USE OF A THERMOCOUPLE-DATALOGGER SYSTEM TO EVALUATE OVERSTORY MORTALITY

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Abstract—In the past, it was difficult to accurately measure dynamic fire behavior during prescribed burns. Peak temperature, flaming duration, and total heat output may be directly related to first-order fire effects such as fuel consumption and vegetative mortality; however, little is known about which of these variables is most closely associated with, and therefore the best predictor of, post-burn conditions. A thermocouple-datalogger system can allow forest managers and scientists to record data related to maximum temperature, heat pulse duration, and total heat output at any location within a prescribed burning treatment area over a user-defined time period. The advantage of this type of system is its ability to evaluate the rate of spread and intensity of a prescribed burn, and to relate those spatial variabilities to short- and long-term effects such as tree mortality. Regression equations of fire attributes and overstory mortality indicated that immediately following the first fire, flaming duration and average flame temperature together explained 43 percent of the mortality observed. After two years, average temperature alone showed the strongest relationship to mortality but only accounted for 24 percent of the variance. Overstory mortality was lower after the second burn, with total heat output explaining 45 percent of model variation.

INTRODUCTION

As the effects of decades of fire suppression become increasingly apparent, it is important for forest managers and researchers to understand the relationships between fire, fuels, and vegetation. The success of a prescribed burn is often judged by the extent of fuel load reduction and by the direct and indirect impacts of the fire on vegetative species of interest, e.g., *Quercus* spp. (Artman 2005, Freckleton 2004). Also of interest is the ability to predict fire characteristics such as flame height and rate of spread from a given fuel complex; although fire models are now proving useful in this area of research, technological limitations have previously made such estimations difficult (Anderson 1969). Thermocouple-datalogger systems have helped to overcome these limitations to some extent, as they can be installed in areas with known fuel loads and species compositions; this allows direct correlations to be made among pre-burn site attributes, fire characteristics, and post-burn site conditions. Additionally, the effects of specific fire characteristics on forest dynamics such as post-burn mortality of target species can be more clearly differentiated.

METHODS

Site Description and Study Design

The Southern Appalachian Mountains site of the National Fire and Fire Surrogates (NFFS) Study is located on the Green River Game Lands in Polk County, NC (GR). The overstory of this area is primarily oak and hickory species (*Quercus alba, Q. coccinea, Q. prinus, Q. rubra, Q. velutina, Carya alba, C. glabra, C. pallida*), with yellow pines (*Pinus echinata, P. pungens, P. rigida, and P. virginiana*) also present along exposed ridges and white pine (*P. strobus*) in the protected cove areas.

The study design at each NFFS site is a randomized complete block, with three replications of four treatments. GR treatments consisted of a control, burn-only, mechanical-only, and mechanical+burn. Treatment areas contain 38 to 40 plots arranged on a 50-m grid spacing; fuels were measured in each plot along three 20-m transects, following Brown's (1974) planar intersect method. In addition, overstory, shrub, herbaceous vegetation, and regeneration data were collected at ten 0.1-ha plots per treatment. The burn-only and mechanical+burn treatments were burned twice- first in spring 2003 and again in spring 2006. Prior to burning, 12-inch stainless steel Type K thermocouples and dataloggers were installed at the center of each plot, co-located with the center fuel transects. For the duration of the fires, dataloggers recorded temperature information every 1.5 seconds. Using these data, values for maximum and average temperatures, flaming duration, and time above 60 °C (the temperature at which vascular cambium cell mortality occurs (Dickinson 2004)), and total heat output were calculated. Correlations and regressions between these fire characteristics and post-treatment overstory mortality were performed on transformed variables.

RESULTS

2003 Burn

The first burn at this study site took place in March 2003. In the burn-only treatment, the fire in all blocks was low-intensity and patchy in nature, whereas complete burn coverage was achieved in the blocks in the mechanical+burn treatment area. Overall maximum temperature for the spring 2003 burn was 256 °C, with an average temperature of 106 °C. Mean duration of the flame peak at a thermocouple was 8.10 minutes, and the mean heat output for this fire was 13.73 MJ/kg. Four months after this burn, mean overstory mortality was 1.95 m^2/ha with average temperature and flaming duration showing the strongest relationship to mortality; together they accounted for 43 percent of the variation in the statistical model. Two years later, mean overstory mortality had reached 2.14 m^2/ha. Average temperature was the strongest predictor of mortality at this point, but it accounted for only 24 percent of the variance.

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2006 Burn

The second burn at Green River was applied in March 2006, with lower overall fire intensities than in 2003. Maximum and average temperatures for this fire were 189 °C and 20 °C, respectively. Mean duration of the flame peak was longer, at 12.33 minutes, but mean heat output was slightly lower than in the 2003 fire, at 10.13 MJ/kg. Four months after the fire, mean mortality was 1.09 m^2/ha. Total heat output was the best predictor of overstory mortality after the second fire, explaining 45 percent of the variation.

Oak Mortality

First-order oak mortality did not follow the expected pattern of greater mortality at higher temperatures (fig. 1). However, many oaks died in the second or third year after burning. Two-year post-burn results better approximate the anticipated trend, as does mortality one year following the second burn. Maximum temperatures above 300 ºC produced a sharp increase in oak mortality between 2003 and 2005. It is likely that the temperatures which the oaks endured during these two burns are influential factors in this delayed response. Use of the thermocouple-datalogger system allowed us to approximate the temperature and duration of fire to which individual trees were exposed, thereby improving our confidence in the relationship between these variables and mortality.

DISCUSSION

The importance of both fire temperature and flaming duration to potential overstory tree mortality was evident shortly after the first prescribed burn in 2003. Our results agree with those of Jones and others (2006), who developed a predictive model of tree mortality based on the relationship between fire-induced heating in tree stems and the tissue necrosis that often results from exposure to such heat. The model accounts for the rate-dependent characteristics of both fire temperature and heating duration with respect to potential fire-induced tree mortality. The value of considering such factors when examining fire's relationship to mortality is borne out by the accuracies observed in the testing of their model; they were able to predict mortality and survival of both hardwood and softwood species with 75 to 80 percent accuracy. Ansley and others (1998) found peak fire temperature and fire duration to be important factors in predicting mortality in honey mesquite (*Prosopis glandulosa* Torr.) communities, and the effects of both variables increased with thermocouple height. Our results and those of others reflect the importance of considering a variety of characteristics when examining fire-induced tree mortality and incorporating the rate-dependent aspects of fire behavior into considerations of vegetative responses. It is evident that the mechanisms by which fires act to damage and destroy plant tissues are more complex than may simply be attributable to flame temperature alone; lower-intensity fires may be just as detrimental to the survival of overstory species as high-intensity burns, provided the flaming duration is long enough to effectively destroy cambial tissues.

Overstory mortality dynamics were different at two years post-burn than immediately following treatment. Delayed mortality continued and slightly increased well into 2005, which is consistent with other research suggesting that most fire-induced mortality occurs within the first two years following burning (Loomis 1973, Regelbrugge 1994). Other studies in eastern forests have reported similar results, citing time-dependent and fire intensity-dependent differences in overstory tree mortality following wildfire (Groeschl and others 1992). This reinforces our observations about the responses of mixed hardwood forests generally, and oak species in particular, to the presence of fire. Recognizing the importance of fire intensity and time since burning to fire-induced hardwood mortality is key if we hope to fully understand and accurately predict the responses of particular species of interest to such disturbances.

Following the 2006 burn, total heat output alone showed a significant relationship to overstory mortality. Kobziar and others (2006) found that fireline intensity, which is itself a factor used in the calculation of total heat output, was important to predicting post-fire mortality of conifer species in the Western United States. However, in both pine and mixed hardwood forests in the Eastern United States, total heat output was judged a better correlate of stem surface heat flux (Wade 1993, Bova and Dickinson 2005). The greater predictive power of total heat output over fire intensity alone highlights the usefulness of thermocouple-datalogger

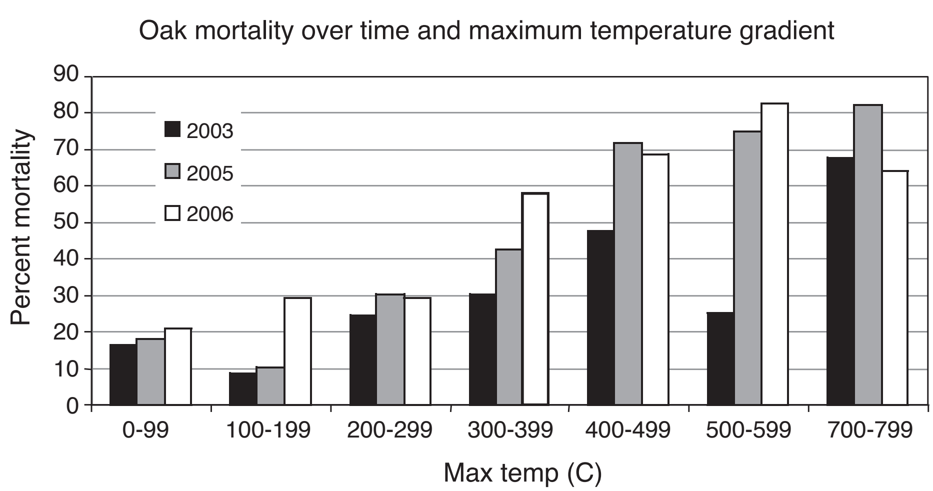

Figure 1—Percent overstory oak mortality across a gradient of time and maximum temperature.

systems in prescribed fire and wildfire research. These systems make the vital time dimension of fire behavior more accurate and more accessible to researchers, providing a wider range of factors with which to understand the dynamic interactions between fire and the ecosystem responses it generates.

CONCLUSION

The capability of the thermocouple-datalogger system we employed to capture the dynamic nature of fire characteristics over time helped us to elucidate some interesting trends at the Southern Appalachian Mountains site of the National Fire and Fire Surrogates Study. While our regression equations were only able to explain approximately 1/4 to 1/2 of the variation observed in this study, we nevertheless gained some useful insights about the changing nature of fire effects in this eastern mixed hardwood forest. Fire temperature, duration, and total heat output are all important factors in understanding the ecological impacts of fire disturbance on vegetation, but their relative importance varies over time and with the changing nature of the post-fire overstory cohort. The thermocouple-datalogger system used in this study proved to be useful and effective tools for discerning the complex relationships between fire and the environments it influences.

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