

Fuel Loadings in Forests, Woodlands, and Savannas of the Madrean Province¹

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Abstract

Natural fire regimes in the southwestern United States have been significantly altered by past land-use practices and the fire suppression policies of land management agencies. One consequence of this alteration has been to increase the loadings of downed woody fuels. Ecologists and land managers are reintroducing fire into the ecosystems of the Madrean Province to reduce the excessive buildups of fuels that have a high probability of igniting and becoming unnaturally severe wildfire. However, incomplete knowledge of fuel loadings often constrains the successful reintroduction of fire because of the inability to forecast the resulting fire behavior. We have quantified fuel loadings in the pine-oak forests and oak woodlands and savannas of the Madrean Province for a range of site conditions and past land-use histories to facilitate the preparation of effective fire prescriptions.

Introduction

Natural fire regimes of the southwestern United States have been significantly altered by past land-use practices and the fire suppression policies of land management agencies. One consequence of this alteration has been to increase the loadings of downed woody fuels and, therefore, increasing the threat of high severity wildfire. In response to this situation, ecologists and land managers are reintroducing fire into the ecosystems of the Madrean Province to reduce the excessive buildups of fuels. Prescribed fire can also improve watershed conditions, wildlife habitats, and other multiple-use values. However, incomplete knowledge of fuel loadings in these arid and semi-arid ecosystems often constrains the successful reintroduction of fire because of the inability to forecast fire behavior. We have quantified fuel loadings in the extensive and diverse pine-oak forests and oak woodlands and savannas of the Madrean Province for a range of site conditions and past land-use histories to facilitate the preparation of effective fire prescriptions.

“Fuel loadings” are the oven-dry weights of fuels per unit of surface area for the size-fraction(s) of interest. Fuel loadings are also measures of the potential energy that might be released by a fire. The “downed woody fraction” of fuel loadings is the focus of this paper.

Study Area

The Madrean Province is at the convergence of the Sonoran, Chihuahuan, Madrean, and Rocky Mountain biogeographic regions and the Sierra Madre Occidentalis and Rocky Mountain ranges. Madrean ecosystems are found in

¹An earlier version of this paper was presented at the 2002 Fire Conference: Managing Fire and Fuels in the Remaining Wildlands and Open Spaces of the Southwestern United States, December 2–5, 2002, San Diego, California.

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southeastern Arizona and southwestern New Mexico and northwestern Chihuahua and northeastern Sonora in Mexico. Elevations range from 2,300 to more than 8,500 feet. The isolated mountains are characterized by pine-oak and other montane forests on the higher elevations and oak and pinyon-juniper woodlands on the lower elevations. These mountains are separated by broad plains and valley floors covered with a variety of desert-shrub and desert-grassland plant communities.

Pine-Oak Forests

Fuel loadings were measured on five sites in the pine-oak forests of the Madrean Province. Trees contributing to the downed woody fraction of fuel loadings on these sites included (in varying intermixtures) Apache (*Pinus engelmannii*), ponderosa (*P. ponderosa*), and southwestern white pine (*P. strobiformis*), alligator juniper (*Juniperus deppeana*), border pinyon (*P. discolor*), and Emory (*Quercus emoryi*), Arizona white (*Q. arizonica*), silverleaf (*Q. hypoleucoides*), and netleaf oak (*Q. rugosa*). Two of the study sites, McClure and Upper Sawmill, were in the Huachuca Mountains of southeastern Arizona; one site, El Tigre, was in the Chiricahua Mountains of southeastern Arizona; and two sites, Plantio and Pinos Grandos, were in the Sierra de Los Ajos of northeastern Sonora, Mexico. All of these sites have the same climate, vegetation, and physiography. It might be assumed, therefore, that the fuel loadings on the sites would be similar. However, their different land-uses have impacted their fuel-loading characteristics. There was a significant reduction of widespread and recurring fires with the settlement of the southwestern United States by Anglos in the late 1880s. The scarcity of tree fire scars after the 1880s is attributed largely to the effects of heavy livestock grazing and other intensive land uses that fragmented the natural landscape and, as a result, reduced the occurrence of fires over large areas (Swetnam and Baisan 1996). The fire suppression policies of public land management agencies after the 1900s have also contributed to this reduction of fires. Fire is more frequent in northeastern Sonora. Because lightning-caused fire has been and currently is infrequently suppressed, fire continues to be a landscape-structuring process throughout northern Mexico (Bojorquez-Tapia 1990). Fire regimes in northeastern Sonora have been largely unchanged for more than a century.

Emory Oak Woodlands

Fuel loadings were also measured on three sites in the Emory oak woodlands of the San Rafael Valley on the southeastern slopes of the Huachuca Mountains in southeastern Arizona. While similar in their site quality, the three sites differed in stand stocking conditions. One stand was stocked with mature Emory oak (60 yr and older) and a few scattered stump sprouts and root suckers. This stand mimicked the stocking conditions commonly encountered in unharvested Emory oak stands. Selection cutting of firewood had last taken place 20 yr earlier in the second stand, which as a result of the harvesting supported a smaller number of mature trees, few (less than 10 stems per ac) pre-harvest stump sprouts and root suckers, and a large number (350 to 400 stems per ac) of post-harvest stump sprouts. Firewood had also been selectively harvested 20 yr earlier in the third stand measured, with clumps of post-harvest stump sprouts thinned to 1, 2, or 3 of the largest and most vigorous 4 yr after harvesting to study the effects of coppice thinning on the growth and volume of the thinned Emory stump sprouts (Touchan and Ffolliott 1999). The resulting slash was left in place on both of the harvested sites.

Emory Oak Savannas

Fuel loadings were measured on 12 small watersheds situated in the Emory oak savannas on the east side of the Peloncillo Mountains of southwestern New Mexico. Characteristics of these watersheds, which vary in size from 20 to over 80 ac, have been described elsewhere (Gottfried and others 2000). The savannas on the watersheds differ from the Emory oak woodlands of San Rafael Valley in that they support fewer trees and, as a consequence, greater amounts of herbage. These watersheds have been established by the USDA Forest Service to evaluate the impacts of prescribed burning treatments on the hydrology and ecology of oak savannas in the southwestern United States. The information on fuel loadings presented in this paper should help in the preparation of these prescriptions.

Methods

Fuel loadings on each site were measured on a randomly located 2.5 ac grid of 25 systematically located plots established at equally spaced intervals. Errors of 20 percent or less, adequate levels of precision for most fuel loading inventories (Brown 1974), were obtained with these plot numbers. Plot centers were the starting points for randomly oriented planer-intersects that were established to measure the fuels. The planar-intersect technique has the same theoretical basis as the line-intersect method (Van Wagner 1968). It involves counting the intersections of fuels with vertical sampling planes that resemble guillotines dropped through the accumulated fuels. A similar grid has been used in studies to measure fuel loadings in other pine-oak and montane forest ecosystems in the region (Harrington 1985, Fule and Covington 1995, Arno and others 1997).

Diameter classes of the fuels that were intersected by the planar transects were tallied by the classification of Brown (1974), that is, sound wood fuels 0.1 to 0.25 inch, >0.25 to 1 in., >1 to 3 in., and >3 in. and decaying (rotten) woody debris >3 in. These diameter classes correspond to the 1-hour, 10-hr, 100-hr, and 1,000-hr time-lag fuel-moisture classes of the National Fire Danger Rating System (Pyne and others 1996), respectively. Sound and decaying fuels >3 inches in diameter were also classified as “coarse woody debris,” which includes limbs, stems, and roots of trees and shrubs in varying stages of decay (Graham and others 1994). Tallies of the respective diameter classes with their standard specific gravity values were used in determining fuel loadings in tons per acre.

Results and Discussion

Means and standard errors of the fuel loadings of downed woody fuels for the measurement sites are summarized in *table 1*. These loadings have been arbitrarily separated into those of “smaller fuels” up to 1 inch in diameter, “larger fuels” greater than 1 inch in diameter, and “coarse woody debris” for presentation and discussion purposes. Again, coarse woody debris includes all fuels >3 inches in diameter.

Smaller Fuels

Fuel loadings in these smaller diameter classes were heavier in the pine-oak forests and Emory oak woodlands than in the Emory oak savannas, but there was no difference between the pine-oak forests and Emory oak woodlands (*table 1*). This finding was not surprising, however, as there was a higher stocking of trees and in

Table 1—Means and standard errors of loadings of downed woody fuels.

Site	Fuels/wood (in.)					Coarse woody debris all fuel >3	Total fuel loading downed fuel
	Small		Large				
	sound 0.1-0.25	>0.25-1	sound >1-3	>3	decaying >3		
Pine-oak forest							
	<i>tons per acre</i>						
McClure	0.25 0.0091	0.40 ± 0.018	1.0 ± 0.091	1.8 ± 0.38	6.5 ± 0.22	8.3 ± 0.44	9.9 ± 0.46
Upper sawmill	0.16 ± 0.0073	0.56 ± 0.019	3.0 ± 0.093	8.7 ± 0.40	0.9 ± 0.19	9.6 ± 0.19	13.3 ± 0.47
El Tigre	0.73 ± 0.0092	0.98 ± 0.036	4.1 ± 0.090	12.6 ± 0.39	3.2 ± 0.20	15.8 ± 0.46	21.6 ± 0.48
Plantio	0.15 ± 0.012	0.16 ± 0.021	0.9 ± 0.12	3.3 ± 0.48	0.6 ± 0.27	3.9 ± 0.52	5.1 ± 0.48
Pinos Grandos	0.14 ± 0.011	0.22 ± 0.020	1.3 ± 0.26	3.1 ± 0.46	0.3 ± 0.26	3.4 ± 0.54	5.1 ± 0.42
Emory oak woodlands							
Unharvested stand	0.29 ± 0.0026	0.39 ± 0.0034	0.55 ± 0.011	0	0.12 ± 0.0048	0.12 ± 0.0048	1.3 ± 0.022
Harvested stand	0.22 ± 0.0019	1.2 ± 0.0086	0.77 ± 0.014	2.5 ± 0.065	0.34 ± 0.0094	2.8 ± 0.071	5.0 ± 0.10
Harvested and Thinned Stand	0.13 ± 0.0013	0.77 ± 0.0068	1.5 ± 0.020	1.8 ± 0.033	0.33 ± 0.013	2.1 ± 0.026	4.5 ± 0.074
Emory oak savannas							
A	0.0081 ± 0.00022	0.059 ± 0.0017	0	0	0	0	0.067 ± 0.0019
B	0	0.063 ± 0.0024	0.33 ± 0.0073	2.4 ± 0.98	0	2.4 ± 0.98	2.8 ± 0.11
C	0.043 ± 0.00091	0.28 ± 0.0049	0.22 ± 0.0061	0.38 ± 0.010	0	0.38 ± 0.010	0.92 ± 0.022
E	0.013 ± 0.00032	0.20 ± 0.0071	0.55 ± 0.011	4.4 ± 0.10	0	4.4 ± 0.10	5.2 ± 0.12
F	0.024 ± 0.00061	0.10 ± 0.0023	0.11 ± 0.0044	0	0	0	0.23 ± 0.0073
G	0.044 ± 0.00094	0.082 ± 0.0025	0	1.3 ± 0.052	0.19 ± 0.0076	1.5 ± 0.061	1.6 ± 0.062
H	0.022 ± 0.00045	0.20 ± 0.0043	0.44 ± 0.010	31.8 ± 0.49	0	31.8 ± 0.49	32.5 ± 0.51
I	0.023 ± 0.00073	0.20 ± 0.0047	0.44 ± 0.014	0	0	0	0.66 ± 0.019
J2	0.012 ± 0.00021	0.16 ± 0.0036	0	14.4 ± 0.41	0	14.4 ± 0.41	14.6 ± 0.41
K	0.083 ± 0.0015	0.36 ± 0.0065	0.22 ± 0.0088	0.79 ± 0.022	0	0.79 ± 0.022	1.4 ± 0.038
M	0.025 ± 0.00043	0.083 ± 0.0019	0.44 ± 0.0082	25.8 ± 0.62	3.7 ± 0.015	29.5 ± 0.63	30.0 ± 0.65
N	0.063 ± 0.0011	0.53 ± 0.010	0.44 ± 0.014	0.19 ± 0.0076	0	0.19 ± 0.0076	1.2 ± 0.032

pine-oak forests and Emory oak woodlands. Within the pine-oak forests, the sites in southeastern Arizona averaged about three-times the fuel loadings as those in northeastern Sonora, presumably because of the infrequent occurrence of fire in the former. Smaller fuels are more readily ignited and consumed by fire than are larger fuels and, therefore, less likely to accumulate and persist in large amounts on sites experiencing repeated or recent fire. El Tigre, a site with no known fires since 1900, had the heaviest loadings of downed woody fuels in these diameter classes.

Fuel loadings in the Emory oak woodlands of San Rafael Valley were heaviest on the site where cutting of firewood had last taken place 20 yr earlier. Subsequent mortality of less dominant post-harvest stump sprouts of low vigor followed by their eventual falling to the ground is the main contributor to these heavy accumulations of fuels in these diameter classes. At the opposite end of the spectrum of measurements, fuel loadings on the unharvested site were indicative of those found in Emory oak woodland stands representing “natural” stocking conditions.

Fuel loadings in these smaller diameters classes were almost 10 times less in the Emory oak savannas in the Peloncillo Mountains than those measured in the Emory oak woodlands. The few trees and occasional shrubs found in these savannas are the causal factor for these low fuel accumulations.

Larger Fuels

Loadings of downed woody fuels in these larger diameter classes were similar among the three broadly defined ecosystems studied (*table 1*). These larger fuels tend to ignite and burn more slowly than the smaller fuels and, consequently, might not be totally consumed in a fire of low to medium severity. However, the larger fuels can burn vigorously with fire of high severity and the rate of their reduction is greater than in the case of smaller fuels. Once again, the sites in pine-oak forests of the southeastern Arizona averaged about three-times the fuel loadings as those in northeastern Sonora. The general pattern of loadings for both smaller and larger downed woody fuels in the pine-oak forests is that lesser loadings occurred on the sites with a more frequent occurrence of fire (Escobedo and others 2001).

Loadings of larger downed woody fuels in the Emory oak woodlands followed the same general sequence as noted for the loadings of smaller fuels. That is, the heaviest fuel loadings were found on the site where firewood cutting had taken place 20 years earlier and the lowest loadings on the unharvested site.

Heavy loadings of sound wood >3 inches in diameter on three of the small watersheds in the Emory oak savannas contributed significantly to the overall heavy loadings of larger downed woody fuels in these ecosystems. Much of the variability in the loadings of larger fuels is attributed to the infrequent occurrence of sound wood fuels in these larger diameter classes on the three watersheds. The estimated loadings of these fuels were skewed to the “high end” of the range in the few instances when the larger fuels were measured on the planar-intersects.

Coarse Woody Debris

The range of coarse woody debris loadings in the pine-oak forests observed in this study (*table 1*) is comparable to the loadings reported in other pine-oak forests of the Madrean Province (Sackett 1979, Harrington, 1981, Alanis-Morales 1996).

However, the loadings of coarse woody debris that are required to sustain the “health” of the soils in the pine-oak forests of the Madrean Province are not known. Graham and others (1994) concluded that loadings of coarse woody debris from 5 to about 25 t ac⁻¹ were “optimal” to maintain the mycorrhizal activity of soils in the forest types of the Rocky Mountains. Lesser loadings are likely to disrupt the functioning of soil that is necessary to sustain a “high level” of plant productivity in these forests. Little is known about the levels of coarse woody debris necessary to sustain the efficient cycling of nutrients in the Emory oak ecosystems.

Total Loadings of Downed Woody Fuels

Total loadings of downed woody fuels in the ecosystems studied were similar when all of the measurement sites are considered together (*table 1*). All of the study sites in pine-oak forests had experienced some timber harvesting in the past and, therefore, unknown amounts of decaying logging slash likely contributed to the total fuel loadings measured in this study. The total loadings of downed woody fuels found in the pine-oak forests were similar to values reported for ponderosa pine forests in the southwestern United States in earlier studies (Sackett 1979, Harrington 1981, Graham and others 1994).

Total loadings of downed woody fuels in the Emory oak woodlands of the San Rafael Valley were heaviest on the sites where firewood had been selectively harvested in the past. Firewood cutters are required to remove stems and limbs that are >2 inches in diameter from the site in these harvesting operations (Bennett 1992). The smaller residuals left on site contribute significantly to the total fuel loadings of a site. The comparatively low total loadings in the unharvested stand are thought to represent the downed woody fuels associated with “pristine” woodland conditions.

Total fuel loadings in Emory oak savannas of the Peloncillo Mountains were largely dependent on the occurrence of woody fuels > 3 inches. Values exceeding 10 t ac⁻¹ were measured when comparatively large quantities of material were present. Otherwise, the loadings of downed woody fuels were 1 t ac⁻¹ or less.

Conclusions

While both site-specific and specific to the size-fraction of the fuel loadings measured, the information presented in this paper should help in improving the knowledge fuel conditions necessary to prepare prescriptions for the successful reintroduction of fire into the Madrean Province. Depending on the loading that might be acceptable for a site, an initial schedule of introduced fire occurrences could be prescribed, tested, and evaluated relative to maintaining the fuel loading at the acceptable level while attaining other land management objectives. This schedule could then be modified as necessary through time to sustain the desired fuel loading conditions and multiple-use values.

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