UNDERSTORY HERBICIDE AS A TREATMENT FOR REDUCING HAZARDOUS FUELS AND EXTREME FIRE BEHAVIOR IN SLASH PINE PLANTATIONS

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Abstract—The 1998 wildfires in Florida sparked a serious debate about the accumulation of hazardous forest fuels and the merits of prescribed fire and alternatives for mitigating that problem. One such alternative is application of understory herbicides and anecdotal evidence suggests they may either exacerbate or lessen the fuel accumulation problem. In 1998, a study was initiated in northern Florida to document changes in fuel characteristics in slash pine (*Pinus elliottii*) plantations treated with a mid-rotation understory herbicide and model their potential impacts on fire behavior. Field data showed unmanaged stands contained the highest loadings of understory fuels and in the first year after herbicide treatment, fuel loading did not change. In subsequent years, fuel loading rapidly decreased and remained low. Potential fire behavior, as predicted by BEHAVE, followed this fuel accumulation trend in that catastrophic stand-replacing fires were predicted for unmanaged and recently herbicided stands, and low-intensity surface fires for stands that had been herbicided several years prior.

INTRODUCTION

In 1998, Florida experienced one of its most active wildfire seasons ever (Karels 1998). From mid-May to mid-July, over 2000 wildfires occurred in central and northern Florida. Over 500,000 acres of forest burned, most of them by high-intensity/high-severity, stand-replacing fires. Over 10,000 firefighters from 49 states fought the fires. Property losses included the destruction of, or damage to, 370 businesses and residences. Commercial timber losses exceeded $350 million, suppression costs topped $100 million, and estimated tourism losses of nearly $140 million all contributed to the total estimated cost of $622 to $880 million (Mercer et al. 2000). The magnitude and severity of the wildfires prompted several land management agencies, including the USDA Forest Service and the USDI Biological Resources Division, to combine resources to study the ecological and economic impacts of the wildfires on Florida's forest ecosystems. One facet of the USDA/USDI study addressed the issue of hazardous fuel reduction in commercial pine stands and in the urban/wildland interface before a wildfire occurs.

Dormant-season prescription fire every 4 to 5 years has been the method of choice to control the buildup of hazardous fuels throughout the southern United States (Pyne and others 1996). The frequent use of fire is necessary because redevelopment of the rough is rapid with fire hazard returning to its preburn level in less than 5 years on most sites (Davis and Cooper 1963). In the past several decades, however, constraints have been placed on this practice because of smoke management concerns, liability issues, and misconceptions about the ecological ramifications of fire among the region's sizeable population of out-of-state retirees (Wade 1993).

The continuing need for hazardous fuel reduction and the social limitations of prescription fire have prompted interest in developing other strategies for managing hazardous fuels. One possible alternative is the herbicides that are often used as a mid-rotation treatment in commercial pine plantations to boost growth and reduce future site preparation costs (Oppenheimer et al. 1989). Herbicides reduce height, percent cover, and/or loading of the highly flammable shrub layer although the degree and longevity of hazardous fuel control is not well defined.

This study is two-phased; a detailed fuels inventory followed by computer simulations based on the fuels data. The objective was to compare fire behavior (flame length and rate-of-spread) that probably would occur in slash pine plantations treated with herbicide at five different times after treatment (age-of-rough). Because the 1998 wildfires occurred during a severe drought, fire behavior was simulated for each age-of-rough under June 1998 weather conditions.

METHODS

The fuels data for this study was collected during winter 1998-1999 on forest industry (Georgia-Pacific and ITT Rayonier) land located between Lake Butler and Starke in Bradford and Union counties in the Coastal Plain Physiographic Province of northern Florida. Fifteen stands varying from 4 to 35 acres in size were chosen based on the age of rough, i.e., number of years (1, 2, 3, 6, or untreated) since the herbicide treatment. The "untreated" age class indicated no herbicide spraying since planting and included stands that had been unmanaged for 17 years.

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All of these stands were slash pine plantations grown on a pulpwood rotation of about 30 years. They were 17 years old with an average stand diameter of 8.5 inches and contained 110 – 140 ft^2 of basal area per acre.

In each stand, understory fuel characteristics (cover, height, and loading by size class) were collected as inputs to BEHAVE to build custom fuel models. Percent cover and height were determined for all stands using line transects. Near the center of each stand, six 215ft-long transects were systematically located parallel to one another 80-ft apart. The vegetation was sampled along each transect at 16-ft intervals by holding a 8-ft tall range pole perpendicular to the ground and recording each plant species touching the range pole and the height of the tallest plant. Percent cover and height to the nearest 0.5 ft were determined for five categories; grass, open space, saw palmetto, small shrub, and tall shrub. Grass included all graminoid species, i.e., *Andropogon* spp., *Aristata* spp., and *Panicum* spp., while saw palmetto was species specific. Tall shrub was primarily gallberry but also included all other woody shrubs ³ 0.5 ft tall while small shrub included all < 0.5 ft tall, e.g., blueberry (*Vaccinium* spp.) and runner oak (*Quercus pumila*). Open space represented areas devoid of vegetation but usually blanketed by pine litter. Because sampling was done in January and February, no forbs were found.

The clip-bag-dry method was used to determine loadings of shrub and litter fuels. In this method, six 3-ft x 3-ft quadrats were located on a 100-ft x 100-ft grid near the center of the stand. Quadrats were delineated by a sampling frame and all vegetation, living and dead, within the frame and between 0.1 and 10.0 ft tall was designated as either grass or shrub fuels and clipped, bagged, and dried. All plant material on or in the forest floor (O_i and O_e horizons) was likewise collected and designated as litter fuels.

Fuel samples were dried at 195°F to a constant weight in a wood-drying oven then separated by type (grasses, pine litter including dead downed woody material, and shrubs) and by diameter size class (<0.25 inches and 0.25 to 1.00 inches). These size classes correspond to the time-lag fuel classes of 1-hr and 10-hr, respectively (Fosberg 1970). Fuels >1.00 inches in diameter were virtually nonexistent and ignored for the purposes of this study. After separation, fuels were weighed to the nearest 0.1 ounces on an electronic scale.

All fuels data were used in the NEWMDL program (Burgan and Rothermel 1984) of BEHAVE to create a custom fuel model for each age-of-rough. Physical and chemical characteristics of the palmetto-gallberry fuel complex were obtained from Hough and Albini (1978).

Custom fuel models were used in conjunction with landform and weather data in the SITE module of the FIRE1 program to develop treatment/age-of-rough specific fire behavior estimates (Andrews 1986). The Osceola National Forest provided weather data for June 1998. Cloud cover, ambient air temperature, relative humidity, 20-ft windspeed, precipitation, and fuel moistures were recorded daily at 1300 hours and averaged for the entire month. Each simulation was of a summer fire (June 15th) burning under drought weather conditions. Outputs were flame length (ft) and rate-of-spread (ft/min) for a head fire for each treatment/age-of-rough combination.

STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuels mean separation test was used to compare differences for cover, height, and loading of fuel types and sizes between the different ages-of-rough (SAS Institute Inc. 1993). In all tests $\alpha = 0.05$ and data were transformed as needed to correct for unequal variances and non-normality of residual values. Flame length outputs from each simulation were compared to fire characteristic – suppression charts (Andrews and Rothermel 1982) to rate the difficulty of controlling a wildfire burning under drought and normal conditions.

Table 1—Fuel characteristics (mean ± 1 s.e.) for rough age 1, 2, 3, 6, and 17 years

Fuel Characteristic/Type	Untreated[a]	Age of Rough (years) 1	2	3	6
Cover (percent)					
Grass	0±0C[b]d[c]	0.9±0.4Cd	6.7±0.5Ad	4.9±0.4Bc	0.9±0.2Cd
Litter	18.7±1.7Cb	20.0±2.0Cb	34.2±1.8Bb	69.8±4.8Aa	69.3±4.2Aa
Saw palmetto	6.7±0.8Cc	3.1±0.2Dc	9.3±0.2Bc	0.2±0.2Ed	19.6±0.3Ab
Short Shrub	1.8±2.1Ad	0.4±0.6Ad	0.2±0.1Ae	0.1±0.1Ad	0.2±0.2Ad
Tall Shrub	72.9±7.5Aa	75.6±7.0Aa	49.8±5.3Ba	25.3±3.2Cb	10.2±0.8Dc
Height (ft)	5.0±0.7A	4.6±0.5A	3.6±0.4B	1.6±0.3C	3.6±0.5B
Loading (tons/ac)					
Grass	0±0Bc	0.1±0.1Bc	0.3±0.2Ab	0.1±0.1Bb	0.1±0.1Bc
Litter, 1-hr	4.7±0.4Ca	5.6±0.6Ba	7.5±0.7Aa	7.5±0.8Aa	5.0±1.1BCa
Litter, 10-hr	0.6±0.7Ac	0.4±0.3Ac	0.9±1.1Ab	0.6±1.1Ab	0.8±0.5Abc
Shrub, 1-hr	3.5±0.6Aa	3.5±0.6Ab	1.1±0.3Bb	0.3±0.3Cb	1.6±0.5Bb
Shrub, 10-hr	2.0±0.5Ab	2.0±0.5Ab	0.6±0.6Bb	0.1±0.2Cb	0.9±0.6Bbc

a—Untreated stands = rough age 17 years.
b—Means followed by different uppercase letters are different within that row (µ = 0.05).
c—Means followed by different lowercase letters are different within that fuel characteristic/type (µ = 0.05).

Table 2—Characteristics[a] of the custom herbicide fuel models for rough age 1, 2, 3, 6, and 17 years

Treatment Age-of-rough (years)	Fuel Loading[b] 1-hr (tons/ac)	10-hr (tons/ac)	Live Woody (tons/ac)	Height (ft)	Surface-to - Volume ratio (in^2/in^3)	Moisture of Extinction (%)
Untreated[c]	9.47	2.54	2.96	0.69	328	35
1	8.54	2.06	0.18	0.08	326	34
2	8.37	1.25	0.13	0.06	294	40
3	7.87	0.72	0.07	0.03	282	41
6	5.32	0.98	0.81	0.04	292	32

a - Other characteristics, i.e., live woody S/V ratio (359), and heat content (8436 BTU/lb), were averages from Hough and Albini (1978) and kept the same for all fuel models.

b - Live herbaceous fuel load was 0.05 tons/ac for all fuel models. No 100-hr fuels were included in any of the fuel models because of their scarcity.

c - Untreated stand with a rough age = 17 years.

RESULTS

Before spraying, gallberry dominated the forest floor in these stands but afterwards this shrub was replaced by open space blanketed with pine litter (table 1). Saw palmetto was lacking in this treatment because of intensive site preparation when the plantations were established. Initially, height reduction was unchanged as the dead shrubs remained standing for 1-2 years. By age 3, the dead shrubs had fallen, creating rather open stands. Some shrub growth was detected in year 5 but this was due to skips in the spraying that allowed some shrubs to survive. Fuel loadings were distributed in similar fashion to the shrub height data. The greatest loadings were found in the untreated stands and were usually dominated by the 1-hr fuels in the litter and shrub fuel types. These decreased through time and shifted from the shrub layer to the forest floor.

Custom fuel models were created from these fuels data (table 2) and used in conjunction with weather and land-form data (table 3) to produce fire behavior outputs for each age of rough.

The flame length predictions were initially unchanged following treatment but then declined dramatically with time (table 4). Under drought conditions in the untreated stands, predicted flame length was 17 ft and declined only slightly by age 1 following herbicide treatment to 16 ft. However, at age 2 flame length dropped precipitously to 8 ft and continued downward to 1.3 ft at age 3 before slightly rebounding to 3.3 ft at age 5. Flame length estimates for normal weather conditions followed this same pattern but were reduced by about 30% relative to drought conditions.

Rate-of-spread predictions followed a similar pattern to flame length estimations (table 4). For drought conditions, it was initially high (49 ft/min) and increased slightly at age 1 to 59 ft/min. From that point, rate-of-spread dropped rapidly to 10 ft/min at age 2, 2.3 ft/min at age 3, and 5.6/min at age 5. Normal weather conditions reduced all rate-of-spread estimates by another 45-60%.

Table 3—Drought, normal weather, and environmental conditions[a] used in the fire simulations

Characteristic	Drought	Normal
Drought Index (KBDI[b])	731	293
Ambient Air Temperature (°F)	97	84
Relative Humidity (%)	42	65
20-ft Windspeed (mi/hr)	11	7
Cloud Cover (%)	10	40
1-hr fuel moisture (%)	5	15
10-hr fuel moisture (%)	6	13
Live Woody fuel moisture (%)	104	166
Days w/o rain	25	15
30-day rainfall total (in)	2.1	5.2
Slope (%)	0	0
Elevation above sea level (ft)	100	100
Latitude	30°N	30°N

a—Data are from the Osceola National Forest as recorded daily at the Olustee Lookout Tower at 1300 hours during June 1997 (normal) and June 1998 (drought). N = 30 for all characteristics except for the last 5 which are totals or site descriptors.

b—Keetch-Byram Drought Index assesses the combined effect of evapotranspiration and amount of precipitation in producing moisture deficits in the soil (Keetch and Byram 1968) It was developed specifically for southern fire managers and provides a scale from 0 to 800 with 800 representing desert-like conditions.

Table 4—BEHAVE-derived estimates of flame length, rate-of-spread, and control difficulty for wildfires burning under normal and drought conditions in herbicide-treated slash pine plantations at rough age 1, 2, 3, 6, and 17 years.

Weather Condition		Age of Rough (years)			
Fire Characteristic	Untreated[a]	1	2	3	6
Drought					
Flame length (ft)	17.0	16.1	8.0	1.3	3.3
Rate-of-spread (ft/min)	49.0	59.0	10.0	2.3	5.6
Control Difficulty	extreme	extreme	moderate	low	low-moderate
Normal					
Flame length (ft)	12.0	11.4	5.6	1.0	2.3
Rate-of-spread (ft/min)	27.0	33.0	6.0	1.3	2.2
Control Difficulty	extreme	extreme	moderate	low	low

a - Stand with a rough age = 17 years.

Suppression difficulty of a wildfire varied among age-of-rough but did not vary between drought and normal weather conditions so these parameters were pooled to ease reporting (table 4). In untreated and 1-year-old stands, a wildfire would probably display extreme fire behavior, i.e., torching, crowning, and spotting, making suppression extremely difficult. However, difficulty of wildfire suppression would decrease with time and after year 2 would become quite easy and would likely remain that way through rotation end.

DISCUSSION

In pine flatwood forests, it is the age and development of the rough that determines fire behavior more than any other forest characteristic (Hough and Albini 1978). This study demonstrates the effectiveness and limitations of herbicides as an alternative to prescribed fire for protecting slash pine plantations from stand-replacing wildfires. In the untreated stands, the rough was nearly impenetrable, consisting of almost complete coverage of highly flammable gallberry and saw palmetto that ranged from 3-12 ft tall. A wildfire in such a setting, regardless of whether during drought-enhanced or normal summer weather conditions, would be extremely dangerous, difficult to suppress, and would probably kill all overstory pines.

Herbicide application can reduce this highly flammable rough but it takes time. For the first year after treatment, fuel characteristics changed little. The shrubs were dead but still standing, densely spaced, and retaining fallen needles. Consequently, BEHAVE predicted a wildfire burning under drought conditions would have 17-ft flame length and 49 ft/min rate-of-spread. Under normal weather conditions, these predictions decreased to 12 ft flame length and 27 ft/min rate-of-spread. Difficulty of control would be high to extreme and suppression strategy would be the same as if the fire was burning in an unmanaged stand; necessitating indirect attack and use of natural barriers. Pine mortality from a wildfire in such a scenario would undoubtedly approach 100 percent.

However, fire danger and control difficulties decrease dramatically beginning in year 2 provided that saw palmetto was eradicated during site preparation and herbicide spraying completely covered the stand. Shrub fuels almost disappear and the only 1-hr fuel is the blanket of pine needles above the developing duff layer. The herbicide stands become quite open beginning in year 2. These favorable conditions exist at least until year 6 and quite possibly until final harvest in plantations managed for pulpwood. Under the same weather conditions, fires in such environments would be much less intense than in recently herbicided stands. Direct attack would be relatively safe and easy.

Unfortunately, the decrease in fire intensity may not translate into a decrease in pine mortality. Herbicide-treated stands will have an increased duff accumulation on the forest floor relative to stands that are regularly prescribe-burned. Roots of overstory pines colonize the bottom of this developing duff layer within 3 to 4 years. During drought years this duff layer will be consumed, significantly increasing fire severity. Consequently, a low-intensity fire in a herbicide-treated plantation is likely to root-kill more pines than a higher-intensity fire in a natural stand managed with recurrent prescribed fire because the southern pines have evolved to survive crown scorch approaching 95 percent (Weise et al. 1990; Wade, unpubl. data on file) but cannot tolerate fire damage to their roots (Outcalt and Wade 2000).

Caution must be exercised in interpreting these results and the limitations of BEHAVE must be kept in mind. It is designed to predict average fire behavior at the flaming front of a head fire for a given set of environmental parameters. In this study, we used fuel and weather conditions that we considered typical for early summer in northern Florida and consistent with a near worse-case scenario. Changing location on the fire (flanks or rear) or one or more of the parameters, i.e., windspeed, fuel moisture, or relative humidity, will alter the outputs. Also, outputs are for relative comparison among treatments. Validation of BEHAVE-generated fire predictions to actual fire behavior for these custom fuel models is still needed for the gallberry-saw palmetto fuel complex, especially under drought conditions. Likewise, comparison of actual fire behavior to BEHAVE-generated estimates for the applicable standard fuel models under drought conditions is another topic awaiting research.

CONCLUSIONS

Fire has long been a component of Florida's pine flatwood ecosystems and will undoubtedly continue to be so because of the prevalence of lightning and a growing human population. Because of excellent growing conditions, the rough quickly becomes a hazardous fuel problem that when combined with ignition sources and dry weather can produce extreme fire seasons such as the 1998 season in Florida.

Active fuels management is essential to reduce both size and intensity of wildfires. A passive do-nothing approach to hazardous fuel loadings will result in catastrophic wildfires and exacerbate damage and control difficulties. Herbicide application can be used as an alternative to prescribed fire to control understory development but the forest manager must be aware of this technique's strengths and weaknesses. A single treatment does provide for a long-term reduction of the rough but does not provide immediate fire protection, many of the other benefits of fire, e.g. duff reduction, heat scarification of seeds, nutrient cycling, necessary to maintain the health of natural ecosystems, and may make pines susceptible to root mortality during drought-year fires.

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