ESTIMATING FUEL CONSUMPTION DURING PRESCRIBED FIRES IN ARKANSAS

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ABSTRACT

While prescribed fire is essential to maintaining numerous plant communities, fine particles produced in smoke can impair human health and reduce visibility in scenic areas. The Arkansas Smoke Management Program was established to mitigate the impacts of smoke from prescribed fires. This program uses fuel loading and consumption estimates from standard fire-behavior fuel models developed elsewhere in the United States. The accuracy of these models for determining fuel loading and consumption in Arkansas, however, is unknown. We established 120 Brown's transects in fifteen burn units and three community types on the Ouachita National Forest in Arkansas to determine fuel loads before and after prescribed fires. The three community types were shortleaf pine-oak (Pinus echinata-Quercus sp.) forest, oak forest, and shortleaf-pine woodland. We also compared fuel-consumption estimates of fine woody fuels derived from Brown's transects with estimates derived from sampling plots, where we physically collected fuels, before and after the prescribed fires. We used Feat Firemon Integrated (FFI) software with localized bulk density values to quantify fuel consumption on six of the fifteen prescribed fires. Preliminary analyses showed that fuel consumption occurring in the Ouachita Mountains is consistent with expected values based on standard fire-behavior fuel models and that fuel consumption in restored woodlands is significantly less than that in closed-canopy forests.

INTRODUCTION

Fire is an important ecosystem process that has influenced the structure and composition of forest, woodland, and grassland communities for millennia (Frost 1998, Pyne 1982). Fire suppression over the last 100 years has changed many fire-dependent communities (Harmon 1982, Harrod and others 1998, Foti 2004). In some forest communities, fuel build up has led to an increase in fire intensity, resulting in stand replacement crown fires where frequent low intensity surface fires once occurred (Agee and Skinner 2005). In many eastern forests, shade-tolerant, fire-sensitive species have invaded fire-dependent communities, making them less susceptible to fire (Nowacki and Abrams 2008). As a result, fire-dependent communities are in decline and some associated species are imperiled or endangered (Ligon and others 1986, Kelly and others 2004). Prescribed fire plays an important role in restoring historic community structure and composition. It also helps prevent catastrophic crown replacement fires (Agee and Skinner 2005) and restores fire-dependent communities and their suite of pyrophilic species (Covington and others 1997, Sparks and others 1998, Sparks and others 1999, Andre and others 2007, Jenkins and others [in press]).

Despite the benefits prescribed fires provide, they also produces smoke containing particulate matter, carbon monoxide, sulfur dioxide, nitrogen oxides, and volatile organic compounds (Liu 2004). These particles and compounds degrade air quality by reducing visibility and impairing healthy respiration (Brunekreef and Holgate 2002). Recently, the Environmental Protection Agency (EPA) reported that fine particles (particles ≤ 2.5 µm or $PM_{2.5}$) were particularly detrimental to human respiratory health and 70% of particulate matter produced during prescribed and wildland fires consists of these fine particles (EPA 1998). This report encouraged many states to establish Smoke Management Programs to address air quality concerns associated with prescribed fire.

The Arkansas Forestry Commission established a Smoke Management Program (SMP) in 2006 to address air quality issues resulting from prescribed fire (Arkansas Forestry Commission 2006). This program addresses many smoke-related issues including: notification requirements, identifying how close a prescribed fire can be to a smoke sensitive area, defining appropriate atmospheric conditions to conduct a prescribed fire, and providing available fuel loading estimates for each community type (Arkansas Forestry Commission 2006). Available fuel-loading values for different Arkansas community types were taken from standard fire-behavior fuel models (Scott and Burgan 2005). These models were derived from a planar intersect method called Brown's transects (Brown 1974) and collection of fuels in 10.76 square foot sample plots in community types around the U.S. (Ottmar and Vihnanek 1998, 1999, 2000, and 2002, Ottmar and others 2003). However, no data existed specifically for community types in Arkansas. Some land managers felt that these models should be validated with local fuel loading data collected in Arkansas community types. Emissions from prescribed fires are a function of both area burned and amount of fuel consumed (EPA 1995). Thus, accurate fuel loading and consumption values are important for determining emissions produced and the number of acres that can be burned at a given time to remain in compliance with Arkansas' SMP.

The Ouachita National Forest (ONF) of Arkansas and Oklahoma houses many fire-dependent communities including shortleaf pine-oak (*Pinus echinata*-*Quercus* spp.)

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forest, oak forest, and shortleaf-pine woodland. Managers use prescribed fire to improve wildlife habitat, prepare sites for tree planting, restore woodland stand structure and diversity, and reduce hazardous fuels. Between 2005 and 2010 the ONF burned an average of 115,700 acres annually (Forest Service 2010).

In this study, we determined fuel consumption in three community types (shortleaf pine-oak forest, oak forest, and shortleaf-pine woodland) during prescribed fires on the ONF. For the purpose of this study, forest communities are defined as closed-canopy forest (>70 percent canopy cover) with little herbaceous cover (<25 percent). Pine-oak forest are pine dominant with an oak component and oak forest are oak dominated. The pine woodland community is defined as an open forest (<70 percent canopy cover) with dense herbaceous cover (>25 percent). We used Brown's transects (Brown 1974) to capture dead and down fuel and 9 square foot sampling plots, where fuel was physically removed (henceforth referred to as collection plots), to capture live fuels (grasses, forbs, and small shrubs attached to the ground). In an analysis of Brown's transect data from the ONF between 2001 and 2009 the variability of fine woody fuels suggested the need for different methods for quantifying these fine fuels (McDaniel and others 2009). Plot-collection methods seemed reasonable; therefore we collected fine fuels in 1 square foot collection plots. Both methods were similar to those used to develop standard fire-behavior fuel models (Ottmar and Vihnanek 1998, 1999, 2000, and 2002, Ottmar and others 2003) and those used in fuels management programs across the U.S. (USDI National Park Service 2003).

We address three questions:
1. Are standard fire-behavior fuel models accurate for assessing fuel consumption during prescribed fires in the dominant community types on the Ouachita National Forest?
2. Is there a difference in fuel consumption of 1- and10-hour fuels between sampling methods?
3. Is there a difference between fuel consumption in forest and woodland communities?

METHODS

STUDY SITE

The ONF is located in the Ouachita Mountain Ecoregion (The Nature Conservancy 2003) of western Arkansas and eastern Oklahoma (Figure 1). Ridges are underlain by Pennsylvania and Mississippi sandstone and shale valleys with clayey colluviums and covered with pine-oak and oak woodlands and forests (U.S. Department of Agriculture, 1999). We conducted our study in the central part of the Ouachita Mountain Ecoregion on the Mena, Oden, and Poteau Ranger Districts of the ONF. The burn units ranged in size from 310 to 1940 acres (average = 851). Elevation on the burn units ranged from 800 to 1400 feet.

DATA COLLECTION

The main community types on the ONF are Ozark-Ouachita shortleaf pine-oak forest, Ozark-Ouachita dry-mesic oak forest, and Ozark-Ouachita shortleaf pine-bluestem woodland (LANDFIRE 2010), henceforth referred to as pine-oak forest, oak forest, and pine woodland, respectively. We used LANDFIRE's Existing Vegetation Type (EVT) layer for the Continental US (LANDFIRE 2010) to select transect locations within planned burn units in 2010 and 2011. We established 40 Brown's transects within each community type for a total of 120 transects. Each Brown's transect was 50 feet long, permanently marked with rebar at each end, and followed Brown's protocol (Brown 1974). We used a 10 factor prism to obtain basal area and species composition of trees at the origin of each Brown's transect. Half of the Brown's transects had collection plots associated (Figure 2).

Due to time and weather constraints, only 54 transects were burned in 2010; thus most data represent only 54 of the 120 Brown's transects (32 pine-oak forest transects with 70 collection plots, 13 oak forest transects with 40 collection plots, and 9 pine woodland transects with 25 collection plots). We installed 10 Brown's transects in an established pattern around a random point in each burn unit (Figure 3). Percent of each community type in burn units varied. Three transects were located 660 feet up-slope and 660 feet down-slope from the random point, and four transects were located at the same elevation as the random point (Figure 3). Transects in each of the three lines ran parallel to the slope and were separated by 330 feet (Figure 3). One burn unit had only four transects because the prescribed fire occurred before all ten transects could be installed.

Along each Brown's transect, before and after prescribed burns, we tallied dead and down woody fuel that bisected the transect. In the first six feet of the Brown's transect we tallied 1- and 10-hour woody fuels (<0.25 inch and 0.25-1.0 inch, respectively). In the first 12 feet of the Brown's transect we tallied 100-hour fuels (>1.0-3.0 inches). We measured the diameter of each 1000-hour fuel (> 3.0 inches) to the nearest tenth inch along the entire 50-foot Brown's transect. We sampled depth (to the nearest 0.1 inch) of litter and duff using a ruler at 10 points along each Brown's transect pre- and post-burn.

Half of the Brown's transects used enhanced methodology where five collection plots were located along two parallel transects 10 feet on either side of the main transect (Figure 2). We collected pre-burn data on the right side transect and post-burn data on the left side transect. We clipped 1-hour combustible live fuels (grasses, forbs, and small shrubs attached to the ground) in five 9 square foot plots located at 10-foot intervals along transects parallel to the initial Brown's transect (Figure 2). We collected samples and placed them in paper bags. Fuel samples were oven-dried at 80 °C for at least 3 days (72 hours) to obtain dry mass. Dead and down 1- and 10-hour fuels were sampled in five 1 square foot plots nested within the live fuel plots (Figure 2). We collected all 1- and 10-hours fuels located within these plots and placed them in paper bags. When woody fuels were only partially within plots, we collected only the portions that were located within plots. We dried samples and obtained a dry weight in the same manner as live fuels.

ANALYSES

We used localized bulk density values to convert inches of litter and duff into tons per acre (2.04 and 6.41 tons/acre/inch for pine-oak forest and pine woodland; 1.38 and 4.84 tons/acre/in for oak forest; Ottmar and Andreu 2007). We used Fire Ecology Assessment Tool-Firemon Integrated (FFI) software to quantify fuel consumption on six prescribed fires. We determined fuel loading differences in community types and data collection methods using a *t*-test and calculated standard error using basic statistics (SigmaStat 3.0 and SigmaPlot 8.0 2002).

RESULTS

Fuel consumption during prescribed fires on the ONF was within the range of the standard fire-behavior fuel models (Table 1). Fuel consumption was 4.2 (2[SE] ± 1.2), 3.1 (± 1.1), 0.9 (± 1.0) tons/acre in the pine-oak forest, oak forest, and pine woodland, respectively. The models generally underestimated fuel consumption in forest communities and overestimated fuel consumption in woodland communities.

Litter was one of the primary fuels consumed in all three communities (Table 2). Substantial duff was consumed in pine-oak and oak forests, but not woodlands. Fine and coarse woody fuel consumption was higher in the forest communities, but variability was high in all community types. Two to three times as much fine woody fuel as coarse woody fuel was consumed in the forest communities. A relatively small amount of fine or course woody fuel was consumed in the woodland community. Lower basal area appears to be associated with lower fuel consumption of all types (Table 2).

There was a significant difference in 1-hour fuel consumption between the plot collection and Brown's transect methods (Table 3). Given the aggregated distribution of fine woody fuel across the landscape and the inherent error associated with Brown's transects, a difference of 0.2 tons/acre is considered negligible (Brown 1974). There was no significant difference in 10-hour fuel consumption between the plot collection and Brown's transect methods (Table 3).

Overall fuel consumption in forest communities was significantly greater ($P < 0.05$) than in woodland communities (Figure 4). Live fuel consumption in forest communities contributed little to overall fuel consumption (<0.1 ton/acre; Table 2). Live fuel consumption in woodland communities was significantly higher than forest communities ($P < 0.05$), but was not more than 0.26 (±0.19) tons/acre in any community (Table 2).

DISCUSSION

Fuel consumption during prescribed fires in Arkansas seems to be accurately represented by the standard fire-behavior fuel models. Nonetheless, fuel consumption in forests is on the higher end of what the models predict, especially for oak forests. This may be a result of small sample size as only 13 of 40 transects have been completed. Slightly lower fuel consumption in pine woodlands was likely a result of small sample size and the burn history of the unit. The low fuel consumption of fine and coarse woody fuel, litter, and duff in the pine woodland was a result of low pre-burn fuel loading (7.3 tons/acre) compared with pine-oak and oak forests (12.1 and 9.4 tons/acre, respectively). This is likely due to the frequent burning of this unit. More data is needed in all communities, but especially the oak forest and pine woodland.

We found little difference in fuel consumption estimates derived from collection plots and Brown's transects. However, the effort required by the two methods differed considerably. We estimated a 50-fold increase in the time needed for collection plots compared to Brown's transects. Additionally, the same piece of ground is measured pre- and post-burn with Brown's transects, whereas collection plots must be in different locations because fuels are removed. We recommend Brown's transects over fuel-collection plots for assessing consumption of fine woody fuels. Although Brown's transects do not capture live fuel consumption, we found the contribution of live fuel to total fuel loading small in all communities. Further, the time required to physically collect live fuels in the communities of the ONF is not justified by the information gained.

Eastern forests were historically more open than they are today (Foti 2004). Early explorers noted the open condition of the forest in their journals and notes (Nuttall 1999). It is also well documented that fire, mostly Native American fire, was a main driving force behind these forest conditions (Guyette and Spetich 2002, Delcourt and Delcourt 1997). In the Ouachita Mountain ecoregion, a lack of fire has lead to a widespread succession of woodlands to closed-canopy forest communities. Of the 8 million acres in the Ouachita Mountain ecoregion that were once woodland, only 6% remain (LANDFIRE 2010).

In 1994, the ONF initiated a large-scale restoration effort for pine-woodland communities located on National Forest System lands (Hedrick and others 2007). The original restoration target of 50,000 acres in 1994 grew to 254,000 acres with the 2005 Forest Plan (Hedrick and others 2007). When compared with untreated controls, studies showed that restoration of pine woodland benefited song birds (Wilson and others 1995), red-cockaded woodpecker (*Picoides borealis*) numbers (Hedrick and others 2007), some herpetofauna (Perry and others 2009), and herbaceous plants (Sparks and others 1998), and was not detrimental to tree growth (Guldin and other 2005). Our study shows that woodland communities consume less fuel per acre than forest communities and thus produce less smoke. While woodlands are burned more often than forests and overall may produce the same amount of smoke, the concentration per unit time is less. The EPA Air Quality Standards are concerned with the hourly average of emissions (EPA 1998) and therefore, restoring forests to the woodland condition may reduce human exposure to highly concentrated smoke and prevent violations in air quality standards. We are continuing this fuels research and hope to have all units burned in the spring of 2012.

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Table 1—Comparison of fuel consumption values predicted by standard fire behavior fuel models and Brown's transect data collected on dormant season prescribed fires on the Ouachita National Forest in Arkansas, 2010

Community Type	Standard Fuel Model	Actual Brown's transect data*
Pine-oak forest	3.0 – 4.4 tons/acre	3.0 – 5.4 tons/acre
Oak forest	0.8 – 2.5 tons/acre	2.0 – 4.2 tons/acre
Pine woodland	1.5 – 5.9 tons/acre	0 – 1.9 tons/acre

* Includes Brown's transect data only (N = 32, 13, and 9 for pine-oak forest, oak forest, and pine woodland)

Table 2—Fuel consumption (tons/acre) derived from Brown's transects and collection plots and basal area (ft^2/acre) by community type on the Ouachita National Forest of Arkansas, 2010

Community Type	FWF*	CWF*	Litter*	Duff*	Total*	Live Fuel ƚ	Basal Area λ
Pine-oak forest	1.23 ±0.92	0.38 ±0.36	1.28 ±0.22	1.30 ±0.44	4.22 ±1.20 [a]	0.07 ±0.07 [a]	105.0 ±11.4 [a]
Oak forest	1.01 ±1.00	0.38 ±0.17	1.25 ±0.30	0.50 ±0.18	3.12 ±1.08 [a]	0.04 ±0.03 [a]	93.5 ± 9.2 [a]
Pine woodland	0.19 ±0.36	0.21 ±0.38	0.46 ±0.3	0.05 ±0.40	0.91 ±0.98 [b]	0.26 ±0.19 [b]	70.5 ± 7.6 [b]

FWF = Fine woody fuel, CWF = Coarse woody fuel; Numbers represent ±2 standard error, within columns different letters indicate a significant difference (p≤0.05) * Data includes Brown's transect data only (N = 32, 13, and 9 for pine-oak forest, oak forest, and pine woodland)

ƚ Data includes plot collection data only (N = 14, 8, and 5 for pine-oak forest, oak forest, and pine woodland)

λ Data includes all 120 plots (N = 40 for all community types)

Table 3—Difference in fuel consumption (tons/acre) values of 1- and 10-hour fuels using Brown's transects and plot collection methods during prescribed fires on the Ouachita National Forest of Arkansas, 2010

	1-hour fuels	10-hour fuels
Brown's transect	0.06 ±0.02 [a]	0.23 ±0.15 [a]
Plot collection	0.19 ±0.04 [b]	0.30 ±0.12 [a]

Mean ±2 standard error, within columns different letters indicate a significant difference (P≤0.05).

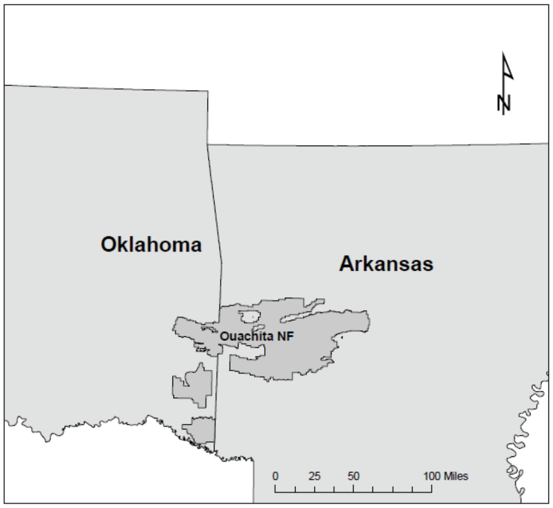

Figure 1—Location of the Ouachita National Forest of western Arkansas and eastern Oklahoma.

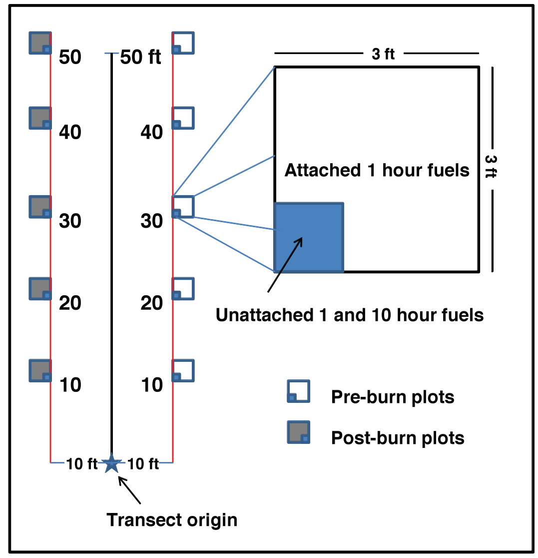

Figure 2—Enhanced Brown's transect plot design consisting of both the center Brown's transect and collection plots on each side transect. Plot design was used to measure fuel consumption on prescribed fires on the Ouachita National Forest of Arkansas, 2010.

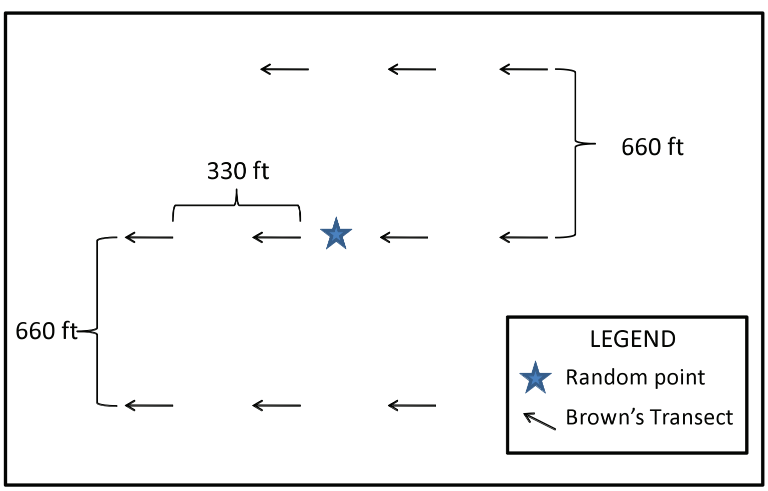

Figure 3—Plot layout for Brown's transects in each burn unit on the Ouachita National Forest of Arkansas, 2010.

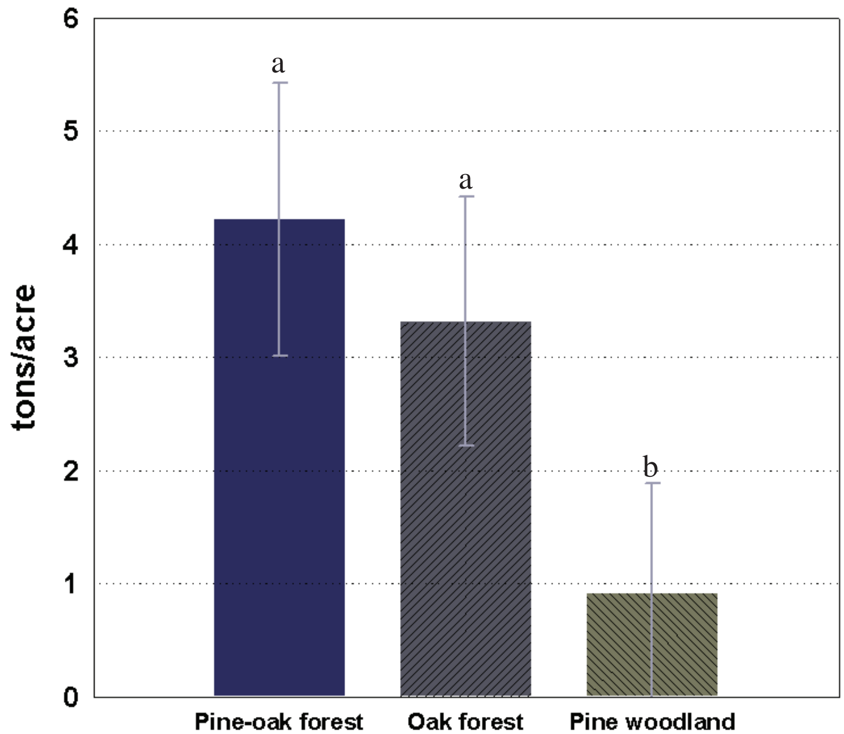

Figure 4—Overall fuel consumption in pine-oak forest, oak forest, and pine woodland using only Brown's transect data on the Ouachita National Forest in Arkansas, 2010. Different letters indicate a significant difference (P≤0.05, Mean ±2SE) among forest types.