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Fuel Consumption and Fire Characteristics during Understory Burning in a Mixed White Pine-Hardwood Stand in the Southern Appalachians

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Abstract

We characterized fire behavior and fuel consumption resulting from an understory prescribed burn in a mixed eastern white pine-hardwood stand in the Southern Appalachians. Three stands were used for the treatment. Flame lengths, ranging from 0.3 to 1.5 meters (m) for backing fires and from 1.2 to 4.5 m for head fires, reached maximum heights where evergreen understory was found. Rates of spread ranged from 1.8 to 3.0 m per minute for head fires and 0.3 m per minute for backing fires. Fire intensity, measured with ceramic tiles painted with heat-sensitive paint, varied across stands. Mean peak flame temperature ranged from 129 to 290 °C. Pre-burn mass totals were similar among stands, except for stand 1, which had substantially greater humus mass than the other stands. Consumption of litter and humus layers in the forest floor was positively correlated with flame temperature. Small wood (<8 centimeters diameter) consumption was not correlated with temperature. Over all stands, 50 percent of the mass in small wood and litter was lost during burning, and 20 percent of the humus layer was consumed. The losses in the humus layer represented about 40 percent more humus mass consumption than would have occurred in a fell-and-burn treatment. The humus layer is an important nutrient reservoir for plant growth. Maintaining this layer through careful selection of burning conditions will minimize losses during burning and maintain long-term site productivity.

Keywords: Blue Valley, eastern white pine, fuel consumption, prescribed fire, Southern Appalachians, understory burning.

Introduction

In the Southern Appalachians, fire is commonly used as a site preparation tool in yellow-pine (includes *Pinus rigida* Mill., *P. virginiana* Mill., *P. pungens* Lamb., and *P. echinata* Mill.)-hardwood ecosystems (Vose and Swank 1993) to stimulate oak advanced regeneration after harvest (DeSelm and Clebsch 1990, Van Lear 1990) and to restore degraded pine-hardwood sites (Vose and Swank 1993). The role of fire in regenerating mixed white pine (*P. strobus* L.)-hardwood ecosystems is less understood. Moreover, information about the effects of fire on other basic ecosystem attributes is also lacking.

Changes in mass and nutrient pools are key parameters used to assess the effects of fire on ecosystem processes. Fire intensity and severity (i.e., fire behavior) largely determine the amount of fuels consumed and site nutrients lost (Clinton and others 1996, Vose and Swank 1993). Fire behavior is dependent on fuel type, amount, and size distribution; moisture content; site macroclimate (Swift and others 1993); and burning techniques such as head fires vs. backing fires. Typically, the forest floor is the largest reservoir of available nutrients for plant growth (Vose and Swank 1993). Fires of high intensity but low severity result in minimal consumption of the forest floor and, hence, minimize nutrient losses from this reservoir (Clinton and others 1996, Vose and Swank 1993).

This paper addresses one part of a project designed to examine the effect of understory burning on hardwood and conifer regeneration.[1] The specific objectives of this part of the study were twofold: (1) to quantify forest floor and small wood mass consumption resulting from prescribed burning in mixed white pine-hardwood ecosystems; and (2) to relate mass loss to fire intensity.

Methods

Study Site—The Blue Valley Experimental Forest[2] is located in the Blue Ridge physiographic province of the Southern Appalachians in Macon County, NC (lat. 35° N, long. 83° W). The 460-hectare (ha) experimental forest is approximately 5 kilometers south of Highlands, NC, and ranges in elevation from 700 meters (m) on Overflow Creek along its southern boundary to 950 m on Ostin Knob. Annual precipitation ranges from 200 to 250 centimeters (cm) per year. The area has a large component of naturally regenerated eastern white pine. Stands for the most part are

[1] Berg, E.C. 1996. Evaluation of shelterwood cutting and understory burning on hardwood regeneration. 24 p. Unpublished study plan and establishment report for Blue Valley Experimental Forest. On file with: Southern Research Station, Bent Creek Experimental Forest, 1577 Brevard Road, Asheville, NC 28806.

[2] Sluder, E.R. February 11, 1964. Establishment report for the Blue Valley Experimental Forest, Southeastern Forest Experiment Station. 5 p. Unpublished report. On file with: Highlands Ranger District, 2010 Flat Mountain Road, Highlands, NC 28741.

mixed white pine-hardwood, although white pine stocking often exceeds 35 m^2 of basal area per ha. Stand age is approximately 70 years. Eastern white pine accounts for 63 percent of the basal area on these sites; oaks (*Quercus alba* L.= *Q. prinus* L.> *Q. coccinea* Muenchh> *Q. velutina* Lam.) make up 25 percent; and hickory (*Carya* spp.) accounts for 6 percent. The remaining basal area is distributed among six species. The understory consists of scattered rosebay rhododendron (*Rhododendron maximum* L.), mountain-laurel (*Kalmia latifolia* L.), huckleberries (*Gaylussacia* spp.), and blueberries (*Vaccinium* spp.). Little or no eastern white pine advanced regeneration is present, but saplings of red maple (*Acer rubrum* L.) and several oak species are found.

Treatment—Three stands were selected for understory burning. Fire lines were established and a combination backing fire/head fire was set on each stand. Burning was completed on two stands on April 12, 1996, and on the third stand on April 13.

Sampling

Forest Floor—Three 16- by 63-m plots were located within each burn stand and in adjacent unburned control stands. A transect was established through the center of each plot along the long axis. Forest floor measurements were taken from five 0.09-m^2 subplots that were systematically distributed at 10-m intervals along each transect, and offset on either side of the transect 5 m in a randomly determined direction. The forest floor (wood <8 cm diameter, litter, and humus) was removed from each subplot for mass determination by cutting and removing the litter (Oi) and humus (Oe + Oa) layers separately. Sample mass was determined by drying at 70 °C to a constant weight and weighing to the nearest 0.01 gram.

Weather and Fire Behavior—Understory air temperature (°C), relative humidity (%), and wind speed (m per second) and direction were recorded every 30 minutes throughout the burning period. Cloud cover was also noted and expressed as a percent. Flame length (FL; m) and rate of spread (ROS; m per minute) for head fires and backing fires were estimated for each stand.

Flame Temperature—Flame temperature was measured using heat-sensitive indicator paint applied to ceramic tiles (Omega Engineering, Inc.) suspended 30 cm above the forest floor and collocated with each forest floor measurement subplot. Heat sensitivities ranged from 52 to 804 °C, at approximately 15 °C intervals between 52 and 430 °C, and 100 °C intervals for > 500 °C. When threshold temperatures were reached during burning for each level of sensitivity, melted paint indicated that the temperature exceeded the threshold temperature but was lower than the next threshold temperature.

Statistical Analysis—Relationships between mass consumption and mean peak flame temperature were examined using regression analysis (PROC GLM; SAS 1987) and Pearson correlation analysis (PROC CORR; SAS 1987).

Results and Discussion

Weather and Fire Behavior

Weather conditions were markedly different between the two burn days (table 1). The first day was clear, warm, and dry, while the second day was overcast, cooler, and more humid. On day 2, temperatures were 6 to 8 °C cooler and relative humidity was 34 to 40 percent higher than on day 1. Winds were steady out of the west with occasional gusts on both days.

Fire behavior also varied between the 2 days. The first day produced longer FL and faster ROS for head fires, where FL was 1.2 to 4.5 m and ROS was 1.8 to 3.0 m per minute. For backing fires, FL was 0.3 to 1.5 m and ROS was 0.3 m per minute across both burning days. Where evergreen understory was found, FL was commonly 3 to 4.5 m. Burning on both days was aided by a dry litter layer and steady winds.

Pre-burn Mass

Pre-burn mass totals were similar among stands, except for stand 1, which had substantially greater humus mass than the other stands (fig. 1). For all stands, the largest pre-burn mass pool was in the humus layer. Within and across stands, equal amounts of mass were found in the wood and litter layers. Other studies in yellow pine-hardwood stands in the Southern Appalachians have also shown comparable amounts of litter and small wood mass, ranging from 5 to 13 and 5 to 16 megagrams (Mg) per ha, respectively (Vose and Swank 1993, Vose and others, in press).

Table 1—Mean, maximum, and minimum flame temperature (°C) by stand (N = 15) and mean air temperature, relative humidity, and wind speed (meters per second) during burning

	Flame temperature					
Stand[a]	Mean	Max.	Min.	Air temp.	Percent RH	Wind speed[b]
1	172 (41.8)[c]	704	52	22.7 (0.5)	22.4 (2.2)	0.6 (0.2)
2	290 (57.6)	704	93	24.8 (0.3)	19.0 (1.2)	1.4 (0.1)
3	129 (13.8)	260	52	16.6 (0.3)	55.6 (2.7)	1.2 (0.1)

[a] Stand 3 was burned on day 2.
[b] Wind direction varied between W and SW on both days.
[c] Values in parentheses are standard errors.

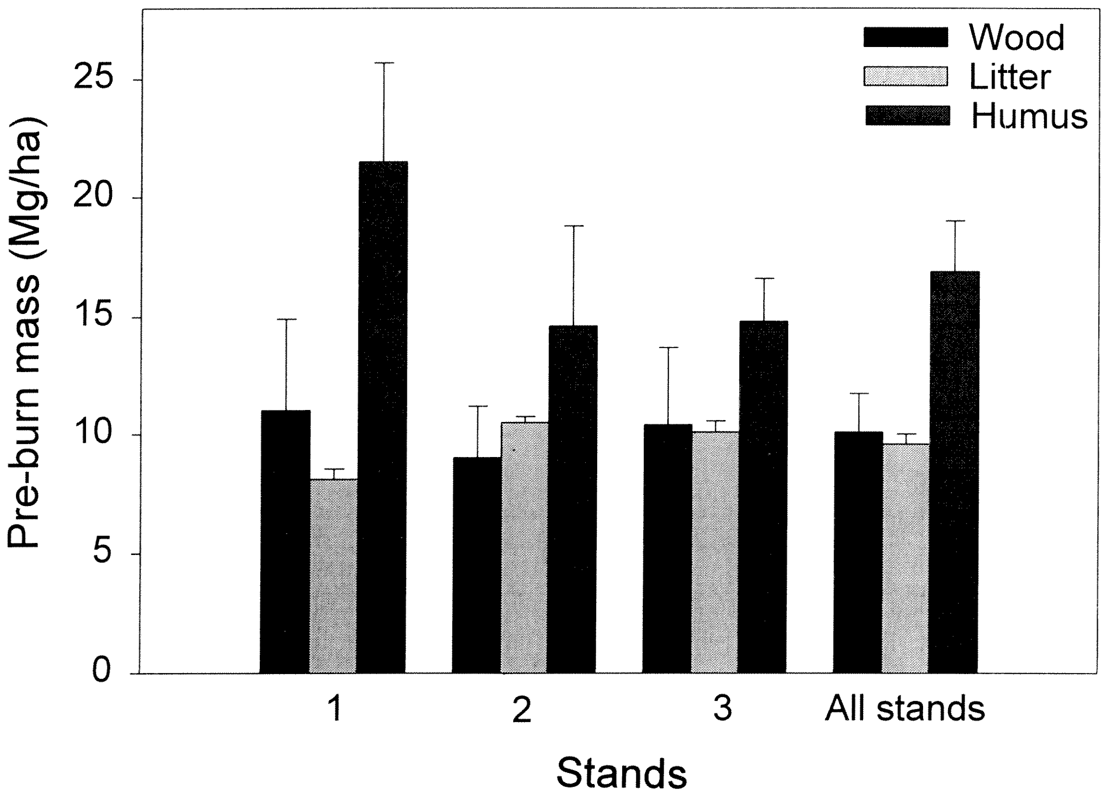

Figure 1—Pre-burn mass (Mg per ha) for three fuel types by stand and for all stands combined. Error bars represent 1 standard error (N = 15).

Fire intensity is defined as the upward heat pulse produced by the fire (Ryan and Noste 1985), and flame temperatures measured by heat tiles provide a direct measure of fire intensity. Fire intensity varied across stands (table 1). Stand 2 had the greatest fire intensity, followed by stands 1 and 3. Swift and others (1993) reported mean peak flame temperatures of 630 to 812 °C for a site preparation burn of chainsaw-felled slash in the Southern Appalachians. In their study, heavy fuel loadings (>135 Mg per ha), higher surface wind speed (1.6 to 4.5 m per second), head fires, and steep topography resulted in greater fire intensity. In the present study, fuel loadings were moderate (fig. 1), wind speed was low (table 1), and the topography was gently sloping. Yet, even under moderate conditions of fuel loading, high intensity or high severity fires can result in bole damage that may ultimately lead to mortality. However, in the first year after burning, mortality directly attributable to the fire was negligible.

Fuel consumption, which indicates fire severity (Van Lear and Waldrop 1988, Wells and others 1979), followed a slightly different pattern (stand 2 > stand 3 > stand 1) (fig. 2). In addition to fire behavior, fuel size and flammability are important determinants of mass consumption, and variation in these factors may explain the consumption patterns. We measured wood <8 cm but did not further quantify fuel size nor flammability. Across all stands, consumption of the humus and litter layers was positively correlated with flame temperature ($r^2 = 0.72$ for humus and 0.30 for litter), but wood was not (fig. 3). The poor correlation for wood may result from the variability in size, amount (fig. 2), and flammability of woody fuels across stands that may not be reflected in measures of fire intensity. Because small wood is more completely consumed at lower temperatures than larger wood, plots high in wood mass in small size classes would lose more mass than plots with similar mass in larger size classes.

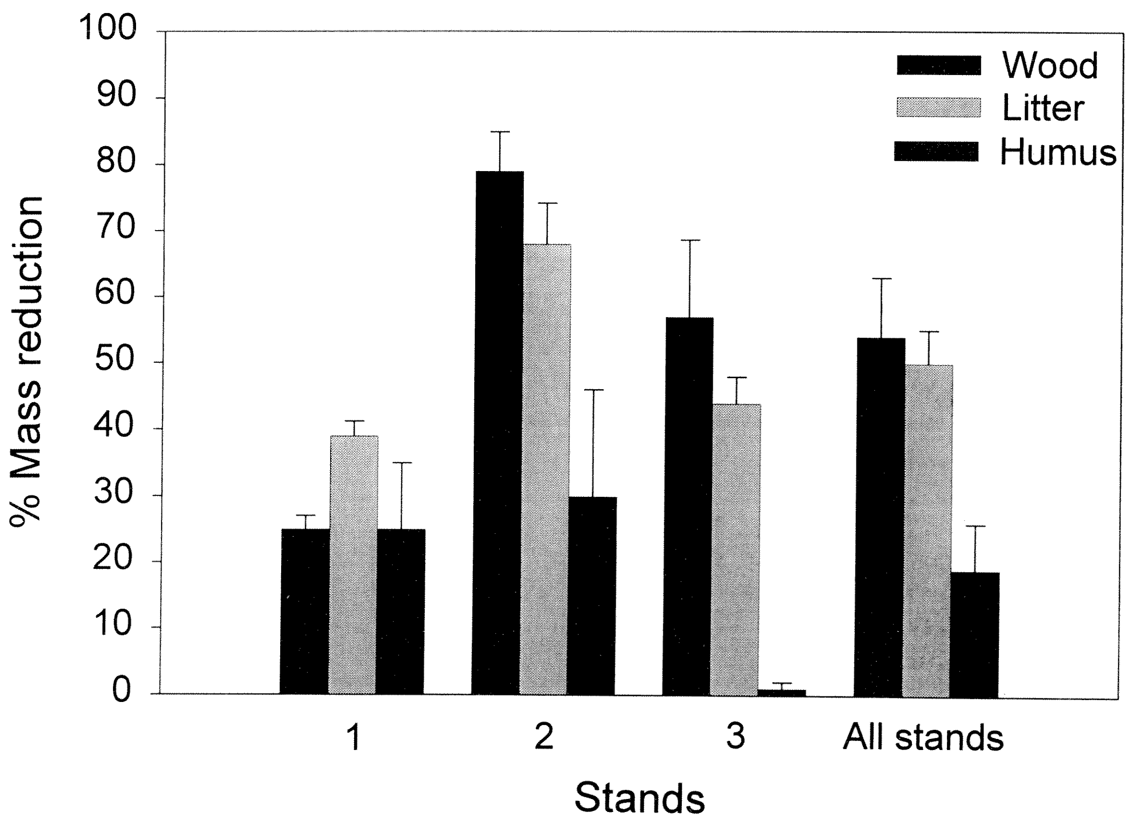

Figure 2—Reduction (%) in mass from understory burning by fuel type and stand and for all stands combined. Error bars represent 1 standard error (N = 15).

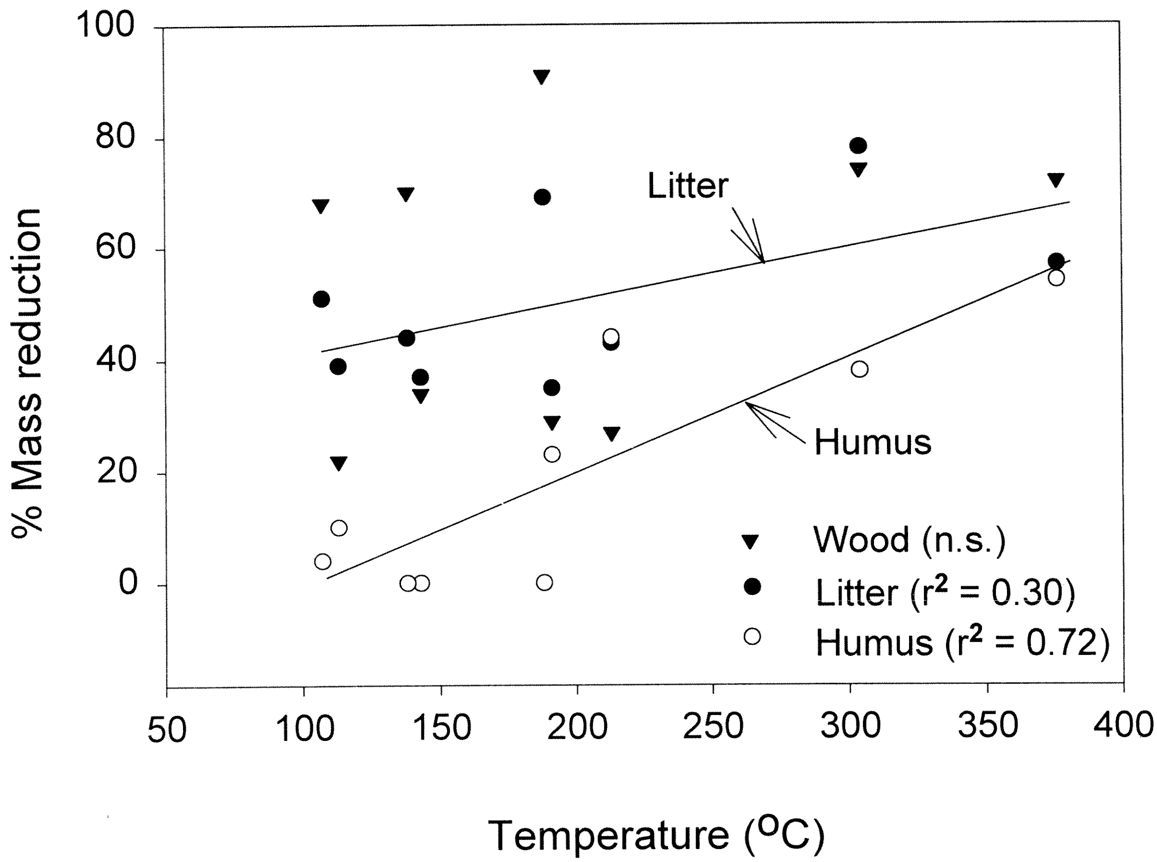

Figure 3—Reduction (%) in mass for three fuel types as a function of mean peak flame temperature (°C) at 0.3 m above the forest floor. Regression lines represent a least squares best fit regression.

Overall, more than 50 percent of the mass in litter and small wood was lost during burning and about 20 percent of the humus layer was lost (fig. 2). Vose and Swank (1993) found similar consumption rates for litter and estimated that only 10 percent of the mass in the humus layer was consumed during a fell-and-burn treatment. The humus layer was the largest pool of nitrogen (N) in the forest floor, and they concluded that high intensity (fig. 4), low severity fires were optimum for maintaining this plant nutrient resource. In our study, fire intensity was lower than in the fell-and-burn prescription but apparently severity was slightly higher. We attribute this higher severity to a more slowly moving fire with a long residence time (figs. 5 and 6). If the humus on our study sites had N pool sizes similar to those described by Vose and Swank (1993), approximately 10 kilograms (kg) per ha more N was lost from the humus in this study (36 kg N per ha) than in their study of the fell-and-burn prescription (26 kg N per ha).

Conclusions

In this study, both fire intensity and severity were moderate. Burning conditions that produce a more intense and less severe fire would conserve more of the humus layer and associated nutrients. To consume less of the humus layer, head fires, which produce faster ROS, hence, shorter residence times, may be necessary. However, head fires produce the greater FL associated with more intense fires, which could potentially result in higher overstory mortality as well as hinder the success of white pine reproduction. To maintain long-term site productivity, understory burning conditions must be carefully monitored to achieve the desired result while minimizing loss of site nutrients by the consumption of deeper forest floor layers. Forest managers must recognize the importance of this pool of site nutrients when burning, and design prescriptions that minimize consumption of site nutrients and maintain long-term site productivity.

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Figure 4—Extremely intense fires, as seen in this fell-and-burn treatment, typically result in heavy consumption of aboveground fuels but minimal forest floor consumption because severity is low. (U.S. Department of Agriculture, Forest Service, Coweeta Hydrologic Laboratory file photo.)

Figure 5—Head fires are fast moving and typically have a wide burning front. Fire intensity diminishes toward the backside of the burning front. (Photo by Pat Brose.)

Figure 6—Backing fires typically have a narrow burning front but are slow to move, resulting in increased consumption of belowground fuels because fire severity increases as fire residence time increases. (Photo by Pat Brose.)

Literature Cited

Clinton, B.D.; Vose, J.M.; Swank, W.T. 1996. Shifts in aboveground and forest floor carbon and nitrogen pools following prescribed fire in the Southern Appalachians. Forest Science. 42(4): 431-441.

DeSelm, H.R.; Clebsch, E.E.C. 1990. Response types to prescribed fire in oak forest understory. In: Proceedings, Fire and the environment: ecological and cultural perspectives; 1990 March 20-24; Knoxville, TN. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 22-33.

Ryan, K.C.; Noste, N.V. 1985. Evaluating prescribed fires. In: Proceedings of a symposium workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 230-238.

SAS Institute, Inc. 1987. SAS user's guide: statistics. SAS Institute, Inc. Cary, NC. 956 p.

Swift, L.W.; Elliott, K.J.; Ottmar, R.D.; Vihnanek, R.E. 1993. Site preparation burning to improve Southern Appalachian pine-hardwood stands: fire characteristics and soil erosion, moisture, and temperature. Canadian Journal of Forest Research. 23: 2242-2254.

Van Lear, D.H. 1990. Fire and oak regeneration in the Southern Appalachians. In: Proceedings, Fire and the environment: ecological and cultural perspectives; 1990 March 20-24; Knoxville, TN. Gen. Tech. Rep. SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 15-21.

Van Lear, D.H.; Waldrop, T.A. 1988. Effects of fire on natural regeneration in the Appalachian Mountains. In: Smith, H. Clay; Perkey, A.W.; Kidd, W.E, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: conference proceedings; 1988 May 24-26; Morgantown, WV. SAF Publ. 88-03. Morgantown, WV: West Virginia University Books: 56-70.

Vose, J.M.; Swank, W.T. 1993. Site preparation burning to improve Southern Appalachian pine-hardwood stands: aboveground biomass, forest floor mass, and nitrogen and carbon pools. Canadian Journal of Forest Research. 23: 2255-2262.

Vose, J.M.; Swank, W.T.; Clinton, B.D. [and others]. 1997. Using fire to restore pine/hardwood ecosystems in the Southern Appalachians of North Carolina. In: Greenlee, J.M., ed. Proceedings of the conference on wildland fire effects on threatened and endangered species and habitats; 1995 November 13-16; Coeur d'Alene, ID: 149-154. Available from: International Association of Wildland Fire, P.O. Box 328, Fairfield, WA 99012 ($40.00).

Wells, C.G.; Campbell, R.E.; DeBano, L.F. 1979. Effects of fire on soil. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service. 34 p.

Clinton, Barton D.; Vose, James M.; Swank, Wayne T.; Berg, Eric C.; and Loftis, David L. 1998. Fuel consumption and fire characteristics during understory burning in a mixed white pine-hardwood stand in the Southern Appalachians. Research Paper SRS-12. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 8 p.

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