Variability in Loading of Mechanically Masticated Fuel Beds in Northern California and Southwestern Oregon

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***Abstract**—The use of mechanical mastication to treat non-merchantable fuels is becoming increasingly popular, but loadings and other characteristics of masticated fuel beds are unknown. Surveys of eight recently masticated sites in northern California and southwestern Oregon indicate that significant site level differences were detected for 1 hr and 10 hr time-lag classes and total woody fuel loading ($P < 0.0001$). The majority of the total woody fuel loading occurred in the 10 hr time-lag class (76.9 ± 14.1 percent) at all 10 sites. At one particular site, planar intercept estimates of woody fuel loading were 181.7 (± 20.3) % higher than estimates using a plot-based method. When the actual average squared quadratic mean diameter values (1 hr = 0.06 cm^2, 10 hr = 1.09 cm^2 and 100 hr = 11.8 cm^2) were used, woody fuel loading estimates between the two methods did not differ statistically. Across sites, fuel depth was not a significant predictor of fuel loading ($R^2 = 0.24$, $P = 0.22$). However, a significant relationship between fuel depth and loading was found at the individual site level, except for one site (WFR). Species masticated, mastication machinery used, and operator experience are some of the potential reasons why the depth to loading relationship differed among sites.*

Introduction

In the foothill and montane regions of northern California and southwestern Oregon, the combination of weather and fuel conditions has led to many recent catastrophic wildfires (e.g., Fountain, Jones and Biscuit fires). These events are a deviation from the historical fire regime of relatively frequent, low to moderate intensity fires of this region (Skinner and Chang 1996, Taylor and Skinner 2003). Due to the successful fire suppression over the last century (Agee 1993), wildfire size and intensity has increased, bringing national attention to fire management and policy. Public awareness is especially pronounced in residential communities located within or adjacent to areas of elevated fuel accumulation. Solutions to reduce the risk of wildfire in these areas have often resorted to the use of mechanical fuel treatments.

One method of mechanically treating non-merchantable fuels that has become increasingly popular in the western United States is mastication. Mastication is the process of converting live or dead standing biomass into surface fuel by "chewing" or breaking up larger pieces into smaller portions by the means of a front-end or boom-mounted rotary blade or head (fig. 1). In northern California and southwestern Oregon, mastication equipment is primarily used to treat shrub and small tree fuels, typically along fuel breaks and within the wildland-urban interface. Machinery used to masticate woody fuels is highly varied but have similar mechanical treatment properties.

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 2006 28-30 March; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Figure 1—General masticator types: front-end mounted, Takeuchi®,TL150 w/ FECON Bull hog®shredder head (left) and a boom-mounted FECON Bull hog® shredder head mounted on an excavator (right). (left-Photo courtesy of Nancy Curran, USDA Forest Service).

Mastication results in the translocation of typically living shrub and midstory fuel beds, thereby increasing dead surface woody fuel loading (fig. 2). The reduction of potential ladder fuels and compaction of surface fuels as a result of mastication are appealing to land managers and have contributed to the dramatic increase in its use.

While the popularity of mastication to treat fuels is increasing, little work has been conducted to quantify and characterize the variability in masticated fuel beds. This lack of information is an important shortcoming to installing subsequent fuel treatments and an impediment to modeling potential fire behavior and effects in treated areas. In order to provide land managers with appropriate information regarding the use of mastication and subsequent fire behavior and effects, research accurately quantifying and characterizing masticated fuel beds is necessary.

Figure 2—Mad River (MAD) masticated site contrasting untreated shrub fuels in the background with treated dead woody fuels in the foreground.

The purpose of this study was to provide preliminary analyses characterizing the variability among masticated sites in northern California and southwestern Oregon as part of a larger study that aims to create custom fuels models for masticated fuel beds. Specifically, the objectives of this paper were to:

1) Quantify site level variability in masticated fuel bed loading
2) Compare and contrast methods of estimating fuel loading in masticated areas
3) Determine if fuel bed depth is significantly related to total woody fuel loading

Methods

Study Sites

Throughout northern California and southwestern Oregon, eight study sites were selected to investigate variability in loading of masticated fuel beds. Study sites were located primarily on federal land (USFS, BLM and NPS), with one site on a private forest (Whitmore). The vegetation masticated within each of the study sites varied but was predominantly shrub (*Arctostaphylos* spp., *Ceanothus* spp.) and/or small hardwood tree species (*Lithocarpus densiflorus*, *Arbutus menziesii*). All mastication treatments were completed using either a front-end or boom-mounted masticator, and all mastication was conducted between November 2002 and May 2005 (table 1).

Table 1—Site names, locations, date of mastication and masticator type for all masticated study sites in northern California and southwestern Oregon, U.S.A. (BM= boom-mounted, FE = front-end mounted).

Site Code	Site Name	Location	Mastication Date	Masticator Type
APP	Applegate Valley	Applegate Valley, Oregon (BLM)	Apr./May 2005	BM-Slashbuster® brush cutter
CFR	Challenge Fuel Reduction	Plumas National Forest, California (USFS)	Dec. 2002 Mar. 2003	BM-Slashbuster® mounted on an excavator
IMR	Iron Mountain Rd	Redding, California (BLM)	Nov. 2004	FE-Masticating head on an ASV Positrack™
MAD	Mad River	Six Rivers National Forest, California (USFS)	Dec. 2004	FE-Takeuchi®,TL150 w/ FECON Bull hog® shredder head
SFR	Sierraville Fuel Reduction	Tahoe National Forest, California (USFS)	May/June 2003	FE-Rayco® Forestry Mower (small) on a bulldozer
TAY	Taylor Ridge	Klamath National Forest, California (USFS)	Apr./May 2005	BM-“Brontosaurus” head on excavator
WFR	Whitmore Fuel Reduction	Whitmore, California (Private)	May 2003	FE-Rayco® Forestry Mower (small) on a bulldozer
WHI	Whiskeytown	Whiskeytown NRA (NPS)	Nov. 2002	FE-Slashbuster® on an ASV Positrack™

Field Sampling

Surface fuel loading was calculated for each study site using two methods: the planar intercept (Brown's transect) method (Brown 1974) and a plot-based sampling method. At each study site, long baseline transects traversing the treated areas were placed at random azimuths. At 25 m increments along these baseline transects, a Browns transect was established at a random azimuth. Brown's transect lengths were typically 20 m but occasionally less when the transect neared the edge of a treated area. At each Brown's transect, 1 hr (0.0-0.6 cm-diameter) and 10 hr (0.6-2.54 cm-diameter) time-lag fuel size classes were tallied along the first 2 m, while 100 hr (2.54-7.6 cm) fuel particles were tallied along the first 4 m. The entire transect length was surveyed for 1000 hr (>7.6 cm) fuel particles and their actual diameters were measured, species recorded, and decomposition category (sound or rotten) assigned. Since masticated fuel particles are often irregularly shaped, determination of the size class of each particle was made along the narrowest diameter that intersected the planar transect. Fuel bed depth measurements were made at three points along the transect (5 m, 10 m, and 15 m).

For the plot-based sampling method, a 50 cm x 50 cm metal frame was placed at the 7 m mark along the planar intercept transect. All woody fuels inside the frame were collected; in the event that a woody fuel particle crossed the frame, the piece was cut along the boundary and the interior portion was retained. To characterize fuel bed bulk density, four large pins were placed 10 cm from each of the frame corners. At each pin, fuel bed depth was measured by progressive removal of each fuel layer. All woody fuels were separated in the lab by time-lag classes and then oven-dried for at least 72 hrs at 75 °C in a mechanical convection oven and then weighed on an analytical balance.

At the Mad River (MAD) mastication site, loading estimates for woody fuels were calculated using the composite squared average quadratic mean diameter values for each fuel size class (1 hr = 0.08 cm^2, 10 hr = 1.3 cm^2, 100 hr = 11.9 cm^2) provided by Brown (1974). In addition, woody fuel loading was calculated using actual squared average quadratic mean diameter values (1 hr = 0.06 cm^2, 10 hr = 1.09 cm^2 and 100 hr = 11.8 cm^2) determined from collected fuels. Fuel quadratic mean diameters were generated by measuring the average of the minimum and maximum squared diameters for a subsample of fuel particle collected with the plot sampling method (1 hr, n = 1187; 10 hr, n = 170; 100 hr, n = 4).

Data Analysis

Means and standard errors were calculated for site-level estimates of total fuel loading and loading of different time-lag classes for both the planar intercept and the plot-based sampling methods. A one-way analysis of variance (ANOVA) was conducted to detect a site level effect for mean total woody fuel loading and mean loading by time-lag classes. If differences were detected, a post-hoc Bonferoni means comparison test was used to detect significant differences among sites (Sokal and Rohlf 1995). Linear regression analysis was used to determine the relationship between total woody fuel loading calculations and fuel bed depth across all sites and at the individual site level. All statistical tests were computed using STATA (Statacorp 2005) and statistical significance was based on an $\alpha = 0.05$.

Results

Site Level Variation

For estimates made using the plot-based method, sites differed significantly in total woody fuel loading and loading by 1 hr and 10 hr time-lag classes ($P > 0.001$; table 2). The MAD site had the highest total woody fuel loading (63.4 Mg ha^{-1}) and contained more 10 hr fuel loading than all sites except Applegate Valley (APP) and Taylor Ridge (TAY; fig. 3). The

Table 2—Plot based sampling method estimates of mean fuel loading (± standard error) of woody fuel classes and fuel height for masticated sites in northern California and southwestern Oregon.

		Plot-based sampling method					
Site	**n**	**1 hr**	**10 hr**	**100 hr**	**1000 hr**	**Total Woody**	**Fuel Depth**
		- - - - - - - - - - - - - - - - - - *(Mg ha^{-1})*	- - - - - - - - - - - - - - - - - -				*(cm)*
APP	15	12.3 (2.8)	24.6 (4.3)	8.6 (4.8)	5.3 (5.3)	50.7 (9.9)	6.9 (0.7)
CFR	40	8.1 (0.7)	19.2 (1.6)	7.9 (1.7)	3.5 (2.2)	38.7 (7.2)	N/A
IMR	15	6.2 (1.7)	13.8 (2.5)	3.6 (1.7)	0.0 (0.0)	23.6 (6.9)	4.9 (0.8)
MAD	15	23.5 (2.6)	34.8 (2.6)	5.1 (2.5)	0.0 (0.0)	63.4 (7.8)	4.6 (0.8)
SFR	15	5.2 (1.0)	11.1 (1.4)	6.6 (2.9)	0.0 (0.0)	22.9 (5.4)	3.2 (0.5)
TAY	15	13.2 (2.9)	21.7 (2.7)	2.1 (0.8)	0.0 (0.0)	37.0 (6.4)	5.0 (0.5)
WFR	40	4.4 (0.7)	9.4 (1.7)	1.6 (0.6)	0.0 (0.0)	15.3 (2.8)	4.4 (0.6)
WHI	15	11.8 (2.4)	16.4 (1.8)	3.6 (1.5)	0.0 (0.0)	31.8 (5.2)	5.8 (0.3)
All Sites		10.6 (2.2)	18.9 (2.9)	4.9 (0.9)	1.1 (2.8)	35.4 (2.8)	4.9 (0.6)

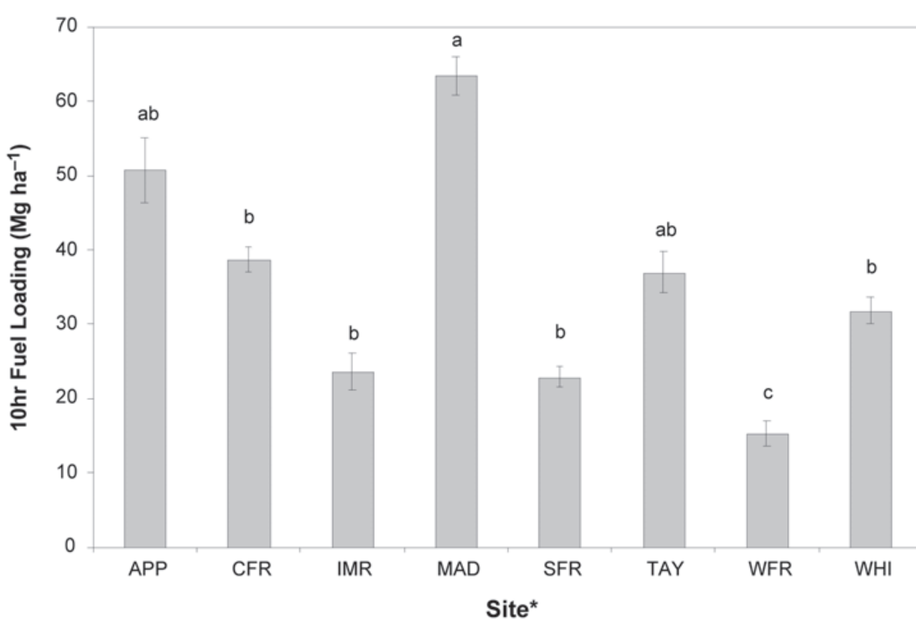

Figure 3—Ten-hour fuel loading in masticated sites in northern California and southwestern Oregon across all sites from the plot-based method estimates (letters above error bars denote significant difference between sites using Bonferoni means comparison test).* = full site names provided in table 1.

Whitmore fuel reduction (WFR) site had the lowest total woody fuel loading (15.3 Mg ha^{-1}) and contained significantly less in 10-hr fuel loading than all other masticated sites (fig. 3). Post-mastication fuel loading was concentrated in the 10-hr and 100-hr time-lag classes, which made up 76.9 (± 14.1) percent and 11.5 (± 5.8) percent of the total woody fuel load, respectively. Loading of 10-hr time-lag class was approximately 250-300 percent greater in some sites (e.g., MAD, APP) than others (e.g., SFR, WFR).

Fuel Load Methods Comparison

At the MAD site, total woody fuel estimates using the Brown's planar intercept method with the composite squared average quadratic mean diameter values given by Brown (1974) were 180.5 (± 55.4) percent higher than the estimates made using the plot-based sampling method. Preliminary results from the MAD site suggest that the actual average quadratic mean diameters of masticated particles are smaller than the composite values given in Brown's formula (1974). When the actual quadratic mean diameter measures at the MAD site were used in the fuel loading calculations, the total loading values no longer differed from those estimated using the plot-based method (fig. 4). Even though the total fuel loading did not differ, Brown's transect values were substantially greater than the plot-based sample values for 10-hr fuels and substantially less than the plot-based sample values for 1-hr fuels (fig. 4).

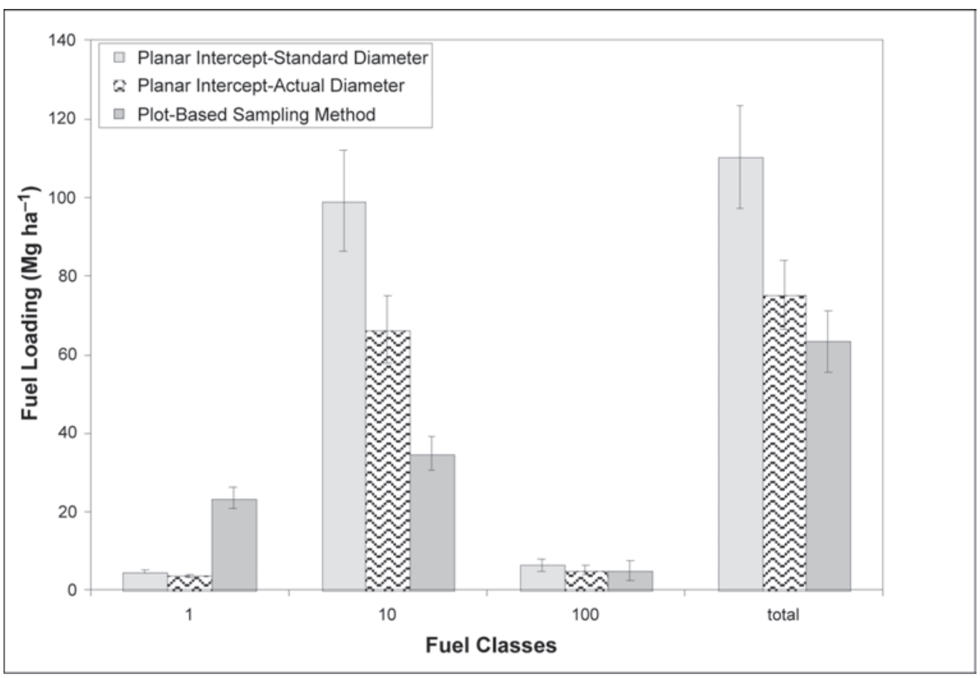

Figure 4—Total woody fuel loading comparisons of the planar intercept method with standard calculation of quadratic mean diameter, planar intercept method with actual quadratic mean diameter and estimates from the plot-based sampling method for the MAD mastication site.

Predictors of Total Woody Fuel Loading

Land managers and researchers are often interested in simplifying measures of fuel loading to improve cost effectiveness and sampling efficiency. Fuel depth is a measure that is often sought to correlate with total woody fuel loading. Average fuel depth values for masticated sites ranged from 3.0 to 6.9 cm. Based on linear regression analysis, fuel depth and total woody fuel loading over all study sites were not related ($P = 0.22$, $R^2 = 0.24$). However, within sites, a significant relationship between depth and woody fuel loading was found at all except the WFR site ($R^2 = 0.03$, $P = 0.28$). The MAD site had the strongest relationship between depth, and woody fuel loading of all sites ($R^2 = 0.84$), while the R^2 values of other sites ranged from 0.24 to 0.74. Equations are still being developed and are not shown here.

Discussion

Variation in woody fuel loading has many implications for both fire behavior and effects. The results of this study suggest that large variations in woody fuel loading exist across 1-hr and 10-hr time-lag classes within masticated areas of northern California and southwestern Oregon. Site level differences in total woody fuel loading found in this study were largely driven by the MAD and WFR sites, which had both the highest and lowest fuel loading in the 10-hr time-lag class, respectively (fig. 3). Variation in woody fuel loading of masticated sites in our study suggests that different fuel models may be necessary to accurately assess fire behavior and effects in these areas.

Site level variation in total woody fuel loading across all time-lag fuel classes for masticated sites was not entirely unexpected. Primary sources of variation in masticated fuel beds may be linked to pretreatment biomass and time since mastication, although secondary factors such as decomposition rate and time since disturbance may be important in determining total woody fuel loading. Masticator type, mastication intensity, and the size and/or age of treated fuels are likely contributors to variation in the proportion of fuels in different time-lag classes.

Independent of the variability found in loading, fine fuel particles (particularly 10 hr) were the dominant woody fuel across all sites. These findings have broader implications, suggesting that in spite of the many different types of masticators used and the level of variability in loading, there are consistent trends in the size of the fuel particles produced by mastication. The presence and quantity of fine fuel particles are well-known to influence fire behavior (Rothermel 1983) and may strongly influence fire effects in masticated areas.

When actual quadratic mean diameter measurements of masticated particles were used in the planar intercept fuel loading calculations, the two methods produced similar estimates of fuel loading. However, the planar intercept method underestimated 1-hr fuel loading while simultaneously overestimating 10-hr fuel loading. An explanation for this inconsistency may be due to the fact that the Brown's transect estimates were made in the field after significant fall rains, while the material collected with the plot-based method was dried in an oven prior to sorting into size categories. Prolonged drying of fuels may have caused a reduction in particle diameter, with 10-hr fuels in the field becoming 1-hr fuels in the lab. Since fires occur when the fuels are dry, the numbers obtained with the plot-based method have greater applicability to fire behavior and fire effects modeling. Results to date suggest that either method can be used to estimate total woody fuel loading (especially if the fuels are dry), but that squared averaged quadratic mean diameters specific to masticated fuels should be used in calculations with the planar intercept method. So far we have only made measurements of fuel particle size at one site and additional measurements are being made to determine if average particle size differs among sites.

While the plot-based sampling method appears to be useful for estimating loading of masticated fuels, several disadvantages exist. The plot-based method is time intensive and therefore, more costly and doesn't evaluate enough area to appropriately account for relatively uncommon 1000 hr fuels, compared to the planar intercept method.

Fuel depth was not found to be a significant predictor of total woody fuel loading possibly because of differences among sites caused by masticator type, operator experience, mastication effort, and vegetation type. It may therefore, not be feasible to create a universal equation relating depth to loading for this type of masticated fuel. While a relationship across all sites was not observed, all but one site's total woody fuel loading was significantly related to fuel depth. Relationships between fuel depth and woody loading may aid in determining simpler and faster means to calculating woody fuel loading within masticated sites. Surrogate measures of total woody fuel loading have been established for other areas (Fulé and Covington 1994) and deserve further investigation in masticated fuel beds.

The quantification and characterization of fuel loading in masticated sites have ramifications for the prediction of fire behavior and effects. Managers and researchers (Bradley and others 2006; Knapp, personal observation) report a high degree of variability in fire behavior with prescribed burning in masticated fuels, which may partially be related to variations in fuel loading. Differences in loading have additionally been shown to influence depth and duration of lethal soil temperatures during burning (Busse and others 2005). In spite of the growing popularity and use of mastication, many unknown factors still exist in characterizing this novel fuel type. The level of variation encountered within our study suggests that several custom fuel models may be necessary to adequately predict fire behavior and effects. Additional work to determine if differences in average particle size exist among sites, how these differences relate to site parameters, and the extent to which mastication alters the surface area to volume ratio of fuel particles, is in progress.

Acknowledgments

These preliminary results are a part of a larger study investigating the development of custom models for masticated fuel beds. Funding for this project was provided by the Joint Fire Science Program. Earlier drafts of this report were improved with the help of Emily Orling. This project was greatly advanced by Elishau Dotson and Emily Orling, who assisted with field data collection.

Literature Cited

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests, Island Press, Washington, DC. 493 pp.

Busse, M. D.; K. R. Hubbert; G. O. Fiddler; C. J. Shestak; R. F. Powers. 2005. Lethal soil temperatures during burning of masticated forest residues. International Journal of Wildland Fire. 14: 1-10

Bradley, T.; J. Gibson; W. Bunn. 2006. Fuels management and non-native plant species: an evaluation of fire and fire surrogate treatments in a chaparral plant community. Final Report to the Joint Fire Science Program. 38 pp.

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report INT-16.

Fulé P. Z.; W.W. Covington. 1994. Double sampling increases the efficiency of forest floor inventories for Arizona ponderosa pine forest. International Journal Wildland Fire. 4: 3-10.

Rothermel, R. C. 1983. How to predict the spread and intensity of forest and range fires. USDA Forest Service, Intermountain Forest and Range Experiment Station. General Technical Report. INT-143.

Sokal, R. R.; F. J. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research. 3rd edition. W. H. Freeman and Company: New York. 887 pp.

Skinner, C. N.; C. Chang. 1996. Fire regimes, past and present. In: Sierra Nevada Ecosystem Project: Final report to Congress. Vol. II: Assessments and scientific basis for management options. Wildland Resourcess Center Publication No. 37. Centers for Water and Wildland Resources, University of California, Davis: 1041-1070.

StataCorp. 2005. Stata Statistical Software: Release 8.2. College Station, TX: StataCorp LP.

Taylor, A. H.; C. N. Skinner. 2003. Spatial and temporal influences and controls on fire regimes in the Klamath Mountains. Ecological Applications 13: 704-719.