
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

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Fire whirl in masticated fuel bed during the spring burn treatment.

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Executive Summary

Fire risk is an ever present management dilemma in many urban interface regions of the west. As options for mitigating this risk are considered, a number of concerns need to be addressed in order to carefully select the most appropriate treatment option. A study investigating effects of understory shrub mastication was implemented at Whiskeytown National Recreation Area with support from the Joint Fire Sciences Program. This study evaluated the response of vegetation, fire behavior and soil resources, to six different fuels treatments. As demonstrated by this study, hazardous fuels treatments do have ecological effects that need to be considered in setting management objectives. Specifically, findings from this study highlight significant differences between treatments, including the following:

- In sites where understory vegetation is masticated and left on site, fire behavior indices actually increased in comparison to unmasticated fuelbeds under the tested parameters.
- Low intensity spring burns can be used to reduce surface fuel loading in masticated fuels, but mortality to residual vegetation may be high.
- Vegetation response to treatments is highly variable, and closely correlated with pre-existing condition.
- Most exotic plant species are adapted to disturbances and will increase post treatment.
- Treatments that retain greater levels of overstory shading and litter/surface cover greatly mitigate risk of increasing exotic plant cover.

Presentations of components of this project have been provided at local, regional and national venues. More importantly, the results of this research have proven valuable to Whiskeytown's fire and resource management staff, and have significantly influenced future fuels treatments in the park's low elevation plant communities. Ongoing studies at the research site will continue for the next several years, investigating medium-term vegetation response as well as effects to soil mycorrhizae. Tiered research from the study is also being analyzed for a local carbon study and a regional fire behavior study.

Continuing efforts by investigators include dissemination of results at two national level fire conferences during 2006 ("Fire Severity and Intensity in Natural and Manipulated Fuels during Spring burning in Mixed Shrub Woodlands" accepted oral paper in March 2006 and "The Response of Vegetation to Brush Mastication and Prescribed Fire" fall presentation submission in process). Current information and summary updates will continue to be available on the park's website.

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Project Background

Rationale

Whiskeytown National Recreation Area (NRA) is characterized by a diverse assortment of oak woodlands, chaparral, mixed conifer, and knobcone pine vegetation types. Low intensity understory prescribed fire has been the primary tool used for ecosystem restoration and risk reduction in this fire-prone landscape. However, narrow target prescription windows, air quality restrictions, and limited staffing or other administrative concerns have made the implementation of prescribed fire across the landscape difficult. The logistics of conducting prescribed burns in Whiskeytown's rugged terrain to meet target objectives for fuel reduction and desired effects to vegetation is not only a challenge, but poses liability risks as well, especially when taking into account the proximity of nearby cities and 67 acres of private landholdings. As a means of expanding options available to managers, a number of alternative treatments including chipping, mastication, and understory thinning have been proposed and adopted as a part of the park's revised Fire Management Plan (2003). Although these treatments have been designed to simulate "natural" conditions, the effects of mechanical reduction and removal of brush and ladder fuels are a concern to resource managers in that the ecological consequences are virtually unknown.

Of greatest concern is that the combination of fire and ground disturbing activities of mechanized equipment, and the resulting reduced canopy cover from these treatments, may seriously alter the soil physical and biological properties and create conditions favorable to the invasion of non-native plant species. Monitoring data collected within Whiskeytown from prescribed fires have shown that exotic plant species frequently increase after fire caused disturbances. Similarly, data from shaded fuelbreak monitoring has demonstrated that the reduction in canopy cover and litter associated with mechanical treatment significantly increases the cover of non-native species. While these data are limited, the present distribution and spread of non-native plant species and the potential threats to native ecosystems are critical issues for most parks, and are generally considered to be one of the greatest threats to biological diversity in natural areas (Soule 1990). In chaparral ecosystems, non-native plant species pose at least two threats: 1) competitive interactions with native species; and 2) an alteration of the processes that control ecosystem functioning (e.g., the fire disturbance regime). More specifically, exotic annual grasses not only compete against native herbaceous and woody species by reducing soil light and competing for water and available nutrients, but also can lead to compressed fire return intervals. The increased frequency in fire can eventually result in a vegetation type-conversion into a non-native invasive community (Brooks 2001, Young and Allen 1997).

Whiskeytown is situated in the Klamath Mountains of northern California where elements of the Pacific Northwest, California, and Great Basin floras meld with a composite of disturbances, creating an area with globally outstanding levels of biodiversity. Biodiversity hotspots are often sites of greatest plant invasion (Stohlgren et al. 1999) and within the Klamath Network of national parks, low-elevation parks such as Whiskeytown have very high levels of invasion. In fact, over 25% of the flora in Whiskeytown is believed to be non-native. Not only is disturbance believed to enhance the probability of non-native plant establishment in native plant communities (Rejmanek 1989, Hobbs 1991), the proposed

combination of fire and mechanical treatment with tracked vehicles could compound issues. Research on fire alone has demonstrated that recently burned areas are considered vulnerable to exotic invasion because competition from established plants may be reduced after fire (Tyler and D'Antonio 1995) and fire can dramatically increase the amount of bare ground available for germination and establishment (Boyd et al. 1993).

The addition of mechanical treatment provides a number of potential impacts. From a vegetation standpoint, concern of non-native plant species is greater in that these activities may favor invasions by transporting propagules, disturbing the soil surface, and by creating gaps that allow the spread of invasives into uninfested areas (Brooks 2001). This combination of treatment also increases the frequency of disturbance, which has been shown to promote exotic annuals (Giessow and Zedler, 1996). Despite taking such precautions as washing equipment and avoiding areas that have well-established patches of exotics, few strategies for minimizing the spread of non-native species exists.

Study Objectives

The overarching goal of this project is to provide feedback to fire managers at Whiskeytown and other land management agencies with similar plant communities on the ecological effects of fire and fire surrogate treatments. This information is derived from a local research project for dissemination during a variety of formal and informal presentations on and off site. A total of six different treatments were implemented in mixed oak-pine-shrublands at the park, including control, hand-thinning, mastication (mechanical grinding) of understory vegetation, and prescribed fire. Specifically, the principle objectives for this research project are the following:

1. To quantify the response of vegetation among the treatments, with an emphasis on non-native and invasive species.
2. To investigate the impacts of such treatments to soils.

In addition to the above objectives, additional questions arose during implementation of the project that were not addressed in the original proposal. Concerns, such as the effect of the seedbank on the vegetation response and subsequent fire severity in the altered fuelbeds developed into additional objectives that were incorporated into this study.

Methods

Site Description

The 45 acre project area is located in Whiskeytown NRA on the southeastern edge of the Klamath Mountains in northern California. The climate in this area varies considerably with season and elevation. In the low elevation (1,250 to 1,500 feet) areas, such as the study site, summers are hot and dry, and winters are cool with occasionally heavy rainfall. Temperature readings over 100° F occur often during the months of May through October, with

occasional sub-freezing temperatures from November through March. The average annual precipitation is 60 inches with seventy-five to ninety percent occurring between November and April.

The study area is characterized by an open to closed overstory dominated by black oak (*Quercus kelloggii*) and knobcone pine (*Pinus attenuata*) with occasional canyon live oak (*Quercus chrysolepis*), grey pine (*Pinus sabiniana*), and interior live oak (*Quercus wislizeni*). The dense shrub understory is dominated by whiteleaf manzanita (*Arctostaphylos viscida*), toyon (*Heteromeles arbutifolia*), and poison oak (*Toxicodendron diversilobum*).

Study Design and Treatments

Funding support for this study was announced by the Joint Fire Science Program in May of 2002. Since the treatments were new to the park and not covered under existing compliance, National Environmental Policy Act guidance triggered the preparation of an Environmental Assessment. A general study site was identified within a larger roadside shaded fuelbreak project and the Environmental Assessment completed in the in the Summer of 2002. Joint Fire Science funds were not used for fuels treatment implementation. Evaluations of the site focused on assessing vegetation characteristics, slope, and aspect, resulting in the selection of 10 different 1 to 2 acre stratified treatment blocks (Figure 1). Each treatment block was divided into 14 approximately equal-sized plots, with two plots from each block representing one of the following seven different experimental treatments:

1. Masticated brush burned in the fall
2. Masticated brush burned in the spring
3. Unmanipulated brush burned in the fall
4. Unmanipulated brush burned in the spring
5. Masticated brush left on the ground as mulch
6. Brush cut by hand and removed to mimic biomass removal
7. Control (no mastication, burning, or thinning)

Brush Mastication Treatment

Brush mastication treatments were completed in November 2002 using a North Tree Fire International ASV Posi-Track with industrial brushcutter (Figure 2). Treatment cost was \$600 per acre. Vegetation mastication was implemented to ensure that at least 90% of machine operations occurred over chipped surfaces to assist in limiting 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 with an average no greater than 3-1/2 pounds per square inch ground pressure, and operation on dry soil (Windell and Bradshaw 2000).

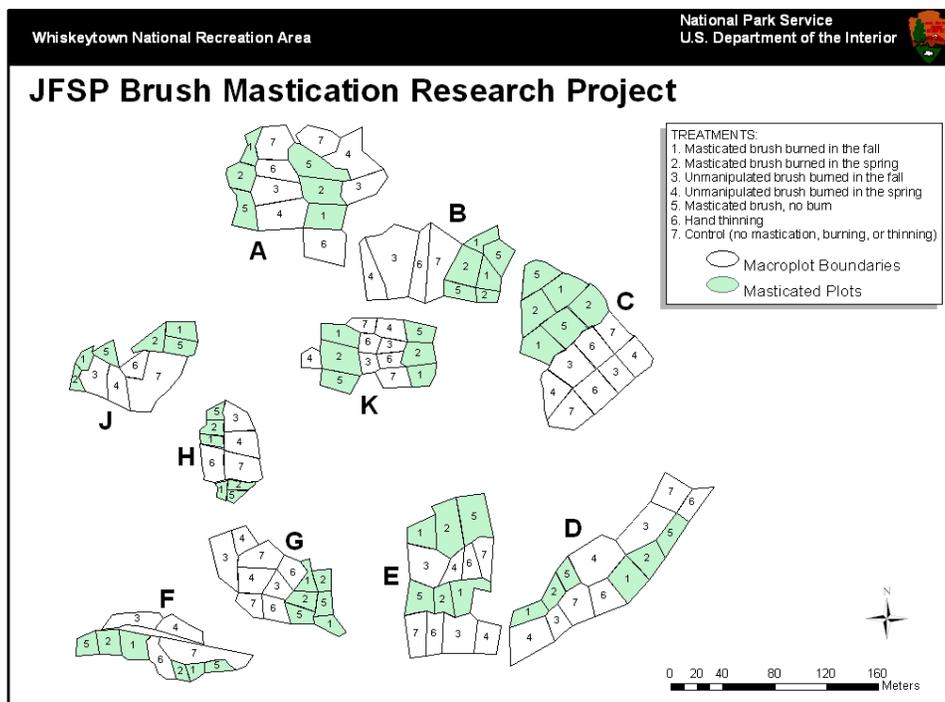


Figure 1. Research treatment plot layout.

The goals of the brush mastication treatment were to reduce understory bulk density 60-95% by thinning shrubs and small trees less than 3-4 meters in height. In areas where overstory trees were absent, a limited cover of shrub species was maintained.



Figure 2. North Tree Fire International's ASV Posi-Track.

Prescribed Fire Treatments

All prescribed fire treatments were designed to be representative of typical prescribed fire treatments occurring within the park. The objectives for the prescribed fire treatments were developed based on the goals outlined in Whiskeytown's Fire Management Plan (2003). The objectives developed for the unmanipulated treatments are consistent with prescribed fire treatments applied throughout the park, while separate project-specific objectives were developed for the application of fire to masticated fuels (Table 1).

Table 1. Management objectives for the prescribed fire treatments.

Objective	Masticated Fuels	Unmanipulated Fuels
Reduce surface fuel accumulation (litter, duff, 1, 10, 100, 1000 hr TLFM)	15-35%	25-70%
Reduce live density of small (<8 inch dbh) knobcone pine trees	0-25%	10-75%
Reduce live density of all other small (<8 inch dbh) trees	0-25%	0-40%
Limit mortality of overstory (>8 inch dbh) trees	0-15%	0-15%
Reduce cover of live shrubs	0-25%	15-75%

Spring burning treatments were initiated on April 8, 2003, following leaf-out of the deciduous oak species (Figure 3). All fires were backing with respect to slope and/or wind, utilizing drip torches and applying a combination of strip and spot ignition patterns. Twenty masticated and sixteen standing brush units were burned as part of the spring treatment. Roughly 50% of the units were completed by April 10, at which point burning was halted due to unfavorable weather. The remaining units were burned on May 15, 2003. Ambient weather conditions were recorded on-site by fire effects monitors. During the burns, temperature extremes ranged from 59°F to 71°F, relative humidity ranged from 34% to 73%, and wind speeds averaged 2 mph with a maximum wind speed of 6 mph. Moisture readings were very high (0.3-0.4 kPa tension) during the burning period as recorded by a Delmhorst KS-D1 soil moisture tester at reference locations .



Figure 3. Spring burning treatment in masticated fuels.

Although the fall burn units were prepared during the Fall of 2003, a suitable prescription window was not attained this year. Fall burning treatments were ultimately initiated on November 8, 2004, after the first rain of the season. All fires were backing with respect to slope and/or wind, utilizing drip torches and applying a combination of strip and spot ignition patterns. Approximately 65% of the plots were burned on November 8th and 9th, although conditions were quite moist. Burning was then halted due to rainy weather, and the remaining plots were left unburned. Ambient weather conditions recorded on-site showed temperature ranged from 52°F to 57°F, relative humidity ranged from 76% to 82%, and wind speeds averaged 1 mph with maximum wind gusts to 4 mph.

Hand Thinning Treatment

Hand-thinned treatment blocks were cut by fire crews in February and March 2003 (Figure 4). Treatment costs for hand thinning units averaged approximately \$1,600 per acre. Crews conducted "heavy" thinning of shrubs to mimic the level of thinning by the brush masticator. After cutting, brush was physically carried by hand crews from the site and pile-burned outside the study area.



Figure 4. Hand-thinning treatment of brush by park staff.

Data Collection and Analysis

Fire Behavior and Effects

Fire behavior and effects measures were recorded for each fire treatment in the research area. Four 1 m² fire behavior plots were randomly installed within each burn treatment prior to burning and pre- and post-burn measurements were collected on fuel loading (1-hr, 10-hr, 100-hr, 1000-hr TLFM cover, litter and duff depth), herbaceous cover, and bare ground.

A garden stake 0.5 m tall was located in the center of each 1 m² fire behavior plot, and pyrometers (brass tags painted with heat-sensitive paint) were placed on the top of the garden stake, on the litter surface, and between the duff and soil layers to measure maximum temperature during the burn (Figure 5 and 6). During the fall burning treatment, HOBO

Thermocouples were also deployed in selected units to further quantify temperature extremes and heat residence time.



Figure 5. Temperature sensitive paint tags.



Figure 6. Installation of pyrometers in fire behavior plot.

Fire behavior measurements were recorded for each 1 m² fire behavior plot during the burn period (Figure 7). Maximum and average flame length, flame zone depth, estimated rate of spread, and fire type were recorded for each plot. Within one month post-burn, scorch estimates were recorded on a macroplot basis for dominant trees and shrubs and approximately six months post-burn, tree and shrub mortality estimates were recorded.



Figure 7. Monitoring fire behavior within a masticated plot during the spring burn treatment. The fire behavior plot can be seen in the middle with white pin flags.

Vegetation Response

The Fall burn treatment was not attained in 2003 and the narrow prescription window in November of 2004 resulted in only a portion of the plots being burned. Even of the plots that were successfully burned in the Fall of 2004, the prescription conditions were so cool that they were deemed inappropriate for comparison with the spring burn treatment. Because of this, vegetation data was not collected in Fall burn treatments.

To determine the differences between treatment in vegetation response, vegetation plots were established in the following treatments: 1) hand-thinned (HU); mastication and spring burn (MS); mastication and no burn treatment (MU); standing brush that was burned in spring (NS); and control (NU). Plot locations were randomly assigned and permanently marked. Each plot measured 1 m x 5 m in a nested frequency design (Figure 8).

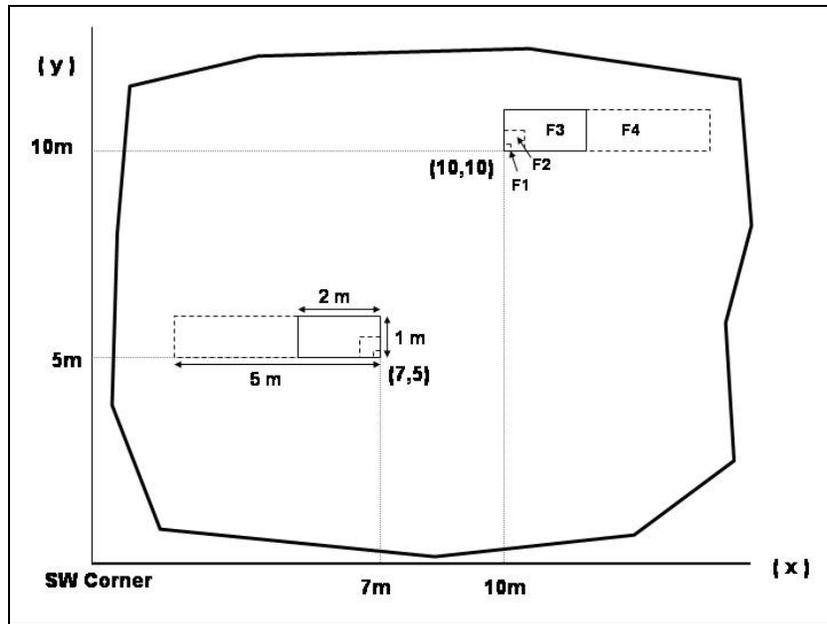


Figure 8. Vegetation plot layout within a treatment unit. Vegetation plots were randomly assigned using x- and y-axes for permanent relocation. Vegetation plots are 1 m x 5 m with a 1 m x 2 m cover plot and four frequency plots nested within them. Frequency plots are: F1—10 cm x 10 cm; F2—0.5 m x 0.5 m; F3—2 m x 1 m; F4—5 m x 1 m.

In each vegetation plot, vegetation parameters (percent cover by species, height of tallest individual by life form), microhabitat parameters (slope, aspect, and canopy cover), and substrate parameters (substrate type, cover, and depth) were measured in control and treated plots each spring (2003, 2004 and 2005) within a 1 m x 2 m cover subplot and frequency of species was measured in four frequency subplots (Figures 9 and 10).



Figures 9 and 10. Vegetation sampling in a hand-thinned plot (left) and a brush plot (right).

Late season vegetation data was also collected in selected plots in the Fall of 2005. This data collection effort was undertaken to capture the “high priority” non-native invasive plant species which have been identified in the revised Fire Management Plan (2003). Density measurements were taken in all treatments for three of the ten replicates. The sampled replicates were subjectively chosen to capture known infestations.

Seedbank

Soil samples for the seedbank analysis were collected along three subjectively chosen transects. Samples were collected in areas that resembled pre-treatment conditions within the research area. Drainages were excluded. Four subsamples were taken at each collection point (0, 2, 4, 6, 8, 10, 15, 20, 25, and 30 meters from the road edge). Each subsample consisted of the bottom 2.5 cm of duff material and the top 5 cm of soil from a 5 cm diameter hole. The four subsamples from each collection point were composited and then transferred to three separate 1 gallon growing pots filled with potting mix and washed sand. The 90 treatment pots (3 transects x 10 collection points x 3 pots per point) along with 20 control plots (potting mix and washed sand only) were randomly placed in growing cages (Figure 11). Plants grown in the treatment and control pots were pulled and counted as soon as they could be identified to species level.



Figure 11. Vegetation response within the seedbank pots.

Soil Chemistry

Soil samples were collected in one treatment block to determine whether there was a detectable difference in soil chemical parameters (pH, nitrogen, phosphorus, potassium) between treatments. Two composite soil samples consisting of four random subsamples each were collected in each treatment unit. The composite samples were dried and then tested with a LaMotte soil test kit.

Results

Brush Mastication

Prior to implementation of the mastication treatment, the vegetation at the study site was characterized as a mix of model 4, 8 and 9 fuels (Anderson 1982). Post treatment, the fuel bed changed drastically, with post treatment fuels best characterized as model 11 logging slash for the unit burn plan. In comparison to untreated sites, mastication resulted in the conversion of live and dead standing materials into downed woody debris resulted in an approximate 200% average cover increase in woody fuel loading for 1 and 1000 hr TLFM size classes, and greater than 300% average cover increase in 10 and 100 hr TLFM size classes.

In addition to a fuel quantity increase, total average canopy cover was reduced by over 50% in masticated plots. This removal of overstory shading directly contributed to an increase in air circulation (drying of fuels) and an increase in direct solar radiation (increased surface fuel temperatures).

Fire Behavior

The fall burn treatment was not attained in 2003 and the narrow prescription window in November of 2004 resulted in only a portion of the plots being burned. Even of the plots that were successfully burned in the Fall of 2004, the prescription conditions were so cool they were deemed inappropriate for comparison and have been excluded from further discussion or analysis within this document.

Despite the overall mild conditions, fire behavior during spring displayed significant variability within treatments. A Principal Components Analysis (PCA) was used to characterize patterns in fire behavior, severity, and surface fuels (Figure 12). 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 in the unmanipulated plots (-0.583). The high Factor 1 scores for masticated plots indicated a high amount of surface fuels (litter, 1 hr, 10 hr, and 100 hr fuels), wide flame zone depth, and high aerial temperatures. Unmanipulated plots had a high percent cover of herbaceous species, bare ground, and low surface fuels, fire behavior and severity values.

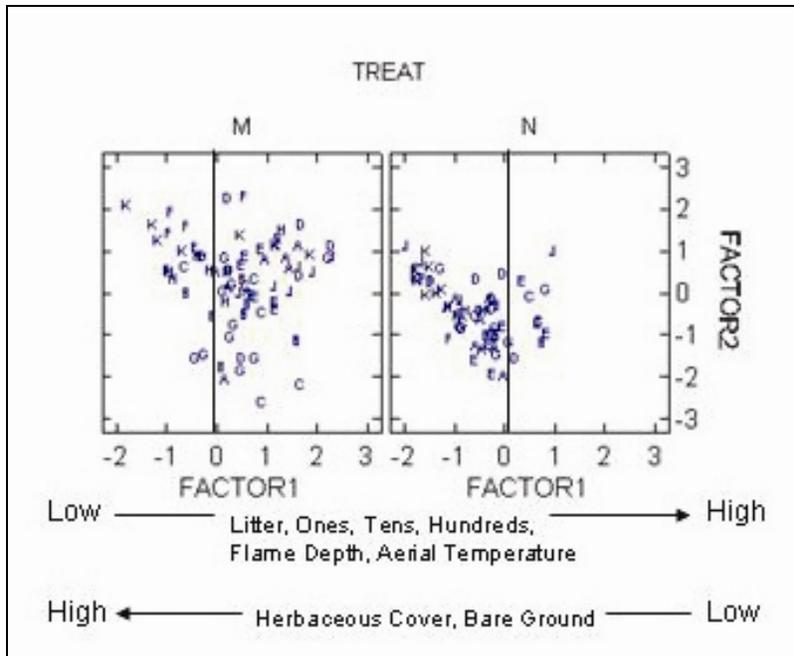


Figure 12. PCA scores for masticated (M) and unmanipulated (N) plots during the spring burn treatment. Masticated plots had a high amount of surface fuels, wide flame zone depth, and high temperatures, while unmanipulated plots had high herbaceous cover and bare ground and low fire behavior and severity values.

A variety of fire intensity measures showed striking differences between the masticated and unmasticated plots. A two-sample independent t-test for both flame length and flame zone depth indicated greater values in masticated plots when compared to unmanipulated plots. Mean flame length (28.28 inches) and flame zone depth (19.15 inches) were significantly greater ($P < 0.001$) in masticated plots than the mean flame length (10.12 inches) and flame zone depth (6.27 inches) in the unmanipulated plots. Two of the three strata tested with pyrometers also indicated significant temperature differences between masticated and unmasticated plots (Chart 1). A two-sample independent t-test showed mean temperatures for litter (657.24°F) and aerial (277.33°F) tags in the masticated plots were significantly greater ($P < 0.001$) than temperatures recorded for litter (218.55°F) and aerial (58.87°F) tags in unmanipulated plots. 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.

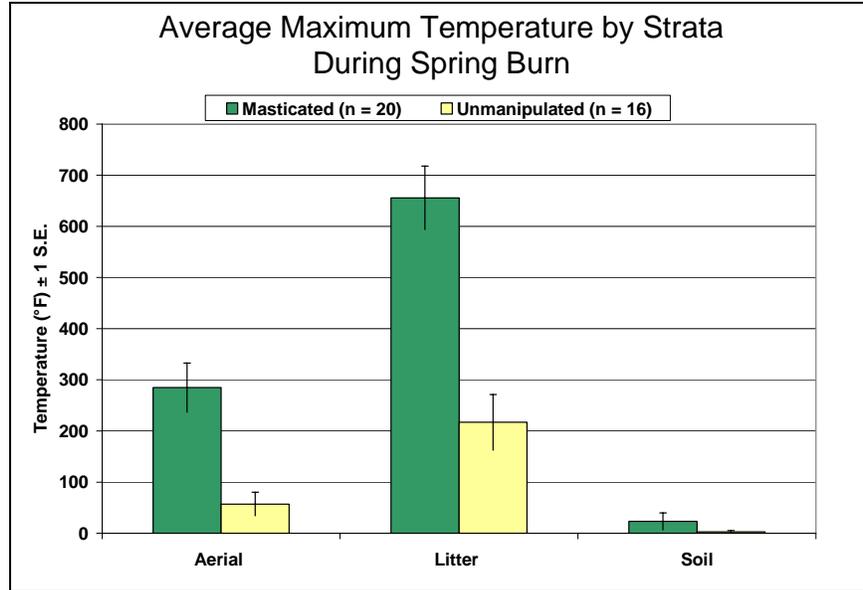


Chart 1. Average temperatures recorded by pyrometers during the spring burn treatment in masticated and unmanipulated plots.

Overall, prescription target goals were met for surface fuel reduction objectives. As noted earlier, surface fuels drove fire behavior, with significant fuel consumption differences noted between treatments (Chart 2). In addition to TLFM size classes listed in Chart 2, litter was also reduced. A two sample t-test showed a significant ($p < 0.05$) mean litter depth reduction of 71% in masticated treatments and 40% reduction in unmasticated treatments. While 28% and 17% mean duff reduction was noted in masticated and unmasticated plots respectively, this drop was not significant and is likely attributable to the high moisture levels underneath the litter that limited fire behavior.

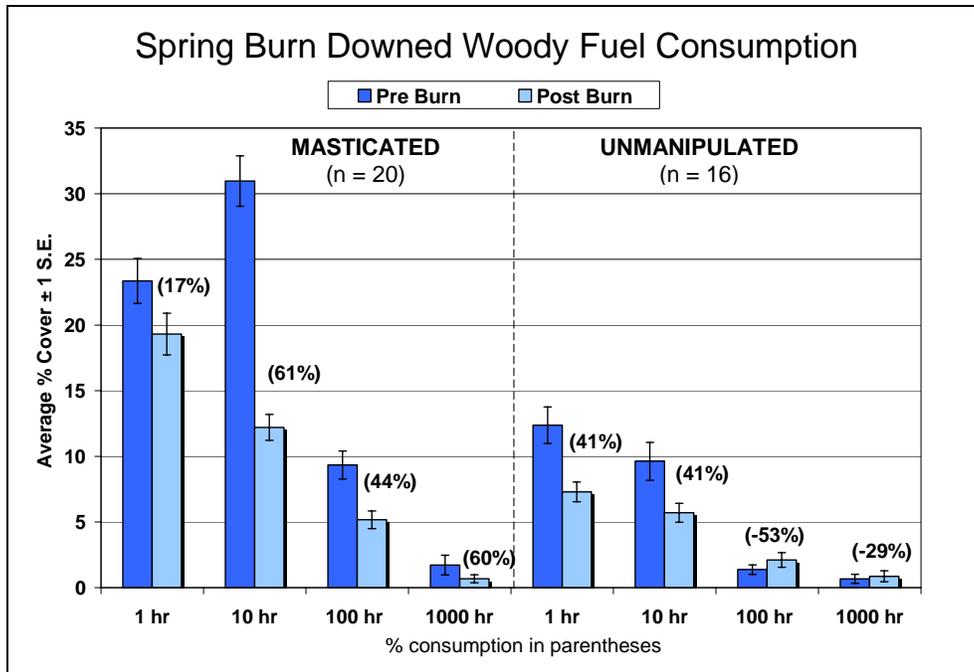


Chart 2. Consumption of woody fuels during the spring burn treatment in masticated and unmanipulated plots.

While fuel reduction goals were met, severity effects to live vegetation did not meet burn plan targets (Table 2). Heat effects to residual overstory trees and shrubs in mastication plots were severe, despite efforts by ignition crews to mitigate effects, and targets for retention of live woody vegetative cover were exceeded. In contrast, goals for reducing live vegetative cover (shrubs and pole sized trees) in unmanipulated plots were below target objectives.

Table 2. Average mortality of trees and shrubs during the spring burn treatment in masticated and unmanipulated plots.

Species	Overstory (>8" dbh)		Pole (<8" dbh)	
	Unmanipulated	Masticated	Unmanipulated	Masticated
Knobcone Pine (<i>Pinus attenuata</i>)	0%	16%	15%	66%
Black Oak (<i>Quercus kelloggii</i>)	0%	23%	17%	47%
Canyon Live Oak (<i>Quercus chrysolepis</i>)	0%	49%	21%	98%
Shrubs	Unmanipulated 30%		Masticated 96%	

Vegetation

Response of vegetation followed many similar patterns in both oak woodland and whiteleaf manzanita dominated plots. For both plant communities, the most dominant resprouting shrub was toyon (*Heteromeles arbutifolia*) which had the highest overall cover response. In the unmasticated plots, whiteleaf manzanita (*Arctostaphylos viscida*) was the second most common species, while a mixture of native perennial herbs (*Odontostomum bartwegii*, *Dichelostemma multiflorum*, *Calochortus tolmiei*) and shrubs (*Toxicodendron diversilobum*) dominated the masticated and hand thinned plots. Non-native species were present in all treatments and were dominated by annual grasses (*Vulpia myuros*, *Aira caryophyllea*, *Gastridium ventricosum*) and herbs (*Hypochaeris glabra*) (See Appendix C).

Results from the first year post fire and mastication vegetation data are inconclusive as they were depauperate in diversity and cover (Figure 13). However, differences between treatments became more evident with time. Preliminary analyses from data collected from the second year after prescribed fire found significant differences between treatments (Table 3). A One-Way Analysis of Variance on the mean cover of whiteleaf manzanita seedlings found that there was a significant difference ($P < 0.001$) between treatments, with the masticated and burned treatments (MS) having the greatest cover (Chart 3, and Figure 14) when compared to the control (NU), standing brush that was burned in spring (NS), hand-thinned (HU), and the masticated material that was not burned (MU). Similarly, preliminary analyses have found significant differences ($P < 0.001$) in the mean cover of native and non-native herbaceous species between treatments (Charts 4 and 5).



Figure 13. Low species diversity and cover in treatments that were masticated and burned (right). Note robust response of toyon in the masticated treatment (left) just one year post treatment.

Table 3. The mean percent cover of species by treatment type. The standard error of the mean is in parentheses. Treatments are represented by HU (Hand-thinned), MS (masticated and burned in spring), MU (masticated material that was not burned), NS (standing brush that was burned in spring), and NU (control).

	HU	MS	MU	NS	NU
Native Grasses	1.872 (0.433)	0.562 (0.199)	0.734 (0.202)	0.431 (0.139)	0.544 (0.154)
Native Herbaceous Species	18.312 (2.355)	15.388 (2.273)	14.319 (1.787)	13.866 (2.90)	13.694 (2.251)
Exotic Grasses	10.625 (2.656)	6.931 (1.728)	4.219 (1.038)	2.400 (0.748)	2.775 (0.971)
Exotic Herbaceous Species	1.466 (0.509)	1.519 (0.407)	0.791 (0.211)	0.356 (0.166)	0.416 (0.192)

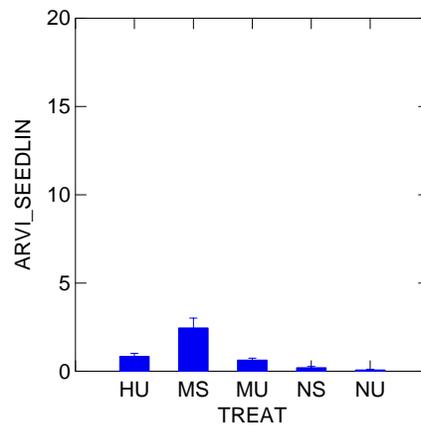
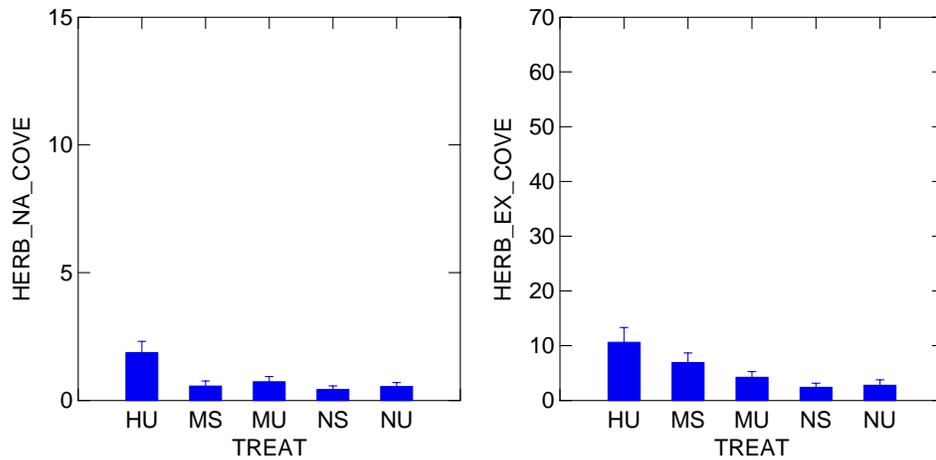


Chart 3. Differences in the mean percent cover of whiteleaf manzanita seedlings between treatments. Error bars represent the standard error of the mean. Treatments are represented by HU (Hand-thinned), MS (masticated and burned in spring), MU (masticated material that was not burned), NS (standing brush that was burned in spring), and NU (control).



Figure 14. Response of whiteleaf manzanita seedlings in treatments that were masticated and burned in spring, one year post fire.



Charts 4 and 5. Differences in the mean percent cover of native and non-native herbaceous species between treatments. Error bars represent the standard error of the mean. Treatments are represented by HU (Hand-thinned), MS (masticated and burned in spring), MU (masticated material that was not burned), NS (standing brush that was burned in spring) and NU (control).



Figure 15. Early growing season response of vegetation in a hand-thinned plot, three years post treatment. The understory is primarily comprised of a mixture of native perennial herbs (*Odontostomum hartwegii*, *Dichelostemma multiflorum*, *Calochortus tolmiei*) and annual grasses (*Vulpia myuros*).

While cover values still remain low the second year post fire, the hand-thinned treatments appeared to have the greatest response of all treatments.

Within the three years of sampling, high priority non-native and invasive species were not detected within this sampling scheme, despite obvious infestations that were becoming locally established. Part of this discrepancy was related to the timing of sampling, with differences between the early and late growing seasons becoming more pronounced with time (Figures 15 and 16). It was also noted that these species were not randomly distributed across the landscape, but occurred in clusters emanating outward from a high density center.



Figure 16. Late season growing response in a plot that had been masticated and burned, two years post fire. The understory shown here is primarily a mixture of annual grasses (*Vulpia myuros*, *Aira caryophylla*, *Gastridium ventricosum*, *Bromus sp.*) and herbs (*Hypochaeris glabra*, *Hypericum sp.*, *Gnaphallium sp.*, *Centaurea mellentensis*).

The late season sampling, which estimated density within certain subjectively chosen replicates, found that there was a considerably greater number of non-native and invasive species (mostly *Centaurea melitensis*, *Cirsium vulgare*, and *Lactuca serriola*) in the masticated plots that were burned in spring (MS) as opposed to any other treatment (Table 4, Figure 17, and Chart 6). The plots that were hand-thinned (HU) or just masticated (MU) appeared to have the second greatest number of exotics, which were primarily *Cirsium vulgare* and *Lactuca serriola*. The density of non-native and invasive species in the control plots (NU) was the least of all the treatments.



Figure 17. *Cirsium vulgare* in a masticated plot that was burned in spring, one year post fire.

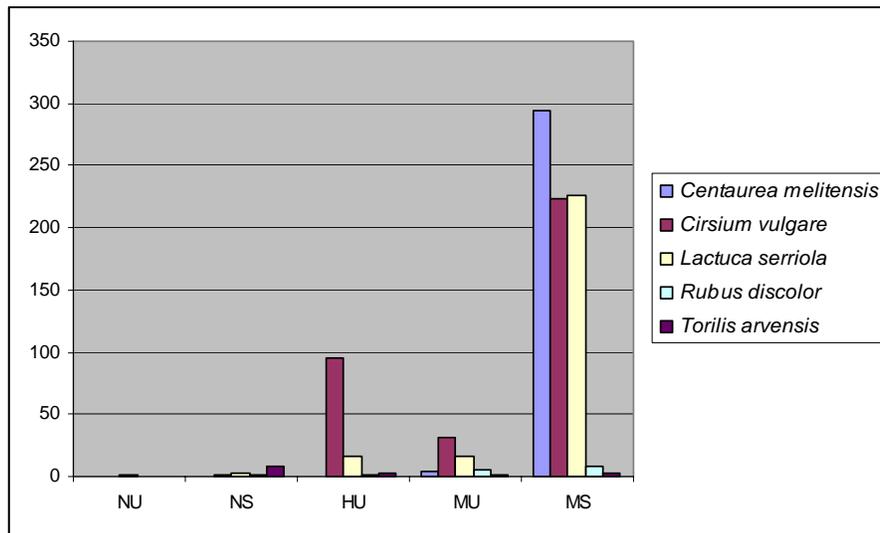


Chart 6. The density of high priority non-native and invasive species collected in three of the ten replicates. The masticated plots that were burned in spring had an overwhelmingly greater density of high priority exotics than any other treatment.

Seedbank

Prior to implementation of the project it was recognized that a high level of spatial variability existed within the general study area. Obvious factors such as micro-site variability and disturbance history were theorized as probable factors influencing this variability and factored into the study design. Still, it was uncertain how the soil seedbank might vary across the study area, in particular with respect to distance from roads that might serve as vectors for exotic species establishment. Such responses, if occurring, would not likely be uniformly distributed but display abundance patterns that were correlated with distance from the roadway. Further, it was recognized that other spatial distribution patterns could exist that would otherwise not be picked up in the primary vegetation sampling. The seedbank component of this study was initiated to investigate these dynamics.

As anticipated, soil taken from the study area had significantly more plants than sterile soil (mean plants per pot 1.92 vs 0.2, $p < 0.001$). All four plants identified in the control pots were of species with light, air dispersed seed, while study site soil consisted of a mix of seed types. A total of 320 plants were tallied in soil from the study site, representing 28 different species plus two plants identified to genera. Of this total, 48% were annual grass or grass like species, 18% annual herbs, 27% perennial herbs, 5% woody perennials, and less than 1% perennial grasses and biennial herbs. Summary statistics also indicated that 63% of these individuals were native species. The most abundant native species in the seedbank pots were *Navarretia divaricata*, *Gnaphalium canescens ssp. beneolens*, *Hypericum concinnum*, and *Dodecatheon hendersonii*, which were all present in the vegetation plot sampling but occupied relatively little cover. The most abundant non-native species from the seedbank also had the highest cover values in the vegetation plot data (i.e. *Aira caryophyllea*, *Vulpia myuros*, *Gastridium ventricosum*, *Hypochaeris glabra*).

To test the relationship between distance from the road and the type and abundance of species, a linear regression was used. Results from this regression indicated that the variation unexplained in the data was greater than the variation explained ($P = 0.06$, $R = 0.065$). No relationship between distance from roads were noted for any of the factors of interest (native, exotic, annual, perennial and life form). While no patterns were detected with distance from road, data did show that one transect had significantly more plants per sample (Transect 1 mean 2.50 vs 1.63 mean for both Transect 2 and 3, $p < 0.01$)

Soil Chemistry

Soil tests were conducted to test differences in pH, nitrogen, phosphorus, potassium. Using the methods employed, no difference in soil chemical parameters between treatments was detected. This could be due to the level of precision and resolution of the test kit.

Discussion and Management Implications

Fire Behavior and Prescription Objectives

Results from this study showed significant differences in fire behavior and effects between masticated and unmanipulated treatments. These differences were driven by the surface fuel conditions created as a direct result of the mastication treatment. Specifically, mastication led to an increase in surface fuel biomass and increased solar radiation and air circulation that facilitated drying of fuels, a fact that had a significant effect during the cool damp spring season. Through time, decomposition and compaction of these materials may eventually promote lowered fire intensity potential for surface fire, but for the short term the mastication treatments clearly contributed to an increase in fire potential.

Although fire severity was much higher in masticated fuelbeds than in unmanipulated fuels, complete consumption of surface fuels was not noted, as all plots had at least some residual surface fuels and overall duff consumption was minimal. These effects were largely attributable to the conditions during the burn, most notable the high level of moisture in the soil and duff layers. Such conditions are typical for early to mid spring seasons when vegetation development and dry environmental conditions have yet to significantly lower soil moisture levels. From a management perspective, these present optimal conditions for implementing burns since spotting potential, flame lengths and rate of spread are minimal. Further, surface fuel reduction objectives were met in the masticated fuelbeds, although only marginally attained in unmasticated vegetation.

While a success from a fuel reduction standpoint, targets for effects to vegetation were not met, although the differing fuel types were on opposing ends of the spectrum. In the unmasticated vegetation, fire intensity was too low to attain mortality objectives for shrubs and small trees. In contrast, fire intensity in the masticated treatments was lethal for much of the residual vegetation, resulting in too much shrub and tree mortality. These results highlight the complexity of burning in varied fuelbeds under similar prescriptions, particularly when objectives extend beyond simple surface fuel consumption. Of added emphasis is the complexity of burning in masticated fuels where objectives have been created to minimize effects to retained vegetation.

One of the major concerns prior to implementation of the burn was potential lasting effects to soil from superheating of soils. Despite concerns, the cool spring prescription tested produced no such effects were not noted, as soil moisture levels buffered temperatures to the soil.

Vegetation Response

Results from the first year post fire and mastication vegetation data are inconclusive as they were depauperate in diversity and cover. The species richness (number of species per square meter) in our data ($X = 3.73$, $SD = 0.29$) is comparable to what Keeley et al. (2003) found in the first year post fire results in southern Sierra Nevada chaparral ($X = 2.7$ species, $SD = 1.1$). It is unknown whether these values fall within the natural range of variation for the southern Sierra Nevada or northern California, but Keeley et al. did find that the general pattern of alien invasion observed in the southern Sierra Nevada chaparral stands is similar to that reported for other parts of California. Their hypothesis that time since fire is

generally the most critical factor in alien invasion and colonization was supported by the four-fold increase in species richness and an almost ten-fold increase in non-native cover three years post fire. It is thought that it is the closed canopy of pre-fire shrublands that reduces alien populations and thus limits the alien seed bank present at the time of fire. Similarly, preliminary data from the construction of shaded fuelbreaks within Whiskeytown indicate a strong correlation between non-native plant species and the amount of canopy cover and litter at each sample site (Gibson 2003). In data collected in 2001 and 2002, the cover of non-native plant species was inversely related to canopy cover, the percent cover of litter, and litter depth. The reduction of overstory trees and shrubs through hand-thinning and prescribed burning increased the amount of direct sunlight and reduced the amount of litter on the soil surface, thus making conditions favorable for non-native plant species.

Results from this study showed the existence of important interactions between vegetation and treatment type. In the plots dominated by an oak woodland overstory, understory vegetation (grass and herbaceous species) showed no detectable difference in composition among the treatments. This lack of difference could be attributable to a few important factors. First, fire in this vegetation type displayed lower severity indices than in shrub dominated vegetation. This reduction in severity was likely attributable to lower levels of masticated fuels, particularly those in 1-100 TLFM classes, as oak stands had much lower levels of understory shrub cover and thus less masticated fuel. Even where fuel loads were high, freshly fallen leaf litter and recent spring growth provided shading that limited drying of fuels. These lower severity factors contributed to greater retention of organic materials that inhibit establishment of some species and greatly reduced vigor of others. A second important factor is the retention of live overstory canopy that shaded the understory environment. These conditions are particularly unfavorable for most of annual species that dominated shrub treatment areas.

In contrast to the plots that were dominated by an oak woodland overstory, some significant differences were noted among the treatments in shrub dominated vegetation types. With the exception of the control and the unmanipulated burned treatment, all shrub dominated treatments displayed a significant increase in cover of native and exotic herbaceous species as well as whiteleaf manzanita seedlings. In unmanipulated shrub vegetation, litter is almost continuous across the soil surface and competition for light and other resources is high. Both of these factors contribute to a limited understory development. Since the spring burn of the unmanipulated brush resulted in little effect to the overstory and only marginal consumption of surface fuels, little physical change occurred and thus no detectable response noted. On the other hand, the masticated and hand thinning units had significant reductions in overstory cover. This alteration significantly increased light and reduced competition for moisture and other soil resources. As a result, cover and diversity of understory vegetation was significantly higher.

The differences in the species composition and structure varied drastically throughout the season and non-native and invasive species became much more evident in the mid to late summer. The considerable response by high priority non-native and invasive species (mostly *Centaurea melitensis*, *Cirsium vulgare*, and *Lactuca serriola*) in the masticated plots that were burned in spring as opposed to any other treatment was perhaps the most interesting. The plots that were hand-thinned (HU) or just masticated (MU) appeared to have the second greatest number of high priority non-native and invasive species, which were primarily

Cirsium vulgare and *Lactuca serriola*. The establishment of high priority non-native and invasive species within treated areas supports the theory that the combination of such factors as disturbance, removal of canopy cover and litter layers, have created conditions favorable to invasion.

Management Implications:

Prior to commencing this project, mastication treatments had never been employed within Whiskeytown and very little information was available detailing the ecological effects of such treatments. Results from this study have greatly expanded upon the existing knowledge base of park managers. While this study was site-specific, it is believed that most of these experiences would apply to a much broader audience, particularly those interested in applying mastication treatments for reduction of understory shrubs. The following list of recommendations highlights some of the more important points derived from this study to date:

- Prescriptions that incorporate multiple objectives across varied fuel and vegetation types may be complex. Under mild burning conditions, fire effects will vary significantly, largely as a function of surface fuel characteristics. In such situations, consideration should be given to develop realistic objectives for each fuel condition. Failure to account for variability in fire effects may lead to a failure to attain objectives. An alternative approach to consider where variability is expected is to limit burning to specified vegetation/fuel types, thus avoiding burning where management objectives are not likely to be met.
- Mastication of fuelbeds results in a short to medium-term increase in fire severity potential. Where utilized, mastication prescriptions should consider the need for greater canopy retention to increase shading at the soil surface and reduce total surface fuel load. Treatments should also focus on spatial arrangements and incorporate breaks within the landscape to mitigate potential fire spread.
- Where residual overstory vegetation is desired and secondary treatment for surface fuel reduction is planned in masticated fuelbeds, managers should;
 - Consider a decrease in the level of mastication intensity. This decrease will contribute to lower fire behavior indices and severity results by reducing surface fuel loading, decreasing wind circulation, and increasing shading of fuels. Such added retention would also accommodate a more realistic level of mortality from burning.
 - Apply fire under a more mild prescription. Masticated fuelbeds experience much different fire behavior than unmanipulated vegetation. Prescriptions must consider the differences in expected behavior and subsequent severity where retention of overstory or residual shrubs is desired.

- Avoid burning within the early growing season 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.
- When considering burning masticated fuel beds, anticipate the introduction and spread of high-priority non-native and invasive species.
- Fuels treatments often hasten the establishment and spread of exotic plant species. This exotic plant establishment may occur in a non-random pattern across the landscape and may not be visible during the early spring growing season.
- Because of the short to medium-term increase in fire severity potential and introduction of high-priority non-native and invasive species, hand-thinning understory species may provide the best option for meeting specific fuels management objectives while mitigating certain negative impacts to ecosystems.

Next steps:

- More extensive analyses will be conducted to further tease out the differences in vegetation response between treatments and the relationships between these responses to the microhabitat created by these treatments and fire severity. The results from these analyses will be submitted for publication in peer-reviewed journals and at symposia.
- Investigators will continue vegetation sampling (three years post fire) with an emphasis on investigating the dynamics of high priority non-native and invasive species.
- This study demonstrated an increase in fire intensity six months following mastication treatment. At this time, the masticated fuelbed was still relatively loosely arranged on the surface, allowing for significant air circulation that contributed to the increased fire intensity. Through time, decomposition and compaction of the masticated fuelbeds would occur, lowering the potential fire intensity, although the rate of change is not known. Further studies are suggested for the purpose of assessing changes through time for masticated fuelbeds.
- Additional study questions for suggested follow-up are the long-term vegetation and fuels response to differences among treatments and repeated treatments.
- The lead investigators of this project will continue to provide logistical assistance and support for studies that have built upon this project. These studies include

“Masticated fuel beds: custom fuel models, fire behavior, and fire effects” (JFSP 05-2-1-20) and the *“Effect of brush mastication on the belowground mycorrhizal community in a mixed hardwood chaparral”* (JFSP 05-2-1-87).

- Investigators will present oral paper “Fire Severity and Intensity in Natural and Manipulated Fuels during Spring burning in Mixed Shrub Woodlands” at March 2006 national fire behavior conference.

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We would like to thank Whiskeytown NRA Fire and Resource Management personnel for assistance in all aspects of this project. In particular, we want to thank Jake Blaufuss for setting up the initial treatment polygons, and Laura Green, Christy Frenzen, Michael Commons, Vanessa Stanger, Sue Kelso, Justin Cully, Anna Hunt, Johanna D’Arcy, Ed Waldron, James Savage, Chris Sprague, and Kerry Barton for data collection assistance. Much appreciation to Patrick Lookabaugh for designing and building the seedbank exclosures. We also want to thank North Tree Fire International for assistance with the mastication treatment, and the California Conservation Corps, California Department of Forestry and Fire Protection, and USFS, Redding Hotshots and Redding Smokejumpers for assistance with the hand thinning and burn treatments. This project was made possible by funds provided by the Joint Fire Science Program.

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Appendix A: Dissemination of Project Results

Webpage

<http://www.nps.gov/whis/exp/fireweb/FireEcology/BrushMastication/intro.htm>

Presentations

“Fire, Fuels and the Urban Interface”. Jennifer Gibson. Kirlin Science Lecture Series, ScienceWorks Museum, February, 27th, 2004, Ashland, OR.

“The Challenges of Managing for Fire and Species Diversity within the Wildland Urban Interface”. Jennifer Gibson and R. Bruce Bury (USGS-FRESC). Society of Northwestern Vertebrate Biologists Annual Meeting. March 22, 2003. Arcata, California.

“Preliminary Findings of the Brush Mastication Research Project.” Tim Bradley and Jennifer Gibson. Whiskeytown National Recreation Area Fire and Resource Management Staff, June 2004, Whiskeytown, CA.

National Park Service Klamath Network Inventory and Monitoring Program Meeting, December, 2003, Ashland, OR.

National Park Service Pacific West Region Fire Ecologist Annual Meeting, 2003, Yosemite, CA.

Posters

Joint Fire Science Program Annual Principal Investigator Workshop. March 2004. Phoenix, AZ.

Second International Wildland Fire Ecology and Fire Management Congress. November 2003. Orlando, FL.

Collaboration

Masticated fuel beds: custom fuel models, fire behavior, and fire effects (JFSP 05-2-1-20). Principal Investigators: Eric E. Knapp, Matt D. Busse, J. Morgan Varner, and Carl N. Skinner, USFS Pacific Southwest Research Station.

Effect of brush mastication on the belowground mycorrhizal community in a mixed hardwood chaparral (JFSP 05-2-1-87). Principal Investigator: Darlene Southworth, Southern Oregon University.

West Coast Regional Carbon Sequestration Partnership. Sandra Brown and Nicholas Martin, Forest Carbon Monitoring Program, Winrock International.

Reports

Effects of Alternative Fuel Reduction Treatments in Mixed Forest Shrublands. *in*

Joint Fire Science Program. 2005. Joint Fire Science Program 2004 Business Summary. BLM/FA/GI-05/006+9200. Denver, Colorado. 44 pp.

Field Trips

Researchers: USFS Pacific Southwest Research Station, November 2005.

Researchers: Winrock International, September 2005.

Students: Humboldt State University and USFS, May 2005.

Students: Humboldt State University, April 2005.

Researchers: Southern Oregon University, April 2005.

Researchers: USFS Pacific Southwest Research Station, October 2004.

Students: Humboldt State University, April, 2004.

Managers: Shasta County Resource Conservation District and Water Quality Control Board,
June 2003.

Students: Humboldt State University, April 2003.

Managers: National Park Service, March 2003.

Appendix B: Deliverables

DELIVERABLES

<i>Proposed</i>	<i>Accomplished/Status</i>
Annual progress reports	Four annual progress reports completed.
Furnish a report to Whiskeytown's Fire and Resource Management Programs that will provide guidelines on which, if any, hazardous fuel reduction treatments best minimize impacts to soils and the introduction and spread of non-native plant species.	<ul style="list-style-type: none"> • The results of this research have been summarized in several fire management planning meetings and have been valuable to Whiskeytown National Recreation Area fire and resource management staff, significantly influencing future fuels treatments in the park's low elevation plant communities. • A formal presentation was given to the park's Fire and Natural Resource Management staff.
Project Webpage	A website has been developed to share current and future findings with managers and scientists nationwide. < http://www.nps.gov/whis/exp/fireweb/FireEcology/BrushMastication/intro.htm >

<i>Other Deliverables</i>	<i>Accomplished/Status</i>
Fire Behavior and Fire Severity Data	Pre- and post-burn measurements of fuels, fire behavior, temperature extremes, canopy scorch and mortality were added to the data collection phase of this project. These data have been very valuable to local fire managers and have been presented to a national audience through conference presentations and a webpage.
Poster Presentations at National Conferences	<ul style="list-style-type: none"> • Joint Fire Science Program Annual Principal Investigator Workshop. March 2004. Phoenix, AZ. • Second International Wildland Fire Ecology and Fire Management Congress. November 2003. Orlando, FL.
Cooperation with other JFSP research projects	<ul style="list-style-type: none"> • JFSP 05-2-1-20: Masticated fuel beds: custom fuel models, fire behavior, and fire effects • JFSP 05-2-1-87: Effect of Brush Mastication on the Belowground Mycorrhizal Community in a Mixed Hardwood Chaparral
Cooperation with non-JFSP research projects	West Coast Regional Carbon Sequestration Partnership. Forest Carbon Monitoring Program, Winrock Int.

Conference Presentations	Accepted oral presentation 1 st Fire Behavior and Fuels Conference, March 2006.
Non-conference Presentations	The preliminary results of this project have been presented to local park staff, regional National Park Service managers and ecologists, and the public in four non-conference meetings.
Fieldtrips	Study tours of the project site have been provided to: <ul style="list-style-type: none"> ▪ NPS and local county land managers (3), ▪ Cooperating researchers (4), and ▪ University fire ecology classes (3)
Reports	Effects of Alternative Fuel Reduction Treatments in Mixed Forest Shrublands. <i>In</i> Joint Fire Science Program. 2005. Joint Fire Science Program 2004 Business Summary. BLM/FA/GI-05/006+9200. Denver, Colorado. 44 pp.

Appendix C: Species Summary Tables

TRTMNT	HIGHEST COVER		MOST FREQUENT	
	NATIVE	EXOTIC	NATIVE	EXOTIC
MS	ODONTOSTOMUM HARTWEGII	VULPIA MYUROS	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	VULPIA MYUROS
	DICHELOSTEMMA MULTIFLORUM ARCTOSTAPHYLOS VISCIDA (SEEDLING)	AIRA CARYOPHYLLEA	DICHELOSTEMMA MULTIFLORUM	GASTRIDIDIUM VENTRICOSUM
		GASTRIDIDIUM VENTRICOSUM		CALOCHORTUS TOLMIEI
		HYPOCHAERIS GLABRA	PINUS SEEDLING	HYPOCHAERIS GLABRA
	CALOCHORTUS TOLMIEI	HYPOCHAERIS GLABRA	PINUS SEEDLING	AIRA CARYOPHYLLEA
HYPERICUM CONCINNUM	VULPIA BROMOIDES	HYPERICUM CONCINNUM	FILAGO GALLICA	
MU	DICHELOSTEMMA MULTIFLORUM	VULPIA MYUROS	DICHELOSTEMMA MULTIFLORUM	VULPIA MYUROS
	ODONTOSTOMUM HARTWEGII	GASTRIDIDIUM VENTRICOSUM	CALOCHORTUS TOLMIEI	AIRA CARYOPHYLLEA
	CALOCHORTUS TOLMIEI	AIRA CARYOPHYLLEA	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	GASTRIDIDIUM VENTRICOSUM
	GNAPHALIUM CANESCENS SSP. BENEOLENS	HYPOCHAERIS GLABRA	GALIUM SP	HYPOCHAERIS GLABRA
	GALIUM SP	FILAGO GALLICA	PINUS SEEDLING	BROMUS MADRITENSIS SSP RUBENS
NS	SALVIA SONOMENSIS	VULPIA MYUROS	CALOCHORTUS TOLMIEI	VULPIA MYUROS
	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA	DICHELOSTEMMA MULTIFLORUM	GASTRIDIDIUM VENTRICOSUM
	GALIUM SP	GASTRIDIDIUM VENTRICOSUM	GALIUM SP	AIRA CARYOPHYLLEA
	CALOCHORTUS TOLMIEI	HYPOCHAERIS GLABRA	ODONTOSTOMUM HARTWEGII	HYPOCHAERIS GLABRA
	ODONTOSTOMUM HARTWEGII	BROMUS MADRITENSIS SSP RUBENS	SANICULA BIPINNATIFIDA	BROMUS MADRITENSIS SSP RUBENS
			VULPIA BROMOIDES	
NU	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA
	ODONTOSTOMUM HARTWEGII	VULPIA MYUROS	CALOCHORTUS TOLMIEI	VULPIA MYUROS
	GALIUM SP	HYPOCHAERIS GLABRA	GALIUM SP	GASTRIDIDIUM VENTRICOSUM
	CALOCHORTUS TOLMIEI	GASTRIDIDIUM VENTRICOSUM	ODONTOSTOMUM HARTWEGII	HYPOCHAERIS GLABRA
	SANICULA BIPINNATIFIDA	VULPIA BROMOIDES	SANICULA BIPINNATIFIDA	VULPIA BROMOIDES
			BROMUS MADRITENSIS SSP RUBENS	
HU	ODONTOSTOMUM HARTWEGII	AIRA CARYOPHYLLEA	DICHELOSTEMMA MULTIFLORUM	VULPIA MYUROS
	DICHELOSTEMMA MULTIFLORUM	VULPIA MYUROS	CALOCHORTUS TOLMIEI	AIRA CARYOPHYLLEA
	SANICULA BIPINNATIFIDA	HYPOCHAERIS GLABRA	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	GASTRIDIDIUM VENTRICOSUM

CALOCHORTUS TOLMIEI	GASTRIDIDIUM VENTRICOSUM	VULPIA MICROSTACHYS	HYPOCHAERIS GLABRA
VULPIA MICROSTACHYS	BROMUS MADRITENSIS SSP RUBENS	GALIUM SP	BROMUS MADRITENSIS SSP RUBENS
	FILAGO GALLICA		

TRTMNT	HIGHEST COVER		MOST FREQUENT	
	NATIVE	EXOTIC	NATIVE	EXOTIC
MS	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	VULPIA MYUROS
	ODONTOSTOMUM HARTWEGII	AIRA CARYOPHYLLEA	DICHELOSTEMMA MULTIFLORUM	GASTRIDIDIUM VENTRICOSUM
	TOXICODENDRON DIVERSILOBUM	GASTRIDIDIUM VENTRICOSUM	HETEROMELES ARBUTIFOLIA	HYPOCHAERIS GLABRA
	DICHELOSTEMMA MULTIFLORUM	HYPOCHAERIS GLABRA	CALOCHORTUS TOLMIEI	AIRA CARYOPHYLLEA
	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	VULPIA BROMOIDES	PINUS SEEDLING	FILAGO GALLICA
MU	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS
	DICHELOSTEMMA MULTIFLORUM	GASTRIDIDIUM VENTRICOSUM	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA
	ODONTOSTOMUM HARTWEGII	AIRA CARYOPHYLLEA	CALOCHORTUS TOLMIEI	GASTRIDIDIUM VENTRICOSUM
	TOXICODENDRON DIVERSILOBUM	HYPOCHAERIS GLABRA	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	HYPOCHAERIS GLABRA
	CALOCHORTUS TOLMIEI	FILAGO GALLICA	GALIUM SP	BROMUS MADRITENSIS SSP RUBENS
NS	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS
	ARCTOSTAPHYLOS VISCIDA (LIVE, MATURE)	AIRA CARYOPHYLLEA	CALOCHORTUS TOLMIEI	GASTRIDIDIUM VENTRICOSUM
	SALVIA SONOMENSIS	GASTRIDIDIUM VENTRICOSUM	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA
	TOXICODENDRON DIVERSILOBUM	HYPOCHAERIS GLABRA	GALIUM SP	HYPOCHAERIS GLABRA
	DICHELOSTEMMA MULTIFLORUM	BROMUS MADRITENSIS SSP RUBENS	ARCTOSTAPHYLOS VISCIDA (LIVE, MATURE)	BROMUS MADRITENSIS SSP RUBENS
			VULPIA BROMOIDES	
NU	HETEROMELES ARBUTIFOLIA	AIRA CARYOPHYLLEA	HETEROMELES ARBUTIFOLIA	AIRA CARYOPHYLLEA
	ARCTOSTAPHYLOS VISCIDA (LIVE, MATURE)	VULPIA MYUROS	DICHELOSTEMMA MULTIFLORUM	VULPIA MYUROS
	DICHELOSTEMMA MULTIFLORUM	HYPOCHAERIS GLABRA	ARCTOSTAPHYLOS VISCIDA (LIVE, MATURE)	GASTRIDIDIUM VENTRICOSUM
	ODONTOSTOMUM HARTWEGII	GASTRIDIDIUM VENTRICOSUM	CALOCHORTUS TOLMIEI	HYPOCHAERIS GLABRA
	TOXICODENDRON DIVERSILOBUM	VULPIA BROMOIDES	GALIUM SP	VULPIA BROMOIDES

				BROMUS MADRITENSIS SSP RUBENS
HU	HETEROMELES ARBUTIFOLIA	AIRA CARYOPHYLLEA	HETEROMELES ARBUTIFOLIA	VULPIA MYUROS
	ODONTOSTOMUM HARTWEGII	VULPIA MYUROS	DICHELOSTEMMA MULTIFLORUM	AIRA CARYOPHYLLEA
	DICHELOSTEMMA MULTIFLORUM	HYPOCHAERIS GLABRA	CALOCHORTUS TOLMIEI	GASTRIDIVM VENTRICOSUM
	TOXICODENDRON DIVERSILOBUM	GASTRIDIVM VENTRICOSUM	ARCTOSTAPHYLOS VISCIDA (SEEDLING)	HYPOCHAERIS GLABRA
	SANICULA BIPINNATIFIDA	BROMUS MADRITENSIS SSP RUBENS	VULPIA MICROSTACHYS	BROMUS MADRITENSIS SSP RUBENS
	FILAGO GALLICA			

