ASSESSMENT OF THE FARSITE MODEL FOR PREDICTING FIRE BEHAVIOR IN THE SOUTHERN APPALACHIAN MOUNTAINS

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Abstract—Fuel reduction treatments are necessary in fire-adapted ecosystems where fire has been excluded for decades and the potential for severe wildfire is high. Using the Fire Area Simulator, FARSITE, we examined the spatial and temporal effects of these treatments on fire behavior in the Southern Appalachian Mountains. With measurements from temperature sensors during prescribed burns, we recreated the fires and compared fire behavior simulated by FARSITE with observed behavior. Following calibration, we simulated effects of different fuel reduction treatments on fire behavior. This paper assesses the potential use of FARSITE and the effects of fuel reduction treatments on fire behavior for the Southern Appalachian Mountains.

INTRODUCTION

Fire has been a factor of the Southern Appalachian Mountain landscape since before Native Americans inhabited the area 10,000 years ago. With the arrival of the Native Americans, the occurrence of fire on the landscape increased as they used fire for maintaining prairies and grasslands, improving wildlife habitat, clearing land for agriculture, and hunting (DeVivo 1991, Van Lear and Waldrop 1989). The presence of fire over this period of time has influenced the species composition and structure of the Southern Appalachian forests (Delcourt and Delcourt 1997).

More recently, fire suppression, logging, and the loss of the American chestnut [*Castanea dentata* (Marsh.) Borkh.] have resulted in a proliferation of mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* spp.) and increased wildfire risk in Southern Appalachian Mountains (Brose and others 2002). As this region becomes more developed, the protection of personal property from wildfire becomes increasingly important.

Studies of the effects of different fuel treatments on fire behavior, vegetation, fuels, and other components of the forest help land managers make informed decisions about how to best apply these treatments. Fire behavior modeling software has allowed researchers, fire management officers, and forest managers to predict fire behavior and allow better planning for allocation of resources for fire suppression. With continued testing and validation, the model outputs will become more reliable, and we can learn more about wildfire behavior while reducing costs of fire fighting and protecting public safety and personal property.

The Fire Area Simulator, FARSITE (Finney 1998), is a fire growth model originally developed for planning and management of prescribed natural fires. Its use has since expanded to suppression efforts for wildfires, evaluating fuel treatments (Finney 2001, Stephens 1998, Stratton 2004, van Wagtendonk 1996), and reconstructing past fires (Duncan and Schmalzer 2004). Developed in the Western United States, the model has been validated on fires in Yosemite, Sequoia, and Glacier National Parks (Finney 1993, Finney and Ryan 1995). While the use of this software is growing in the Southwestern United States, the Midwestern United States, and Florida, as well as in other countries, it has not received much attention in the Eastern United States.

The objectives of this work were to evaluate FARSITE by comparing fire behavior from simulations to that from a prescribed burn and to test the effects of different fuel treatments on fire behavior in the Southern Appalachian Mountains.

Study Site

The study is located on the Green River Game Lands in Polk County, NC. The North Carolina Wildlife Resources Commission manages the 5,800-ha game lands for hunting, fishing, habitat conservation, wildlife management, timber production, and recreational activities.

The forest canopy is primarily mixed oak-hickory [*Quercus alba* L., *Q. coccinea* Muenchh., *Q. prinus* L., *Q. rubra* L., *Q. velutina* Lam., *Carya alba* (L.) Nutt. ex Ell., *C. glabra* (Mill.) Sweet, *C. pallida* (Ashe) Engl. & Graebn.) with yellow pines (*Pinus echinata* Mill., *P. rigida* Mill., *P. virginiana* Mill., and *P. pungens* Lamb.) located along the ridge tops and white pines (*P. strobus* L.) interspersed in cove areas. A well-developed shrub layer dominated by mountain laurel, rhododendron (*R. maximum* L., *R. minus* Michx.), and blueberry (*Vaccinium* L. spp.) is scattered throughout the study area.

This site is 1 of the 13 National Fire and Fire Surrogate (NFFS) study sites located across the country. The NFFS study attempts to quantify the effects of fuel reduction treatments on vegetation, fuels, fire behavior, soils, entomology, pathology, wildlife, and economics/utilization in forests that were historically characterized by short-interval, low to medium intensity fire regimes. Each study site has implemented the same randomized complete block design, which calls for three replicates for each treatment: (1) untreated control, (2) burn only, (3) mechanical only, and (4) a combination of mechanical treatment and burning. We present results from replicate 1 only.

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Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

For the Southern Appalachian site, our prescriptions for burning were to have a low to medium intensity fire that would remove the shrub layer and topkill some trees in the suppressed and intermediate canopy classes. Using aerial ignition, we conducted prescribed burns on March 12 and 13, 2003. For our mechanical treatment, we targeted small trees (taller than 2 m and diameter at breast height < 10 cm) and shrubs of mountain laurel and rhododendron, which were cut by contract chain saw crews. The mechanical treatment occurred in the winter of 2001-2002. All fuels created from this treatment were left on site.

METHODS

FARSITE requires a minimum of five raster layers to generate simulations. These layers are elevation, aspect, slope, fuel model, and canopy cover. The landscape data (elevation, slope, and aspect) are used for making adiabatic adjustments for temperature and humidity as well as computing slope effects on fire spread and solar radiation effects on fuel moisture. We created these files from a 30-m digital elevation model (DEM) for the Cliffield Mountain quadrangle.

Photo interpretation of color infrared aerial photographs with 1-m resolution obtained April 2, 1998, was performed to aid in determining fuel model assignment. We based polygon delineations on tone, texture, and shape. We developed five classes for photo interpretation: (1) deciduous overstory, (2) deciduous overstory with dense evergreen understory, (3) deciduous overstory with sparse evergreen understory, (4) evergreen overstory, and (5) mixed overstory. Based on overstory composition and evergreen understory, we then assigned these polygons to 1 of the 13 standard Northern Forest Fire Laboratory fire behavior fuel models (Albini 1976, Rothermel 1972). Classes 1, 4, and 5 were grouped as fire behavior fuel model (FBFM) 9 for all treatments. Polygons classified as 2 or 3 that occurred within the burn only or the control treatment boundaries were assigned FBFM 6 because of the height and flammability of the shrub component (Anderson 1982). Polygons containing an evergreen understory (classes 2 and 3) within the mechanical treatment boundaries were assigned to FBFM 11 because of the prescriptions and the fuels created from the mechanical treatment.

We took hemispherical images in each treatment area and analyzed them for crown closure. A digital camera modified with a Nikon FC-E8 fish-eye lens converter and mounted in a self-leveling tripod was positioned 1.5 m above the ground, high enough so that shrub cover would not be included in the image. We analyzed the images for percent open sky using WinSCANOPY (Regent Instruments) and then converted them to crown closure. This information was transferred into a geographic information system to create a canopy cover raster layer for the entire area, which was then exported to FARSITE.

In addition to these layers, text files of wind and weather are necessary. We created wind and weather files from data collected on March 13, 2003, the day of the actual burn. Temperatures ranged from 19 to 26 °C, relative humidity was 39 to 49 percent, and wind, when there was any, gusted from 3 to 5 miles per hour out of the southwest.

The geographic information system was used to create fireline barriers and ignition sources that followed the pattern observed during the prescribed burn. These ignition files were then imported into FARSITE during the simulation at the appropriate time.

Model parameters for the simulations were set so the time step and the primary visible step were 15-minute intervals, fine enough to visualize fire behavior at the small scale yet not too fine as to slow processing time. Perimeter and distance resolutions were set to the same scale as the DEM (30 m) to make the fire spread sensitive to small-scale variations in topography and fuels. The burn period extended from 1130 to 1415 to coincide with data recorded by thermocouples during the actual burn.

We compared results from the simulations to data recorded during the prescribed burn. Fifty-six HOBO® data loggers (Onset Computer Corporation) with stainless steel type K thermocouples were co-located with fuel transects and vegetation sampling plots within each treatment area to record time of arrival, maximum temperature, and residence time. Visual observations of rate of spread and flame length were also recorded during the burn. With these data we calibrated the fire simulations by adjusting rates of spread for each fuel model to accurately describe the fire's progression.

After calibrating FARSITE, we tested the effects of different fuel treatments on fire behavior. We developed a new fuel model layer to reclassify the areas burned by the prescribed fire; custom fuel model FBFM15 reduced specified fuel loadings for 1-, 10-, and 100-hour fuels and fuel height by 50 percent (Stevens 1998, van Wagtendonk 1996). We also created a new canopy layer using hemispherical images taken following treatment implementation. New simulations were performed for each treatment area under identical wind and weather conditions with the same fuel moistures for the same time period. Ignition sources were placed in the center of each treatment area to prevent fire spreading from one treated area and its associated fuel complexes into another area.

RESULTS AND DISCUSSION

Simulation vs. Actual Burn

Initial simulations using default settings of FARSITE for fuel moisture values resulted in overpredictions for all FBFM. These results were expected because the standard fuel models estimate fire behavior during the fire season when fuel moisture contents are low (Anderson 1982). Fuel moisture values collected prior to burning (table 1) were input into FARSITE, and subsequent simulations underpredicted fire spread for FBFM 9 and FBFM 11 but still overpredicted spread for FBFM 6. Adjustment factors were then used to tune the FBFM appropriately so the spread rate would resemble that of the actual burn. For FBFM 6, we decreased the adjustment factor to 0.2, increased FBFM 9 to 1.5, and increased FBFM 11 to 2.0. These changes resulted in average rates of spread of 1.4 m per minute for the burn only and 1.6 m per minute for the mechanical/burn treatment areas.

The predicted rate of spread is slightly less than that observed during the burn (table 2). We attribute the differences to the influence of the multiple fires from the pattern of burning, which would cause some fires to draw in others and thus increase rates of spread. This result violates one assumption of Huygens's principle, which is the basis for the vector modeling approach: that fire acceleration is dependent on fuel but

Table 1—Fuel moisture content for fine fuels in burn only and mechanical/burn treatments prior to prescribed burn

Treatment	Fuel moisture content	1 hr	10 hr	100 hr
Burn only	Percent moisture content	17.28	26.51	41.98
	Standard deviation	6.63	24.84	41.8
Mechanical/burn	Percent moisture content	15.83	13.56	32.49
	Standard deviation	1.83	3.32	37.86

Table 2—Average flame length and rate of spread for observed and simulated fire behavior

Fire characteristic	Observed		Simulated output	
	Burn only	Mechanical/burn	Burn only	Mechanical/burn
Flame length (m)	0.5	1	0.8	0.9
Rate of spread (m/min)	1.8	2.5	1.4	1.7

independent of fire behavior. One weakness of FARSITE is that it does not address the effects of the two-dimensional fire shape on acceleration. Instead, it models point-source fire acceleration because of simplicity.

Slope had a significant effect on fire behavior. Figure 1 depicts the simulated fire perimeters at each 15-minute interval for the burn only and mechanical/burn treatment areas, where the distance between perimeter lines indicates rate of spread. Frequent runs in the more rugged terrain of the mechanical/burn treatment occurred in areas classified as FBFM 9. Here, 1-hour fuels dry out more quickly than the 10- and 100-hour fuels associated with FBFM 11.

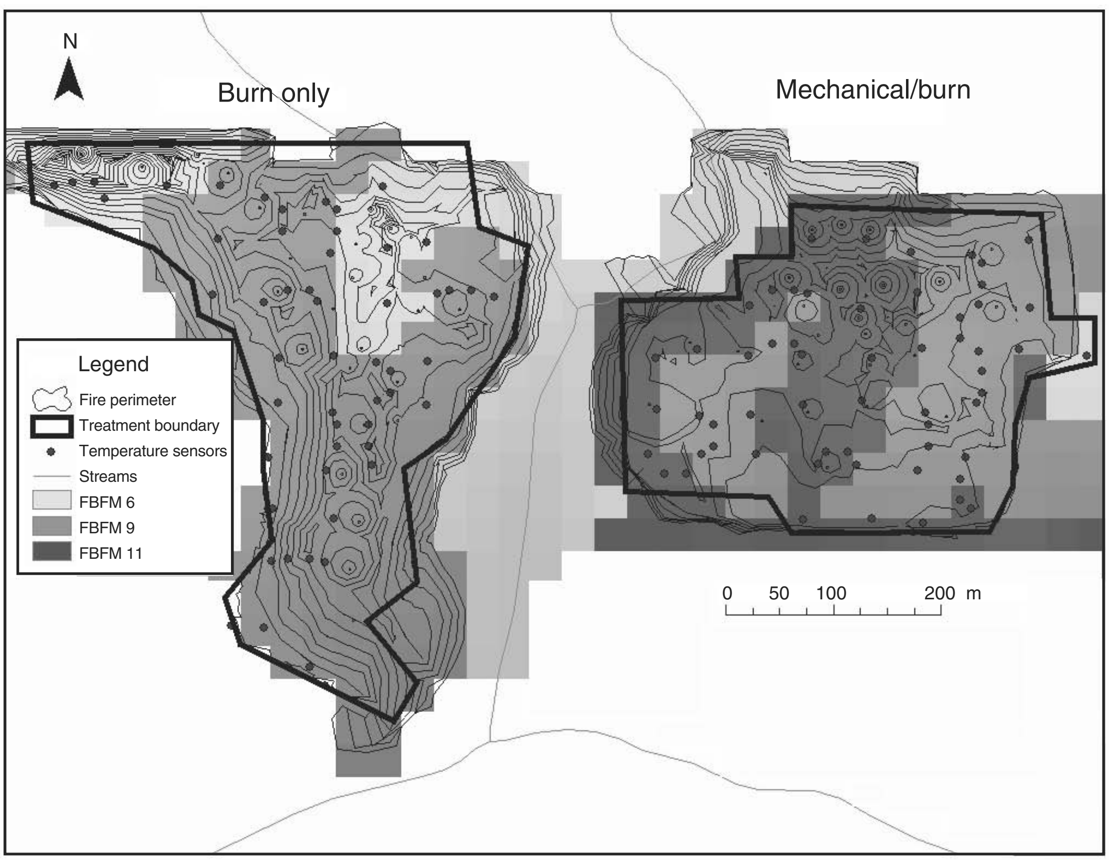

Figure 1— FARSITE output of simulated fire perimeters for every 15-minute interval. Spacing between lines indicates rate of spread.

Fuel moisture content is an important factor in this area. The standard fuel models have not incorporated high fuel moisture contents characteristic of the Southern Appalachian Mountains and thus proved to be problematic for the simulations. Scott and Burgan (2005) developed a new set of dynamic fuel models, which might better represent the high dead fuel moistures typical of the region. FARSITE version 4.1.0 accommodates these new models, but it was not available at the time of this work.

After adjustments, the rate of spread, flame length, and fire intensity for FBFM 9 appeared to adequately represent fire behavior in the leaf litter of oak-hickory forests. Also, FBFM 11 seemed appropriate for modeling the mechanical treatment.

For FBFM 6, adjustments allowed realistic rate of spread. However, the other variables of flame length and fire intensity were excessive, with predicted flame lengths of up to 20 m and fire intensities up to 27,000 kW/m, which were not observed during the prescribed burn. A new fuel model needs to be developed to better represent fire behavior in ericaceous shrubs of the Appalachian Mountains.

Changing the scale and type of the fuel model may also improve the ability to model fires for this region. Using 10-m DEM would allow for higher resolution and a more accurate representation of the heterogeneity of fuels. Grupe (1998) showed that FARSITE's sensitivity to small spatial variations in fuel models (areas that occupied only 10 percent of the landscape) would affect the average rate of spread, flame length, and fire-line intensity. Another option is to develop site-specific fuel models from fuel data collected at this location, which will help decrease the uncertainty in simulation results (Miller and Yool 2002).

Effects of Different Fuel Treatments on Fire Behavior

Simulations testing the effects of different fuel treatments showed the mechanical/burn treatment produced the least intense fire while areas left untreated would exhibit more extreme behavior (table 3). Fire intensity and flame length for the mechanical only and control treatments were considerably higher than burn only and mechanical/burn treatments. In the control treatment, fire intensity approached the level at which heavy equipment would be required for suppression.

Results for rate of spread and area burned show a similar pattern (table 3). The burn only and mechanical/ burn treatments are comparable, while the mechanical only and control treatments are much higher. The numbers for the thin only treatment do not entirely represent that treatment because, in spite of the efforts to keep fires within each treatment area's boundary, it was not possible to keep the mechanical only simulated fire from expanding into other treatment areas.

CONCLUSIONS

FARSITE should be viewed as an option for fire modeling in the Southern Appalachian Mountains, but work needs to be done on developing fuel models that better represent existing conditions of fuels before the model receives wide use in this region. In particular, fuel moisture and presence of ericaceous shrubs presented difficulties for simulations. A new fuel model is necessary for areas with high ericaceous shrub cover. Once the FARSITE model is calibrated for the region and/or more representative fuel models are developed, fire managers will be able to run "what-if" scenarios under various conditions to help direct fuel management for areas of the Southern Appalachian Mountains.

ACKNOWLEDGMENTS

This is Contribution Number 67 of the National Fire and Fire Surrogate Project, funded by the U.S. Department of Interior and U.S. Department of Agriculture Forest Service Interagency Joint Fire Science Program. The authors express their gratitude to the field technicians who made this work possible.

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Table 3—Range of fire behavior variables for simulated fires in different fuel treatments (burn period from 1130 to 1415)

Variable	Burn only	Mechanical/burn	Mechanical only	Control
Fire intensity (kW/m)	9.9 – 53.6	9.5 – 43.3	32.0 – 230.5	50.9 – 328.2
Flame length (m)	0.3 – 0.5	0.2 – 0.4	0.3 – 1.0	0.4 – 1.1
Rate of spread (m/min)	0.3 – 1.4	0.3 – 1.1	0.5 – 3.4	0.6 – 3.8
Area burned (ha)	0.9	0.7	5.4	2.3

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