Fire Severity and Intensity During Spring Burning in Natural and Masticated Mixed Shrub Woodlands

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Abstract—*Fire risk is an ever present management concern in many urban interface regions. To mitigate this risk, land management agencies have expanded their options beyond prescribed fire to include vegetation mastication and other mechanical fuel treatments. This research project examined fire severity and intensity in masticated and unmanipulated units that were burned in spring in a Northern California mixed shrub woodland. Mastication treatments significantly altered the fuel profile, resulting in an approximate 200 percent average increase in woody fuel cover for 1-hr and 1000-hr TLFM size classes, and greater than 300 percent average cover increase in 10-hr and 100-hr TLFM size classes. The mean flame length (29 vs. 10 inches/ 74 vs. 25 cm) and flame zone depth (20 vs. 6 inches/ 51 vs. 15 cm) were significantly greater ($P<0.001$) in masticated units than in unmanipulated units as were the mean temperatures at the litter surface (657°F vs. 219°F/ 347°C vs. 104°C) and 1.64 ft (0.5 m) above the litter surface (277°F vs. 59°F/ 136°C vs. 15°C) ($P<0.001$). Greater flaming and heat release in the masticated units led to increased mortality of overstory and pole-sized oaks and conifers posing conflicts with the management objective of retaining overstory vegetation.*

Introduction

Land managers in the Western United States are increasingly faced with the challenge of implementing wildland fuel reduction treatments that are both effective and achievable within reasonable time frames. Traditionally, managers have relied on prescribed fire as the primary tool for landscape level risk reduction and ecosystem restoration in fire prone plant communities. However, a number of challenges complicate the achievement of fuel reduction goals using prescribed fire alone. These challenges include air quality restrictions, limited burn windows, insufficient staffing, and the liability associated with escaped burns. Due to these limitations, managers are increasingly turning to the use of mechanical treatments as a supplement to prescribed fire for the accomplishment of fuels management objectives.

One option that has gained popularity with land managers in Western states is vegetation mastication, which can allow managers to quickly and safely decrease shrub and other understory vegetation at a fraction of the cost of comparable manual thinning treatments. Tens of thousands of acres of shrubs and other understory species in fire-prone plant communities are being treated with vegetation mastication to reduce fire hazard. Most land management agencies prefer to leave masticated biomass on the ground to cycle nutrients, prevent soil erosion, and to impede the establishment of non-native and invasive plant species. However, since mastication does not remove

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this biomass, but rather converts the standing brush to dead surface fuels, fire risk can still be high. Despite gaining acceptance as a landscape-scale treatment, significant uncertainty exists regarding the effects of these alterations on fire behavior in both prescribed fire and wildland fire scenarios.

Like many National Park Service units throughout the country, Whiskeytown National Recreation Area recently revised its Fire Management Plan (National Park Service 2003). This plan greatly expands the options available to park managers and includes a suite of mechanical treatments, such as manual thinning, small-scale logging, and vegetation mastication that have yet to be tested in the park or in similar habitat types elsewhere. With support funding from the Joint Fire Science Program, a research project was initiated in 2002 to provide managers with a better understanding of the effects of one of these treatments, vegetation mastication, on fire behavior and intensity.

Since fuel beds resulting from the mastication of shrubs and small trees are most similar to those of a logging slash fuel model, it is hypothesized that the increase in small-sized surface fuels would increase fire intensity and severity. The overall goal of this project was to evaluate key fire behavior indices and severity effects to vegetation in both masticated and unmanipulated vegetation during a spring prescribed burn. Specific objectives for the unmanipulated vegetation were consistent with prescribed burn treatments applied throughout the park, while separate project-specific objectives were developed for the application of fire to masticated vegetation (table 1). These objectives targeted the reduction in specific fuel classes and the retention of overstory trees.

Study Site

Whiskeytown National Recreation Area is located on the southeastern edge of the Klamath Mountains in Northern California. The climate is characterized as Mediterranean, with cool, wet winters and hot, dry summers. Temperature readings are often over 100˚F (38 ˚C) from May through October and occasional sub-freezing temperatures occur from November through March. The annual precipitation averages 60 inches (152 cm) at

Table 1—Management objectives for the prescribed fire treatments in masticated and unmanipulated fuelbeds.

	Targeted percent change	
Objective	Masticated	Unmanipulated
Reduce surface fuel accumulation (litter, duff, 1, 10, 100, 1000 hr TLFM)	15 to 35	25 to 70
Reduce live density of small knobcone pine trees (<8 inch/20 cm d.b.h)	0 to 25	10 to 75
Reduce live density of all other small trees (<8 inch/20 cm d.b.h)	0 to 25	0 to 40
Limit mortality of overstory trees (>8 inch/20 cm d.b.h)	0 to 15	0 to 15
Reduce cover of live shrubs	0 to 25	15 to 75

park headquarters, most of which falls between November and April. The 45 acre study site is located in a low elevation (1,250 to 1,400 ft/380 to 460 m) area that has slopes less than 30 percent (the upper limit for the selected machinery). Overstory vegetation is dominated by black oak (*Quercus kelloggii*) and knobcone pine (*Pinus attenuata*), with limited presence of other species such as canyon live oak (*Quercus chrysolepis*), grey pine (*Pinus sabiniana*), and interior live oak (*Quercus wislizeni*). The understory vegetation is typically dense and dominated by whiteleaf manzanita (*Arctostaphylos viscida*), with toyon (*Heteromeles arbutifolia*) and poison oak (*Toxicodendron diversilobum*) also common.

Experimental Design and Treatments

The research site was stratified based on vegetation, slope, and aspect, resulting in the selection of ten different 1 to 2 acre (0.4 to 0.8 ha) treatment blocks. Each treatment block was divided into fourteen approximately equal-sized units, with two units from each block representing masticated (n=20) and unmanipulated (n=16) vegetation burned in the spring. The remaining experimental units are part of a separate long-term research project focusing on vegetation response to mastication and other fuels treatments.

Mastication treatments were completed in November of 2002 using an ASV Posi-Track™ with industrial brush-cutter. At least 90 percent of machine operations occurred over surfaces covered with chipped wood to limit soil disturbance and compaction (Poff 1996). To further minimize soil impacts, the tractor specifications required rubber tires or tracks, a vehicle no larger than 10,000 gross pounds (4,500 kg), an average of less than 3.5 pounds per square inch (0.25 kg/cm^2) ground pressure, and operation on dry soil (Windell and Bradshaw 2000). The goal of this treatment was to reduce understory bulk density by 60 to 95 percent by thinning shrubs and small trees less than four meters in height. In areas where overstory trees were absent, a limited cover of shrub species was maintained.

Prescribed burn treatments were designed to be representative of treatments typically applied within the park. All fires were backing with respect to slope and/or wind, utilizing drip torches and applying a combination of strip and spot ignition patterns. Ambient weather conditions were recorded on-site by fire effects monitors. During the burning period (April-May 2003), temperature extremes ranged from 59°F to 71°F (15°C to 22°C), relative humidity ranged from 34 to 73 percent, and wind speeds averaged 2 mph (3 km/h) with a maximum wind speed of 6 mph (9.5 km/h). Soil moisture readings were very high (0.3 to 0.4 kPa tension) as recorded by a Delmhorst KS-D1 soil moisture meter at reference locations 18 inches (45 cm) below the surface.

Fire behavior and effects measures were recorded for each burn unit in four 1 m^2 fire behavior plots (n=140). Within each fire behavior plot, pre- and post-burn measurements were collected for litter, duff, 1-hr (<0.25 inches or 0.6 cm), 10-hr (0.25 to 1 inch or 0.6 to 2.5 cm), 100-hr (1 to 3 inches or 2.5 to 7.6 cm) and 1000-hr (>3 inches or 7.6 cm) time lag fuel moisture (TLFM) cover. In addition, percent cover values for herbaceous vegetation and bare ground were recorded. Using a method similar to Hobbs and Atkins (1988), a garden stake with pyrometers was located at the center of each fire behavior plot to record maximum temperature. Pyrometers were constructed using brass tags painted with heat-sensitive paint (OMEGALAQ®, Omega

Engineering, Inc.), and were positioned in three strata: 1) between the duff and soil layers; 2) on top of the litter; and 3) 0.5 m (1.64 ft) above the litter surface. During the burn, fire behavior data were recorded on the maximum and average flame lengths, flame zone depths, rates of spread, and fire types (head, backing, or flanking). One month after the burn, scorch estimates for dominant trees and shrubs were recorded for each burn unit and tree and shrub mortality estimates were recorded approximately six months post-burn.

To examine potential patterns in fire behavior, severity, and surface fuels, all fire behavior plots were characterized through a Principal Components Analysis (PCA) (Tabachnick and Fidell 1996). A two-tailed t-test (Zar 1996) was used to determine the difference in the mean PCA factor scores for masticated and unmanipulated vegetation. Similarly, a two-tailed t-test was used to determine the mean difference in flame length and flame zone depth for masticated and unmanipulated vegetation. To ascertain differences in pyrometer temperature between masticated and unmanipulated vegetation, a two-tailed t-test was used. A multiple regression (Zar 1996) was used to model relationships for aerial and litter level pyrometers with surface fuels and fine dead fuel moisture.

Results and Discussion

The effect of the brush mastication treatment did not result in a reduction of fuels, but rather the rearrangement of standing live material into dead and small-sized surface fuels. Prior to implementation of the mastication treatment, the fuels at the site were best characterized as a mix of fuel models 4, 8, and 9 (Anderson 1982). After mastication, the fuel bed changed drastically, with post treatment conditions representative of fuel model 11 (logging slash). This conversion of standing vegetation into downed woody debris resulted in an approximate 200 percent average cover increase in woody fuel loading for 1-hr and 1000-hr TLFM size classes, and greater than 300 percent average cover increase in 10-hr and 100-hr TLFM size classes. In addition to a surface fuel quantity increase, average shrub canopy cover was reduced from 64% down to 2% by the mastication treatment. This removal of canopy cover can contribute to an increase in air circulation, surface temperature, and direct solar radiation (Aussenac 2000), which can dry fuels quickly and increase flammability (Weatherspoon 1996). The results from this research strongly suggest that the combination of rearranging the structure of fuels while simultaneously altering the site microhabitat characteristics, led to an increased potential for high intensity fire.

To examine potential patterns between surface fuels and indices of fire behavior and severity, a Principal Components Analysis (PCA) was used (figure 1). Positively skewed data were transformed using the square root and the Pearson's product moment correlation coefficient (Zar 1996) was used to eliminate variables that were highly correlated (>0.6). The PCA illustrated differences between masticated and unmanipulated plots for Factor 1 scores. A two-tailed t-test on the PCA scores demonstrated a difference in the amount of surface fuels, fire behavior, and fire severity variables with mean Factor 1 scores for masticated plots (0.480) significantly ($P<0.001$) greater than those for unmanipulated vegetation (–0.583). The high Factor 1 scores for masticated plots indicate a high amount of surface fuels (litter, 1-hr, 10-hr, and 100-hr fuels), wide flame zone depth, and greater aerial temperatures. Plots in unmanipulated vegetation had a high percent cover

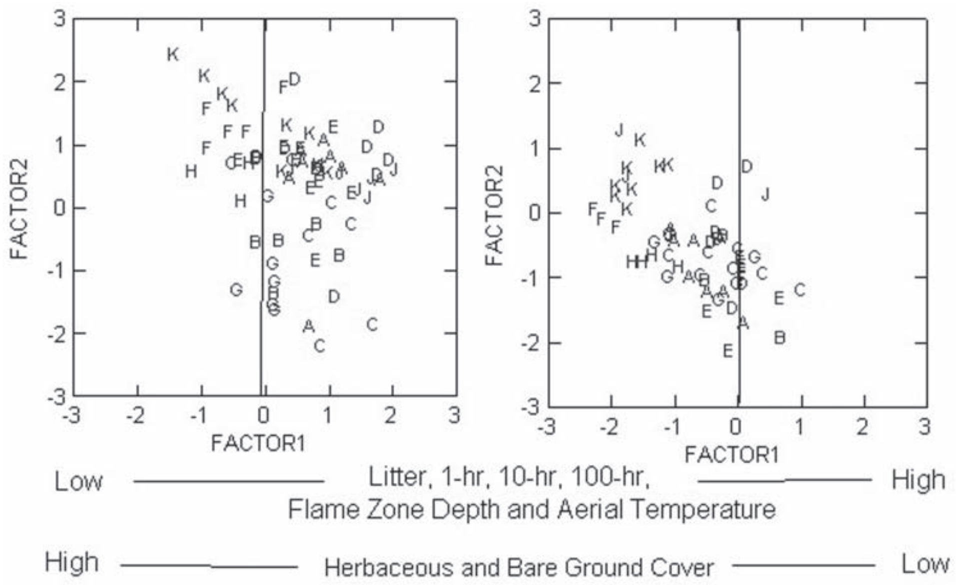

Figure 1—PCA scores for masticated (left) and unmanipulated (right) plots during the burn treatment.

of herbaceous species, bare ground, and low surface fuels, fire behavior and fire severity values.

A variety of fire intensity measures showed striking differences between the masticated plots and those in unmanipulated vegetation. A two-tailed t-test for both flame length and flame zone depth indicated greater values in masticated plots when compared to plots in unmanipulated vegetation. Mean flame length (29 inches/ 74 cm) and flame zone depth (19 inches/ 48 cm) were significantly greater ($P<0.001$) in masticated plots than mean flame length (10 inches/ 25 cm) and flame zone depth (6 inches/ 15 cm) in the unmanipulated plots. Two of the three strata tested with pyrometers also indicated significant temperature differences between masticated and unmanipulated plots (figure 2). A two-tailed t-test showed that mean temperatures for litter (657°F/ 347°C) and aerial (277°F/ 136°C) pyrometers in the masticated plots were significantly greater ($P<0.001$) than temperatures recorded for litter (219°F/ 104°C) and aerial (59°F/ 15°C) pyrometers in unmanipulated vegetation. While above ground temperatures were moderate to high, high duff and soil moistures moderated intensity effects to the soil, with only limited heating recorded by the lowest pyrometer. As a result of these conditions, duff reduction was not complete in either masticated (27 percent consumption) or unmanipulated (16 percent consumption) fuels.

The data for aerial and litter pyrometers were analyzed by multiple linear regression models to investigate the relationship among variables. With aerial pyrometer temperature as the dependent variable, the best fitting model ($P = 0.004$) included 100-hr fuels and fine dead fuel moisture as independent variables (table 2). With litter pyrometer temperature as the dependent variable, the best fitting model was also highly significant ($P = 0.026$) and included litter depth, 10-hr fuels, and 100-hr fuels as dependent variables (table 3). Despite their high significance, each of these models demonstrated relatively mediocre fit with $r^2 = 0.314$ for aerial pyrometers and $r^2 = 0.478$ for litter

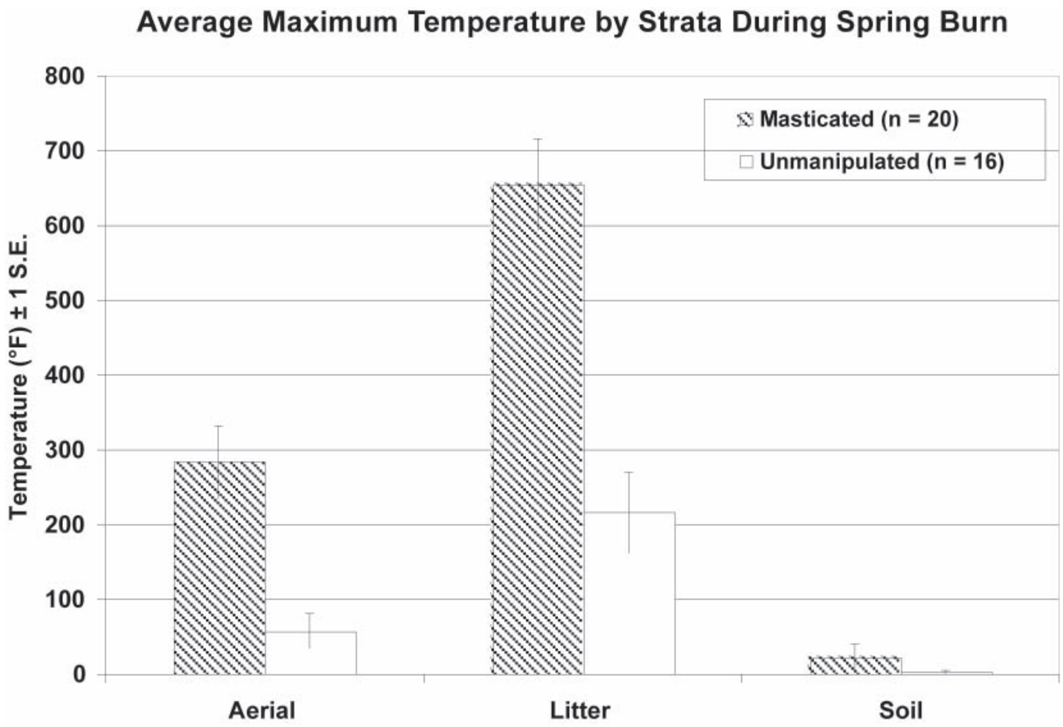

Figure 2—Average temperatures recorded by pyrometers during the burn treatment in masticated and unmanipulated plots. Aerial pyrometers were located 0.5 m/1.64 ft above the ground surface, litter pyrometers were located on the surface of the litter, and soil pyrometers were located between the duff and soil layers.

Table 2—Regression statistics for aerial (0.5 m/1.64 ft above ground surface) pyrometers

Model Term	Parameter estimate	SE	Pr(>|t|)
Intercept	357.9272	122.6933	0.0041
100 hr. Fuels[a]	14.4611	2.5365	0.0000
FDFM[b]	–28.1747	12.2782	0.0233

[a] 100 hour TLFM size class
[b] Fine dead fuel moisture

Table 3—Regression statistics for pyrometers placed at the litter surface.

Model Term	Parameter estimate	SE	Pr(>|t|)
Intercept	453.5598	201.7489	0.0262
Litter Depth	91.0512	21.3446	0.0000
10 hr Fuels[a]	8.6276	1.8347	0.0000
100 hr Fuels[b]	13.1951	4.0239	0.0013
FDFM[c]	–46.1797	19.2146	0.0176

[a] 10 hour TLFM size class
[b] 100 hour TLFM size class
[c] Fine dead fuel moisture

pyrometers. It is probable that a more accurate quantification of the fuelbeds would have improved our results, although at a significant increase in time. Regardless, given the high level of variability that existed within individual fuelbeds, such findings are not surprising and perhaps highlight the differences frequently found between laboratory and field experiments. Of note is the correlation shown by fine dead fuel moisture in both models. While a coarse value, fine dead fuel moisture is sensitive to changes in canopy cover and regularly recorded ambient weather conditions.

Based on the multiple regression analyses, surface fuel loading was a primary driver of fire behavior, with significant fuel consumption differences noted between treatments (figure 3). With the exception of 1-hr fuels, total percent consumption in the masticated fuelbeds was higher for all TLFM size classes. It is probable that the apparently low consumption of 1-hr size class fuels in the masticated fuels (17 percent) was actually much higher, and includes larger 10-hr and 100-hr fuels that were only partially consumed during the burns. Interestingly, an increase was noted in 100-hr and 1000-hr TLFM size classes following the burn treatment in unmanipulated vegetation. While only a marginal increase, this finding is consistent with other monitoring completed at the park, reflecting the addition of recently killed vegetation to the surface fuelbed.

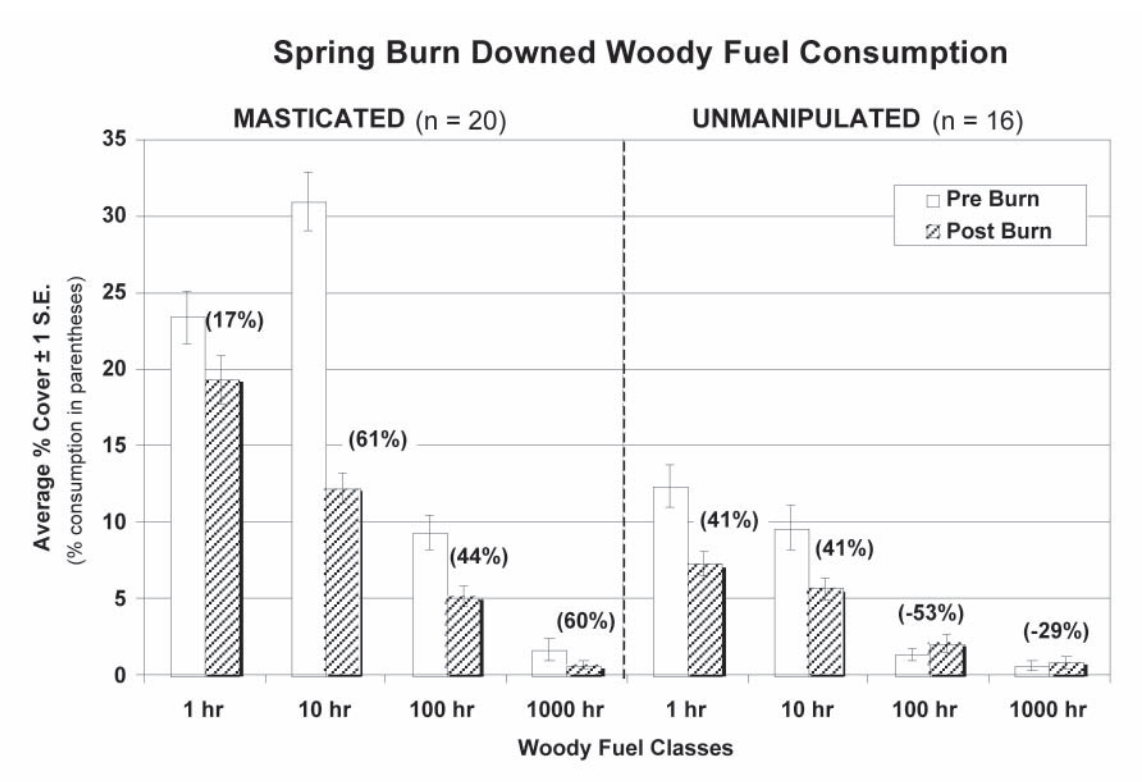

Figure 3—Consumption of downed woody fuels during the burn treatment in masticated and unmanipulated plots. Fuels are categorized as 1 hour, 10 hour, 100 hour, and 1000 hour time lag fuel moisture (TLFM).

The total surface fuel reduction objectives (table 1) were achieved in both masticated and unmanipulated vegetation, but the fire effects to live vegetation were more complex. In the unmanipulated units, reduction targets were met for pole-sized (<8 inches or 20 cm d.b.h.) trees and shrubs and there was no mortality of overstory (>8 inches or 20 cm d.b.h.) trees (table 4). However, in the masticated units, reduction and mortality targets were greatly exceeded for pole-sized trees, shrubs and overstory trees (table 4). Despite efforts by ignition crews to mitigate effects to overstory trees, the heat effects to these trees and to residual shrubs in the masticated units were severe. While applying prescribed fire during the early growing season was likely a contributing factor to this mortality, the increased fire intensity in masticated fuels was the primary cause.

Management Implications

Results from this study showed significant differences in fire behavior and effects during spring prescribed burns in units with masticated vegetation versus those with unmanipulated vegetation. These results strongly suggest that the differences were driven by the surface fuel conditions created as a direct result of the mastication treatment. Through time, decomposition and compaction of these materials may promote lowered fire intensity potential, but in the short term mastication appeared to contribute to an increase in fire severity and intensity.

While vegetation mastication followed by prescribed fire was a success from a fuel reduction standpoint, fire intensity in the masticated units was lethal for much of the residual vegetation. Since the mastication treatment had already eliminated shrubs and small trees, the effect of the prescribed burn on retained vegetation was undesirable. In natural areas the retention of overstory trees is a primary resource management concern during prescribed burns, and these results highlight the potential conflicts of burning in varied fuelbeds when objectives extend beyond surface fuel consumption.

While this study was restricted to one site, the results apply to many land management agencies that are interested in applying mastication treatments

Table 4—Average percent mortality of trees and shrubs during the spring burn treatment in masticated and unmanipulated plots.

	Overstory (>8 inch/20 cm d.b.h)		**Pole (<8 inch/20 cm d.b.h.)**	
	Unmanipulated	**Masticated**	**Unmanipulated**	**Masticated**
	- - - - - - - - - *percent mortality*[a] - - - - - - - - -			
Knobcone Pine (*Pinus attenuata*)	0	16	15	66
Black Oak (*Quercus kelloggii*)	0	23	17	47
Canyon Live Oak (*Quercus chrysolepis*)	0	49	21	98
Shrubs	**Unmanipulated**		**Masticated**	
	30		96	

[a]Mortality figures for resprouting oak species refers to top-killed individuals.

for reduction of understory vegetation. The following list highlights some of the management implications derived from this research:

1) Mastication of vegetation results in a short to medium-term increase in fire intensity and severity potential. Where utilized, mastication prescriptions should consider the need for greater canopy retention to increase shading at the soil surface, thus increasing fine dead fuel moisture and contributing to slower seasonal drying of fuels. In addition, lowering intensity of mastication will directly reduce total surface fuel load.

2) Mortality of remaining overstory vegetation may be high in areas where masticated treatments are followed by prescribed burning. Managers may be able to reduce this secondary mortality by:

    - Decreasing the level of mastication intensity. This will contribute to lower fire behavior indices and severity results by reducing surface fuel loading, increasing shading of fuels, decreasing wind circulation and thus, drying of surface fuels.
    - Applying fire during mild conditions. Mastication treatments significantly alter the fuelbed and result in significantly different fire behavior than in unmanipulated vegetation. Prescriptions must consider these differences in expected behavior and subsequent severity.
    - Avoiding spring or early growing-season burns when desirable species are in a susceptible period of development. The post green-up application of fire in this study coincided with a vulnerable phenologic period in plant development, when leaf, bud, and cambium tissues were particularly susceptible to thermal effects. Prescription windows that are scheduled during the dormant season would likely minimize severity effects to retained vegetation.

3) Short-term increases in fire intensity occur following mastication; however, long-term trends are still unknown. This study was conducted six months after mastication when the masticated fuelbed was still loosely arranged on the surface. Through time, it is expected that decomposition and compaction of the masticated fuels would occur, lowering the potential fire intensity, but the rate of change is not known. Research on assessing changes in masticated vegetation over time would provide valuable information for long-term management.

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