Fuel Loadings in Southwestern Ecosystems of the United States

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Abstract.--Natural forest fuel loadings cause extreme fire behavior during dry, windy weather experienced during most fire seasons in the Southwest. Fire severity is also exacerbated from burning heavy fuels, including heavy humus layers on the forest floor. Ponderosa pine and mixed conifer stands possess more than 21.7 and 44.1 tons per acre of total forest floor fuel, respectively, in Southwestern forest ecosystems.

INTRODUCTION

The ignition, buildup, and behavior of fire depends on fuels more than any other single factor (Brown and Davis 1973). Fuels, made up of the products of photosynthesis, continually accumulate as any ecosystem progresses. In any fire, the rate at which readily available fuels are consumed determines fire intensity (Byram 1959). This dynamic fire behavior has a direct effect on the environment in which it is burning, usually seen in above-ground flora. Once the active flaming front has passed, glowing, smoldering combustion creates totally different effects on the same environment, usually the unseen fire severity effects at or below ground. Fuels and their many characteristics provide the basis for assessing the outcome of fire, in any form, whether it be the above-ground fire intensity effects or the belowground fire severity effects.

Of the many types of fire that exist in wildland ecosystems, live fuels in the Southwest tend to be the most spectacular when they burn. Chaparral fires, whether in California or Arizona, can spark the attention of even the most passive observer. Fire in live ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) crowns can race over the countryside at breakneck speeds, uncontrollable by even the most aggressive suppression efforts.

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But for all the live fuel fires, fires occurring in long-needle conifer surface and ground fuels in the southwestern United States and northern Mexico have more relevance to protecting and maintaining the health of forested ecosystems. The amount of forest floor fuel has a pronounced effect on fire hazard, moisture relations, forage production, and the general health of coniferous forests.

FACTORS AFFECTING FUEL ACCUMULATION

The structural and compositional changes in southwestern ponderosa pine over the past 100 years or more have been repeatedly documented (Biswell and others 1973, Brown and Davis 1973, Cooper 1960). What was once an open, park-like ecosystem, maintained by frequent, low-intensity fires, is now a crowded, stagnated forest. In addition to stand changes, general fire absence has led to uncharacteristically large accumulations of surface and ground fuels (Kallander 1969).

The natural accumulation of pine needles and woody fuels is exacerbated by the very slow decomposition rates characteristic of the dry, southwestern climate (Harrington and Sackett 1992). Decomposition rate (k) (Jenny and others 1949) is the ratio of steady state forest floor weight to the annual accumulation weight. Harrington and Sackett (1992) determined k values of 0.074, 0.059, and 0.048 for sapling thickets, pole stands, and mature old-growth groves, respectively. Decomposition rates this slow, and which Olson (1963) considers quite low, border on desert-like conditions. Humid, tropic conditions would have k values approaching 1.0 where decomposition occurs in the same year as the material is dropped on the ground.

Fuel loading estimates can be obtained in a number of ways. Slash loading can be predicted from information obtained in timber sale surveys (Brown and others 1977, Wade 1969, Wendel 1960). Although originally developed to inventory activity-generated downed woody material, Brown's (1974) planar intersect method is oftentimes used by managers to determine natural woody fuel loadings. Forest floor weights, however, have been studied only to a limited extent in Arizona, with conditional success because of inherent variability. Ffolliott and others (1968, 1976, 1977), Aldon (1968), and Clary and Ffolliott (1969) studied forest floor weights in conjunction with water retention on some Arizona watersheds. These and other works included prediction equations relating forest floor weight to stand basal area (Ffolliott and others 1968, 1976, 1977), age (Aldon1968), height and diameter (Sackett and Haase 1991), and forest floor depth (Harrington 1986, Sackett 1985).

Because of the variable nature of forest floor fuel loading, Sackett (1979) set out to determine the range over the entire Southwest of unmanaged ponderosa pine and mixed conifer stands.

PONDEROSA PINE FUEL LOADINGS

The importance of forest floor loadings has been generally overlooked by managers when accessing total fuel loadings. The forest floor consists of the litter (L) layer, recently cast organic material; fermentation (F) layer, material starting to discolor and break down because of weather and microbial activity; and the humus (H) layer, where decomposition has advanced. The loosely packed L layer and upper portion of the F layer provide the highly combustible surface fuel for flaming combustion and extreme fire behavior during fire weather watches and red flag warnings. This combined layer of fuel could be referred to as the fire intensity (FI) layer of the forest floor. The lower, more dense part of the F layer and the H layer make up the

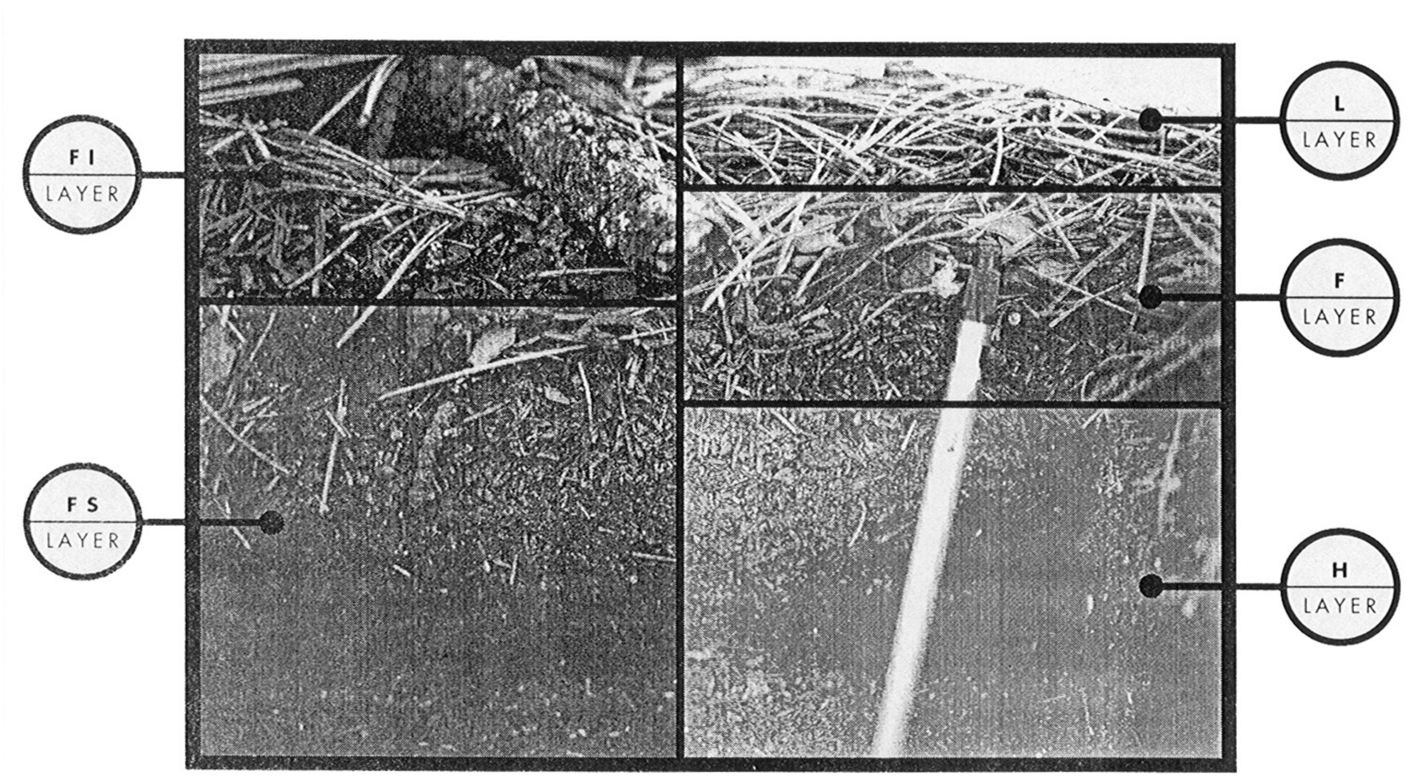

Figure 1. Section of heavy forest floor material indicating fire intensity (FI) layer of fuel and fire severity (FS) layer of fuel in relation to the three layers of forest floor material (L, F, and H).

ground fuel that generally burns as glowing combustion. This combined layer of the forest floor could be referred to as the fire severity layer (FS) (Figure 1).

Sixty-two Case Studies

In the late 1970's, forest floor fuels were sampled in 62 stands in Arizona and New Mexico (Sackett 1979). Throughout the Southwest, unmanaged stands of ponderosa pine had from 4.8 tons per acre in a stand on the Tonto National Forest to more than 20 tons per acre in a stand on the north rim of the Grand Canyon National Park. The next two heaviest weights (18.3 and 18.0 tons per acre) also occurred on the north rim of the Grand Canyon. Mean forest floor loading for the entire 62 stands measured was 12.5 tons per acre. When woody material greater than 1-inch diameter was added, the average increased to 21.7 tons per acre. The heavier material does not have much to do with extreme fire behavior, except as a spotting potential; these fuels do contribute to localized severity when burned. Table 1 provides a summary of forest floor fuel loadings observed in the Southwestern ponderosa pine ecosystem.

Of the 12.5 tons per acre average of forest floor fuel load found in the Southwest, about 1.0 ton per acre was L layer material, 3.8 tons per acre was in the F layer, and 6.1 tons per acre was made up of humus (H layer). Small diameter woody material and other material comprised the remaining 1.8 tons per acre. Large, woody material that accounted for 42 percent of the total fuel load consisted of 1.4 tons per acre of material 1 to 3 inches in diameter, 5.0 tons per acre of rotted, woody material 3 inches or more in diameter, and the remaining 2.8 tons per acre was sound wood greater than 3 inches in diameter.

Stand Conditions Affecting Fuel Loadings

Soon after this extensive fuel survey w.-is conducted, two prescribed burning studies were established; one at Fort Valley Experimental Forest on a basalt soil, the other on the Long Valley Experimental Forest on a sedimentary soil. Both are located near Flagstaff, Arizona. Additional forest floor fuel sampling was done on those areas. At Fort Valley, 15.2 tons per acre of forest floor lay on the site before burning (Sackett 1980). Although more than the Southwest average, it was not much different than that found on the Coconino National Forest (14.7 tons per acre) or the Kaibab National Forest (15.5 tons per acre), both of which were nearby. Only 7.2 tons per acre were found in woody material greater than 1-inch diameter.

At Long Valley, an almost identical forest floor fuel load was measured (15.7 tons per acre). The difference between the sites was the larger amount of large, woody material (16.6 tons per acre) at Long Valley because of some sanitation logging during the 1960's.

Another site at both areas was established to glean more information about initial prescribed burns in heavy forest floor fuels. At that time, a concentrated effort was made to develop an easier method of estimating forest floor fuel loading. Earlier attempts were made by others to define forest floor fuel loading by the depth of forest floor (Eakle and Wagle 1979, Sackett 1979). To date, nearly 900 individual square foot samples have been taken between the two areas to further define forest floor fuel loading and residual fuels after burning. Prediction equations have proven extremely accurate (r^2 = 0.87 to 0.90), but tend to be site specific. For instance, Fort Valley has about 17.7 tons per acre where the forest

Table 1. (Ponderosa pine fuels in the southwestern United States (Sackett 1979).

Location	No. of sites	Forest floor and 0-1 inch dia. wood (T/ac.)	Woody fuel >1-inch dia. (T/ac.)	Total fuel (T/ac.)
Kaibab NF	4	15.5	8.6	24.1
Grand Canyon NP	4	17.5	5.6	23.1
Coconino NF	4	14.7	19.8	34.5
Tonto NF	2	6.5	2.7	9.2
Apache Sitgreave NF	14	11.3	11.2	22.5
San Carlos Apache IR	3	14.4	8.4	22.8
Fort Apache IR	2	15.1	20.5	35.6
Gila NF	10	11.2	7.3	18.5
Navajo IR	1	9.4	4.9	14.3
Cibola NF	3	8.8	8.8	17.6
Santa Fe NF	3	13.2	14.6	27.8
Carson	4	13.3	4.3	17.6
Bandalier NM	1	1 1.6	3.0	14.6
Lincoln	2	13.9	7.1	21.0
San Juan NF	5	11.9	4.8	16.7

floor is 2 inches thick, whereas Long Valley has 22.2 tons per acre of forest floor fuel where the depth is 2 inches.

Not only is there wide variation from site to site in ponderosa pine ecosystems, but vast differences exist within stands with respect to overstory characteristics. Experience indicates four separate conditions: sapling (doghair) thickets, pole stands, mature, old-growth (yellow pine) groves, and open areas in the groves without crowns overhead. In the two additional study areas, the following forest floor fuel loadings with woody material 1 inch or less, were measured in each of four overstory conditions (Sackett 1985).

Annual rates of forest floor accumulation are also commensurate with overstory conditions. Sapling thickets produce as much as 1.1 tons per acre per year,

Sampling T/ac	Poles T/ac	Open T/ac	Mature T/ac
14.8	18.2	10.4	48.4

pole stands 1.5 tons per acre per year, and mature, old-growth groves as much as 2.1 tons per acre per year.

A substantial amount of forest floor material remains after an area is initially burned. This amount persists even with repeat applications of fire. Figure 2 shows the mean amount remaining (old) after burning, and the average accumulation of fuel (new) since the last fire on the various rotation plots of the two long term study areas.

SOUTHWESTERN MIXED-CONIFER FUEL LOADINGS

Southwestern mixed-conifer stands contain varying proportions of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], white fir [*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.], corkbark fir [*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.], ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.), blue and Engelmann spruce (*Picea pungens* Engelm.

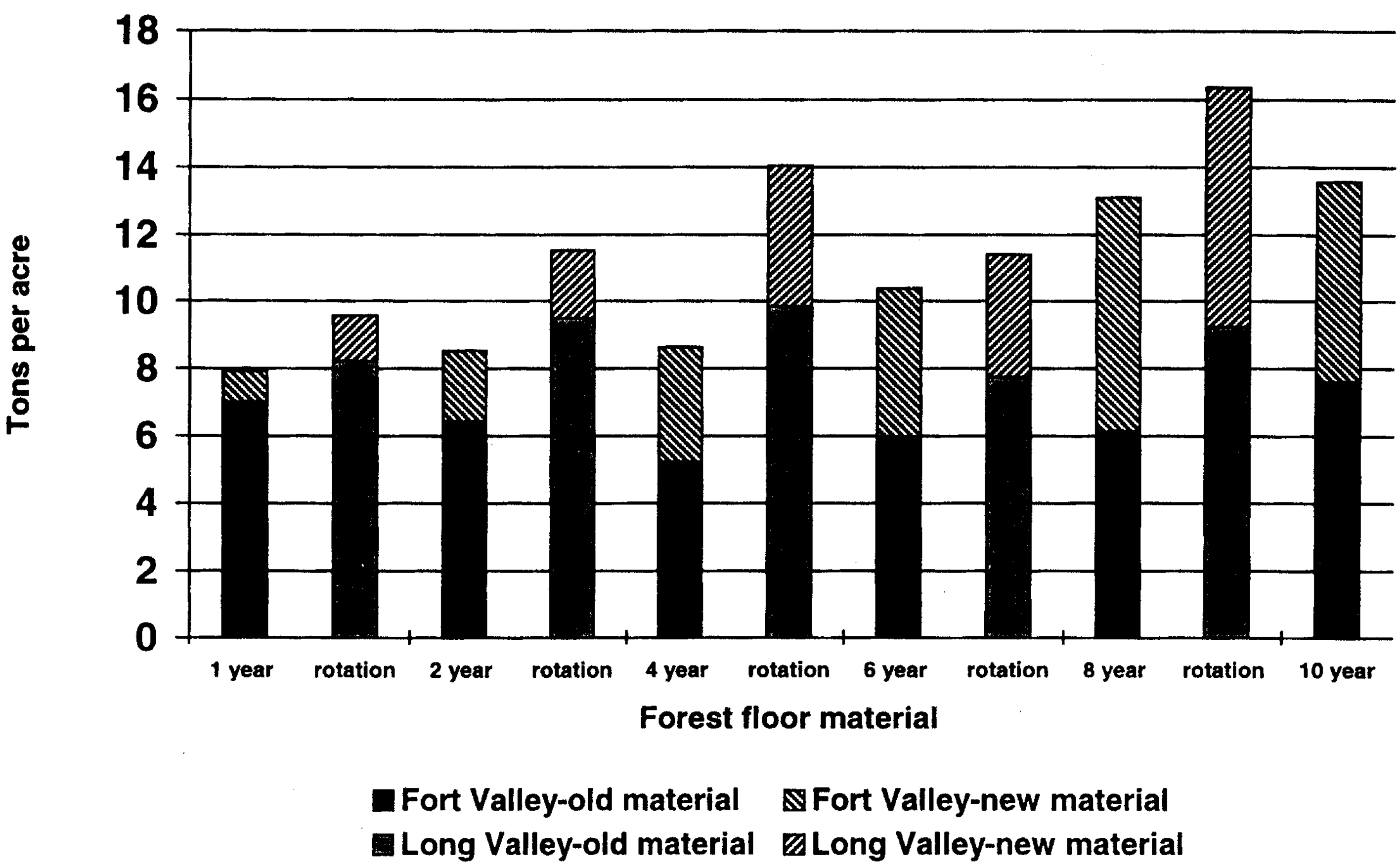

Figure 2. Mean forest floor remaining after prescribed burning (old) and average amount of forest floor accumulating since the last fire (new) for Fort Valley and Long Valley.

and *Picea engelmannii* Parry ex Engelm.), and aspen (*Populus tremuloides* Michx.). Forest floor loadings in 16 stands with varying degrees of species composition were also sampled (Sackett 1979). Mean forest floor fuel loads were more than 22 tons per acre, with a range from 13.6 to more than 30 tons per acre (Table 2). Woody fuels greater than 1-inch diameter, with most of the weight in classes greater than 3-inch diameters, ranged from 9.6 to 58.4 tons per acre and on average added another 21.9 tons per acre to the forest floor fuel average. L and F layers were comparable to ponderosa pine, but the H layer was found to be more than twice (12.3 tons per acre) that of ponderosa pine. In three watersheds located in east-central, Arizona, Ffolliott and others (1977) found an average of 21.1 tons per acre in mixed conifer stands. Gottfried and Ffolliott (1983) found annual litterfall in a southwestern mixed-conifer stand to be about 0.4 ton per acre per year.

Table 2. ---Mixed conifer fuels in the southwestern United States (Sackett 1979).

Location	No. of sites	Forest floor and 0-1 inch dia. wood (T/ac.)	Woody fuel >1-inch dia. (T/ac.)	Total fuel (T/ac.)
Apache Sitgreaves NF	9	26.2	27.0	53.2
Bandalier NM	1	18.7	13.6	32.3
Carson NF	3	20.0	13.7	33.7
Lincoln NF	2	13.4	20.5	33.9
Sante Fe NF	1	13.6	11.4	25.0

SUMMARY

Forest floor fuel loadings and total fuel loadings in southwestern coniferous forests are substantial. Rapid accumulation and extremely slow decomposition of fuels, coupled with extreme fire weather, produce extremely hazardous conditions that produce intense, severe wildfire. Fuel accumulation is site specific, but can be estimated using prediction equations developed for those sites that relate loading with stand basal area, tree height or diameter, or with depth of forest floor. Stand overstory age also influences the rate of accumulation of fuel. It needs to be remembered too, that not all forest floor fuel is consumed in an initial prescribed burn. A logical response is to develop burning programs that reduce and maintain much lower loadings of forest fuels.

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