Fuels Management Reduces Tree Mortality from Wildfires In Southeastern United States

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ABSTRACT: *The objective was to determine the effectiveness of a regular prescribed burning program for reducing tree mortality in southern pine forests burned by wildfire. This study was conducted on public and industry lands in northeast Florida. On the Osceola National Forest, mean mortality was 35% in natural stands and 43% in plantations two growing seasons after a June 1998 wildfire. Burn history significantly affected mortality with those stands prescribe-burned 1.5 yr prior to the wildfire having the lowest mortality, while stands prescribe-burned 2 or more years prior had higher mortality. Although significant tree mortality did occur on the Osceola National Forest, with all trees killed in some stands, many trees in other burned stands did survive. The overall mortality was lower in both plantations and natural stands on the Osceola than at Tiger Bay where prescribed burning had been less frequent. The highest mortality rates occurred on the Lake Butler Forest where prescribed burning had not been used since plantation establishment. Thus, a regular prescribed burning program will reduce mortality following wildfires in both natural and planted stands of southern pines on flatwoods sites, even when wildfires occur under severe drought conditions. South. J. Appl. For. 28(1):28–34.*

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As noted by DeBano et al. (1998), there is a general trend in many forest types of increasing fuel buildup and therefore fire intensity with a lengthening of the fire-return interval. Thus there exists an implied relationship between overstory tree mortality and time since the last burn. Mortality can result from high-intensity crown damaging fires or from high-severity ground fires consuming accumulated litter around the bases of trees (Ryan and Frandsen 1991).

Fuel buildup is quite rapid the first 10 yr following disturbance in the saw palmetto (*Serenoa repens* [Bartr.] Small)/ gallberry (*Ilex glabra* L.) fuel complex found on flatwoods sites in the southern coastal plain (Sackett 1975, McNab et al. 1978). For decades, frequent, regular judicious use of prescribed burning has been promoted as a practical method to limit the accumulation of these fuels. Past research supports the assumption that wildfires would be kept small and damage limited with regular use of prescribed burning. Davis and Cooper (1963) found a strong relationship between the acres burned in wildfires and elapsed time since the last prescribed burn for sites in North Florida and South Georgia. They also found that height of bark char, a measure of fire intensity, was related to the age of the rough, i.e., years of fuel accumulation. Martin (1988) indicated fire intensity during the Florida wildfires of 1985 was lower on areas previously prescribe-burned.

Much recent research in the South has concentrated on tree injury and growth following prescribed burns (Boyer 1987, Johansen and Wade 1987, Lilieholm and Shih-Chang 1987, Weise et al. 1990). Little information exists, however, on tree mortality following wildfires in areas where fuels are routinely reduced through prescribed burning. The primary objective of this study was to determine the effects of fuel management through prescribed burning on wildfire severity as measured by overstory damage. The null hypothesis was that during a severe drought, prewildfire fuel treatments have no effect on fire severity or overstory mortality. A secondary objective was to determine if overstory mortality is related to other factors such as site moisture level.

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Methods

This study was initiated following the 1998 Florida wildfires. An attempt was made to locate plots throughout northeast Florida covering a range of prescribed burning regimes resulting in fuel buildup times of 3 months to 10 or more years. Extensive salvage operations on industry-owned lands prior to the initiation of the study limited the stands available for sampling. The three areas selected for the study were the USDA Forest Service's Osceola National Forest, Georgia Pacific's Lake Butler Forest, and Florida Division of Forestry's Tiger Bay Forest. Three additional study sites were added during the 2000 wildfire season to increase the sample size on industrial lands and to verify results from public lands. These included a wildfire area on the Osceola National Forest and two wildfire sites on land owned by Georgia Pacific (Table 1).

Sample stands from the 1998 wildfire on the Osceola National Forest were in a 25,000-ac area of flatwoods forest type containing natural stands, with a mixture of slash (*Pinus elliottii* Engelm.) and longleaf pine (*P. palustris* Mill.), and slash pine plantations. Intermixed throughout the area were wet depressional ponds and stands occupied by slash pine, pond cypress (*Taxodium distichum* var. *nutans* [Ait] Sweet), swamp blackgum (*Nyssa sylvatica* var. *biflora* [Walt.] Sarg.), and loblolly bay (*Gordonia lasianthus* [L.] Ellis). The understory was typical flatwoods containing a mixture of grasses, saw palmetto, and gallberry on dry and moist sites and loblolly bay and fetterbush (*Lyonia lucida* [Lam.] K. Koch) on wetter areas. The entire area had been managed with regular prescribed burning for the previous 25 yr, using dormant season burns for 20 yr and growing season burning during the most recent 5 yr.

On June 3, 1998 when the Keetch-Byram drought index (KBDI) (Keetch and Byram 1968) was above 700, an arson fire was set at six to eight locations. KBDI is a measure of the relative dryness based on precipitation and potential evapotranspiration, which ranges from 0 to 800. Wildfire intensity is likely to be extreme and control difficult for KBDI values above 600 in the spring or 650 in the summer in Florida. Thus, it was not surprising that this wildfire burned 18,000 ac in 4 days when the KBDI was 750, temperature over 90°F, and relative humidity 35%.

All pine stands within the 1998 burn area on the Osceola National Forest were stratified by origin as natural or planted. Twenty-one stands were randomly selected from each type for sampling between November 1998 and February 1999. Within each stand, five circular plots were located 100 ft apart along a transect with a randomly selected starting point. Plot size varied with tree density from 0.025 to 0.124 ac to sample 15 to 20 trees per plot. When dominant tree height was greater than 50 ft, all pines with a diameter at breast height (dbh) greater than 2 in. were measured. In plantations with dominant trees less than 50 ft tall, all pine trees taller than 4.5 ft were measured. For each sample tree, the species, dbh, condition (live or dead), crown death (%), and bole char (%) were recorded. Crown death was defined as the portion of the crown with fire killed branches. Crown scorch could not be accurately determined because of the time lag between the wildfire and data collection. The first five live trees going clockwise from north in each circular plot were labeled and resurveyed in October 1999 to determine second year mortality rates. At each plot, site type (dry, moist, or wet), based on topographic position and understory indicator species, was noted. The burn history (time since last prescribed burn) and wildfire type (heading or backing) were obtained from Osceola Ranger District records.

The wildfire on the Osceola National Forest in 2000 was also an arson fire set in flatwoods type similar to the area burned in 1998. Before containment on March 11, it burned 6,179 ac with 1,820 ac on Forest Service property. The KBDI was 500 on the day of ignition and increased to 540 before the wildfire was contained. During the wildfire, minimum relative humidity averaged 30%, maximum temperatures were in the mid 80s, and wind speeds varied from 3 to 14 mph. The most recent prescribed burn of the Forest Service property had occurred in 1997. All seven of the natural pine stands within the burned area on the Osceola National Forest were sampled 1 yr after the wildfire using the procedures previously described.

Data were also collected from 10 stands at Tiger Bay State Forest (Table 1). The plantations were in two age classes, 10 or 28 yr old. The 10-yr-old plantations had a grass-dominated understory while the older plantations had an understory dominated by loblolly bay. Three stands were sampled on the Lake Butler Forest that had burned by wildfire in June 1998. Stands were 12- to 15-yr-old slash pine plantations established by machine planting on chopped, raked, and bedded sites. The understory had been sprayed with Triclopyr 9 to 21 months prior to the wildfire. Herbicide had killed most of the gallberry, but the dead stems were still standing between the rows of pines. No prescribed burning had been conducted in the plantations since establishment.

Some salvage cutting had occurred at Tiger Bay State Forest and the Lake Butler Forest in 1998. At Tiger Bay, some bias was likely introduced because the staff had selected the most severely damaged older plantations for harvest first, and they were not available for sampling. On the Lake Butler Forest, much of the 1998 burn area had been salvaged. Areas

Table 1. Location and characteristics of stands sampled following wildfires in Florida.

Location	Wildfire dates	Forest type	Prescribed burn history
Osceola National Forest	June 1998	Natural mixed longleaf/slash pine and slash pine plantations	Every 3 to 4 yr for previous 25 yr
Tiger Bay State Forest	June 1998	Natural mixed longleaf/slash pine and slash pine plantations	Every 3 to 6 yr since 1994
Lake Butler Forest	June 1998	Slash pine plantations	No burning
Osceola National Forest	March 2000	Natural mixed longleaf/slash pine	Every 3 to 4 yr for previous 25 yr
Lake Butler Forest	June 2000	Slash pine plantations	No burning since 1993
Waldo Area Forest	June 2000	Slash pine plantations	No burning since 1993

sampled were smaller portions of stands around the perimeter of the wildfire and a small wildfire that had not been salvaged.

One of the wildfires sampled on Georgia Pacific land in 2000 occurred on the Lake Butler Forest within 5 miles of the stands sampled in 1998. It was ignited on June 5 when the KBDI was 660 and contained that same day. The 250 ac 17-yr-old slash pine plantation burned by this wildfire was last prescribe-burned in 1993. The other 2000 wildfire on Georgia Pacific lands was part of a larger arson fire set on May 30 west of Waldo, Florida, when KBDI was 678. Before containment on June 8, the wildfire burned nearly 5000 ac of slash pine plantations, ranging in age from 15 to 25 yr. None of the 10 plantations sampled had been burned since 1993, but some had received a Triclopyr herbicide treatment. Two plantations that had no herbicide and two each treated in 1996, 1997, 1998, and 1999 were randomly selected for sampling. All sample plots were measured 2 wk following the wildfire.

Data from the 1998 wildfire on the Osceola National Forest were compared using analyses of variance in an unbalanced split-split-plot design (Snedecor and Cochran 1967). The main plot was prewildfire fuel treatments, which were done on a compartmental basis. Wildfire type was at the next level because it was the same over an entire stand. Site moisture level was the sub-sub-plot factor that was assigned for each sample plot within a sample stand. Response variables tested by this technique included tree mortality and basal area loss. Data from plantations and natural stands were analyzed separately.

A pooled measure of wildfire severity was assigned to 1998 Osceola data based on a damage index calculated by multiplying mean percent crown loss by mean percent bole char on a sample plot and then dividing by 100. Plots were categorized in four levels with damage index less than 25 at level 1, 25 to 50 level 2, 51 to 75 level 3 and greater than 75 level 4. Percent relative tree size was calculated for each tree by dividing its dbh by the mean tree dbh for the entire plot and then multiplying by 100. This value was then averaged for all live and dead trees on a plot.

Regression was used to test for relationships between tree mortality and plot density, plot basal area, tree bole char, and tree crown loss. Standard linear and logistic regression (Hintze 1990) was also used to test for a relationship between delayed mortality and bole char or crown loss. Average tree mortality for each stand was calculated for data from Tiger Bay State Forest. This was used to test a regression equation developed from 1998 Osceola National Forest wildfire data to determine if time since last prescribed burn was a good indicator of mortality from wildfire.

Results

Osceola National Forest

Natural stands burned in 1998 on the Osceola National Forest contained mostly pole (5 to 9 in.) and sawtimber size (> 9 in.) trees. The average dbh for sample trees in natural stands was 9.6 in. Mean height for dominants and codominants was 85 ft. Plantations ranged in age from 8 to 35 yr. Average tree dbh in plantations was 5.7 in., and mean height was 52.5 ft. Eight of the 21 plantations sampled had mean heights less than 50 ft. All natural stands and plantations with trees over 50 ft tall had been thinned at least once prior to the wildfire. Basal area averaged 66 ft^2/ac in natural stands and 70 ft^2/ac for planted stands, excluding the two seedling plantations.

Burn Interval

Wildfire severity and therefore tree mortality varied. In some stands, the wildfire totally consumed most crowns, directly killing the trees. In other stands, trees were stressed, and many succumbed to bark beetle attacks over the first summer and fall following the wildfire. Some stands had little apparent damage and only a few dead trees. After the first growing season following the wildfire, mortality averaged 27% in natural stands and 41% in plantations based on stems/ac. Additional trees died during the second growing season increasing mortality to 43% in plantations and 35% in natural stands. Average tree mortality after the first growing season was lowest in areas that had been prescribe-burned 1.5 yr prior to the wildfire (Figure 1). Mortality was higher for those areas prescribed-burned within 6 months of the wildfire and for those burned 2 or more years before the fire. Additional mortality during the second growing season was evenly distributed across all prescribed-burn histories. Mortality remained lowest on areas prescribed-burned 1.5 yr prior to the wildfire and was significantly higher in stands prescribed-burned within the last 6 months or 2 or more years prior to wildfire in both plantations and natural stands.

Basal area loss averaged about 5% less than loss based on number of stems, but followed the same pattern with smallest losses in stands that were prescribed-burned 1.5 yr prior to the wildfire for both natural and planted stands. Mean basal area loss was 22% in natural and 36% in planted stands at the end of the first growing season following the wildfire. By the end of the second growing season, basal area loss had increased to 31% in natural stands and 38% in plantations.

Time since the last prescribed burn had a significant effect on relative wildfire intensity based on damage level index. Stands prescribed-burned 1.5 yr before the wildfire had low intensities with 93% of the sample plots at level 1 intensity and no plots in levels 3 or 4 (Table 2). As time since the last prescribed burn increased, the percent of the sample plots at the highest intensity (level four) also increased.

Site and Fire Type

Relative moisture level of an area influenced tree mortality within natural stands where losses were significantly higher on wetter areas (Table 3). There were no plantations on the wettest sites and no difference in tree mortality between dry and moist areas. There were no significant differences in tree mortality between areas burned by heading wildfire and those burned by backing wildfire in either plantations or natural stands. Losses based on basal area were about 5% less than mortality based on number of stems, but followed the same patterns.

Tree Size

The relative dbh of trees killed by wildfire in natural stands was 14% less than mean tree dbh, while the trees that survived

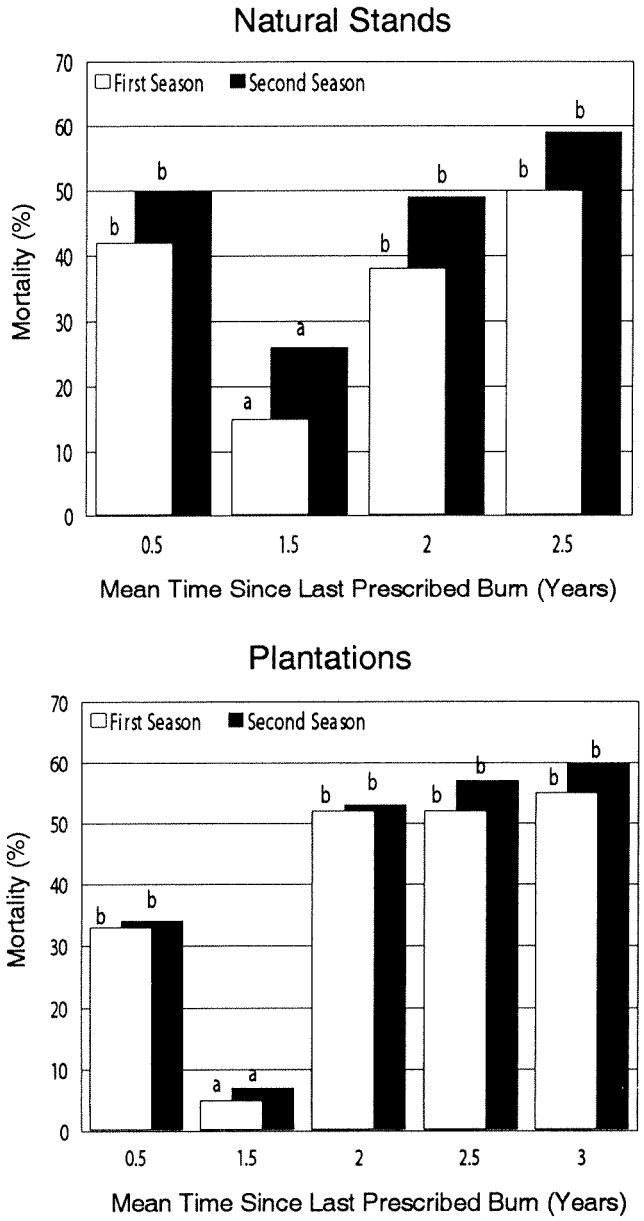

Figure 1. Mortality of southern pine trees after first and second growing seasons following June 1998 wildfire in natural stands and plantations on Osceola National Forest, Florida. Letters denote significant differences at 0.05 level.

Table 2. Distribution of sample plots by damage level index, for stands of southern pines following June 1998 wildfire on the Osceola National Forest, Florida.

	Time since last prescribed burn (yr)			
Damage level*	0.5	1.5	2	2.5
	(% of plots)			
1	40	93	62	53
2	23	7	15	11
3	27	0	8	16
4	10	0	15	20

* Damage index calculated by multiplying mean percent crown loss by mean percent bole char divided by 100. Index less than 25 equals level 1, 25 to 50 level 2, 51 to 75 level 3 and greater than 75 level 4.

the wildfire were 6% larger than average. Relative size of trees killed by wildfire was 24% lower than mean tree size in natural stands prescribe-burned 1.5 yr before the wildfire. In plantations, dead relative tree diameter was 10% smaller than the overall average tree diameter, while trees that survived wildfire were 6% larger compared to average tree size. As with natural stands, trees killed by the wildfire had the lowest relative diameter on sites prescribed burned 1.5 yr before wildfire.

Although dbh did affect mortality, there was no relationship between mean tree height and mortality from the wildfire. Young short trees in plantations had average mortality rates similar to those of large trees in natural stands if all other factors, such as time since the last prescribed burn and site moisture level, were equal. In addition, tree mortality was not significantly related to stand density, expressed as either stems/ac or basal area/ac.

Delayed Mortality

Methods to predict potential mortality in fire damaged trees can aid in salvage decisions. Logistic regression analyses indicated no relationship between likely condition (live or dead) of trees after the second growing season and height or percent bole char. A significant logistic regression was found for both natural and planted stands between condition after the second season and percent of crown loss at the end of the first season. However, these regressions had low *r* square values and performed poorly, especially in plantations where trees were predicted to live regardless of the level of crown loss. The most effective system for predicting delayed mortality was based on simple classification into crown loss levels. In planted stands, delayed mortality was low and most trees alive after one season were also alive after the second season, although there was a slightly increased chance of mortality when crown loss exceeded 75% (Table 4). In natural stands, once crown loss exceeded 70%, second season mortality increased substantially. The probability of a tree surviving with greater than 75% crown loss was low.

Table 3. Average mortality of overstory southern pines by site moisture level and fire type after second growing season following June 1998 wildfire on Osceola National Forest, Florida.

	Natural stands	Planted stands
	Mortality (%) (sample size)	
Relative moisture level		
Dry	26a*	28a
	(43)	(77)
Moist	33a	34a
	(41)	(28)
Wet	65b	
	(21)	
Fire type		
Backfire	36a	21a
	(40)	(25)
Headfire	47a	41a
	(65)	(80)

* Within a column, for each section, means not followed by the same letter are significantly different at the 0.05 level.

Table 4. Second year mortality rates for southern pine trees by crown loss category after June 1998 wildfire on Osceola National Forest.

Crown loss (%)	Natural stands	Planted stands
	[Tree mortality (%)]	
1–10	3	3
10–25	12	5
26–50	11	5
51–70	13	3
71–75	56	5
76–95	82	8

Stands burned on the Osceola National Forest in the 2000 wildfire had average tree dbh ranging from 5.7 to 7.6 in. with an overall mean of 6.5 in. Mean basal area was 73 ft^2/ac with a range of 58 to 113 ft^2/ac. Average tree mortality from the wildfire was 35%. There was no difference in mortality rates on dry and moist plots where the average death rate was 15%. Mortality was significantly higher on wet plots, however, at 75%. For all stands, combined, dead trees had an average dbh of 5.3 in. while live trees averaged 7.2 in. Basal area loss averaged only 6% on dry and moist sites but 64% of the basal area was in dead trees on wet plots.

Tiger Bay State Forest

At Tiger Bay, mean tree dbh was 8.5 in. for natural stands, 5.6 in. for plantations 28 yr old, and 3.1 in. for plantations 10 yr old. Natural stands and older plantations had similar basal areas at 91 and 100 ft^2/ac, respectively, while younger plantations averaged 30 ft^2/ac. Tree mortality 2 growing seasons after wildfire averaged 61% in natural stands and 55% in plantations.

Data from Tiger Bay State Forest provided an opportunity to test for a general relationship between tree mortality and time since the last prescribed burn before wildfire occurrence. A regression equation was generated using data collected on dry and moist plots in natural stands on the Osceola National Forest. The regression (Percent tree mortality = 11.71 + 11.74 * time since last burn in years) although significant had an r square of only 0.16. Thus, much of the variation in the data was caused by other factors. This equation was applied to data from the natural stands at Tiger Bay to test its usefulness (Table 5).

Georgia Pacific Forest Lands

Plantations sampled on Lake Butler forest after the 1998 wildfires had sample trees with a mean dbh of 5.5 in. and an average height of 50 ft. Only three stands were sampled, but mortality levels were 100% after the first growing season in two stands and 67% in the third. This gave an average tree mortality following wildfire of 89%.

Plantations sampled immediately following the 2000 wildfires had a mean tree dbh of 6.5 in. Mean stand heights ranged from 35 ft to 61 ft with an average for all stands combined of 53 ft. Stand basal area ranged from 57 to 110 ft^2/ac with an overall mean of 81 ft^2/ac. Trees killed by wildfire had an average dbh of 6.1 in. and an average height of 52 ft, while live trees averaged 8.3 in. dbh and 62 ft tall. The overall mortality rate was 85%. Plantations that had been treated with herbicide in 1997 appeared to have lost fewer trees than stands sprayed in other years or those not treated with herbicide (Table 6), but there were not enough samples to test for significance.

Table 5. Predicted and actual mortality rates for southern pines in natural stands on Tiger Bay State Forest burned by June 1998 wildfire.

Time since last prescribed burn (yr)	Predicted	Actual
	[Tree mortality (%)]	
1	23	ND*
2	35	ND
3	47	22
4	59	82
5	70	ND
6	82	80

* No data because no stands that burned had this history of prescribed burning.

Discussion

Tree mortality following the 1998 wildfire on Osceola National Forest was influenced most by time since the last prescribed burn. Accumulation of understory and forest floor fuels in longleaf and slash pine stands is rapid during the first 10 yr following a prescribed burn (McNab et al. 1978). In addition, prescription burning is generally done under weather conditions where only part of this fuel is consumed. During severe drought conditions, however, consumption of the understory and forest floor by wildfire is virtually complete. Thus, it is not surprising that mortality levels increased significantly in those stands that had not been prescribed burned for 2 or more years. The lowest wildfire severity, based on damage level index, occurred in stands that had been prescribe-burned 1.5 yr prior to the wildfire. Those stands burned 1.5 yr prior to wildfire also had the lowest mortality. The low severity and mean tree mortality in both plantations and natural stands on the Osceola National Forest likely occurred on those areas because they had not yet accumulated large amounts of fuel (Brose and Wade 2002) because they had only one full growing season since the last prescribed burn.

Although stands burned just before the Osceola wildfire had not accumulated much new understory growth, these stands had a quantity of small standing dead woody stems and fresh fallen needles, caused by prescribed burn crown scorch, that contributed to fire severity, as shown by the damage index. In addition, trees in these stands had limited time to recover from stress of prescribed burning prior to wildfire because most of these stands had been burned just 3 months before the wildfire. The combined stress of prescribed burning and wildfire in a short time likely caused the increase in tree

Table 6. Tree mortality from 2000 wildfire in northeast Florida slash pine plantations, with or without herbicide.

Herbicide application (yr before fire)	Plots sampled	Tree mortality (%)
No Herbicide	10	91
1	5	97
3	10	53
4	5	100

mortality. Increased mortality on wet sites was also likely related to greater fuel quantities. Prescribed burning normally creates a mosaic burn pattern in these flatwoods types, as these fires rarely enter the wetter depressions. When these wet areas do burn, it is typically a light surface burn that consumes only a portion of the understory and little of the litter and duff because it is too wet to burn. However, under extreme drought conditions, both coverage and consumption of litter, duff, and understory are nearly complete, resulting in high tree mortality as occurred on wet sites for both 1998 and 2000 wildfires.

A headfire can produce greater intensities, but backing fires can cause greater cambial heating near the ground because of their increased residence time (Wade and Johansen 1986). Trees in stands sampled in this study burned by a heading wildfire had greater initial crown damage, while trees in stands burned with a backing wildfire had healthy green crowns for a number of weeks. However, on areas with 2 or more years of fuel accumulation, these trees experienced substantial bark beetle attack and subsequent mortality during late summer and fall. Thus, there was no significant difference in mean tree mortality by fire type, even though the nature of the injury to trees differed.

Mean basal area mortality for natural stands on dry and moist sites was 27%. This was the same rate found for plantations after adjusting for an imbalance in sample distribution. There was a greater amount of delayed mortality in natural stands. In plantations, most of the trees that died were already dead by the end of the first growing season following wildfire. Greater delayed mortality in natural stands likely resulted from larger trees being able to survive longer following girdling from severe cambial damage because of greater carbohydrate reserves.

When selecting trees for salvage following wildfire, it is desirable to select those not likely to survive. Thus, if delayed mortality can be predicted based on tree damage it will aid in this decision. Bole char expressed as either percent of the total bole or absolute height has been used successfully to predict mortality in western conifers (Peterson et al. 1991, Regelbrugge and Conard 1993). This variable was not a reliable indicator of mortality in this study or for others working with southern pines (Bourgeois 1985, Mann and Gunter 1960, Villarrubia and Chambers 1978). Crown loss, however, was effective for predicting delayed mortality in natural stands, where all trees with greater than 70% crown loss had a high probability of dying.

Mortality following both 1998 and 2000 wildfires was greater for the smaller trees in a stand. This was apparent by the difference in relative tree diameter between dead and live trees. It was also the reason tree mortality based on stems/ac was higher than basal area loss. However, average mortality was no greater in younger plantations with smaller trees than it was in older plantations with larger trees. Therefore, tree size relative to the rest of the stand was the determining factor. This likely resulted from greater crown damage to the smaller than average trees in a stand.

Although some stands on the Osceola had 100% tree mortality, many trees in burned area did survive even though wildfire occurred under extreme conditions. No areas in any sample stands were left unburned. Thus, survival was not due to trees escaping the wildfire. Overall, tree mortality averaged less than 40% from the 1998 wildfires; but this could have been the result of prescribed burning or just a chance occurrence since the prescribed burn treatments were not applied at random. Results from the 2000 wildfire on the Osceola validate 1998 data with a similar overall tree mortality of 35%. This benefit of prescribed burning has also been shown by others. In the New Jersey Pine Barrens, Moore et al. (1955) reported tree mortality following a wildfire was 64% in previously unburned areas but only 17% in areas prescribed-burned during the preceding 3 yr. Prescribed burning provided similar reductions in tree damage following wildfire under extremely dry conditions in the same area of New Jersey (Cumming 1964) and in the ponderosa pine (*Pinus ponderosa*) type in Arizona (Wagle and Eakle 1979). Under severe drought conditions, which occur every 10 to 20 yr, mortality of southern pines following wildfires in areas with 5 or more years of fuel accumulation is high (Eldredge 1935). Those few trees that do survive the immediate effects of these wildfires are usually killed by subsequent bark beetle attacks. Bickford and Bull (1935) reported near total southern pine mortality for such a wildfire in stands with a 16 yr rough. The 31% basal area loss measured in plantations and 38% in natural stands after the June 1998 Osceola wildfires was quite low by comparison. Increased mortality with time since the last burn found in the current study also indicates that prescribed burning can reduce timber loss.

Wet sites on the Osceola accumulate fuels because they normally do not burn during prescription burns. Mortality rates for the 1998 and 2000 wildfires were more than twice as high on these sites as on moist sites where regular prescribed burning had reduced total fuel loads. At Tiger Bay State Forest, where prescribed burning was less frequent, mortality was 55% in plantations that had not been prescribed-burned for 6 yr and 61% in natural stands where time since the last burn ranged from 3 to 6 yr. Thus, a regular prescribed burning program, although it will not prevent all losses, does reduce tree mortality if a wildfire occurs. This reduction in tree mortality occurs in both natural and planted stands of southern pines on flatwoods sites, even with wildfires under extreme drought conditions. Fuel reduction is the key. A regular prescribed burning program keeps both fuel accumulations on the forest floor and understory stature within tolerable levels. Regular prescribed burning also prunes lower branches and limits development of ladder fuels that can lead to greater crown damage during a wildfire. Once fire return interval exceeds 4 yr in this community type, wildfires can be expected to cause significant increases in overstory mortality.

On the Lake Butler Forest, where prescribed burning had not been used, mortality averaged 89% in plantations burned by wildfire in 1998. These stands had received herbicides less than 2 yr prior to the wildfire. Similar stands treated 1 to 4 yr prior to the 2000 wildfire had average tree mortality of 85%. These herbicides may be able to decrease the fireline intensity of subsequent wildfires (Brose and Wade 2002), but there is a lag period following application. After herbicide treatment, dead stems of woody ground flora are still standing and

contain a substantial amount of needle drape. Until these stems decay sufficiently to fall over and reduce the height of the flammable layer, they can increase tree mortality from wildfires. Saw palmetto is resistant to the herbicide treatment used, and thus likely increases in cover in response to the removal of competition. Even where palmetto is not prevalent, the herbicide treatment only removes the woody understory fuels, but does not reduce the accumulation of needles in the forest floor. Under severe drought conditions, wildfire is likely to cause high mortality because of root and cambial damage from consumption of this accumulated fuel. Even in the stands treated in 1997 where mortality was only 53%, the surviving trees were severely impacted. Average crown death was 92%, and delayed mortality will likely be at least 10%, with significant growth loss in those trees that do survive. Thus, herbicide seems to be a partial replacement for prescribed burning providing wildfire protection during most years, but the risk of significant tree mortality is much higher than in prescribed burned stands if wildfires occur during severe droughts.

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