Estimating Fuel Bed Loadings in Masticated Areas

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Abstract*—Masticated fuel treatments that chop small trees, shrubs, and dead woody material into smaller pieces to reduce fuel bed depth are used increasingly as a mechanical means to treat fuels. Fuel loading information is important to monitor changes in fuels. The commonly used planar intercept method however, may not correctly estimate fuel loadings because masticated fuels violate the assumption that fuel particles are round. A sampling method was developed for estimating masticated fuel bed loadings using percent cover, average depth, and bulk density in three vegetation types: Jeffrey pine-white fir, ponderosa pine-Gambel oak, and pinyon-juniper. Masticated material, duff, and litter samples were collected to determine bulk densities. Loadings were calculated as the product of bulk density and depth. Total fuel median bulk densities equaled 129 (Jeffrey pine-white fir), 128 (ponderosa pine-Gambel oak), and 226 kg/m^3 (pinyon-juniper). Correlations between loading and depth were best for the Jeffrey pine-white fir type. Bulk density was most variable in pinyon-juniper. Woody material loadings calculated from the cover-depth method were generally lower than the loadings calculated from the planar intercept method, while duff and litter loadings from the cover-depth method were higher than the loadings calculated from the vertical profile measurements on the planar-intercept transect.*

Introduction

Mechanical methods to treat fuels are used increasingly in the wildland urban interface (WUI). The goal of many of these projects is to reduce wildfire or prescribed fire intensity and spread rate through modification of surface fuels and increased canopy base heights. Masticating fuels compacts the surface fuel bed by both shredding small trees and shrubs and by chipping dead and down fuels into smaller size classes. While the mastication treatment reduces fuel bed depth, it can also result in a more continuous horizontal surface fuel layer and cause mixing of the woody material into the duff and litter layers. Because mastication is a relatively new fuels treatment, it is unclear how these treatments will affect surface fire behavior or the resulting fire effects.

Gathering fuel loading information is important for predicting fire behavior and explaining post-fire effects for any fuels treatment. However, Brown's planar intercept and duff/litter profile method (Brown 1974; Brown and others 1982) may not estimate fuel loadings accurately in masticated areas because masticated fuels are highly irregular in shape and size and may violate the assumption of round fuel pieces. In this paper, we propose the cover-depth method as an alternative to the planar intercept method when estimating masticated fuel bed loadings. For the cover-depth method, square one meter frames are placed along a fuel transect and the percent cover of the fuel bed (masticated/woody material, litter, and duff) and masticated/woody only is estimated. Depth to mineral soil is then measured and the percent that

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is masticated/woody and the percent that is litter of the vertical profile are estimated. Loadings can then be estimated by multiplying the bulk densities presented here by the fuel bed depth and cover class.

Specifically our objectives were: 1) determine bulk densities of the total fuel bed and the individual woody, litter, and duff layers, 2) test a new method to estimate fuel loadings using cover and depth (cover-depth method), and 3) compare loadings estimated from the cover-depth method and the planar intercept method in masticated areas.

Methods

Study Sites

Treatment areas were located on the San Juan National Forest in southwestern Colorado (CO) and the Lassen National Forest in northern California (CA). We chose sites on the San Juan National Forest that had pre-treatment fuels data in two vegetation types: pinyon-juniper (*Pinus edulis* Engelm. and *Juniperus osteosperma* (Torr.) Little) and ponderosa pine-Gambel oak (*Pinus ponderosa* P. & C. Lawson and *Quercus gambelii* Nutt.). There were three pinyon-juniper sites, IC, MAHN, and KRC, and three ponderosa pine-Gambel oak sites, HAYD, MLCK, and NJAK. The California site, GRAYS, was dominated by Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and had no pre-treatment fuels data. It was part of a separately funded Joint Fire Science Program proposal.

Both vertical and horizontal shaft machines were employed for mechanical treatment of fuels. Vertical shaft hydro-mowers or hydro-axes were used more commonly because of superior maneuverability on steep slopes and less ground disturbance. The size and distribution of fuel pieces after a treatment was dependent on the equipment, the operator, and site conditions. No material was removed from the CO sites. The CA site was thinned from below and merchantable trees were whole tree yarded before mastication treated activity fuels and small trees and shrubs.

Field Measurements

Existing fuel transects were used to compare loadings estimated from the planar intercept method and the cover-depth method on all sites. The CA site had two transects per plot, with transects radiating from plot center at right angles to each other. The CO sites had multiple transects per plot and followed FIREMON protocols (Lutes and others 2006). All transects were established from random start locations. We placed square frames (1 m^2 area) at 5, 10, 15, 20, and 25 meters at the CA site and at 15 and 24 meters at the CO sites on each transect (fig. 1). Photographs were taken approximately one meter above each frame in order to develop a visual aid for estimating cover. Total cover of duff, litter, and woody material and only woody cover (dead and down fuels and masticated material) were estimated for each frame using FIREMON cover classes (Lutes and others 2006).

If fuels were evenly distributed throughout the frame, depth was recorded at each corner and the middle of the plot to the nearest 0.5 cm. Fuel depth was measured from the top of the masticated material to the mineral soil. We

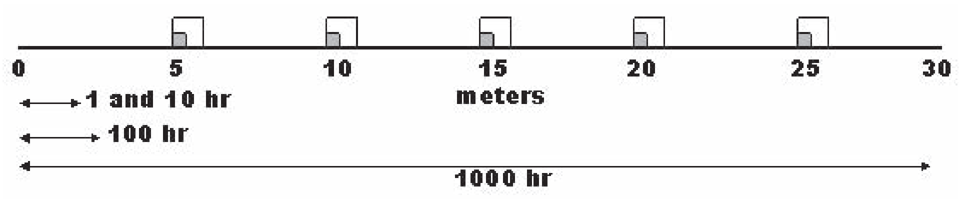

Figure 1—Example transect and frame layout of masticated fuel loading study. Each plot contained multiple transects.

estimated the percent of the vertical profile consisting of masticated/woody material and the percent litter following FIREMON methodology at each point where depth was measured. If fuel distribution inside the frame was markedly uneven, we assessed fuels by visually dividing the area into homogenous clumps. The proportion of each clump was recorded and fuel bed depth measured. We took one depth measurement for every 25 percent area the clump covered.

A 30 x 30 cm square sub-frame was placed in the lower left-hand corner of each one meter frame for collection of fuels to determine bulk density (fig. 1). If fuel bed total cover inside the sub-frame was 100 percent, depth was recorded using the same method as described for the 1 m^2 frame. Care was taken to minimize disturbance to the fuel bed while measuring depth. We did not sample the sub-frame if total cover was less than 100 percent because of the difficulty in calculating volume and bulk density. We collected all fuels inside the sub-frames with 100 percent cover to mineral soil separately by three fuel types: masticated/dead and down fuels, litter, and duff. Duff and litter were combined on the pinyon-juniper subplots because of difficulty in separating the two layers. While the fuels were generally arranged in layers, we found more mixing and compression of the woody material into the litter and duff layers than is seen on unmasticated sites. Woody material was placed into litter and duff collection bags if the particle's cross-section was in the litter or duff layer, leading to higher weights for these layers. Pieces extending outside the sub-frame were cut with clippers or a hand saw.

Dead and down woody fuels were counted along 23 m transects using the planar intercept method (Brown 1974). Masticated pieces are often irregularly shaped; therefore, diameters of the pieces were averaged for placement into a time-lag fuel size class (1, 10, 100, and 1000 hour). Duff and litter depths were recorded at 14.5 m and 24 m along each transect.

Data Analysis

Fuel bed samples from the sub-frames were dried at 105°C for 48 hours or until sample weight stabilized and then weighed to the nearest gram. Total fuel bed volume and individual fuel bed component volume was calculated by multiplying dimensions of the sub-frame by the average depth of the vertical profile. Bulk density of each sample was then calculated by dividing the oven-dry weight of the sample by the volume. Because of the mixing and compression of fuel bed layers and difficulty in separating the layers during collection, we feel it is more accurate to use the total subplot sample weight and the individual fuel component depth to calculate loadings and bulk densities.

Fuel bed loading was determined by multiplying the median bulk density of each vegetation type by the average depths of the one meter frames as if cover was 100 percent. The loadings were then reduced based on recorded cover class and clumping proportions. Loadings were calculated individually by fuel bed component and together. The total bulk density and loadings were calculated using average total depths and summed masticated, duff, and litter weights. All loadings reported here were calculated using the median total fuel bed bulk density and individual fuel bed component depth.

We also developed linear regression equations by vegetation type to estimate loadings using fuel bed depth as the independent variable (SAS Institute Inc. v 9.1). If the intercept was not significant (*p-value* ≥ 0.05), it was dropped from the regression equation.

Five sub-samples of duff and litter from each vegetation type were randomly selected to determine mineral ash content because of potentially higher mineral soil contents in the fuel bed from the mixing and compression of layers during mastication. Higher mineral soil content increases bulk densities. The samples were placed in a muffle furnace at 450°C for 24 hours to combust all organic matter. The mineral ash content (percent) was calculated by dividing the weight of the mineral ash by the weight of the oven-dried sample.

Loadings were also calculated from data collected using the planar intercept/duff-litter profile method. We used the FIREMON v. 2.1.2 software to calculate these fuel loadings (Lutes and others 2006). All frame loadings and transects loadings were averaged by vegetation type and site to determine average site loadings.

Results and Discussion

We collected 17, 41, and 26 sub-frame (30 x 30 cm) samples on 3, 17, and 13 plots in the Jeffrey pine-white fir, ponderosa pine-oak, and pinyon-juniper vegetation types, respectively. Fuel bed depth was highest on the Jeffrey pine-white fir site and lowest on the Pinyon-Juniper sites (fig. 2). The masticated layer averaged approximately 3.0 cm for all vegetation types.

Average litter mineral ash content was 3.9 percent in the Jeffrey pine-white fir, 11.2 percent in the ponderosa pine-oak, and 26.2 percent in the pinyon-juniper (includes duff). Average mineral content of the duff samples were high. We found 32.4 and 42.4 percent mineral content for Jeffrey pine-white fir and ponderosa pine-oak, respectively. The high mineral content for the pinyon-juniper litter samples was probably a result of combining the duff and litter into one sample bag during collection. The pinyon-juniper sites also have a much higher percentage of bare soil than the other vegetation types which may have resulted in mixing of bare soil into the duff and litter material when the mastication treatment was applied.

Median fuel bed bulk density was very similar for Jeffrey pine-white fir and ponderosa pine-oak (129 and 128 kg m^{-3}), but pinyon-juniper bulk density was much higher (226 kg m^{-3}) (fig. 3a). Median bulk density of the masticated/woody layer only was 155, 136, and 218 kg m^{-3} for Jeffrey pine-white fir, ponderosa pine-oak, and pinyon-juniper, respectively (fig. 3b). Variability decreased when litter, duff, and woody material samples were combined into one forest floor sample per plot to calculate bulk densities (fig.3). This was likely due to the difficulty of accurately separating the individual fuel components during collection.

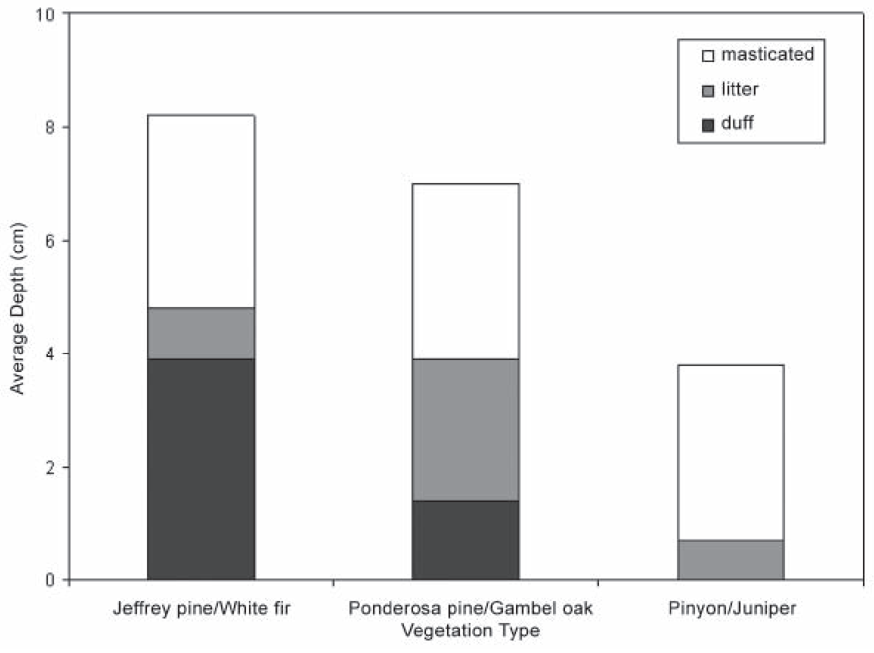

Figure 2—Average depth of surface fuels and forest floor by vegetation and fuel type.

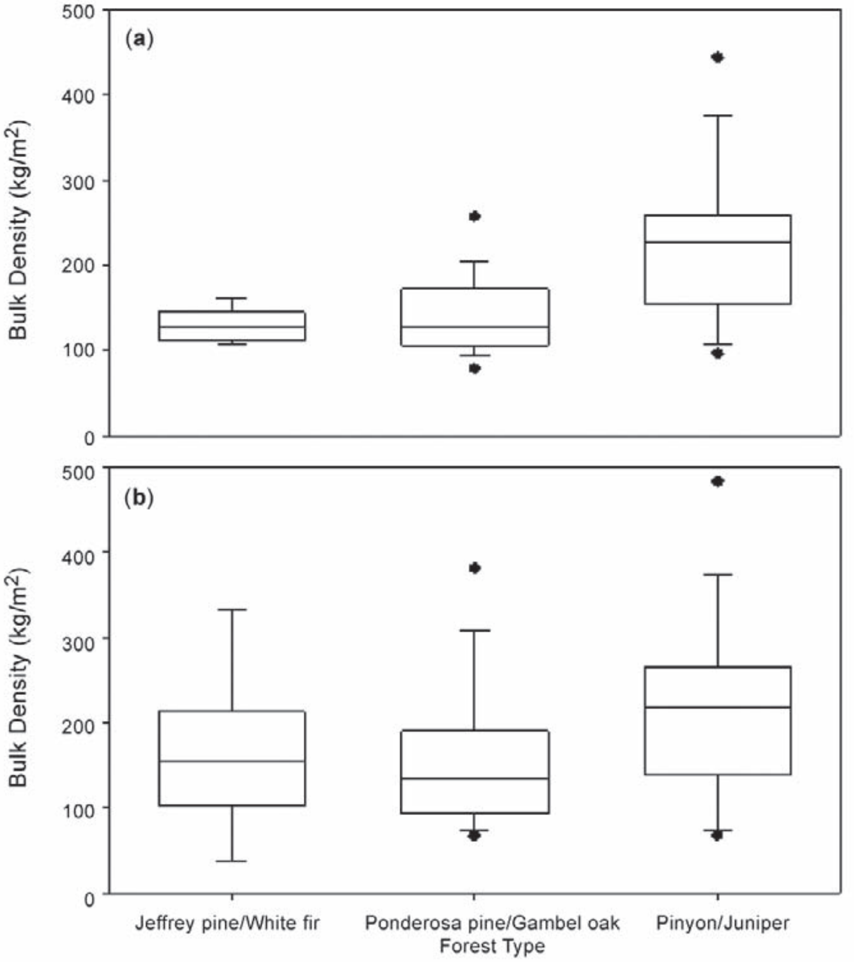

Figure 3—Bulk density of (a) total surface and forest floor fuel loadings and (b) only surface masticated and woody fuel loadings in subplots by vegetation type. Solid lines represent median values. Dots are 5th and 95th percentile outliers.

Total fuel bed loadings calculated from the sub-frames where cover was 100 percent were highest in the Jeffrey pine-white fir type (9.6 kg m^{-2} (42.8 tons/acre)), followed by ponderosa pine-oak (8.2 kg m^{-2} (36.6 tons/acre)) and pinyon-juniper (7.3 kg m^{-2} (32.6 tons/acre)). Average masticated/woody fuel loadings were highest in the pinyon-juniper plots (5.6 kg m^{-2} (25.0 tons/acre)). Masticated loadings in the Jeffrey pine-white fir and ponderosa pine-Gambel oak plots were similar (4.0 and 3.9 kg m^{-2} (17.8 and 17.4 tons/acre)). Loadings increased generally linearly with depth. Variability was high except for the Jeffrey pine-white fir type (fig. 4). The intercept was non-significant for only the Jeffrey pine-white fir type. Regressions equations for estimating total loadings are given in figure 4.

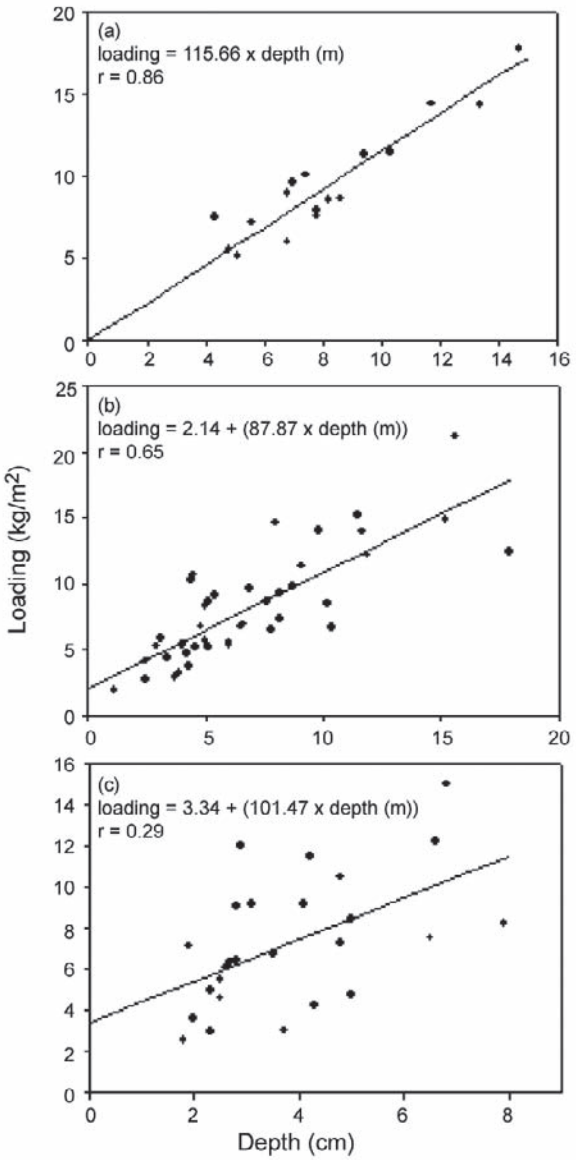

Figure 4—Regression showing relationship of total fuel bed depth and loading for samples in (a) Jeffrey pine-white fir, (b) ponderosa pine-Gambel oak, and (c) pinyon-juniper vegetation types.

Woody fuel loadings estimated with the cover-depth method were usually lower (fig. 5a) and duff and litter loadings higher (fig. 5b) than the loadings estimated with the planar intercept method. The difference between the two methods can be attributed to both differences in average depths and bulk densities. The cover-depth method requires more depth measurements (5 per 1 m^2 per frame) than the planar intercept method (2 per transect). The duff and litter bulk densities calculated from the 30 x 30 cm sub-frames were higher than the ones used by FIREMON to calculate loadings (44 kg m^{-3} for litter and 106 kg m^{-3} for duff), especially for the pinyon-juniper vegetation type.

The Jeffrey pine-white fir vegetation type had the strongest correlation between loading and depth. This could be due to more uniform stand conditions than the ponderosa pine-Gambel oak and pinyon-juniper types, both inherently and from treatment application. Also, all data collected in the Jeffrey pine-white fir type came from one site, whereas data for the other vegetation types were collected across several sites. The pinyon-juniper type was the most variable type and had the highest bulk density.

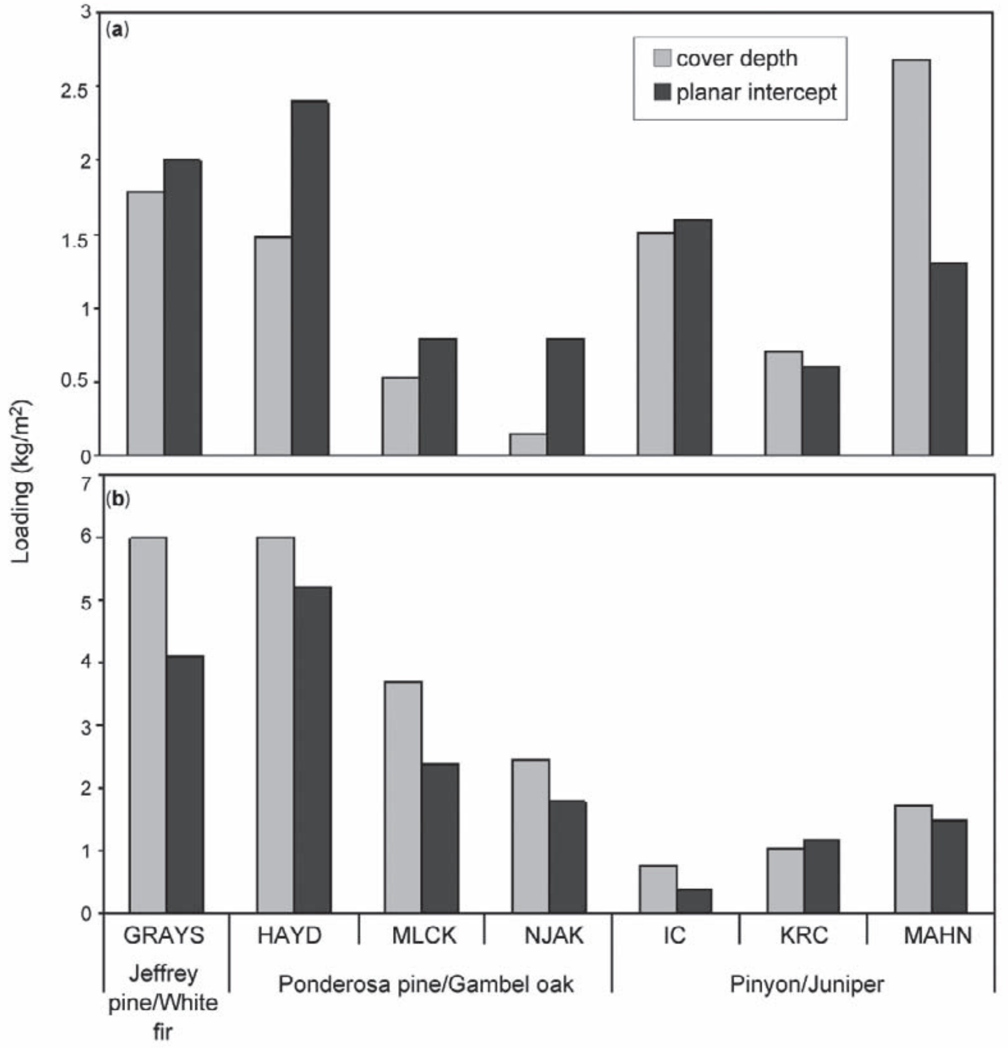

Figure 5—(a) Masticated and down woody and (b) litter and duff fuel loading estimations using the cover-depth method and Brown's planar intercept/duff-litter profile method.

The cover-depth method estimated higher duff and litter loadings and lower woody fuel loadings than the planar intercept method for most sites. Our next step is to perform an accuracy assessment based on the data collected in the sub-frames to determine which method is better for estimating fuel bed loadings in masticated areas. We also plan to assess if fewer depth measurements would produce similar results, thereby speeding the data collection process. If the cover-depth method proves to more accurately estimate loadings than the planar intercept method, more sampling in more vegetation types will be necessary to completely test this method.

Aknowledgements

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