Fuel Loadings in Masticated areas on the San Jacinto District of the San Bernardino National Forest

Final Report
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Findings Summary

- Tons/acre of masticated fuels can be roughly estimated by multiplying the average masticated fuel depth in cm by 4 for areas of head-high shrubs masticated roughly 2 years ago.
- Tons/acre of masticate fuels can be roughly estimated multiplying the average masticated fuel depth in cm by 7 for areas of head-high shrubs masticated roughly 1 year ago.
- Over half of masticated fuels were 10 h, one-quarter to one-third were 1 h and less than a quarter were 100 h. Very few masticated fuels were 1000 h.
- Bulk densities for the litter/duff/masticated fuel layer were 40 to 80 kg/m^3
- Masticated fuels loadings of 17 to 34 tons/acre were found. Litter, duff, herbaceous and shrub fuels were minimal.
- Percent bare ground was less than 25% at all sites.
- Average masticated fuel bed depths were 3 to 5 cm.
- Custom fuel models were created as a starting point for fire behavior modeling in masticated fuel beds.
- Predicted fire behavior for the masticated areas of this project modeled with two variations of custom fuel models and dry weather with 3 mph winds included rates of spread between 0 and 2 chains/hour and flame lengths between 0 and 3 feet.
- A prototype for a masticated fuel photo series was created (Appendix B).

Introduction

Despite the increasing use of mastication to treat hazardous fuels, little information exists on masticated fuel loadings and associated fire behavior. It is thought that mastication reduces fire flame lengths and rates of spread, however, fire intensity and residence time may be increased. No fuel models exist specifically for masticated fuel beds. Knapp et al. (2008) found an average of SB1 (low load activity fuel) and SB2 (moderate load activity fuel) predicted observed flame heights and rates of spread well.

Additional information on masticated fuels would aid in understanding potential fire behavior in masticated fuel beds. Because masticated material varies based on several factors, masticated particle sizes and total loadings vary between sites (Kane et al. 2006). Baseline field data on masticated fuels across several sites would give land managers tools to begin to understand masticated fuel loads and potential fire behavior. Field data on the combustion of masticated fuels would help land managers understand ecosystem processes such as fuel consumption, plant mortality and nutrient cycling (Reinhardt et al., 2008).

Objectives

The question driving this monitoring was, “how much masticated material is too much?” The objective of this monitoring project was to quantify fuel loads and characteristics in masticated areas at several elevations and vegetation types, as well as varying levels of masticated material coverage. Simple relationships were calculated for each site to obtain basic estimates of tons/acre of masticated material based on masticated material depth and coverage. Fuel particle size distribution (1, 10, 100, 1000 h) of the masticated material was also determined by site. This data could be used in the future in conjunction with anecdotal fire behavior observations or fire behavior measurements in order to better develop and test potential masticated fuel models.

Treatments

Four areas treated with mastication methods were monitored in this project. Indian Vista was masticated between 09/14/2007 and 05/07/2008 utilizing a boom-type masticator. The project began with the head mounted on a CAT 318 excavator and was later upgraded to a CAT 320 Excavator. Pine Cove was masticated between 10/03/2007 and 01/22/2008 utilizing a drum-type masticator. The Highway 74 West project was masticated in 2007 with two large track-mounted boom-type masticators for that job in tandem with 2 smaller track mounted drum-type masticators. Highway 243 plots were masticated with a track-mounted boom-type masticating head in the spring of 2009, days to weeks before plot data were gathered. The prescriptions for the projects were to reduce brush until only 30-40% of the treatment area was occupied by brush. Less developed shrubs were target for removal, which favored treatment efficiency and management goals (personal communication, Harold Carey, District Forester, San Jacinto District, San Bernardino National Forest).

Field Methods

Post-treatment data were gathered on masticated fuel beds. Three sites were originally identified for monitoring, and a fourth site (Highway 243) was added after it was masticated during the timeframe of the project. Because plots were not initiated pre-treatment, photos and data were taken for adjacent fuels to supplement analysis.

Approximately 20 plots were established at each site in order to gather enough data to represent fuel conditions in masticated fuels, which are often variable, even within a treatment area. Plots were placed in a stratified manner, 5 to 8 chains apart, depending on the treatment area. Efforts were made to divide the plots evenly on both sides of roads on which treatments were centered. Although some treatment areas were actually a matrix of masticated and unmasticated areas, plots were always placed in masticated areas.

Plots have been marked with 18” pieces of conduit, etched with plot numbers. GPS points and distances and bearings from landmarks were recorded to facilitate plot remeasurement. Plots consisted of a 50 ft transect originating from the GPS location. All plots were oriented north.

Table 1. Field data were gathered at four sites between March and April 2009.

Field site	Number of plots
Highway 74	25
Indian Vista	21
Pine Cove	20
Highway 243	15

The aspect, percent slope, overstory tree cover and tree species were recorded in each plot. Shrub species, cover, average and maximum height were recorded for adjacent, untreated fuels. In the plot, depth measurements were taken for litter, duff and masticated fuel along the transect line at five foot intervals (5, 10, 15, 20, 25…45). The max fuel height was also measured within five foot intervals along the transect line (0-5, 5-10…45-50). The herbaceous and shrub fuels were estimated using the Burgan-Rothermel method with a one meter wide belt centered along the transect line. A photo was taken at the origin, the 50 foot mark, and of the adjacent unmasticated shrub layer.

A sample of the masticated material was gathered from each plot using a 50X50cm frame. The frame was placed at the five foot mark approximately 1 meter away from the transect line. Masticated material inside the frame was gathered and any pieces crossing the frame were cut at the sample boundary. Masticated fuel samples were floated to remove soil, then dried at 70 C for 72 hours and weighed. Several samples from each field site were separated into time lag categories. For approximately 10 samples from each site, fuel particle size distribution was estimated by separating fuels into 1, 10, 100 and 1000-hr categories and weighing each time lag class separately.

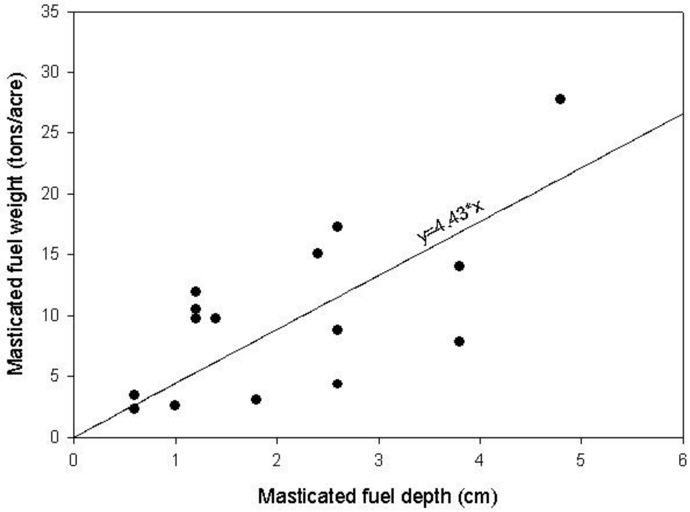
Results

Mastication fuel depth to loading ratios

The regression analyses, or depth-to-weight relationships, were fairly strong. These relationships were slightly different between the four sites. The regression for Highway 243, sampled days after mastication, showed more weight per unit volume than the other three sites, which were sampled between 1 and 1.5 years after mastication.

Hwy 74

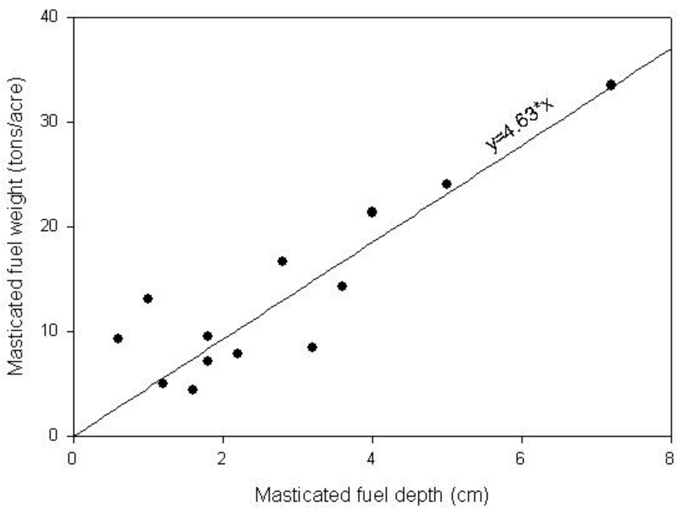
Figure 1. Scatter plot and regression line for masticated fuel depth (cm) and masticated fuel weight (tons/acre) for plots sampled along Highway 74.



R^2 = 82%   Standard error of coefficient = 0.55
For field calculations:
Estimate average depth of masticated fuel in area (including bare areas) in centimeters.
Depth(cm) * 4.43 = masticated fuel (tons/acre).

Pine Cove

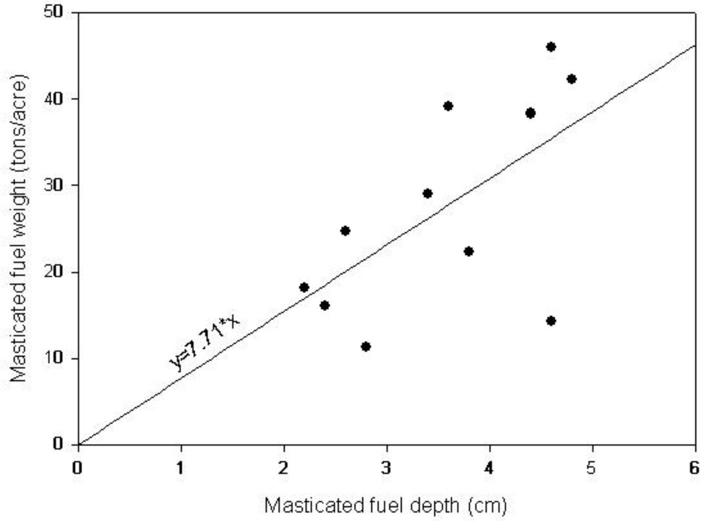
Figure 2. Scatter plot and regression line for masticated fuel depth (cm) and masticated fuel weight (tons/acre) for plots sampled at Pine Cove.



R^2 = 94%   Standard error of coefficient = 0.34
For field calculations:
Estimate average depth of masticated fuel in area (including bare areas) in centimeters.
Depth(cm) * 4.63 = masticated fuel (tons/acre).

Hwy 243

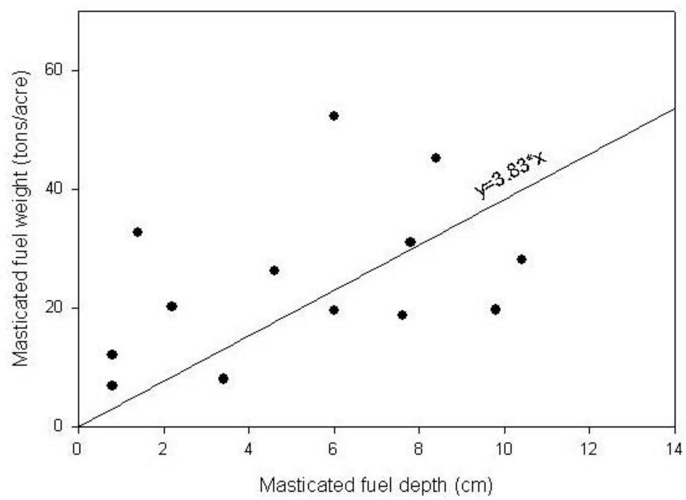
Figure 3. Scatter plot and regression line for masticated fuel depth (cm) and masticated fuel weight (tons/acre) for plots sampled along Highway 243.



$R^2 = 91\%$ Standard error of coefficient = 0.79
For field calculations:
Estimate average depth of masticated fuel in area (including bare areas) in centimeters.
Depth(cm) * 7.71 = masticated fuel (tons/acre).

Indian Vista

Figure 4. Scatter plot and regression line for masticated fuel depth (cm) and masticated fuel weight (tons/acre) for plots sampled at Indian Vista.



$R^2 = 73\%$ Standard error of coefficient = 0.66
For field calculations:
Estimate average depth of masticated fuel in area (including bare areas) in centimeters.
Depth(cm) * 3.83 = masticated fuel (tons/acre).

Particle size distribution

Particle size distribution was calculated from samples which were divided into 1, 10, 100 and 1000 h time lag fuel classes after drying and weighing. Most fuels were in the 10 h category (Table 2). Some fuels were 1 h and a few were 100 h. Very little masticated material was in the 1000 h category. Size class distributions found for these sites were roughly equivalent to the size class distributions found by Kane et al. (2006), of 30, 53 and 14 percent for 1, 10 and 100 h fuels, respectively in masticated shrub and small hardwood sites.

Table 2. Mean (standard error) percent 1, 10, 100 and 1000 hour of total fuel loadings by site and number of samples.

Site	% 1 h	% 10 h	% 100 h	% 1000 h	n
Hwy 243	24 (4)	59 (4)	15 (5)	1 (1)	11
Hwy 74	36 (5)	58 (4)	6 (4)	0 (0)	15
Indian Vista	20 (4)	57 (6)	23 (7)	0 (0)	13
Pine Cove	33 (5)	54 (4)	13 (5)	0 (0)	13

Bulk density

Bulk density and fuel compactness are potentially a more important fuel characteristic than total loading. Bulk densities in the first table (Table 3) were calculated as the sum of duff, litter and masticated fuel loads divided by maximum downed woody height along plot transects (fuel bed depth). Masticated fuel makes up the majority of the fuels by weight. The bulk densities for Highway 74, Indian Vista and Pine Cove are similar to the bulk densities of the most dense litter/twig strata of forested ecosystems sampled by Brown (1981). Highway 243, which was sampled days after mastication, had the highest bulk densities of all sites sampled. Highway 74, the oldest mastication treatment had the lowest bulk density. The bulk densities of masticated material found in this study (Table 4) were lower than the bulk density of 136 kg m^{-3} presented by Hood and Wu (2006) for ponderosa pine-Gambel oak (*Quercus gambelii* Nutt.) sites, which were located on the San Juan National forest in southwestern Colorado.

Table 3. Bulk density for the surface/ground fuel layer (duff, litter and masticated fuel).

Site	Bulk density (lbs/ft^3)	Bulk density (kg/m^3)
Highway 243	5.0	80
Highway 74	2.5	40
Indian Vista	2.8	44
Pine Cove	3.5	57

Table 4. Bulk density for masticated fuel layer only.

Site	Bulk density (lbs/ft^3)	Bulk density (kg/m^3)
Highway 243	4.6	73
Highway 74	2.3	37
Indian Vista	2.4	38
Pine Cove	2.8	46

Summary of fuel loads

Masticated fuels made up the largest portion of surface fuels (Table 5). Masticated fuels at the three sites masticated 1 to 1.5 years ago, (Highway 74, Indian Vista and Pine Cove) were between 12.6 and 17 tons/acre (28.2 and 38.1 Mg/ha). These values were within the range found by Kane et al. (2006) who found masticated fuels from 6.8 to 22.6 tons/acre in California and southwestern Oregon shrub/small hardwood tree ecotypes. These values are also within the range found by Reiner et al. (In Review), where 11.6 to 19.1 tons/acre of masticated fuels were found after mastication in a 25 year old pine plantation in the southern Sierra Nevada. The loading of masticated material found at Highway 243, which was measured days after sampling, was higher than has been found before in similar projects. Litter and duff loadings were less than 3 tons/acre at all four sites. Fuel loading contributions from herbs, grasses and shrubs were fairly low at all sites. Essentially no herbs, grasses or shrubs were found at the freshly masticated site, Highway 243. Almost all of the understory plant fuel found was live fuel, only a slight fraction was dead material.

Table 5. Means and standard errors (standard error in parenthesis) for total and live herbaceous (herbs and grasses) and shrub fuels. All units are in tons/acre.

Site	Litter	Duff	Masticated fuel	All herbaceous fuels	All shrub fuels	Live shrub fuels
Highway 243	0.5 (0.1)	2.6 (0.6)	34.3 (4.6)	0 (0)	0 (0)	0 (0)
Highway 74	0.1 (0)	1 (0.3)	12.7 (2.1)	0.01 (0)	1.8 (0.48)	1.8 (0.48)
Indian Vista	0.5 (0.1)	2.3 (0.3)	17 (2.3)	0 (0)	0.23 (0.08)	0.22 (0.08)
Pine Cove	0.5 (0.1)	2.6 (0.3)	12.6 (1.7)	0 (0)	0.01 (0.01)	0.01 (0.01)

Note: numbers of samples are 15 at Highway 243, 25 at Highway 74, 21 at Indian Vista and 20 at Pine Cove.

Bare ground ranged from 3 to 5 percent at Highway 243, Indian Vista and Pine Cove (Table 6). The highest levels of bare ground, 14%, were found along highway 74, which had the most sparse vegetation type prior to mastication. Fuel bed depths ranged from 6.2 to 10.5 cm. Average masticated fuel depths were 2.7 to 4.5 when zeros in the dataset (areas with no masticated material) were factored in. The percent cover of masticated fuel was between 73 and 91 percent. The highest coverage of masticated material was at the highway 243 site, also the most recently masticated. This data may be higher than the actual percent coverage of masticated material within the treatment polygon because treatments were sometimes done in somewhat of a matrix within the boundary polygon due to slope limitations or other specifications (i.e. Highway 74). When only the point counts where masticated material was found were averaged, mean depths ranged from 3.3 cm at Pine Cove to 5.1 cm at Indian Vista. These values represent the average depth of only areas covered by mastication.

Table 6. Mean and standard errors for percent cover of bare ground, fuel bed depth, masticated fuel bed depth in centimeters (average across whole plots), percent cover and the average depth of masticated fuel (cm), where only areas covered with mastication were averaged.

Site	Bare ground % cover	Fuel bed depth (cm)	Masticated fuel depth (cm) (total plot)	Masticated fuel % cover	Masticated fuel depth (cm) (masticated areas)
Highway 243	3 (1)	10.5 (1)	4.5 (0.6)	91 (2)	4.9 (0.6)
Highway 74	23 (4)	7.8 (0.7)	2.9 (0.5)	73 (4)	3.7 (0.4)
Indian Vista	5 (1)	10 (0.6)	4.4 (0.6)	83 (4)	5.1 (0.5)
Pine Cove	3 (1)	6.2 (0.4)	2.7 (0.4)	79 (4)	3.3 (0.3)

Note: numbers of samples are 15 at Highway 243, 25 at Highway 74, 21 at Indian Vista and 20 at Pine Cove.

Custom fuel models

Custom fuel models were created for masticated conditions for each site by entering actual fuel loading values for 1, 10, 100 h and live shrub fuels. Total masticated fuel loads were multiplied by size class distribution percentages to get loadings of 1, 10 and 100 h fuels. Fuel characteristics from SH7, Very high load, dry climate shrub, were used for 1 h surface area/volume (SAV) ratio (750), live shrub SAV (1600), heat content of dead, live herb and live shrub (8000), and moisture of extinction (15%). Fire behavior estimates were derived using the 1 h, 10 h, 100 h, herb and shrub fuel moistures of 5, 6, 7, 75 and 90 percent, respectively along with a midflame windspeed of 3 mph (Table 7).

Fuels and fire behavior for Very high load, dry climate shrub, SH7, was presented first for comparison. Two versions of custom fuel models were run for each site. The first version includes actual values as measured in the field for all fuels and fuel bed depth. In the second versions (2Xfbd), values for fuel bed depth are doubled in order to give fire behavior results that are potentially more realistic. Because these custom fuel models have not been calibrated with free-burning wildfire, care should be used when interpreting fire behavior results obtained from these models.

Table 7. Custom fuel models for masticated fuel conditions at each of four sites for observed values and observed values with fuel bed depths twice the actual values (2Xfbd).

Fuel model	1 h (t/ac)	10 h (t/ac)	100 h (t/ac)	Live shrub loading (t/ac)	Fuel bed depth (ft)	Rate of spread (ch/h)	Flame length (ft)
SH7	3.5	5.3	2.2	3.4	6	22	10.2
Hwy 74	4.6	7.4	0.8	1.8	0.25	0.2	0.5
Hwy 74 2Xfbd	4.6	7.4	0.8	1.8	0.5	1.1	2.2
Indian Vista	3.4	9.7	3.9	0.2	0.33	0.4	0.9
Indian Vista 2Xfbd	3.4	9.7	3.9	0.2	0.66	1.8	3.3
Pine Cove	4.2	6.8	1.6	0	0.2	0.2	0.5
Pine Cove 2Xfbd	4.2	6.8	1.6	0	0.4	1.4	2.4
Hwy 243	8.2	20.2	5.1	0	0.34	0.1	0.2
Hwy 243 2Xfbd	8.2	20.2	5.1	0	0.68	1.2	2.4

Note: 2Xfbd denotes fuel bed depths are doubled from values observed in the field.

Potential Smoke Emissions

Fuel loadings from summarized field data for each site were run through FOFEM to predict potential particulate and emissions for a summer condition with dry fuels and a winter condition with moderately moist fuels (Table 8). Most emissions occurred during the smoldering phase, and so total emissions are higher than emissions for flaming combustion only (Tables 9 and 10). Highway 243, which had the highest fuel loadings, also had the highest emissions. Slightly higher emissions were predicted for summer conditions, possibly because slightly more consumption was predicted in FOFEM for summer conditions with dry fuels. Total flaming combustion time predicted by FOFEM was 4 hours and 30 minutes for all of the older treatments, Highway 74, Pine Cove and Indian Vista. The newly masticated site, Highway 243, had the longest potential flaming combustion duration of 10 hours and 30 minutes.

Table 8. Fuel inputs used in FOFEM. All units are tons/acre.

Site	1 h	10 h	100 h	1000 h	Litter	Duff	All shrub fuels
Hwy 243	8.2	20.2	5.1	0.3	0.5	2.6	0
Hwy 74	4.6	7.4	0.8	0	0.1	1	1.8
Indian Vista	3.4	9.7	3.9	0	0.5	2.3	0.2
Pine Cove	4.2	6.8	1.6	0	0.5	2.6	0

Note: Herbaceous fuels were less than 0.1 and so not included.

Table 9. Emissions of particulate matter (PM) size 10 and 2.5 and CO_2 lbs/acre potentially produced in summer conditions with dry fuels during flaming combustion and total emissions.

	Flaming			Total		
Site	PM 10	PM 2.5	CO_2	PM 10	PM 2.5	CO_2
Hwy 243	200	170	115946	369	314	123735
Hwy 74	83	71	48206	149	127	51252
Indian Vista	91	77	52870	304	258	62662
Pine Cove	71	61	41312	227	193	48476

Table 10. Emissions of particulate matter (PM) size 10 and 2.5 and CO_2 lbs/acre potentially produced in winter conditions with moderately moist fuels during flaming combustion and total emissions.

	Flaming			Total		
Site	PM 10	PM 2.5	CO2	PM 10	PM 2.5	CO2
Hwy 243	199	169	115097	359	304	122431
Hwy 74	83	71	48213	138	118	50762
Indian Vista	88	74	50667	304	257	60575
Pine Cove	72	61	41487	198	168	47282

Conclusions

Masticated fuel beds will likely have lower flame lengths and rates of spread than unmasticated shrub fuels. However, increased residence time and fireline intensity could negate some of the benefits to suppression operations such as lowered rates of spread and flame lengths. Areas with heavy loadings of masticated material may not have greater flame lengths or rates of spread than light mastication, because the compactness of the fuel bed also affects fire behavior. Plots with the highest fuel loadings were predicted to have the highest smoke emissions also. It is thought that masticated fuel characteristics vary due to vegetation type, topographic variables or masticator equipment used. In this study, time since mastication appears to have the greatest impact on masticated fuel characteristics. Annual data gathered from these plots could give more insights into how masticated fuels change over time. Fire behavior measurements correlated with masticated fuel bed data could help to fine-tune custom fuel models for masticated areas.

Acknowledgements

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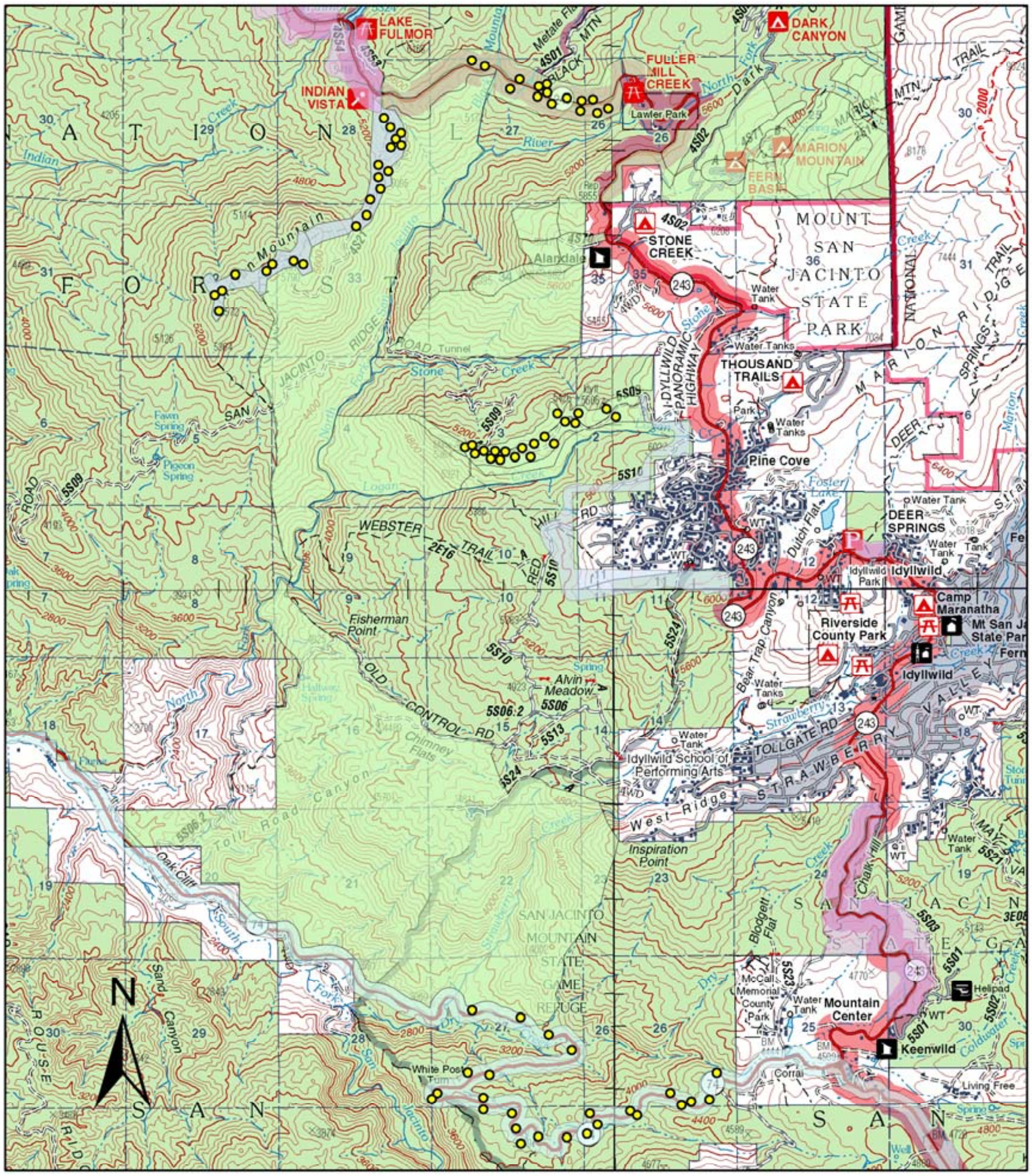
Appendix A. Maps

Mastication Monitoring Plots
San Bernardino National Forest
San Jacinto District
6/23/09



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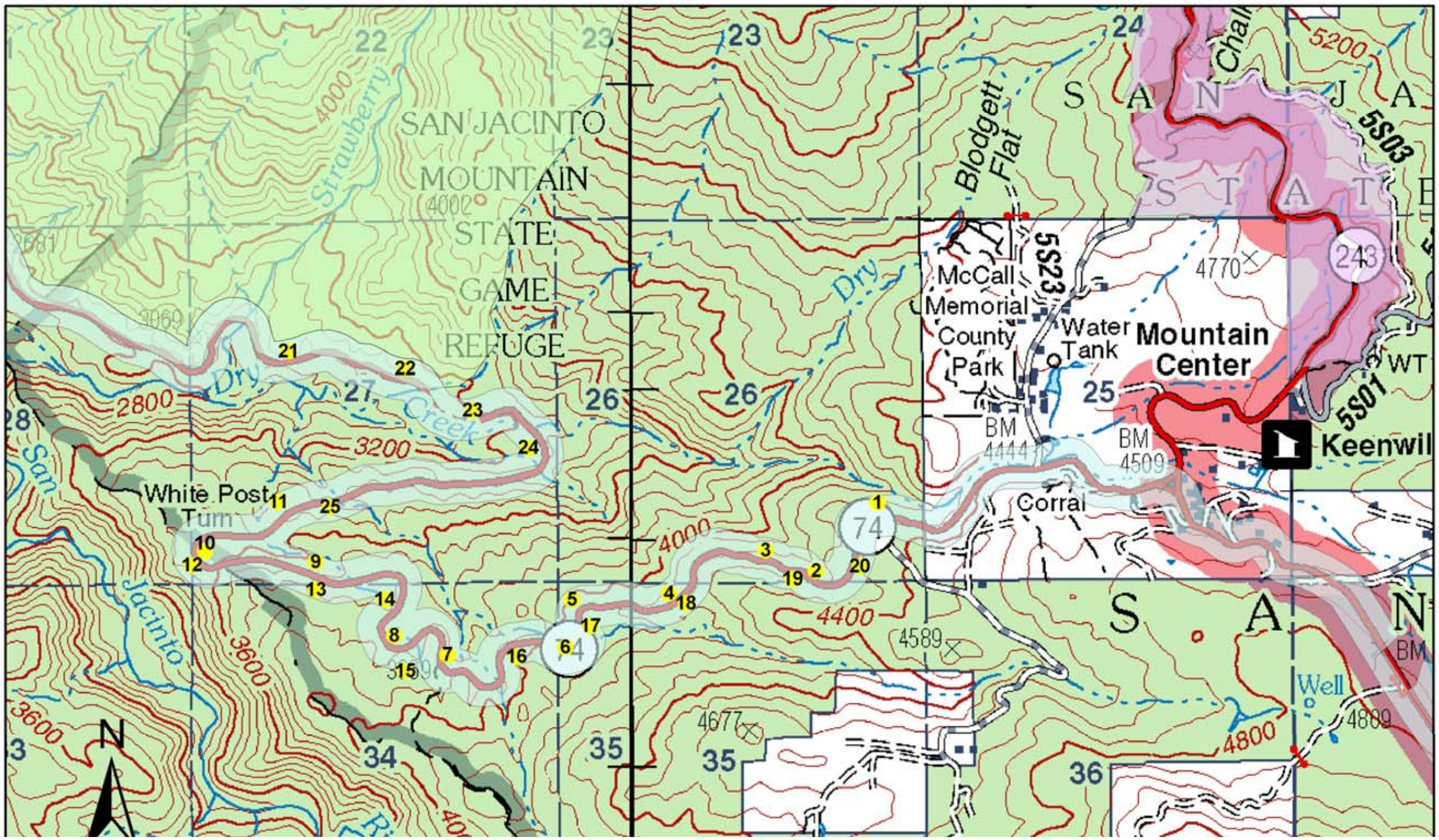
Mastication Monitoring Plots

San Bernardino National Forest

San Jacinto District

6/23/09

Highway 74 plots



Mastication Monitoring Plots

San Bernardino National Forest

San Jacinto District

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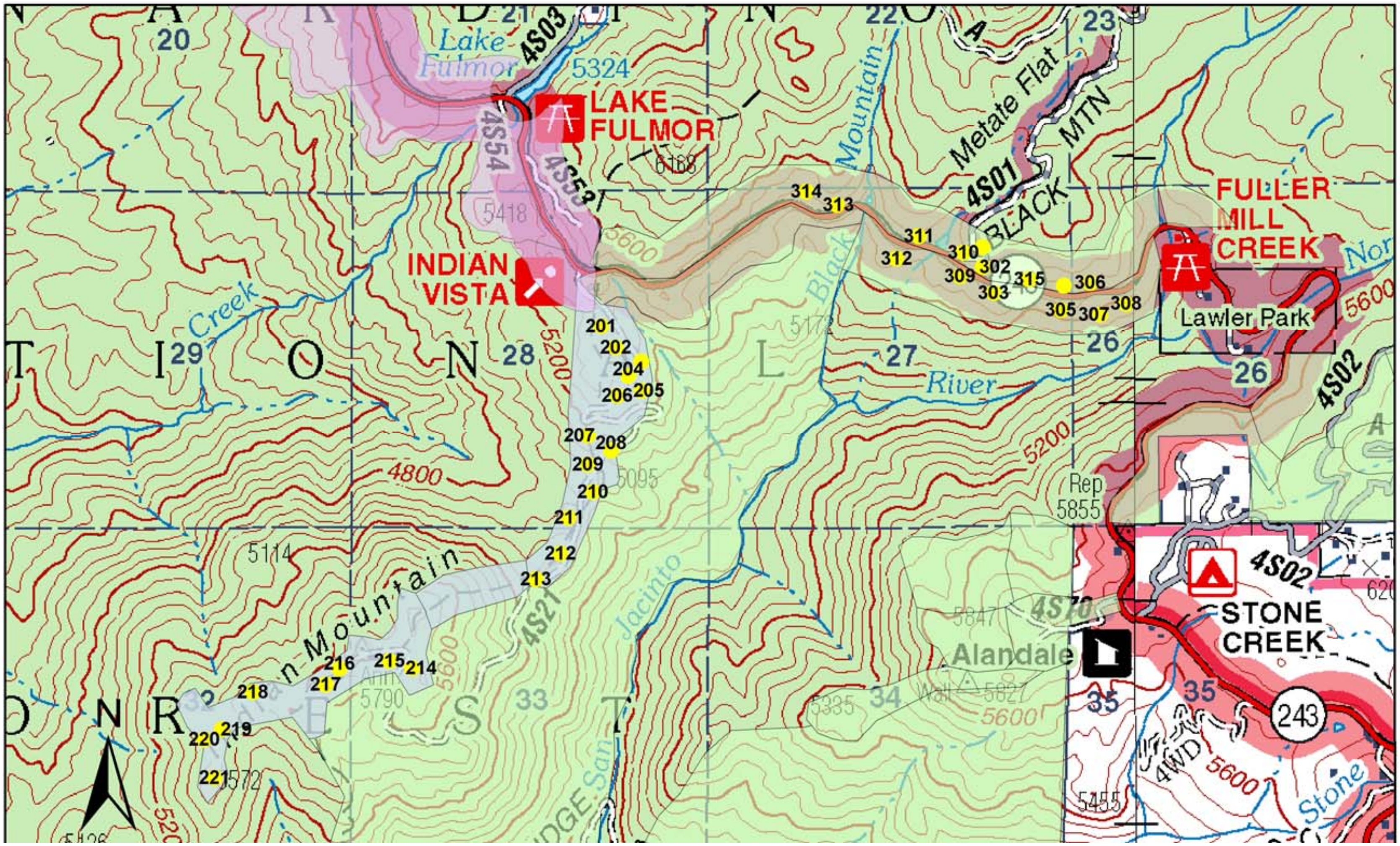
Indian Vista and Highway 243 plots



Mastication Monitoring Plots

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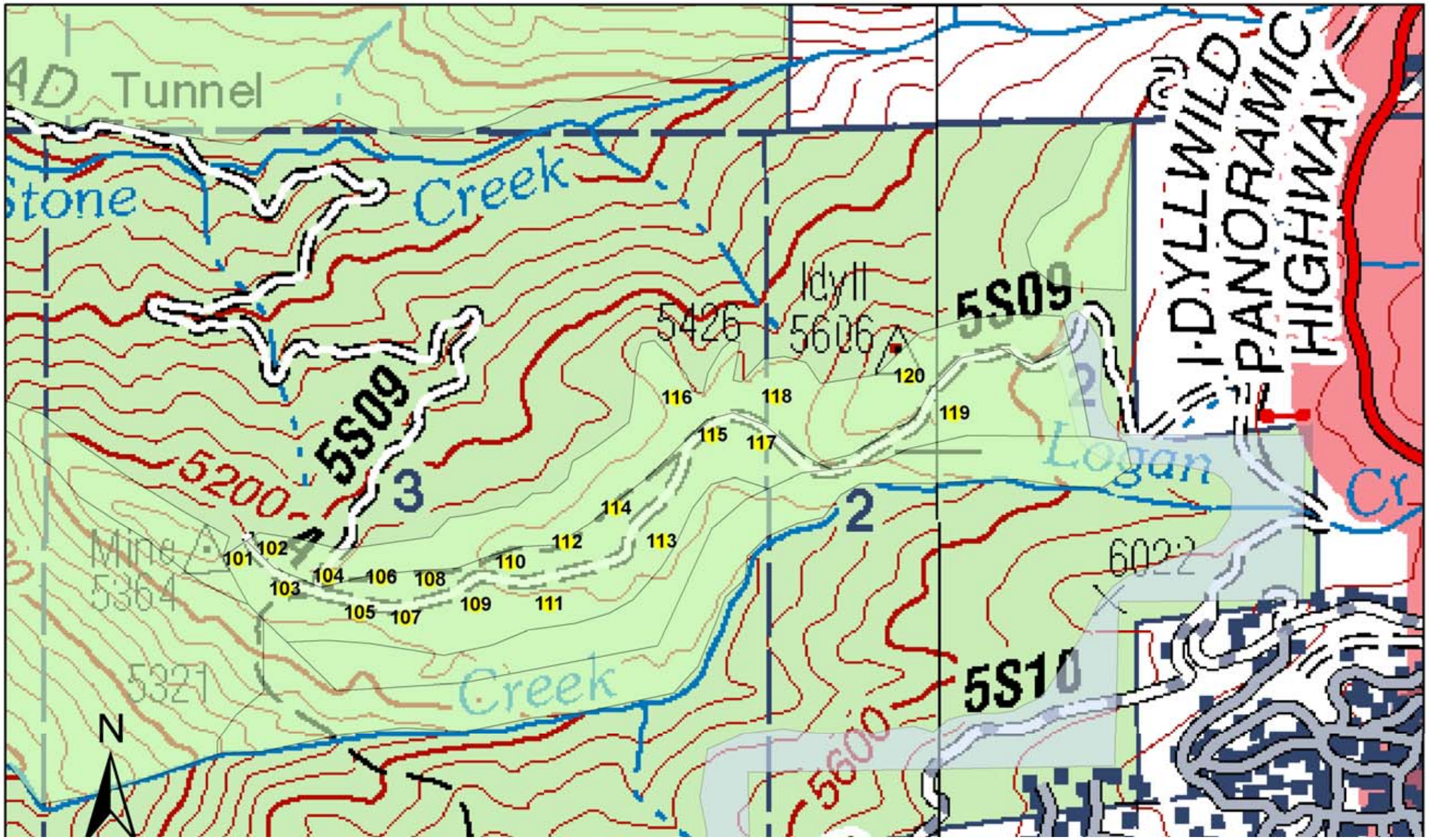
Pine Cove plots



Appendix B. Prototype Masticated Fuel Photo Series

1.5 year old chamise, manzanita and redshank masticated fuel bed
(example from Highway 74 west treatment area)

6 tons/acre	12 tons/acre	24 tons/acre
		

1 year old mixed conifer, hardwoods and brush (manzanita & oak) masticated fuel bed
(example from Pine Cove treatment area)

5 tons/acre	15 tons/acre	30 tons/acre
		

1 year old oak, manzanita and chamise masticated fuel bed
(example from Indian Vista treatment area)

5 tons/acre	15 tons/acre	40 tons/acre
		

Newly masticated manzanita, oak and chamise masticated fuel bed
(example from highway 243 treatment area)

15 tons/acre	30 tons/acre	70 tons/acre