Washington, Col l ege of Forest Resources: 1980. 176 pp. Tbesis.

McConkey. Thomas W.: Gedney, Donald R. A guide for sal vaging whi te pine inj ured by forest fi res. Res. Notes 11. Broomall. PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1951. 4 pp.

McCulley, R.O. knagemeat of natural slash pine stands in tbe flatwoods of soutb Georgia and north Florida. Circular No. 845. Washington, DC: U.S. Department of Agriculture, Forest Service; 1950. 57 pp.

McCulley, R.O. Progress report on a study of tbe significant factors affecting fire injury and tbe effect of such injury on tbe mortality and growth of slash pine on the Osceola National Forest. Asheville, NC: U.S. Deoartment of Aqriculture, Forest Service, Southeastern Forest Experi ment Station; 1948. 27 pp.

McMinn, James W. Comparative fire resistance of two seed sources of South Florida slash pine. Res. Note SE-68. Ashevil Je, NC: U.S. Department of Agricul ture, Forest Service, Soutbeastera Forest Experiaeat Station; 1967. 3 pp.

McNab, W.H. An overcrowded pine stand thinned with fire. Southern Journal of Applied Forestry 1(1) :24-26; 1977.

Metbven, Ian R. Prescribed fire, crown scorch and mortality: Field and Jaboratory studies on red aud white piue. Inf. Rep. PS-X-31. Chalk River, Ontario: Canadian Forest Service, Petawawa Forest Experiment Station; 1971. 10 pp.

Mil ler, Sharon R.; Malac, Barry F.; Johnson; John W. A case bistory of slash and longleaf pine survival following a winter wildfire. Woodland Res. Notes 11. Savannah, GA: Union Bag-Camp Paper Corporation; 1961. 3 pp.

Minor, Charl es 0. Loblol Jy pine bark tbickaess. LSU For. Notes 1. Baton Rouge, LA: Agricultural Experiment Station; 1953. 2 pp.

Morrell, Fred. Effects of fire on longleaf pine. Serv. Bull. 16(22):5-6. Washington, DC: U.S. Department of Agriculture, Forest Service; 1932.

Morris, William G.; Mowat, Edwin L. Some effects of tbinaiag aponderosa pine thi cket with a prescribed fire. Journal of Forestry 56(3):203-209; 1958.

Nelson, Ralph M. Observation on beat tolerance of soutbera pine needles. Sta. Pap. 14. AsbeviJJe, NC: U.S. Department of Agriculture, Forest Service. Soutbeastera Forest Experiment Station; 1952. 6 pp.

Nelson, Ralph M., Jr. An evaluation of tbe carbon balance technique for estimating emission factors and fuel consumption in forest fires. Res. Pap. SE-231. AsbeviJJe, NC: U.S. Department of Agriculture, Forest Service, Soutbeas tern Forest Experiment Station, 1982. 9 pp.

O'Neil, L.C. Some effects of artificial defoliation on the growth of jack pine (Pinus banksiana Lamb). Canadian Journal of Botany (2):273-280; 1962.

O'Neil, L.C. The suppression of growth rings in jack pine in relation to defoliation by tbe Swaine jack-pine sawfly. Canadian Journal of Botany 41(2) :227-235; 1963.

Paul, Benson H. Influence of fires oa growtb of pine. Soutbem Lumberman 122(1582) :41; 1926.

Pearson, H.A.; Davis, J.R.; Schubert; G.H. Effects of wildfire oa timber and forage production in Arizona. Journal of Range Nanagement 25(4):250-253; 1972.

Pederick, Leon A. Variation and inheritance of stem form and bark thickness in young loblolly pine. Tech. Rep. 41. Raleigh, NC: North Carolina State University; 1970:8-35.

Peterson, David L. Predicting fire-caused mortality in four aortbern Rocky Mountain conifers. In: Convention of Tbe Society of American Foresters proceedings; 1983 October 16-20; Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Soutbwest Forest and Range Experiment Station; 1984:276-280.

Phillips, D.R.: Schroeder, James G. Some pbysi cal characteristics of bark from plantation-grown slash and loblolly pine. Forest Products Journal 22(10) :30-33; 1972.

Redmond, D.R. Mortality of rootlets in balsam fir defoliated by tbe spruce budworm. Forest Science 5(1):64-69; 1959.

Reifsnyder. William E.: Herrington, Lee P.; Spalt, Karl W. Thermophysical properties of bark of shortleaf, Jongleaf, and red pine. Bull. 70. New Haven, CT: Yale University School of Forestry: 1967. 41 pp.

Ryan, Kevin C. Evaluating potential tree mortali ty from prescribed burning. In: Baumgartner, David M., ed. Proceedinqs, symposium site preparation and fuels management ou steep terrain; 1982 February 15-17; Pullman, WA: Wasbiagton State University Cooperative Extension: 1982: 167-179.

Sackett, Stephen S. *Scheduling* prescribed burns *for* hazard reduction *in* the *Southeast.* Journal of Forestry 73(3) : 143-147 ; 1975.

Somes. H. A. ; *Moorhead,* 6. R. *Do* thinning and prescribed *burning* affect tbe growth of *shortleaf pine? Res.* Notes 34, *Broomal l.* PA: *U.* S. Department of Agriculture, *Forest* Service, Wortbeastern Forest Experiment Station; 1954. 2 pp.

Spal t , *Karl W. ;* Reifsayder, *Wil liam* E. Bark *characteristics and* fire resistance: *a Ji terature survey.* New *Orleans,* LA: *U.* S. Departneat of AgricuJ *ture,* Forest Service, *Southern* Forest Experiment Station, 1962. *19* pp.

Stark, R.W.; Cook, J.A. *The* effects of defoliation by the *lodgepole needle miner. Forest Science* 3(4) : 376-396; 1957.

Stickel, *Paul W. On tbe relation between bark character* aud resistance to fire. *Tech.* Note 39. *Broomal l.* PA: *U.* S. Departwent of AgricuJ *ture,* Forest Service, Nortbeasteru *Forest* Experiwent Station; *1941.* 2 pp.

Stone, E. L. Effect *of* fire on radial growth *of longleaf* pine. Soutb. For. Notes 43. New Orleans, LA: *U.* S. *Department* of Agriculture, Forest Service, *Southern* Forest Experiweat Station; 1942 (p. 3). 4 PP.

Storey, *Theodore* G. ; Merkel , *Edward* P. *Mortali* ty in a *longleaf-slash* pine stand following a dater wildfire. *Journal of* Forestry 58(3) :206-210; 1960.

Sucoff , *Edward I.;* Allison, *J.H. Fire defoliation and survival* in *a 47-year-old* red *pine plantation. Res.* Notes *187. St. Paul,* HN: *University of Hinnesota;* 1968. *2pp.*

Swaiae, J. M. ; Craigbead, F. C. Studies on tbe spruce budworm *(Cacoecia fumiferana Clem.) Part 1. A* general *account of* tbe outbreaks, injury and asso- *ciated insects. Ted. Bull. 37. Dominion of Canada,* Department *of AgricuJ ture; 1924. 91 pp.*

Thimann, R. V. ; Kaufman, D. Cytoplasmic streaming in the cambium of *whi te* pine. D: *Thimann, K. V.,* ed. *Tbe physiology of forest* trees. *Mew York: Ronald Press;* 1958:479-492.

Ursic, *S.J. Lethal root* temperatures of 1-O JobJoJJy *pine seedlings.* Tree *Planters'* Notes 47(12) :25-28; 1961

Van Loon, A. P. Some effects of a *wild* fire oa *a southern* pine plantation. Res. *Note 21.* Taree, New Soutb Wales, *Australia:* Forestry Commission of *New Soutb* Wales; *1967. 38* pp.

Van Wagner, C.E. Fire *and red pine.* In: Proceedings, 10th annual *Tall* Timbers *fire ecology conference; 1970 August 20-21;* Frederictoa. New Brunswick. Tallahassee, FL: Tall *Timbers- Research Stati on;* 1970;10:211-219.

Vaa Wagner, C. E. Prescribed burning experiments: red *and* wbite pine. *Publ. 1020,* Ottawa, *Canada:* Department *of Forestry,* Forest *Research Branch;* 1963. 27 PP.

Vi J *larrubia, Charles R. ;* Chambers, Jir *L.* Fire: J ts *effect* on *growth and survival of JobJoJJy* pine (Pi nus taeda L. *).* Louisiaaa *Academy of Science* 41:85-93. Baton Rouge, *LA: Louisiana State Uni versi ty; 1978.*

Vines, R. G. Beat transfer tbrough *bark, and tbe resistance of trees to fire. Australian Journal of Botany* 16: 499-514; 1968.

Wade, Dale D. *Survival* in *young* JobJoJJy pine *plantations following wildfire. In: Proceedings, 8th national* coufereuce *on fire* and *forest* meteorology: *1985 April 29-May* 2; Detroit, HI. 1985:52-57. *[Available from Society* of *American* Foresters, *Washington, DC]*

Wade, Dale D. ; Ward, *Darold E. Management* decisions *in* severely dawaged stands. *Journal of Forestry* 73(9) :573-577; 1975.

Wagener, Willis W. *Preliminary guidelines for estimating tbe survival of fire- dawaged trees. For. Res.* Notes 98. Berkeley, CA: U.S. Department *of Agriculture,* Forest Service, California Forest and Range *Experiment* Station; *1955. 9 pp. [Available from Pacific* Soutbwest *Forest and Range Experiwent Station.* Berkeley, CA]

Wahlenberg, W. G. Loblolly pine: its *use,* regeneration, protection, growtb and *management. Durham,* NC: *School* of Forestry, *Duke Uni versi* ty; 1960. 603 pp.

Wahlenberg, W.G. Longleaf pine: its use, *regeneration,* protection, growtb and *management. Washington, D. C. : Charles* Latbrop Pack Forestry Foundation: 1946. 429 pp.

Wahl enberg. W. 6. ; Greene, S. W. ; Reed, JLR. Effects *of* fire and cattle grazing on longleaf pine lands as *studied at* McNeill, *Bississippi. Tech. Bull.* 683. Wasbington, OC: U. S. Department *of Agriculture,* Forest Service: 1939. 52 pp.

Wakeley, Philip C. Effect of a single *winter* fire on *planted* slash *pine. Forest Worker* 7(2):11; 1931.

Waldrop, Tbowas A. ; Van Lear, David *H.* Effect of *crown* scorch on *survi val* and growth of *young loblol* Jy pine. Southern *Journal of* Applied Forestry 8(1) :35-40; 1984.

Wal Per, Laurence *C. ; Wiant, Harry V. , Jr. Si J vicul ture* of *shortleaf* pine. *Bull.* 9. Nacogdocbes, TX: *Stephen* F. Austin State College, *School* of *Forestry: 1966.* 60 PP.

Wilkinson, R. C.; Becker, 6. C.; *Benjamin,* D.M. *The* biology of Neodiprion rugifrons, s, *a sawfly infesting* jack pine in Wisconsin. Annals of the *Entomological Society of* America 59:786-792; 1966.

Wilson, L.F. Effects of different population levels of tbe Europeaa pine *sawfly on young* scotch *pine trees. Journal of Economic Entomology* 59:1043-1049; *1966.*

Wyant, James 6 . ; Laven, Richard D. ; Omi , *Phi lip* N. *Fire effects on shoot growth characteristics of ponderosa pine* in Colorado. *Canadian* Journal of Forest *Research* 13(4) :620-625; *1983.*

Wyant, James G.; Omi, *Philip N.; Laven, Richard D.* Fire induced tree *mortali* ty in a Colorado ponderosa pine/Douglas-fir stand. Forest Science 32(1):49-59; 1986.

Wyman, Lenthall. Resul ts from sample plots in *southern* pines *experiments.* Journal of Forestry 20(7) : 780-787 ; 1922.

Wade, Dale D.; Johansen, R. W.

Effects of ffre on southern pine: observations and recommendations. Gen. Tech. Rep. SE-41. Asheville. NC: U.S. Department of Agrfculture, Forest Service, Southeastern Forest Experiment Station: 1986. 14 pp.

Systematically discusses fire damage as it relates to all parts of the tree: available literature is critiqued, apparent contradictions resolved, and some commonly held misconceptions dispelled. Suggestions for avoiding fire damage during prescribed burns are given.

Keywords: Fire damage, fire injury, crown scorch, fire mortality, bark char.

Wade, Dale D.; Johansen, R. W.

Effects of fire on southern pfne: observations and recommendations. Gen. Tech. Rep. SE-41. Asheville, NC: U.S. Department of Agrfculture, Forest Service, Southeastern Forest Experiment Statfon: 1986. 14 pp.

Systematically discusses fire damage as it relates to all parts of the tree: available literature is critiqued, apparent contradictions resolved, and some commonly held misconceptions dispelled. Suggestions for avoiding ffre damage during prescribed burns are given.

Keywords: Fire damage, fire injury, crown scorch, fire mortality, bark char.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives -as directed by Congress-to provide increasingly greater service to a growing Nation.