Fire Hazard Reduction in Ponderosa Pine Plantations: Final Report to the Joint Fire Science Program

Project number 00-2-30

GROVELAND RANGER DISTRICT, STANISLAUS NATIONAL FOREST, CA

Understory burn in masticated stand

Mastication

Pre-treatment conditions

Understory burn in pruned stand

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EXECUTIVE SUMMARY

Ponderosa and other pine plantations add to the complexities of forest resource management. Assuring the health and fire resilience of dense young stands (1-30 years old) is a relatively new challenge faced by the USDA Forest Service and other natural resource managers. Although tree density in most Northern California plantations is currently at an "acceptable" level, as these stands continue to grow, mortality risk from inter-tree competition, disease, insect infestation and fire is likely to increase significantly over the next 10 to 20 years. Without an active fuels management program, losses will almost assuredly occur in these plantation areas. Located in the central Sierra Nevada Stanislaus National Forest (SNF), the “Fire Hazard Reduction in Ponderosa Pine Plantations” project is predicated upon implementation of the larger Granite Stewardship Pilot Project. The Pilot Project is one of the original, most complex and largest ventures authorized under Section 347 of the Omnibus Consolidated Appropriations Act of Fiscal Year 1999 (PL 105-277). The initial attempt to award the various fuels treatments under a single, multi-million dollar contract failed. By late summer, 2004, the SNF instead successfully awarded three multi-year stewardship contracts to accomplish the plantation fuels manipulations that are the basis of this Joint Fire Sciences Program (JFSP)- supported research project. Within the time frame originally proposed (2001-2003) and including the two years’ no-cost extensions granted by the JFSP, the University of California, Berkeley/ SNF partnership has worked to maximize the research results based on the fuels reduction treatments completed by the end of 2005.

All fire hazard reduction treatments were implemented in 25-30 year old ponderosa / Jeffrey pine plantations, which were established following the 1973 Granite Fire. The forest manipulations evaluated in this study include 1) shredding of understory vegetation and all trees < 9 inches in diameter (mastication), 2) mastication followed by understory prescribed fire, 3) understory burning alone, and 4) control. The effectiveness of these treatments is evaluated using a recently-developed fire modeling program, Fuels Management Analyst (FMA), that incorporates numerous previously published methodologies to provide not only fire behavior predictions, but tree-level fire severity assessments. The stand-scale fire behavior analyses produced by FMA are appropriate for the dissemination of research results to actual forest management needs, and represent an effective tool for this and future scientist-manager partnerships in fire science.

The Project deliverables include: (a) the successful establishment of collaborative relationships with all partners, including a Monitoring Team comprised of representatives from local environmental, industry, and native American groups (b) establishment of 15 permanent plantation forest research sites, (c) baseline and post-treatment data collection, (d) implementation of three experimental treatments, (d) documentation of treatment costs, (e) analysis of treatment effectiveness, and (f) designation of research site as demonstration area for technology transfer to professionals and for the education of students and the public. We have also developed a world-wide website, and look forward to establishing a signed public field tour after all treatments have been installed. Three publications have been submitted to peer-reviewed journals, and a Ph. D dissertation (UC Berkeley) has been filed based on these fire hazard reduction treatments.

Key findings described in detail in this report include:

- Prescribed understory fire was most effective at reducing surface fuel loads and decreasing modeled parameters of potential fire behavior and severity.
- All fire behavior indices were highest in masticated stands in comparison to both burned and control units, and would be expected to remain high pending additional treatments or natural decomposition-related reduction of fuel loads.
- Predictions of tree mortality under weather conditions conducive to wildfire events were most severe in masticated units.
- Spring burning reduced fuel loads in both masticated and untreated plantation units.
- Actual tree mortality following understory burning in masticated units is likely to be higher than in the untreated unit.

At present, additional mastication and thinning treatments are being implemented throughout the plantation. In the next 2 years, prescribed understory burning will also be used to reduce forest floor fuel loads in the Granite plantations. The permanent plots installed in the 15 stands provide the baseline data for continued monitoring as additional (cut-to-length followed by prescribed fire, whole tree removal, and whole tree removal followed by burning) treatments are implemented, while the results reported here can be immediately incorporated into adaptive management strategies to help managers reach fire hazard reduction goals.

1. Introduction[a]

In California alone, plantation forests cover nearly 162,000 ha in the Modoc, Lassen, Plumas, Tahoe, El Dorado, Stanislaus, Inyo, Sierra and Sequoia National Forests combined (Landram 1996). Extreme fire hazards are present in and around many of these plantations, linked to: high success rates in replanting and dense post-fire understory growth; low summer fuel moisture; steep, mountainous terrain; frequent ignitions from lightning; and increased public recreation in national forests. These and other considerations have led to broad-ranging forest fuels reduction prescriptions for plantation and other forests on US public lands (HFRA, 2003). The efficacy of the variety of available fuels reduction strategies for plantations has received little attention, but should be addressed before large-scale prescriptions are implemented.

To be effective, fuels reduction prescriptions must be designed specifically for the forest type, the local environmental conditions, and the particular hazards associated with the surrounding vegetation and/or structures.

In fire-adapted ecosystems, evaluation of the longer-term goals of prescriptions should reflect an understanding of the historical range of variability in that forest's fire regime (Morgan et al. 1994). Although plantations are not naturally fire-adapted forest stands, they are considered the most effective means of reforestation after fire, and are often planted where fire is historically frequent. In addition, they are most often comprised of fire-adapted species such as ponderosa pine (Pinus ponderosa Dougl. ex P. & C. Laws), and are subjected to the same ignitions and environmental conditions as their fire-prone predecessors and neighboring stands. Whether in natural or plantation forests, fire hazard reductions have the same ultimate goal: to manipulate forest structure so that the possibility for stand-replacing, intense crown fire behavior is reduced. Such forest structures would then be considered fire-resilient, or capable of sustaining natural fire occurrence with minimal loss of basal area (Agee and Skinner, 2005).

Common principles of successful fuels reduction strategies for all forest types in the American West have been defined as 1) reduction of surface fuels, 2) increases in the height to live crowns,

[a] Similar versions of this report have been submitted in the Ph. D. dissertation of L. Kobziar, (UC Berkeley), and as a manuscript for publication in the International Journal of Wildland Fire.

3) decreases in crown density, and 4) retaining of the largest trees in a stand (Agee and Skinner, 2005). The techniques available for achieving these outcomes include mastication (shredding of understory vegetation and small trees), various types of thinning (i.e. low thinning from below; Keyes and O'Hara, 2002), prescribed burning, and combinations thereof (Weatherspoon, 1996; Omi and Kalabokidis, 1998). Evaluations of the efficacy of such techniques in reducing potential crown fire behavior, and thereby increasing resilience after fire, must rely on fire behavior modeling, as experimental crown fires are not feasible in the dry forests of the western US. Evidence in other forests has been amassed by observing the effects of wildfires in fuels-treated areas (Weatherspoon and Skinner, 1995), by modeling both fuels treatments and potential fire behavior, (van Wagtendonk, 1996; Stephens, 1998) or by treating fuels and then modeling potential fire behavior (Kalabokidis and Omi, 1998; Stephens and Moghaddas, 2005a).

This study uses fire behavior and effects modeling to address the efficacy of four actual fuels reduction procedures in a Sierra Nevada pine plantation located in the Stanislaus National Forest, CA. The manipulations include 1) mastication of understory and small trees, 2) mastication followed by understory burning, 3) understory burning alone, and 4) control. The study design also provides the opportunity for a novel comparison of actual and predicted fire behavior and effects. The overall objective is to evaluate the relative benefits of the treatments within the context of future fire severity, and the eventual re-introduction of fire as a management tool in plantations.

2. Methods

2.1. Background and site description

In the Groveland Ranger District of the Stanislaus National Forest (Fig. 1), approximately 70% of the second-growth mixed-conifer vegetation has been significantly impacted by large (>1000 ha) and typically high severity wildfires since the 1970s. Ponderosa pine (Pinus ponderosa Dougl. ex P. & C. Laws) and Jeffrey pine (Pinus jeffreyi, Grev. & Balf.) plantations were established following the stand-replacement Granite Fire of 1973 to restore forests to the burned area. Dense young stands now cover 6000 ha of previously mixed-conifer forest habitat. The

Granite Stewardship Pilot Project includes a range of treatments designed to accomplish a wide array of goals. Increased spotted owl habitat, noxious weed elimination, stream restoration, road and meadow rehabilitation, vegetative diversity enhancement, improvement of tree health, and reduction of fire hazards are all included in the overall project scope, which covers not only plantations but also mixed-conifer stands. The specific objectives of the SNF silvicultural and burning prescriptions in the established plantations include wildfire hazard reduction, reduction of competition between trees, and creation of a more resilient plantation forest.

Extending from 1500-1800 meters in elevation, the Granite plantations are influenced by a Mediterranean climate with summer drought and total annual precipitation averaging 130 cm, 80% of which is snowfall. Snowpack can at times linger through to the end of June. Summer drought conditions are common. Average summer and winter temperatures are 21°C and 4°C. (WRCC 2005). Soils, formed from weathered granitic or metasedimentary rocks, are Inceptisols in the Pachic Xerumbrepts class, and belong to the Fiddletown series. They are moderately deep to deep (50-100 cm depth), with a gravelly sandy loam texture in the upper horizons (USDA 1981).

Seedlings planted on this substrate were germinated from seed sources within the local western slope Sierra Nevada mixed-conifer forest type, and included Jeffrey pine, sugar pine (Pinus lambertiana Dougl.), ponderosa pine, Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), white fir (Abies concolor Gord. & Glend), incense-cedar (Calocedrus decurrens [Torr.] Floren.), and infrequent giant sequoia (Sequoiadendron giaganteum (Lindl.) Buchh). Ponderosa and Jeffrey pine comprise more than 90% of the pretreatment and over 95% of the post-mastication tree composition in all stands. Infrequent California black oak (Quercus kelloggii Newb.), and dogwood (Cornus nutallii Audubon ex. Torr. and Gray) were established in the plantations via natural seed dispersal mechanisms from proximate mixed-conifer forests. The understory is largely composed of whitethorn (Ceanothus cordulatus Kellogg), and greenleaf manzanita (Arctostaphylos patula E. Greene), with less abundant species including gayophytum (Gayophytum diffusum Torrey & A. Gray), Sierra current (Ribes nevadense Kellog.), Sierra gooseberry (Ribes roezlii Regel.) and bracken fern (Pteridium aquilinum (L.) Kuhn).

2. 2. Experimental design

The Granite plantation stands were similar in aspect, slope, and soil type, and were between five and 82 ha in area. Permanent plots were established in replicated stands for three of the four treatments types, while the Fire Only treatment was only implemented in one stand. Due to a limited burn window (one day) and other logistical constraints, the Fire Only treatment could not be replicated. Each plantation research stand consisted of seven, 0.04-ha circular plots, arranged at 50 x 50 m grid spacing with a randomized starting point location.

The fuels manipulation techniques included 1) mastication of small trees (≤ 23 cm in diameter) and surface fuels, all materials left on site, (Mastication), 2) mastication of small trees as in 1), followed by understory burning (Mastication + Fire), 3) understory burning alone (Fire Only), and 4) control (Control) (Table 1a). Stands used in this study were randomly chosen from predetermined groups of stands assigned to particular treatment types, as defined by the US Forest Service. The mastication of trees ≤ 23 cm was used to decrease the density of stems to between 4 x 4 and 6 x 6 m spacing, with emphasis on the removal of suppressed, diseased, or otherwise weakened trees. Four total stands underwent this treatment (Table 1a). Understory shrubs and trees were also masticated, and all activity fuels (residual slash created by the mastication) were left on site. Mastication in stands 5-106, 5-185, 5-89, and 5-188 was conducted between 2003 and early 2004, and cost an average of $1050/ha ($425/acre: USFS Contracting Officer, K. Stillwell, personal communication). Burning in 5-106 and 5-185 followed mastication, after fuels were left to cure for over a year. All burns were conducted on June 28, 2005, and the estimated cost per hectare was $1580/ha (~$640/acre). Stand 5-132 had been masticated and pruned up to 2.5 m in the early 1990s, but was otherwise untreated before the burn. The remaining stands where pre-treatment forest inventory, fuels, and vegetation data was collected but where no treatment had been installed before 2005 served as controls (Table 1a).

In addition, nine soil carbon respiration measurement plots were established in each of the five units as described in Table 1a. Analyses of treatment effects on soil carbon efflux rates were included in the UC Berkeley Ph. D dissertation, but were not an original component of the JFSP project. The results of this work are summarized in the abstracts found in Appendix B.

Table 1a. Changes between original treatment designations and 2005 status of fifteen ponderosa/ Jeffrey pine plantation stands in the Stanislaus National Forest, CA.

STAND	ORIGINAL PRESCRIPTION	2005 STATUS	DESCRIPTION OF PLOTS IN STAND
5-79	CTL+Rx fire	Untreated (Control)	7 Forest, fuels, vegetation inventory plots
5-81	CTL+Rx fire	Untreated (Control)	7 Forest, fuels, vegetation inventory plots
5-132	CTL+Rx fire	Burned	7 Forest, fuels, vegetation inventory plots, 9 soil plots
8-50	WTR+Rx fire	Untreated (Control)	7 Forest, fuels, vegetation inventory plots
5-150	WTR+Rx fire	Untreated (Control)	7 Forest, fuels, vegetation inventory plots, 9 soil plots
5-41	WTR+Rx fire	Untreated (Control)	7 Forest, fuels, vegetation inventory plots
5-106	Mastication	Masticated, Burned	7 Forest, fuels, vegetation inventory plots, 9 soil plots
5-89	Control	Masticated	7 Forest, fuels, vegetation inventory plots
5-188	Mastication	Masticated	7 Forest, fuels, vegetation inventory plots
5-185	Mastication	Masticated, Burned	7 Forest, fuels, vegetation inventory plots
5-69	WTR+Shred	Untreated (Control)	7 Forest and Fuels Inventory plots
5-112	WTR+Shred	Untreated (Control)	7 Forest and Fuels Inventory plots
5-184	WTR+Shred,	Untreated (Control)	7 Forest and Fuels Inventory plots, 9 soil plots
2-5	Control	To be shredded 2006	7 Forest and Fuels Inventory plots
2-166	Control	To be shredded 2006	7 Forest and Fuels Inventory plots

2. 3. Vegetation and fuels measurements

In each of the 0.04 ha plots (63 total), all tree diameters, heights, live crown ratios, crown position (i.e. dominant, suppressed) and heights to live crown were documented, along with basal area, and percent canopy cover before and after each treatment. Pretreatment data was collected from 2001-2002. Canopy cover was measured at 5 grid points per plot in each stand using a GRS densitometer (Gill et al., 2000). There were no seedlings or saplings found within 0.004 ha nested subplots centered at the center point of each plot. Post-treatment plot data was collected in each stand within five months of mastication, and within three months of prescribed burning treatment implementation.

Both before and after treatment implementations, surface and ground fuel loads (tons/ha) were measured using the standard planar intercept technique (Brown 1974). In each plot, three fuels transects were established, resulting in a total of 189 transects for the overall study. Along the 10 m long transect, from 0-2 m one-hour (0-0.64 cm) and ten-hour (0.64-2.54 cm) fuels were sampled, while 100-hour (2.54-7.62 cm) fuels were inventoried from 0-3 m and 1000-hour (>7.62 cm) and larger fuels from 0-10 m. Duff and litter depth in cm were measured at 5 and 10 m on each transect. Fuel depth (cm) was measured at three points between 1 and 2 m. Intercepted fuel particles were converted to fuel loading according to equations generated for California ponderosa pine forests (van Wagtendonk et al., 1996; 1998).

Understory vegetation was measured using a line-intercept method starting from a 2 m randomized displaced location (to prevent trampling of vegetation) from each plot's center. A 5 m transect was established, and understory vegetation species, rock, litter, or bare ground recorded at each decimeter. A total of 350 points were tallied in each unit before and after each treatment implementation. Understory vegetation was consistently measured between June and July to correspond with seasonal flowering and to aid in proper identification of species. Post-treatment understory vegetation sampling was generally conducted in the growing season following each treatment to allow for sprouting recovery and germination of seeds. Because burns were conducted in June of 2005, understory sampling for 2006 was only recently completed and results are summarized in Appendix E.

2. 4. Prescribed burning

Three stands were burned on the same day in the late spring of 2005. Although June 28th would typically be associated with summer and even fire season conditions in this location, it was an uncharacteristically late spring throughout the Sierra Nevada, with precipitation falling through to the second half of June. In the study area, nearly 2 cm of rain fell on the 17th of June. Objectives for the prescribed burning treatments were to 1) reduce 1-100 h fuels to 1.1-6.7 tons/ha, 2) retain mature brush, down logs > 38 cm, and 5 cm of duff and litter, and 3) limit mortality to less than 20% of the pre-burn stand stocking.

One hour prior to burning, fuel samples were collected to determine live and dead moisture contents on a dry weight basis. Each fuel type (1 h, 10 h, 100 h, 1000 h sound and rotten, live shrub, canopy, and duff and litter) had 3 replicates collected and oven dried at 105 °C for 24 hours. Fires were ignited using a combination of backing and strip-head fires (Martin and Dell, 1978). Burning was conducted from 10:00 AM to 11:00 PM. Desired environmental conditions for the burns were achieved, including relative humidity between 25-60%, windspeeds below 8 km/h, temperatures between 0-24°C, and 10 h fuel moistures between 7-15% throughout the day. During the prescribed fires, rate of spread was measured between multiple segments of distance which had been marked on trees prior to the burn. Numerous fire effects monitoring personnel also estimated flame lengths and rates of spread. Flame lengths were used to calculate fire line intensity (I) in kW/m for each stand burned using the following equation from Byram (1959):

$$I = 259.83L^{2.17} \tag{1}$$

where L = flame length. This measure describes the rate of heat release per unit length of flaming front (kW m^{-1}) and is associated with fire-caused injuries in above-ground plants (Van Wagner 1973). Post-fire sampling of fuel transects were conducted within one month of the burns, while assessments of tree injuries were conducted in the late fall of 2005. Burned stand overstory characteristics were also re-measured in the late fall. The resulting percent crown volume scorched (PCVS) and scorch height data are used for a comparison of actual vs. modeled fire effects. Because tree mortality can continue for up to eight years after fire-induced injuries are sustained, and post-fire mortality is typically assessed at least a year after fires, (Ryan et al. 1988), comparisons of actual vs. predicted mortality were not possible. Instead, logistic regression equations developed for ponderosa pine in the Sierra Nevada were used to estimate mortality of different size classes given particular degrees of PCVS (Stephens and Finney, 2002).

2. 5. Potential fire behavior modeling

Fire Family Plus (Main et al. 1990) was used to determine fire weather conditions for modeling potential fire behavior at the 80th, 90th, and 97.5th percentiles fire weather. These percentiles represent moderate, high, and extreme fire weather, respectively. Climate information was compiled using a long-term Remote Access Weather Station (RAWS) data set. The Mount Elizabeth RAWS station has collected data from 1961-1970, and from 1972-2003, and is located approximately 30 km from the sites at an elevation of 1504 m.

Fuels Management Analyst (FMA) was used to model potential fire behavior and effects (Carlton, 2004). Fire behavior output variables include average flame length, fireline intensity, size of fire one hour after ignition, and torching and crowning indices (TI and CI). These indices portray the wind speed at 6.1 m height that would result in torching (passive crown fire) or a sustained crown fire (active crown fire) (Scott and Reinhardt, 2001). FMA utilizes published methodologies in its computations of potential fire behavior, crown bulk density, and scorch and tree mortality patterns for each tree evaluated. Stand characteristics are entered as individual tree datum, including crown class (dominant, codominant, intermediate, or suppressed), live crown ratio, height, diameter, and species. Fire behavior modeling is based on the intersection of stand characteristics, fuel loads and distribution, and fire weather. A synopsis of methods used by FMA can be found outlined in Stephens and Moghaddas (2005a and 2005b).

2. 6. Data analysis

Differences between pretreatment fuel loads and stand characteristics were evaluated using analysis of variance (ANOVA). Because all stands were not re-measured after each of the treatments, a standard repeated measures analysis could not be employed without numerous complicating assumptions. Instead, an analysis of covariance (ANCOVA) is used, with the prior measurement serving as the covariate for each stage of treatments (Milliken and Johnson, 2002; Stephens and Moghaddas, 2005a). After each treatment, Bonferroni multiple pairwise comparisons (Zar, 1999) evaluated at the mean of the covariate were used to test for significant differences between all stand and fuels characteristics ($p < 0.05$). The Jump Statistical Software package was employed for these analyses (Sall et al., 2001). Modeled potential fire behavior and effects were not statistically compared, as the propagation of error associated with the numerous methodologies employed in their development would have precluded the detection of significant differences.

3. Results

3. 1. Stand and fuels characteristics

Pretreatment stand and fuels characteristics did not differ between treatment types (Tables 1b and 2). One-hundred eighty, 141, 95, and 166 trees ha^{-1} under 23 cm in diameter were shredded and remnants were distributed throughout stands 5-89, 5-106, 5-185, and 5-188, respectively. Following mastication, trees ha^{-1} were reduced while mean height to live crown, tree height, and diameter were significantly increased in the Mastication and Mastication + Fire stands relative to the Controls (Table 3). Mean basal areas were not significantly changed, although tree growth between the sampling years in Mastication + Fire stands resulted in a slight increase in mean basal area even following mastication. This is probably a result of a lesser percentage of trees being removed in the Mastication + Fire stands (32%) than in the Mastication stands (52%). Canopy cover was reduced in the Mastication stands, but not in the Mastication + Fire treatment (Table 3). In these stands, increased canopy cover was, again, reflective of high growth rates between 2001-2004 and a lower degree of tree removal.

When compared with the Controls, prescribed burning increased basal area in the Mastication + Fire treatment but not in the Fire Only stand (Table 4). Basal area increases in Mastication + Fire were also detectable when compared with Mastication (Table 4). The Fire Only mean diameter and height increased in relation to Controls after burning, while height to live crown base increased in both Mastication + Fire and Fire Only manipulations (Table 4). Burning had no significant impact on canopy cover in burned stands, although scorched foliage had not fallen at the time of post-fire measurements.

The mastication prescription resulted in an increases in 100 h fuels in both the Mastication + Fire and in the Mastication stands, but the increase was not statistically significant in the Mastication only stands when compared with Controls (Table 5). Based on the analysis of covariance, there were no other detectable differences between fuel loads resulting from mastication. When pre- and post-treatment fuels are compared within treatments, mastication increased all fuel loads except 1000 h (Table 6). In the Fire Only stand, duff, litter, 1000 h, and total fuel loads were lowered, while 1 and 100 h fuels increased relative to the pre-burn conditions (Table 6). Following prescribed burning, all fuels were lower in Mastication + Fire stands in relation to their post-mastication loads (Table 6). When compared to pretreatment loads, 10 and 100 h fuels along with duff load were still higher after the succession of treatments (mastication followed by fire) in Mastication + Fire stands (Table 6), which may have been a residual effect from the mastication treatment. When compared with post-mastication fuel loads, all fuel types were reduced after prescribed burning in Mastication + Fire stands. Compared with the Controls, there were no detectable differences in total fuel loads following the prescribed burns (Table 7). In the Mastication + Fire and Fire Only stands, post-burning litter loads were lower than in the Mastication stands, while decreases were not detectable when compared with the Controls. Burning reduced 1 and 10 h fuel loads in the Mastication + Fire stands when compared with the Mastication treatment (Table 7).

3. 2. Fire modeling

Potential fire behavior was determined for the 80th, 90th, and 97.5th fire weather and fuel moisture conditions (Table 8). Mastication treatments resulted in longer flame lengths, higher fireline intensity, and a greater potential for torching when compared with the Controls and pretreatment Fire Only stands (Table 9). Fire rates of spread were similar between all treatment types after mastication. Passive crown fire behavior was predicted at the 90th and 97.5th percentile weather scenarios for the Control, Mastication, and Mastication + Fire stands (Table 9). At the 97.5th percentile, mastication resulted in 100% and 50% passive crown fire behavior in the Mastication and Mastication + Fire stands, respectively (Table 9). Only surface fire behavior was predicted for the pretreatment Fire Only stand, where pruning and mastication in the early 1990s had removed ladder fuels.

Following prescribed burning, rate of spread, flame length, and fireline intensity were markedly lower in Mastication + Fire and Fire Only treatments when compared to Control and to Mastication treatments, and fires were exclusively surface fires compared to at least 20% passive crown fire behavior in the 90th and 97.5th percentiles (Table 10). When compared with masticated and pretreatment Mastication + Fire and Fire Only stands, fire sizes one hour after ignition were orders of magnitude lower after prescribed burning (Tables 2.9 and 2.10).

Canopy bulk density was lower following mastication and higher after burning relative to Controls (Table 11). Canopy bulk density in Mastication + Fire stands was reduced by mastication, then regained near-pretreatment values following prescribed burning and two years' worth of diameter and height growth (Tables 11, 1b, and 3). Canopy bulk density was also higher in the Fire Only stand between 2002 and after prescribed burning in 2005, reflective of increases in diameter and height as shown in Tables 1b and 4. Eventual fire-induced mortality will likely decrease future post-fire canopy bulk density measures.

3. 3. Predicted fire effects

Because of the narrow range of diameters in plantations, modeled mortality rates are shown within 10 cm diameter ranges for each treatment stage (pretreatment, mastication, and burn) in Table 12. Predicted mortality rates for trees of all diameters and weather scenarios were highest in masticated stands. Even under the moderate weather scenario, over 95% of the smallest trees and over 35% of trees over 30 cm in diameter would succumb to fire in masticated stands. Only the fire treatments resulted in lower predicted mortality than in the Controls. In all pretreatment and post-burn stands, total mortality rates for larger-diameter trees (≥ 31 cm) were lower than 35% given any weather scenario (Table 12). Different weather scenarios did not influence predicted mortality in burned stands (Table 12).

3. 4. Comparison of modeled and actual fire behavior and effects

Actual fuel moisture contents (dry weight) measured on the day of the prescribed burns are shown in Table 13. These values, along with the environmental conditions described in Table 14, were used as inputs for the FMA modeling of predicted fire behavior, PCVS, and percent mortality in the three burned stands. Inputed stand characteristics for 5-106 and 5-185 reflected post-mastication conditions, to mirror those in place during the actual burns. One h and duff fuel moistures were highest in stands 5-106 and 5-185, respectively. Ten- and 100 h fuel moisture contents were similar between the stands (Table 13).

Because 5-132 burned only during the late-morning to afternoon hours, average relative humidity (RH) was lower, and because ignitions in the other two stands extended from the late afternoon until evening, average temperatures and RH were higher (Table 14). Flame lengths, elliptical fire sizes, and fireline intensites were generally higher in the actual fires than predicted by FMA (Table 14). In stand 5-106, modeled fire rate of spread and flame length were identical and nearly so to actual observed values (Table 14). The largest discrepancies between observed and predicted fire behavior variables were in stand 5-185 (Table 14).

In all cases, modeled percent crown volume scorched was lower than actual PCVS (Table 15). The discrepancy was greatest at diameters ranging from 10-20 cm, where actual PCVS was over 95% on average in two of the three stands (5-106 and 5-132; Table 15). In actual fires, modeled overall PCVS and predicted mortality were highest in 5-132, while modeled PCVS was highest in 5-185 (Table 15).

4. Discussion

The need for fuels reduction treatments in the Granite plantations is evidenced by predictions of crown fire behavior in the Control stands at 90^{th} percentile weather conditions. When pretreatment fire behavior was evaluated (Table 16), passive crown fire was predicted under extreme weather scenarios for 70% of the plantations. These small-scale fuels manipulation experiments are an important first step in determining which techniques are most effective in increasing fire-resilience in pine plantations. We are aware of only one other empirical study that addresses fuels treatments and potential fire behavior in plantations (Stephens and Moghaddas, 2005b). Therefore treatment effectiveness is also compared to results reported for other Sierra Nevada forest systems.

4. 1. Mastication of understory and smallest trees

Mastication resulted in increases in 1-100 h fuel loads, similar to reports from other studies (Stephens, 1998; Stephens and Moghaddas, 2005a). The largest fuel loads (1000 h) decreased as a result of being mechanical reduced in size during the mastication procedure. A study using FMA to address fuels reduction treatments in CA mixed-conifer stands found that mastication was effective in reducing potential torching and crown fire behavior, while fire rate of spread and flame lengths increased as a result of the addition of activity fuels (Stephens and Moghaddas, 2005a). In Stephens and Moghaddas (2005a), the mitigation of crown fire behavior was attributed to increases in height to crown base, along with a reduction of ladder fuels. In contrast, in the Granite plantation, mastication resulted in a higher potential for torching in relation to the Controls, even with the decrease in crown bulk density. Because most trees in these plantations were of the same age and similar size, mastication did not effectively decrease ladder fuels; there were few ladder fuels to begin with. In addition, pre-treatment shrub height in Mastication units was less than 1 m on average, with mean percent coverage less than 45%. Although fire rate of spread was lower in masticated plantation stands than in the Controls, longer flame lengths contributed to a higher degree of predicted torching. Increased spacing between trees helped reduce the predicted active crown fire potential. Yet the increase in spacing between trees and height to crown base was not effective in offsetting how the contribution of activity fuels influenced predicted fire behavior, and surface fire intensity has been linked to the initiation of crown fires (Van Wagner, 1977). These results are most similar to those reported by van Wagtendonk (1996) and Stephens (1998), where, when compared to numerous other fuels reduction manipulations, modeled fireline intensity and estimated mortality (based on scorch height) were highest in masticated mixed-conifer stands where activity fuels were distributed and left on site.

Mastication treatments in younger (< 20 yrs old) but structurally similar pine plantations also in the Sierra Nevada resulted in predictions of both passive and active crown fire behavior under severe weather conditions (Stephens and Moghaddas 2005b). Potential rates of spread were nearly identical to those produced for the Granite stands. The difference in age, and associated diameter and height, between the two plantations likely explains why active crown fire was not predicted in the masticated Granite stands under even the most severe weather scenario. Mortality predictions were severe for the smallest size classes in both plantations (Stephens and Moghaddas 2005b). In the Granite area, predicted mortality from fire under moderate weather conditions in masticated stands would result in a loss of nearly all trees under 30 cm in diameter, with overall losses averaging nearly half of the stands (Table 12). In this study, no treatment proved less effective at reducing potential wildfire severity and behavior. Although eventual compaction of masticated materials could lower potential fire behavior, the concurrent regrowth of understory vegetation from residual root systems (i.e. Ceanothus and Arctostaphylos spp.) should also be considered. These results should be viewed within the context of the temporal scope of this study. Natural decomposition over time and compaction during the heavy snow seasons will likely decrease potential fire behavior in masticated stands significantly over the next few years.

4. 2. Prescribed burning in masticated and untreated stands

Because both pre- and post-treatment measures indicate minimal, sparsely distributed 1 h fuel loads, the 200% increase of 1 h fuels in the Fire Only stand is only a mathematical artifact, and probably does not represent a change that would impact fire behavior. The forest floor in this stand is composed almost entirely of needle cast, and understory vegetation is sparse. Another seemingly anomalous finding in the Fire Only stand, the increase in 100 h fuels after the burn, is attributable to the specifications of the sampling methodology. The Brown fuel transect sampling method instructs the researcher to tally fuels encountered along a transect line which are "in and above the litter layer" (Brown, 1974). The reduction in litter depth following the fire exposed more 100 h fuels, which having been previously completely covered by the litter layer or embedded in the duff, probably evaded measure before the burn. Fuels of the 100 h timelag class were most likely accumulated in the early 1990s, when stand 5-132 was pruned and the sparse understory was masticated. These fuels were also relatively wet prior to the burn, especially compared with the smaller fuel sizes, reducing their ignitability (Table 8).

All post-mastication fuel loads in the Mastication + Fire treatment were reduced by the prescribed burn. In comparison with the pretreatment stands, the increase in 10-hr and 100-hr fuels due to mastication remained evident following the prescribed burn, and this is not surprising. These stands had heavy understory shrub cover and mastication transformed this vegetation from live to ground fuels. Decreases in fuel loads following the burn averaged 61.5% across all fuel classes. Although these decreases did not result in fuel loads significantly different from the Controls, they were lower than the Mastication stands. Prescribed burning has been shown to be one of the most effective fuels and fire severity reduction treatments in both modeled and empirical studies (van Wagtendonk, 1996; Stephens, 1998; Stephens and Moghaddas, 2005a).

In ponderosa pine-dominated plantations, post-wildfire analysis found that plantations previously treated with understory burning were less severely burned, and untreated plantations burned completely and severely (Weatherspoon and Skinner, 1995). Also, from the edge of previously understory-burned plantations inward toward the middle of the stands, wildfire behavior was markedly reduced in intensity and severity. In contrast to mastication alone, mastication plus prescribed fire or fire alone in the Granite plantations was more effective in reducing potential fire behavior and severity. Compared to the Controls, the increases in height to live crown base in both burned treatment types along with the increase in tree diameter in the Fire Only treatment played a role in reducing potential mortality and PCVS. Prescribed fire in both treatment types was the only manipulation which resulted in lower modeled mortality and PCVS for the smaller size classes (< 30 cm diameter), and overall in comparison to the Control. Whether the mitigation of fire behavior provided by the three stands within the context of the larger (6000 ha) plantation is effective presents an interesting question for further research and fire modeling. The placement, timing, and size of fuels reduction treatments are each important in predicting their effectiveness on a landscape scale (Finney, 2001).

4. 3. Actual and modeled fire behavior and effects

Because stands 5-106 and 5-185 had been masticated before the prescribed burning treatment, the fuel model incorporated into the FMA fire behavior and severity predictions was a slash-based model (Fire Behavior Prediction System, or FBPS fuel model 11; Rothermel 1972). This is in contrast to 5-132, where fuel loads and distribution were best represented by a long-needle pine forest fuel model (FBPS fuel model 9). This may have explained the shorter predicted flame lengths and lower fireline intensity in 5-132 compared with the other two stands. Pruning treatments in 5-132 implemented in the early 1990s may have also impacted this finding. Amongst the three burned stands, the highest relative humidity and lowest temperature corresponded to the lowest rates of fire spread and highest windspeed index required for torching and crown fire behavior (5-106; Table 14). Stand 5-106 also had the lowest tree density, the fewest small trees (< 30 cm DBH), and more large trees (> 40 cm DBH) in comparison to the other two stands. It is likely that these structural differences resulted in lower potentials for torching and crowning, along with lower predicted mortality rates.

In stand 5-106, the predicted fire behavior was nearly identical to that observed, and in stand 5-132, rate of spread and flame lengths were also similar. Discrepancies were greatest for stand 5-185, where actual fire rate of spread was more than three times the rate predicted. The actual distribution of fuels in stand 5-185 was quite patchy, with small forest openings dominated by live herbaceous species interspersed within areas of continuous and deep activity fuels. Ignitions in some areas of this stand therefore required more aggressive tactics than in the other two stands, and the resulting high rate of fire spread reflects this. It is likely that, if only backing fire was used in 5-185, that the predicted and observed fire behavior would have been better aligned.

The most consistent difference between the actual and modeled fires was in percent crown volume scorched estimates. In all size classes and stands, the higher actual PCVS was pronounced. FMA uses scorch heights (based on the height and temperature of the modeled convection column) and tree heights, along with live crown ratios, to determine the PCVS for each tree (Carlton, 2004). Because the other variables are unequivocal, it is most likely that the modeled convection columns failed to predict actual conditions encountered during the prescribed burns. Fire behavior was influenced by localized variability in topography, fuels distribution and loads, and vegetation structure. For example, if every tree had a pile of 10-100 h activity fuels at its base, the amount of heat transferred to the trees in the convection column would be greater than predicted by the model which assumes that all fuels in the stand are distributed evenly. Importantly, FMA models wildfire behavior with a single ignition, while prescribed fire ignitions are repeated and often vary in terms of the amount of fuel subjected to each in the series of ignitions. This may, in part, explain the notable difference between observed and predicted prescribed fire behavior.

Although it is too early to accurately assess tree mortality in the burned stands, predictions based on logistic regression models developed for ponderosa pine in the Sierra Nevada (Stephens and Finney, 2002), suggest that actual PCVS would result in higher mortality rates in the smaller size classes in 5-132 and 5-106, and lower mortality in all size classes in 5-185 (Table 15). Other species, including Douglas-fir and white fir, comprised a higher component of 5-185 than the other two stands, (totaling about 5% more). FMA uses species-specific algorithms to calculate bark thickness, and this is combined with PCVS to predict mortality (Carlton, 2004). The sensitivity of the FMA model to the differences in fire resistance between species is evident in the comparison presented here. Over the next few years, actual measures of mortality resulting from the prescribed burns will help illuminate the differences between mortality prediction methods.

5. Conclusions

The longer-term efficacy of each of the treatments addressed here depends on a number of as-yet unpredictable factors, and the complexity of modeling potential tree mortality adds to the challenge. Will prescribed burning instigate insect or pathogen infestations that will significantly increase the degree of mortality? In the context of the region's frequent fire return interval, how long before the activity fuels from mastication compact and decompose, and what impact does this have on future fire behavior and fuels management? Will the fire-caused scorched crowns and dead trees contribute significantly to fuel loads, eventually increasing fire behavior potential? Continued monitoring of the effectiveness of these fuels reduction treatments is essential if these and other important questions are to be addressed.

In both untreated and post-mastication plantation stands, prescribed fire was the most effective fuels reduction technique, while mastication was least effective. Understory burning was also most effective at decreasing fire behavior metrics as well as severity, and in this sense, was successful in increasing fire-resilience in the plantation forest. There are also important fire hazard tradeoffs between the treatment types to consider. In terms of reducing potential fire behavior, mastication (including small trees) has positive effects on stand structure, but negative impacts on fuel loads and continuity. The relative ecological impacts of different manipulations must also be considered, and the spatial scale and patterning of treatments is critical to reducing large, severe fire potential (Omi and Kalabokidis, 1998; Finney, 2001; Agee and Skinner, 2005). These issues can best be addressed through adaptive management approaches (Walters and Holling, 1990; van Wagtendonk, 1996) and continued experimentation with various fuels reduction techniques, timing, placement, and sizes in plantation forests.

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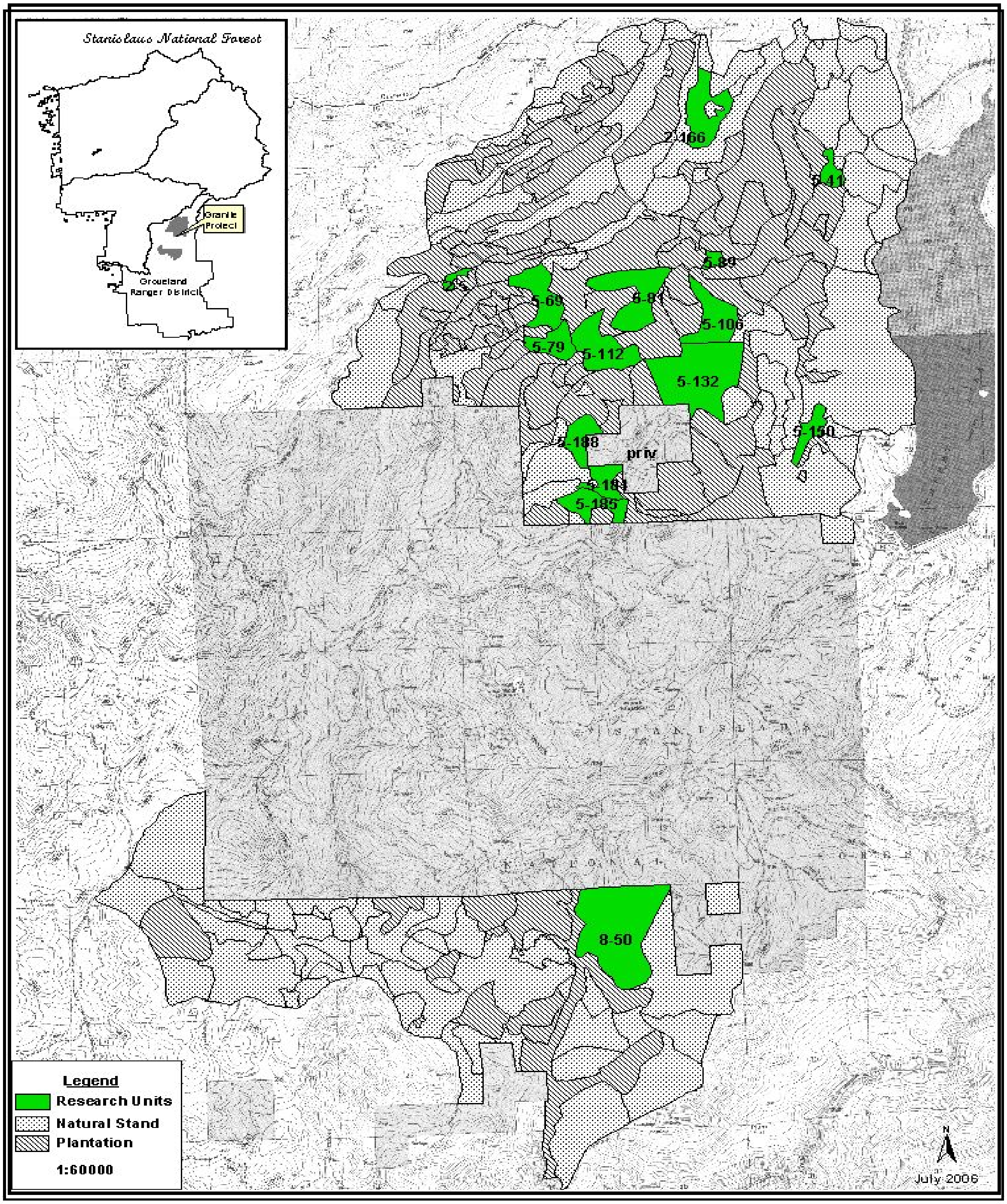
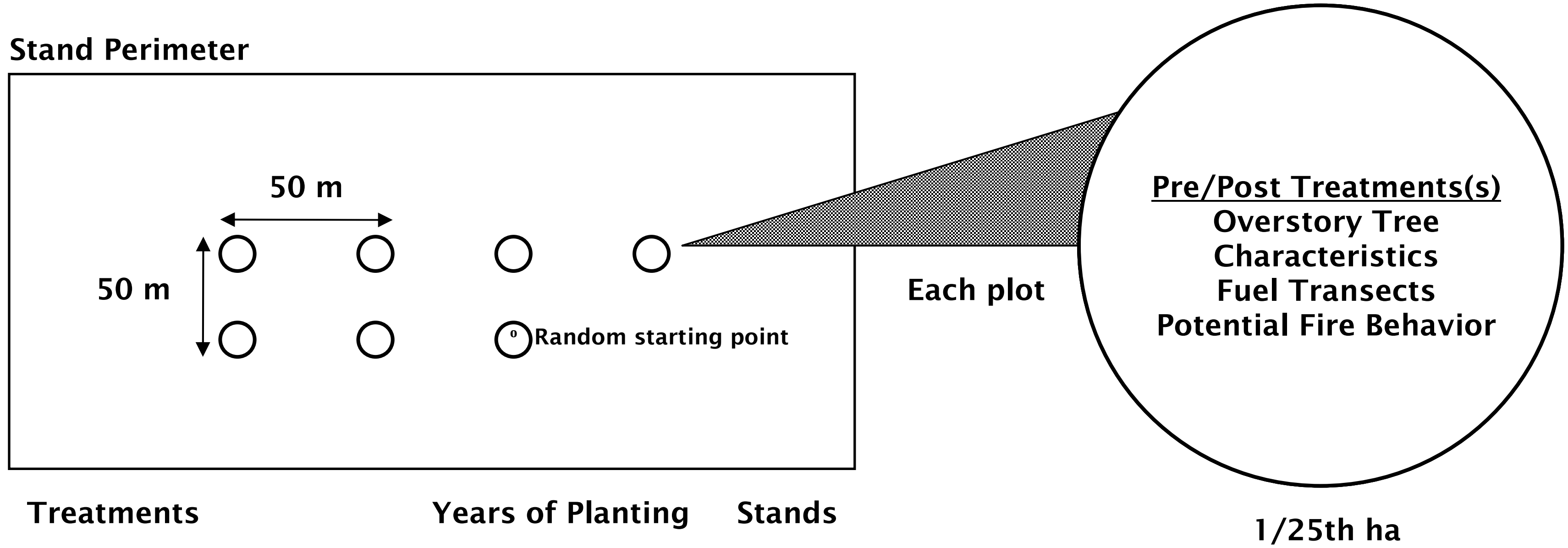


Fig. 1. Map of location of the 15 permanently established research units in Stanislaus National rest pine plantations, California, USA. Shaded area within District boundary depicts the extent of the pine plantations west of Cherry Lake, and south of the privately-owned parcel.



Treatments	Years of Planting	Stands
• 5 Control Stands	1978-1981	5-69, 79, 81, 112, 184
• 2 Mastication Stands	1978-1982	5-89, 188
• 2 Mastication + Burn Stands	1978-1981	5-106, 185
• 1 Burn Only Stand	1976-7	5-132

Fig. 2 Diagram of study design and list of stands included in each fuels treatment in the Granite plantation forests of the Stanislaus National Forest, CA.

Table 1b. Mean (standard error) pre-treatment stand characteristics for four treatment types in ponderosa/Jeffrey pine plantations, Stanislaus National Forest, CA.

Treatment Type	Trees (ha^{-1})	BA (m^2 ha^{-1})	Diameter (cm)	Ht. (m)	Ht. to live crown base (m)	Canopy cover (%)	Slope (%)
Control	338.03 (44.19)	23.12 (0.48)	27.95 (1.58)	12.35 (1.0)	3.19 (1.43)	47.14 (24.90)	14.15 (6.11)
Mastication	370.49 (3.50)	13.70 (4.80)	20.07 (3.1)	8.64 (2.76)	1.69 (0.20)	41.07 (1.80)	22.00 (2.40)
Mastication +Fire	363.09 (0)	24.02 (7.60)	27.25 (0.22)	12.00 (0.05)	2.29 (0.29)	46.43 (15.13)	13.86 (8.13)
Fire	368.03 (0)	28.54 (0)	30.84 (0)	14.47 (0)	3.86 (0)	53.57 (0)	13.00 (0)

No significant differences were found between any variables in pretreatment stands (ANOVA). BA = basal area.

Table 2 Mean (standard error) pre-treatment fuel loads (metric t ha^{-1}) for four treatment types in ponderosa/Jeffrey pine plantations, Stanislaus National Forest, CA.

Treatment Type	1 h	10 h	100 h	1000 h	Litter	Duff	1-100 h	[a]Total
Control	0.49 (0.21)	3.05 (0.79)	3.16 (1.68)	79.74 (32.64)	15.01 (1.99)	18.97 (4.69)	6.68 (2.14)	40.66 (7.98)
Mastication	0.93 (0.50)	4.37 (0.32)	7.20 (2.21)	33.61 (2.48)	12.40 (2.88)	5.17 (2.64)	12.50 (2.39)	30.07 (7.90)
Mastication +Fire	0.47 (0.12)	1.43 (0.53)	1.24 (1.07)	46.14 (10.43)	15.23 (5.37)	15.97 (4.66)	3.15 (1.72)	34.35 (11.72)
Fire	0.06 (0)	3.98 (0)	3.85 (0)	31.96 (0)	17.70 (0)	21.06 (0)	7.89 (0)	46.66 (0)

No significant differences were found between any variables in pretreatment stage (ANOVA).

[a]Total fuel loads include 1-100 h, duff, and litter.

Table 3 Mean (standard error) post-mastication stand characteristics for four treatment types in Stanislaus National Forest, CA, ponderosa/Jeffrey pine plantations.

Treatment Type	Trees (ha^{-1})	BA (m^2 ha^{-1})	Diameter (cm)	Ht. (m)	Ht. to live crown base (m)	Canopy cover (%)	Slope (%)
Control	338.03 (44.19) a	23.12 (0.48)	27.95 (1.58) a	12.35 (1.0) a	3.19 (1.43) a	47.14 (24.90) a	14.15 (6.11)
Mastication	176.43 (21.17) b	11.92 (5.20)	27.67 (4.39) b	11.55 (2.45) b	2.25 (0.33) b	28.55 (3.55) b	22.00 (3.39)
Mastication +Fire	247.00 (24.70) c	26.78 (4.17)	34.76 (0.79) b	14.83 (0.01) b	3.49 (0.24) c	55.35 (16.05) a	13.86 (5.75)
Fire[a]	368.03 (0) a	28.54 (0)	30.84 (0) a	14.47 (0) a	3.86 (0) a	53.57 (0) ab	13.00 (0)

Significant differences are denoted by different letters following values in a column ($p < 0.05$)

[a] Fire stand was not treated during the mastication stage.

Table 4 Mean (standard error) post-fire stand characteristics for four treatment types in Stanislaus National Forest, CA, ponderosa/Jeffrey pine plantations.

Treatment Type	Trees (ha^{-1})	BA (m^2 ha^{-1})	Diameter (cm)	Ht. (m)	Ht. to live crown base (m)	Canopy cover (%)	Slope (%)
Control	338.03 (44.19) a	23.12 (0.48) ab	27.95 (1.58) a	12.35 (1.0) a	3.19 a (1.43) a	47.14 (24.90) a	14.15 (6.11)
Mastication[a]	176.43 (21.17) b	11.92 (5.20) b	27.67 (4.39) b	11.55 (2.45) b	2.25 (0.33) b	28.55 (3.55) b	22.00 (3.39)
Mastication +Fire	247.00 (24.70) c	26.04 (3.75) c	36.30 (0.96) ac	15.10 (0.32) a	6.36 (1.09) b	52.65 (13.35) a	13.86 (5.75)
Fire	367.13 (0) a	28.50 (0) ac	35.02 (0) c	17.31 (0) b	9.30 (0) c	54.10 (0) a	13.00 (0)

Significant differences are denoted by different letters following values in a column ($p < 0.05$)

[a] Mastication stand was not treated during the fire stage.

Table 5 Mean (standard error) post-mastication fuel loads (metric t ha^{-1}) for four treatment types in Stanislaus National Forest, CA, ponderosa/Jeffrey pine plantations.

Treatment Type	1 h	10 h	100 h	1000 h	Litter	Duff	1-100 h	[a]Total
Control	0.49 (0.21)	3.05 (0.79)	3.16 (1.68) a	79.74 (32.64)	15.01 (1.99)	18.97 (4.69)	6.68 (2.14)	40.66 (7.98)
Mastication	2.93 (1.44)	12.25 (3.70)	11.97 (0.94) ab	17.85 (0.08)	26.07 (15.44)	43.18 (29.46)	18.27 (10.20)	87.52 (30.17)
Mastication +Fire	1.26 (0.62)	8.31 (4.14)	7.42 (2.97) b	32.02 (17.60)	18.98 (3.72)	29.12 (0.92)	16.99 (7.72)	65.10 (9.44)
Fire[b]	0.06 (0)	3.98 (0)	3.85 (0) ab	31.96 (0)	17.70 (0)	21.06 (0)	7.89 (0)	46.66 (0)

Significant differences are denoted by different letters following values in a column ($P < 0.05$)

[a]Total fuel loads include 1-100 h, duff, and litter.

[b]Fire stand was not treated during the mastication stage.

Table 6 Percent change in fuel loads (metric tons/ ha) for various fuel types following two treatment stages in pondersa pine plantations, CA.

Treatment Type	Stage 1	Stage 2	1 h	10 h	100 h	1000 h	Litter	Duff	1-100hr	[a]Total
Mastication +Fire	Pre-treatment	Mastication	166.06	479.58	496.25	-30.61	24.67	82.34	439.19	89.52
Mastication	Pre-treatment	Mastication	216.13	180.40	66.34	-46.89	110.18	734.59	46.22	191.03
Fire	Pre-treatment	Fire	200.29	-46.26	104.74	-68.77	-79.90	-46.38	29.26	-46.31
Mastication +Fire	Pre-treatment	Fire	-15.09	107.19	284.28	-52.91	-62.02	28.65	158.82	0.40
Mastication +Fire	Post-mastication	Fire	-68.09	-64.25	-35.55	-32.14	-69.54	-29.45	-52.00	-47.02

[a]Total fuel loads include 1-100 h, duff, and litter.

Table 7 Mean (standard error) post-fire fuel loads (metric t ha $^{-1}$) for four treatment types in Stanislaus National Forest, CA, ponderosa/Jeffrey pine plantations.

Treatment Type	1 h	10 h	100 h	1000 h	Litter	Duff	1-100 h	[a]Total
Control	0.49 (0.21) ab	3.05 (0.79) ab	3.16 (1.68) ab	79.74 (32.64)	15.01 (1.99) ab	18.97 (4.69)	6.68 (2.14)	40.66 (7.98)
Mastication[b]	2.93 (1.44) b	12.25 (3.70) b	11.97 (0.94) b	17.85 (0.08)	26.07 (15.44) b	43.18 (29.46)	18.27 (10.20)	87.52 (30.17)
Mastication +Fire	0.40 (0.01) a	2.97 (0.73)a	4.78 (0.75) a	21.73 (4.09)	5.78 (0.48) a	20.55 (2.60)	8.16 (1.50)	34.49 (3.76)
Fire	0.17 (0) ab	2.14 (0) ab	7.89 (0) ab	9.98 (0)	3.56 (0) a	11.29 (0)	10.20 (0)	25.05 (0)

Significant differences are denoted by different letters following values in a column ($p < 0.05$)

[a]Total fuel loads include 1-100 h, duff, and litter.

[b]Mastication stand was not treated during the fire stage.

Table 8 Weather and fuel moisture conditions for modeled potential fire behavior and severity in three ponderosa/Jeffrey pine plantations, Stanislaus National Forest, CA.

Variable	80th percentile conditions	90th percentile conditions	97.5th percentile conditions
Dry bulb temperature (°C)	86	88	92
Relative humidity (%)	23	19	13
1 h fuel moisture (%)	3.8	3.4	2.6
10 h fuel moisture (%)	4.8	4.2	3.3
100 h fuel moisture (%)	6.8	6.5	5.2
Herbaceous fuel moisture (%)	55.3	54.2	45.4
Woody fuel moisture (%)	73.8	70.5	65
Foliar fuel moisture (%)	100	80	75
Wind Direction	North to northeast	North to northeast	North to northeast
Probable max. 1-min. wind speed (km h $^{-1}$)	13	15	18

Table 9 Modeled one-hour fire size, behavior, and type (standard error) in control and post-mastication stands in Stanislaus National Forest pine plantations.

Weather percentile	Treatment	Fire Type	Fire rate of spread (m min-1)	Flame length (m)	Fireline intensity (kW m-1)	Torching index (km h-1)	Crowning index (km h-1)	Elliptical fire size (ha)
80th								
	Control	SF	2.90 (0.07)	0.82 (0)	166.73 (5.68)	59.29 (26.46)	42.96 (11.98)	1.13 (0.04)
	Mastication	SF	2.06 (0.75)	1.08 (0.20)	323.43 (129.72)	46.50 (16.86)	68.47 (4.51)	0.68 (0.35)
	Mastication +Fire	SF	2.75 (0.07)	1.27 (0.02)	442.77 (10.38)	49.91 (2.56)	43.89 (2.65)	1.00 (0.03)
	Fire[a]	SF	2.85	0.82	162.58	69.57	38.58	1.1
90th								
	Control	80 % SF, 20% PCF	3.63 (0.06)	0.90 (0.02)	206.86 (3.79)	50.14 (22.60)	42.58 (11.89)	1.78 (0.41)
	Mastication	50% SF, 50% PCF	3.25 (0)	1.40 (0)	529.25 (0)	24.32 (2.12)	62.10 (1.31)	1.51 (0.26)
	Mastication +Fire	SF	3.20 (0.05)	1.39 (0.02)	518.87 (10.38)	38.08 (1.90)	43.51 (2.63)	1.24 (0.02)
	Fire[a]	SF	3.59	0.88	204.09	58.97	38.24	1.58
97.5th								
	Control	60 % SF, 40% PCF	5.32 (0.07)	1.11 (0.17)	325.85 (5.68)	42.83 (17.17)	39.84 (11.16)	4.52 (2.31)
	Mastication	PCF	4.33 (0)	1.62 (0)	750.63 (0)	19.04 (1.72)	57.95 (1.46)	9.29 (0.83)
	Mastication +Fire	50% SF, 50% PCF	4.26 (0.07)	1.62 (0)	738.53 (12.1)	30.31 (1.42)	40.73 (2.50)	2.01 (0.05)
	Fire[a]	SF	5.26	1.1	321.7	51.19	35.79	2.98

SF = surface fire, PCF = passive crown fire.

[a] Fire stand was not treated during the mastication stage.

Table 10 Modeled one-hour fire size, behavior, and type (standard error) in control and post-fire stands in Stanislaus National Forest pine plantations.

Weather percentile	Treatment	Fire Type	Fire rate of spread (m min-1)	Flame length (m)	Fireline intensity (kW m-1)	Torching index (km h-1)	Crowning index (km h-1)	Elliptical fire size (ha)
80th								
	Control	SF	2.90 (0.07)	0.82 (0)	166.73 (5.68)	59.29 (26.46)	42.96 (11.98)	1.13 (0.04)
	Mastication[a]	SF	2.06 (0.75)	1.08 (0.20)	323.43 (129.72)	46.50 (16.86)	68.47 (4.51)	0.68 (0.35)
	Mastication +Fire	SF	0.96 (0.02)	0.43 (0)	39.78 (2.44)	383.76 (82.29)	36.69 (5.67)	0.12 (.01)
	Fire	SF	0.94 (0)	0.43 (0)	38.05 (0)	500.52 (0)	32.51 (0)	0.12 (0)
90th								
	Control	80 % SF, 20% PCF	3.63 (0.06)	0.90 (0.02)	206.86 (3.79)	50.14 (22.60)	42.58 (11.89)	1.78 (0.41)
	Mastication[a]	50% SF, 50% PCF	3.25 (0)	1.40 (0)	529.25 (0)	24.32 (2.12)	62.10 (1.31)	1.51 (0.26)
	Mastication +Fire	SF	1.157 (0.24)	0.46 (0)	48.43 (0)	317.20 (68.05)	36.37 (5.62)	0.16 (0.04)
	Fire	SF	1.14 (0)	0.46 (0)	48.42 (0)	413.84 (0)	32.22 (0)	0.16 (0)
97.5th								
	Control	60 % SF, 40% PCF	5.32 (0.07)	1.11 (0.17)	325.85 (5.68)	42.83 (17.17)	39.84 (11.16)	4.52 (2.31)
	Mastication[a]	PCF	4.33 (0)	1.62 (0)	750.63 (0)	19.04 (1.72)	57.95 (1.46)	9.29 (0.83)
	Mastication +Fire	SF	1.59 (0.02)	0.55 (0)	70.91 (2.45)	273.13 (58.59)	34.01 (5.33)	0.27 (0.01)
	Fire	SF	1.58 (0)	0.55 (0)	69.18 (0)	356.41 (0)	30.13 (0)	0.27 (0)

SF = surface fire, PCF = passive crown fire.
[a] Mastication stands were not treated during the fire stage.

Table 11 Average canopy bulk density for each treatment stage and type in Stanislaus National Forest plantation stands, CA.

	Control	Mastication	Mastication + Fire	Fire Only
Pre-treatment	0.0055	0.0041	0.0064	0.0057
Post-mastication	0.0055	0.0029	0.0048	[a]
Post-fire	0.0055	[a]	0.0062	0.0072

[a] Stands not treated during this stage.

Table 12 Average predicted mortality (%SD) before and after shredding and burning in plantation stands, Stanislaus National Forest, CA.

Weather percentile	DBH Range (cm)	Control	Pre-Mastication	Pre-Mastication + Fire	Pre-Fire	Mastication, masticated	Mastication + Fire, masticated	Fire, burned	Mastication + Fire, burned
80th									
	10-20	61.14 (20.55)	65.58 (20.56)	57.38 (20.83)	62.70 (16.34)	95.50 (2.08)	99 (0)	49.80 (9.98)	43.00 (4.24)
	21-30	23.54 (6.70)	31.90 (8.10)	26.42 (11.13)	4.86 (6.34)	71.32 (27.35)	51.68 (22.45)	23.13 (5.78)	23.64 (6.53)
	31-40	13.60 (3.26)	16.30 (3.81)	14.86 (3.20)	14.94 (2.50)	20.40 (7.58)	31.24 (17.30)	15.34 (1.61)	13.29 (2.52)
	41-50	8.89 (1.54)	N/A	10.33 (2.00)	11.25 (0.50)	10.00 (0)	20.10 (10.57)	11.25 (0.05)	8.67 (1.42)
	51+	N/A	19 (0)	3.50 (2.12)	N/A	8.00 (0)	9.40 (5.50)	N/A	4.50 (1.29)
	All	25.21 (18.09)	53.13 (25.30)	31.53 (22.22)	22.79 (15.04)	58.31 (33.38)	32.63 (22.29)	21.49 (11.13)	15.04 (7.26)
90th									
	10-20	66.72 (21.69)	69.15 (20.44)	59.63 (21.54)	66.60 (17.51)	98.50 (1.30)	99 (0)	49.80 (9.97)	43.00 (4.24)
	21-30	25.01 (8.90)	33.73 (9.47)	27.20 (11.95)	23.43 (6.63)	86.62 (15.52)	57.11 (22.91)	23.13 (5.78)	23.64 (6.53)
	31-40	14.05 (4.70)	16.55 (4.03)	15.25 (3.60)	15.34 (1.61)	47.12 (18.72)	36.07 (18.62)	15.34 (1.61)	13.29 (2.52)
	41-50	9.25 (2.08)	N/A	10.83 (2.32)	11.25 (0.50)	16.00 (0)	24.45 (12.43)	11.25 (0.05)	8.67 (1.42)
	51+	N/A	19 (0)	3.50 (2.12)	N/A	22.00 (0)	10.93 (7.09)	N/A	4.50 (1.29)
	All	26.90 (20.23)	55.98 (26.16)	32.62 (23.21)	23.22 (16.22)	75.87 (26.02)	37.16 (23.52)	21.49 (11.13)	15.04 (7.26)
97.5th									
	10-20	83.35 (22.35)	95.65 (5.77)	69.48 (23.07)	78.10 (19.80)	99.50 (0.58)	99 (0)	49.80 (9.97)	43.00 (4.24)
	21-30	37.68 (23.69)	68.83 (22.02)	33.51 (16.07)	25.18 (2.57)	97.62 (3.07)	63.32 (22.76)	23.13 (5.78)	23.64 (6.53)
	31-40	17.82 (13.79)	31.20 (13.25)	18.60 (7.40)	15.60 (2.04)	85.88 (10.30)	47.12 (23.60)	15.34 (1.61)	13.29 (2.52)
	41-50	12.06 (9.43)	N/A	14.83 (5.23)	11.25 (0.50)	48.00 (0)	41.14 (18.36)	11.25 (0.05)	8.67 (1.42)
	51+	N/A	19 (0)	5.00 (2.24)	N/A	63.00(0)	21.57 (13.48)	N/A	4.50 (1.29)
	All	36.90 (29.42)	83.32 (23.67)	38.98 (26.73)	24.42 (18.54)	93.92 (9.50)	47.98 (24.76)	21.49 (11.13)	15.04 (7.26)

Note: Diameter ranges encompass all trees in stands.

Table 13 Fuel moisture contents (percent by dry weight basis) on day of prescribed burning implementation in three plantation stands, Stanislaus National Forest, CA.

Fuel Component	**5-132**	**5-106**	**5-185**
1-hr	2.33	9.95	5.33
10-hr	11.37	11.46	10.31
100-hr	12.29	10.53	11.71
1000-hr sound	16.67	11.83	9.02
1000-hr rotten	15.48	14.48	n/a
Herbaceous	75.91	69.38	74.78
Woody	53.55	51.74	50.11
Duff	18.84	7.70	75.06
Litter	15.13	13.58	13.83

Table 14 Modeled/ observed fire behavior using actual burn condition varaibles in three prescribed fire stands in the Stanislaus National Forest, CA.

Variable	5-132	5-106	5-185
Dry bulb temperature (°C)	21	18	19
Relative humidity (%)	30	55	54
Probable max. 1-min. wind speed (km h^{-1})	8.9	8	8
Wind direction	S-SE	E-SE	S-SW
Fire type	SF	SF	SF
Fire rate of spread (m min^{-1})	1.11/ 1.91	0.77 /0.77	0.87/ 3.65
Flame length (m)	0.55/ 0.78	0.64/ 0.69	0.73/ 1.09
Fireline intensity (kW m^{-1})	69.18/ 151.54	96.86/ 116.14	124.53/ 313.26
Torching index (km h^{-1})	61.61	97.27	63.13
Crowning index (km h^{-1})	33.46	45.14	44.47
Elliptical fire size (ha)	0.27/ 0.29	0.13/ 0.26	0.18/ 0.38

[a]Fireline intensity was computed using flame lengths in m (L) in the equation $I = 259.83L^{2.17}$ (Byram, 1959).

Table 15 Average modeled and observed percent of crown scorched (PCVS) and mortality after mastication and fire in three plantation stands, Stanislaus National Forest, CA.

Stand	Diameter range (cm)	Trees/ha	Modeled PCVS	Actual PCVS	Modeled potential mortality (%)	[a]Predicted mortality (%)
5-106						
	10-20	3.53	0	95.00 (0)	32.00 (0)	81
	21-30	35.29	9.60 (18.00)	60.91 (25.57)	26.20 (16.58)	29
	31-40	81.16	1.70 (5.41)	45.87 (31.86)	12.22 (2.19)	6
	41-50	35.29	0	54.00 (34.53)	7.40 (0.70)	6
	51+	49.40	0	10.00 (0)	5.63 (0.96)	1
	All	204.66	2.14 (8.08)	48.57 (31.27)	12.0 (9.84)	N/A
5-132						
	10-20	34.28	14.00 (9.43)	97.50 (3.53)	53.20 (12.76)	83
	21-30	141.02	0.15 (0.95)	66.11 (23.11)	23.15 (5.88)	37
	31-40	177.51	0	56.47 (20.57)	15.34 (1.61)	18
	41-50	14.32	0	49.69 (30.03)	11.25 (0.50)	10
	51+	0.00	N/A	N/A	N/A	N/A
	All	367.13	1.40 (5.02)	57.88 (23.43)	21.83 (12.22)	N/A
5-185						
	10-20	10.59	7.00 (12.12)	45.00 (63.64)	44.67 (11.85)	22
	21-30	84.69	4.29 (8.16)	20.43 (20.54)	24.83 (5.59)	4
	31-40	127.03	4.23 (9.24)	24.00 (24.12)	14.17 (3.56)	4
	41-50	38.81	5.36 (9.18)	17.37 (17.67)	9.00 (2.00)	2
	51+	10.59	10.00 (9.54)	40.00 (52.20)	5.34 (2.08)	5
	All	271.70	4.74 (8.85)	22.74 (24.44)	17.60 (9.34)	N/A

[a] Predicted mortality uses actual PCVS values in a logistic regression model for ponderosa pine developed by Stephens and Finney (2002).

Table 16 Modeled one-hour fire size, behavior, and type (standard error) in control and pre-treatment stands in Stanislaus National Forest pine plantations.

Weather percentile	Treatment	Fire Type	Fire rate of spread (m min^{-1})	Flame length (m)	Fireline intensity (kW m^{-1})	Torching index (km h^{-1})	Crowning index (km h^{-1})	Elliptical fire size (ha)
80th								
	Control	SF	2.90 (0.07)	0.82 (0)	166.73 (5.68)	59.29 (26.46)	42.96 (11.98)	1.13 (0.04)
	Mastication	SF	2.98 (0)	0.82 (0)	172.96 (0)	34.17 (2.9)	49.09 (2.21)	1.18 (0)
	Mastication +Fire	SF	2.92 (.07)	0.82 (0)	167.77 (7.34)	45.62 (2.58)	36.27 (5.66)	1.14 (0.06)
	Fire	SF	2.85	0.82	162.58	69.57	38.58	1.1
90th								
	Control	80 % SF, 20% PCF	3.63 (0.06)	0.90 (0.02)	206.86 (3.79)	50.14 (22.60)	42.58 (11.89)	1.78 (0.41)
	Mastication	SF	3.69 (0)	0.91 (0)	211.0 (0)	26.64 (2.49)	48.67 (2.20)	1.64 (0)
	Mastication +Fire	SF	3.64 (0.07)	0.90 (0.02)	207.55 (3.46)	38.51 (2.16)	35.95 (5.62)	1.61 (0.03)
	Fire	SF	3.59	0.88	204.09	58.97	38.24	1.58
97.5th								
	Control	60 % SF, 40% PCF	5.32 (0.07)	1.11 (0.17)	325.85 (5.68)	42.83 (17.17)	39.84 (11.16)	4.52 (2.31)
	Mastication	PCF	5.4 (0)	1.13 (0)	332.08 (0)	24.58 (2.18)	45.54 (2.08)	8.0 (1.84)
	Mastication +Fire	SF	5.33 (0.07)	1.11(0.02)	326.89 (5.20)	33.29 (1.84)	33.6 (5.25)	3.04 (0.06)
	Fire	SF	5.26	1.1	321.7	51.19	35.79	2.98

SF = surface fire, PCF = passive crown fire.

APPENDIX A. OUTREACH ACTIVITIES

Granite Local Monitoring Team, Field Trips and Meetings:

- **Attendees**

Monitoring Team:

Vicki Biggs, Tuolumne Band of Mi-Wuk Indians
John Buckley, Executive Director of Central Sierra Environmental Resource Center
Joe Haratani, Civil Engineer
John Romena, Forester, Sierra Pacific Industries
Mark Thornton, Tuolumne County Supervisor, Tuolumne County Board of Supervisors
Ken Blonski, Fire Mitigation Advisor, UC Berkeley Forest Products Lab

Stanislaus National Forest:

John Swanson, District Ranger, Groveland Ranger District
John Schmechel, District Silviculturist, Groveland RD
Linda Johnstone, Fuels Officer, Groveland RD
Jenny Haas, Botanist, Groveland RD
Kathi Stillwell, Silvicultural Technician, Groveland RD
Timothy Evans, Soil Scientist, Groveland RD

University of California:

Ken Blonski, (former) Fire Mitigation Advisor, UC Berkeley Forest Products Lab
(presently with East Bay Municipal Utility District)
Leda Kobziar, Graduate Student, UC Berkeley

- **Dates**

February 27, 2002
April 15, 2002
November 14, 2003
May 28, 2004
October 17, 2005

USDA Forest Service Retiree Field Days:

(Visits to Granite Plantation stands and discussion of fuels reduction treatments)

Hosted by: John Swanson, Groveland Ranger District

Dates: April 16, 2004

October 15, 2004

Attendees: 12-20 retired Forest Service personnel

Presentations:

Kobziar, L. N., Research seminar, “Fire and Fire Surrogate Studies in a Sierra Nevada Pine Plantation”, University of Florida, April 26, 2006.

Kobziar, L. N. Upcoming presentation, “The Effects of Fuels Treatments and Fire on Soil Carbon Respiration in a Sierra Nevada Pine Plantation”. Third Annual Fire and Fuels Congress, San Diego, CA, November, 2006.

Kobziar, L. N. Poster, “Fire Hazard Reduction in Ponderosa Pine Plantations”. Joint Fire Science Program Principle Investigator Workshop, March, 2004, Phoenix, AZ.

Kobziar, L. N. Poster-presentation, “Fire Hazard Reduction in Ponderosa Pine Plantations”. Joint Fire Science Program Principle Investigator Workshop, March, 2003, Phoenix, AZ.

World Wide Website:

Groveland Ranger District (address may change)
www.r5.fs.fed.us/stansislaus/groveland/granite/index.html

Also see UC Berkeley, Stephens Lab (this website is currently undergoing revisions and will be expanded):
www.cnr.berkeley.edu/stephens-lab/research.htm#Ecological%20Effects%20of%20Fire%20and%20Silviculture%20Treatments%20in%20the%20Stanislaus%20National%20Forest

Appendix A, cont. Crosswalk between proposed and delivered outreach activities, as indicated in our original Proposal, dated August 15, 2000.

Proposed	Delivered	Status
(a) Establishment of collaborative relationships with all partners	(a) UC Berkeley and Stanislaus National Forest personnel continue to collaborate on project. See "Field Trips and Meetings", Appendix A, above	**(a) Done**
(b) Establishment of research site	(b) Fifteen permanent research stands established	**(b) Done**
(c) Baseline data collection	(c) All permanent stands baseline data collection completed	**(c) Done**
(d) Documentation of treatment costs and short-term responses to treatments	(d) Explained in detail in this report for those treatments completed by 2005	**(d) Done**
(e) Reporting of results	(e) This report	**(e) Done**
(e_1) Publications	(e_1) Three submitted manuscripts described in Appendix B	**(e_1) Submitted to journals**
(e_2) Posters	(e_2) Two poster sessions, see Appendix A above	**(e_2) Done**
(e_3) Presentations	(e_3) Research seminar, and upcoming presentation at the Third Annual Fire and Fuels Congress, San Diego, CA	**(e_3) Done, and planned for November 13-17, 2006.**
(e_4) Ph. D. Dissertation	(e_4) "The Effects of Fire and Fuels Reduction Treatments on Fire Hazard and Soil Carbon Respiration in a Sierra Nevada Pine Plantation", by Leda N. Kobziar, filed June, 2006.	**(e_4) Done**
(f) Designation of research site as demonstration area	(f) Plans for signed public field tour depicting five different fuels reduction treatment types	**(f) To be produced after all treatments are in place (predicted date of 2008)**
(g) World Wide Websites	(g) USFS website, final address to be announced UC Berkeley website, http://nature.berkeley.edu/stephens-lab/JFSPlinks.htm	**(g) UFSF website, under construction, to be completed by approx. Nov., 2006** **UC Berkeley website, to be completed by Aug. 1, 2006**

APPENDIX B. ABSTRACTS FROM SUBMITTED PAPERS

Kobziar, L. N., Stephens, S. L., McBride, J. R. 2006. How to keep plantations from burning: the efficacy of fuels reduction treatments in a Sierra Nevada pine plantation. (*In Review*; submitted June, 2006). International Journal of Wildland fire.

Abstract

Plantations are the most common means of reforestation following stand-replacing wildfires. As wildfires continue to increase in size and severity as a result of a century of fire suppression, establishment of plantations will also increase. Plantations' structural characteristics, including dense spacing and abundant ladder fuels, present significant wildfire hazards. Large-scale fuels reduction techniques may be necessary to reduce potential fire behavior in plantations and to protect surrounding forests. In this study, four different manipulations aimed at reducing potential fire behavior in a Sierra Nevada pine plantation are compared. The treatments include: mechanical shredding, or mastication, of understory vegetation and small trees; mastication followed by prescribed fire; fire alone; and control. Fire behavior and effects modeling show that mastication is detrimental, and prescribed fire most effective in reducing potential fire behavior at moderate to extreme weather conditions. Predicted fire behavior and effects were compared with actual values from the prescribed burns in an effort to explore the limitations of fire modeling. Because of the homogeneity of pine plantation stands, results of this work are applicable to other regions, as empirical evidence is used to evaluate the efficacy of manipulations aimed at increasing fire-resilience in plantation forest types.

Kobziar, L. N., Stephens, S. L., 2006. The Effects of Fuels Treatments and Fire on Soil Carbon Respiration in a Sierra Nevada Pine Plantation. (*In Review*; submitted June, 2006). Agricultural and Forest Meteorology.

Abstract

Fire-prone forests in the American west are presently slated for extensive fuels reduction treatments, yet the effect on soil CO_2 efflux rates, or soil respiration, has received little attention. This study utilizes the homogeneity of a Sierra Nevada ponderosa (Pinus ponderosa Dougl. ex P. & C. Laws)- Jeffrey pine (Pinus jeffreyi, Grev. & Balf.) plantation to investigate changes in soil respiration following: mechanical shredding of understory vegetation, or mastication, in 2004; mastication coupled with prescribed burning in 2005; and burning alone also in 2005 as measured over the growing seasons from 2003 to 2005. Soil respiration, soil temperature and soil moisture were measured in two masticated stands, which were burned the following year, and in one burned stand; the three of which were compared with two controls stands. Soil respiration response to treatments was detectable even though spatial variability within sites was high (coefficients of variation of 39-66%). Mastication produced short-term reductions in respiration rates, reduced soil moisture by 20%, and mitigated a year-to-year reduction in soil

temperature evidenced by controls. Prescribed fire in masticated stands lowered soil respiration from 3.42 to 2.68 μmol $m^{-2} s^{-1}$ while fire in the untreated stand raised rates from 3.41 to 3.83 μmol $m^{-2} s^{-1}$, although seasonal increases in control sites were also detected. Masticated then burned site soil moisture increased by 52% while soil temperature decreased. Microclimate variables were not consistently effective in explaining spatial trends. Exponential (Q_{10}) models using soil temperature and/or moisture to predict temporal trends in respiration were only significant in treated stands, suggesting that treatment implementation increased sensitivity to environmental factors. These results imply that fuels reduction practices in water-stressed forests may have important consequences for ecosystem carbon dynamics.

Kobziar, L. N., 2006. The role of environmental factors and tree injuries in soil carbon respiration response to fuels treatments in pine plantations. (*In Review*; submitted June, 2006). Biogeochemistry.

Abstract

Soil CO_2 exchange with the atmosphere (soil respiration) is second only to gross primary productivity in its importance in global carbon flux. The need to understand how forest management practices affect soil respiration has increased with the recognition of a likely feedback effect of climate warming on respiration rates. Previous research addressing the mechanisms driving soil respiration have yielded inconsistent and/or conflicting results. This study looks to alternative above-ground forest characteristics to help explain spatial variability in soil respiration in a 25-30 year old (Pinus ponderosa Dougl. ex P. & C. Laws)/ Jeffrey pine (Pinus jeffreyi, Grev. & Balf.) plantation in the central Sierra Nevada over a three year span (2003-2005). Fire hazard mitigation is one of the predominant management goals in these and other western US forests. Therefore, this analysis examines how fuels treatments, including shredding of understory vegetation (mastication), prescribed fire, and a combination thereof, affect soil respiration and its relationship to environmental factors and post-fire tree injuries. Multiple regression models indicated that mastication had no significant impact on soil respiration, but the roles of soil temperature, litter and duff depth in the models increased after the treatment. Burning reduced soil respiration by ~14%, and increased its sensitivity to tree proximity and the amount of bare mineral soil exposed. Scorch height in both masticated then burned and burn only treatments was negatively correlated with soil respiration. Models incorporating only tree injury or tree proximity parameters explained between 63% and 91% of the variability in burned plantations. These results suggest that measures of above-ground forest features can increase understanding of how management activities impact soil respiration and the mechanisms by which these impacts occur. These results are especially applicable in Mediterranean climates, where moisture stress reduces the effectiveness of soil microclimate in explaining soil respiration rates.

APPENDIX C. REPORTS TO CONGRESS AND HOUSE OF REPRESENTATIVES

United States Department of Agriculture
Forest Service
Stanislaus National Forest
19777 Greenley Road
Sonora, CA 95370
(209) 532-3671
FAX: (209) 533-1890
TTY/TDD: (209) 533-0765
http://www.r5.fs.fed.us/stanislaus

File Code: 1510
Date: October 11, 2002

The Honorable George P. Radanovich
United States House of Representatives
Washington,, DC 20515

Dear Congressman Radanovich:

I'm pleased to provide this update on the Stanislaus National Forest's Granite Watershed Enhancement and Protection Stewardship Pilot Project, in Tuolumne County, California. In a sense, the Granite Project began on a hot August day nearly 30 years ago, when a vehicle fire ignited a forest conflagration that intensely burned over 17,000 acres of mature timber, valuable watershed and key wildlife habitat on public and private lands. Successful post-fire reforestation on the national forest and adjacent private lands produced extensive, vigorous, dense pine plantations. The ensuing three decades saw five stand-replacing wildfires incinerate over 150,000 acres of forestland around the new Granite timber stands. The likelihood of losing the Granite plantations to wildfire is obvious.

In the mid-90's, a group of local residents with diverse interests formed "Our Back Yard" out of their concerns for the future of the Granite watershed and its susceptibility to wildfires. They described how they wanted the future Granite watershed to look and function, and identified actions they felt would move it from its current condition to their desired future condition. They identified certain monitoring needs as well.

Two federal laws in the late '90's formally launched the Granite Project. The Granite Watershed Enhancement and Protection Act of 1998 (PL 105-281) authorized the Secretary of Agriculture to *"enter into a contract with a single private contractor to perform multiple resource management activities on Federal lands within the Stanislaus National Forest in the State of California for the purpose of demonstrating enhanced ecosystem health and water quality, and significantly reducing the risk of catastrophic wildfire in the Granite watershed at a reduced cost to the government."* It required that activities include hazardous fuel reduction through thinning and prescribed burning, other actions to enhance ecosystem health and water quality, as well as monitoring of ecosystem health, water quality and wildlife presence.

Section 347 of the Omnibus Consolidated Appropriations Act of FY 1999 authorized the USDA Forest Service Chief to establish a number of forest stewardship pilot projects using end result contracts with private parties, and required the agency to convene multiparty monitoring and evaluation teams to assess the effectiveness of each project. The Forest Service's Washington Office identified the Granite Project as meeting the Act's criteria.

Over the course of two years, the Forest completed seven environmental analyses and decisions. Only the decision to conduct thinning was appealed, but was upheld. The seven decisions resulted in a single contract that will:

- Thin over 3000 acres of overly dense plantations to improve tree growth and reduce fire hazard;
- Thin over 1000 acres of mature forests to improve their resilience to future fires;
- Prescribed burn nearly 5000 acres of thinning slash, dense brush and fuelbreaks to reduce hazardous fuels, and improve fire protection, wildlife habitat and grazing conditions;
- Shred brush and small understory trees on over 3000 acres of second-growth stands, plantations and fuelbreaks;
- Construct over a mile of new road, improve nearly 65 miles of existing roads, and decommission 42 miles of roads that contribute to watershed degradation;
- Construct an Off-Highway Vehicle (OHV) staging area, reconstruct over six miles of OHV trails, and sign nearly 50 miles of OHV trails and roads;
- Enhance degraded streams and nearly 150 acres of compacted meadows;
- Control noxious weeds on over 75 acres; and
- Conduct much of the required monitoring.

Thinning will generate 4.3 million board feet of sawlogs appraised at approximately $430,000 in value to help offset total contract costs, and nearly 20,000 tons of wood chips available for generation of electrical power.

Nearly 40 small businesses expressed interest in the Granite Project during its lengthy advertisement earlier this year. Bids were received in late July 2002. We are currently in negotiations with all who submitted bids, to assure that contract award results in the best value for the government. At the same time, we are finalizing our search for alternative funding sources, since existing legislation appropriates no separate financing for Granite Project contract work.

The local, multiparty Granite Monitoring Team formed last winter to evaluate and report on the Project's effectiveness. Members include the local county supervisor, a representative of the commercial timber company that owns adjacent private lands, a charter member of "Our Back Yard," a representative of the Tuolumne Band of Mi-Wuk Indians, the executive director of a local environmental organization, and a fire mitigation advisor from the University of California-Berkeley.

The federal interagency Joint Fire Sciences Program granted $90,000 to a PhD candidate in University of California-Berkeley's renowned forest fire sciences program to conduct her dissertation research into forest fire hazard reduction in Granite's ponderosa pine plantations.

The Stanislaus National Forest's Granite Watershed Enhancement and Protection Stewardship Pilot Project epitomizes innovative efforts to achieve fire hazard reduction and other goals of the federal wildland fire management agencies' National Fire Plan, as well as the forest health initiatives currently under discussion in Congress and the administration. I look forward to announcing the award of the Granite Watershed Enhancement and Protection Stewardship Project Contract within the next six to ten weeks. In the meantime, if you would like further details, please feel free to contact me (phone 209-532-3671, Ext. 232) or Resource Management Program Area Leader Dan Young (Ext. 332).

Sincerely,

GLENN J. GOTTSCHALL
Acting Forest Supervisor

cc: Regional Forester, Kent Connaughton, Bernie Weingardt, Brent Handley

USDA United States Department of Agriculture | Forest Service | Washington Office | 1400 Independence Avenue, SW Washington, DC 20250

File Code: 2400
Date: May 9, 2006

The Honorable Richard B. Cheney
President of the Senate
Washington, D.C. 20510

Dear Mr. Cheney:

Enclosed is the Calendar Year 2005 Report to Congress for the Granite Watershed Enhancement and Protection Stewardship Project. This project is located on the Stanislaus National Forest near Sonora, California. PL 105-281, "Granite Watershed Enhancement and Protection Act of 1998," requires the Secretary of Agriculture to annually submit to Congress a report describing: (1) the resource management activities performed under the stewardship contract during the period covered by the report; (2) the source and amount of funds used to carry out the contract; and (3) the resource management activities to be preformed during the calendar year.

Specific questions on this report may be directed to Megan Roessing at (202) 205-0847 or mroessing@fs.fed.us.

Sincerely,

/s/ Joel D. Holtrop
JOEL D. HOLTROP
Deputy Chief for National Forest System

cc: Donald K Golnick
Tom Quinn
John R Swanson
Deb Romberger
Megan Roessing

GRANITE WATERSHED ENHANCEMENT AND PROTECTION STEWARDSHIP PROJECT

STANISLAUS NATIONAL FOREST
PACIFIC SOUTHWEST REGION
USDA FOREST SERVICE

THIRD ANNUAL REPORT TO CONGRESS 2005

As mandated by the Granite Watershed Enhancement and Protection Act of 1998

PREFACE

The "Granite Watershed Enhancement and Protection Act of 1998" (PL 105-281) authorized the Secretary of Agriculture to contract for "multiple resource management activities on Federal lands within the Stanislaus National Forest for the purpose of demonstrating enhanced ecosystem health and water quality, and significantly reducing the risk of catastrophic wildfire, in the Granite watershed at a reduced cost to the Government." It further required the Secretary annually "to submit to Congress a report describing (1) the resource management activities performed under the contract during the period covered by the report; (2) the source and amount of funds used under subsection (d) to carry out the contract; and (3) the resource management activities to be performed under the contract during the calendar year in which the report is submitted." It is useful to note that, in 1999, the USDA Forest Service also designated the Granite Watershed Enhancement and Protection Stewardship Project as one of the original projects authorized by Section 347 of the "Omnibus Consolidated Appropriations Act of Fiscal Year 1999" to test new contracting authorities approved by Congress.

This report covers the period January through December, 2005. It presents details of resource management successes, and a glimpse of the work and challenges ahead. The Forest Service is committed to fulfilling the goals of the Granite Watershed Enhancement and Protection Act of 1998.

RESOURCE MANAGEMENT ACCOMPLISHMENTS AND FUNDING SOURCES FOR CALENDAR YEAR 2005 AND PLANNED ACCOMPLISHMENTS FOR CALENDAR YEAR 2006

A. Granite Stewardship Commercial Sawlog and Biomass Removal Contract

The contractor, Sierra Resource Management, mechanically thinned 418 acres during this first year of their operations, removing 2.3 million board feet of small diameter sawlogs for manufacture at the sawmill in Chinese Camp, CA and 6075 dry tons of biomass to the electrical power co-generation facility also located a Chinese Camp, CA. In addition, 11.5 miles of road were reconstructed to allow for safe removal of the forest products.

Within this reporting period, the contractor was paid $482,902 for thinning and biomass removal. The stumpage value of the sawlogs, $43,355, was used to partially offset the costs of this work.

During Calendar Year (CY) 2006, 1000 acres are anticipated for treatment by mechanical thinning and biomass removal, generating an estimated 4 million board feet of small diameter sawlogs and 12,000 dry tons of biomass for power co-generation. An estimated 25 miles of road will be reconstructed to accomplish this.

B. Granite Stewardship Mechanical Shredding Contract

In CY 2005, the third operating season for this contract, contractor GH Ranch, mechanically thinned 228 acres of precommercial-sized plantations, shredding competing brush and trees, at a cost of $35,700.

In CY 2006, 532 acres will be treated.

C. Granite Stewardship Hand Thinning Contract

The contract with GH Ranch was terminated in CY 2005, as all required hand thinning was successfully completed, as reported in the CY 2004 Granite Watershed Enhancement and Protection Stewardship Report to Congress.

D. Granite Stewardship Noxious Weed Eradication Contract

Seventy-seven acres were treated with chemicals and hand-pulling by Summit Forest, Inc during this second year of their contract, at a cost of $21,090.

In CY 2006, 115 acres will be treated.

E. Granite Stewardship Road Decommissioning Contract

Dambacher Construction successfully completed this contract in CY2005, decommissioning 10.5 miles of road unneeded for future administrative or recreational use, at a cost of $99,562. This work was accomplished in partnership with the State of California, with funding provided by a grant from the State OHV Commission.

F. Granite Stewardship Stream and Meadow Restoration
Again we received no bids on our request for proposals to accomplish this critical work. By negotiated agreement, meadow subsoiling and tree thinning around meadow perimeters were added to the existing contract with Sierra Resource Management. No work was accomplished in CY 2005.

In CY 2006, subsoiling will be completed on 20 acres of meadow. A traditional time-and-materials contract will be advertised and awarded for restoration along 6,600 lineal feet of stream channel. A separate contract for 35,000 feet of fence construction will be advertised. Stream channel restoration and fence construction work will probably begin in CY 2007.

G. Granite Stewardship Prescribed Underburning
As part of a Joint Fire Sciences Program project, 10 acres of thinned and shredded plantations and 5 acres of untreated plantations were underburned in CY 2005, by personnel from the national forest and adjacent Yosemite National Park.

In CY 2006, a contract will be prepared and advertised for award in CY 2007 covering several thousand acres of prescribed underburning within thinned and shredded plantations treated under earlier contracts.

H. Granite Stewardship OHV Trails and Staging Area Development
Funding upon which this work depends was sought without success from the State of California OHV Commission in CY 2005.

In CY 2006, we will again seek an OHV Commission grant to contract for design and construction of an OHV staging area. No work is scheduled for accomplishment in 2006.

Source and Amount of Funds Used in CY 2005

The Pacific Southwest Regional Office allocated funding to the Stanislaus National Forest for Stewardship Contract work accomplished in CY 2005. These included vegetation management (NFVW), hazardous fuel reduction (WFHF) and road construction and maintenance (CMRD) funds. The State of California granted funds through the State OHV Commission (CAOHV). The following table displays the source and amount of funds expended on Granite Stewardship contracts and their administration in CY 2005:

Source	Amount
NFVW	$404,457
WFHF	154,771
CMRD	12,588
NFCC	10,425
RTRT	7,140
NFTM	3,198
CAOHV	$102,200
Total	$694,779

APPENDIX D. PERIODICAL

Woman studies forest thinning

Published: August 30, 2004 in the Union Democrat, Sonora, CA

Click this picture to view a larger image.

UC Berkeley Doctoral candidate Leda Kobziar uses a tape measure to find the circumference of a tree in a ponderosa pine plantation in the Groveland Ranger District of the Stanislaus National Forest.
Photo courtesy of Jerry Snyder

By GENEVIEVE BOOKWALTER

On some parts of Stanislaus National Forest's Groveland Ranger District, machines whirl and crash, removing small trees from the woods and drowning out all other sounds.

But elsewhere, on about 15,000 acres burned by the 1973 Granite Fire, 30-year old Leda Kobziar works quietly. Near Cherry Lake, at 5,500 feet, she spends her days listening to birds and other creatures as she methodically measures tree rings and the rate at which soil breathes.

It is part of her University of California, Berkeley, doctoral thesis.

As politicians across the country debate the best way to stop catastrophic fires that have ravaged many parts of the Western United States, Kobziar hopes to provide science to evaluate arguments for forest thinning.

Mechanical removal of brush and debris has become a popular way to clean the woods of slash and packed-in trees that could fuel forest fires.

Although fire is a natural part of many ecosystems in the West, forests overgrown during a century of fire suppression efforts are fueling blazes that burn out of control.

Where fire once crawled sleepily along the ground and left giant trees unharmed, flames now climb brush and limbs like ladders, jumping from one rung to another until they reach the top and wipe out great stands. Risk to forest neighborhoods and communities has grown as well.

"There's never been any work done showing what we're doing reduces fire," said Groveland District Ranger John Swanson. "Hers is the first study aimed at getting scientific evidence."

The Granite Fire burned in 1973. In 1974, loggers cut the scorched logs from the forest, and the Forest Service replanted the area with ponderosa pine between 1975 and 1978. In 2003, shredders and saws thinned the plantation, which had become crowded with trees and brush.

Now, Kobziar said, she wants to see the difference in tree growth rates pre- and post-thinning and shredding, and in the amount of carbon dioxide released from the soil.

With fewer trees competing for food, water and sunlight, Kobziar seeks to discover if trees will grow more next season than in years past, as she expects. She measures the trunks' rings to determine what effect thinning plays on the remaining trees' size.

But she does not cut trees down to get these results. Instead, Kobziar and her assistant, Vincent Causse, 23, from Montreal, twist thin metal cylinders into the trunks and come out with a pencil-sized sample. The lines on that rod mark how much a tree has grown during each year of its existence. The duo also wraps tape measures around the trunks to measure their circumference.

For the soil tests, the doctoral candidate sets a special machine with a temperature probe, vacuum tube and infrared detector on the soil and measures how much carbon dioxide the plant roots, bacteria, fungi and other organisms in the soil release as they breathe. She also collects specimens and carts them back to the lab for more research.

With all its living things, soil holds more carbon than anything else in the forest, Kobziar said.

The goal is to limit the amount released into the atmosphere during fires, which contributes to global warming.

The bigger the wildfire, the more trees, plants and other organic material burn. Consequently, more carbon escapes into the sky.

Kobziar will also watch, after a scheduled prescribed fire sweeps through the plot this fall, to see if the carbon release will be different. This is the first time she will measure respiration after fire.

"It's so exciting that all these treatment are getting done and they're looking so good," Kobziar said.

About 18 months remain before Kobziar completes her doctorate, she said. In the meantime, she and Causse spend their off-hours rock climbing in Yosemite National Park and hanging out at the Cherry Lake Fire Station, where they both live.

After she's done working on the Stanislaus, Kobziar said she hopes to lead college classes as a professor.

"I love teaching," Kobziar said, who has already instructed basic biology classes at UC Berkeley as a teaching assistant.

"It's so incredibly rewarding. There's a lot of stuff we don't know and understand."

Contact Genevieve Bookwalter at gbookwalter @uniondemocrat.com.

APPENDIX E. UNDERSTORY VEGETATION SAMPLING RESULTS

Table E1. Understory vegetation species cover and ground cover for five treated units in the Stanislaus National Forest Granite plantations. Counts are out of 350 sampling points for each unit. Percent columns represent percentage of ground covered.

Stand	Species/ Ground cover	Count, Pre-treatment	Count, Post-mastication	Count, Post-burning	Percent Pre-treatment	Percent Post-mastication	Percent Post-burning
5-188	*Acnatherum occidentale*	5	1	n/a	0.0	0.3	n/a
	Bare ground	17	12	n/a	4.9	3.4	n/a
	Ceanothus cordulatus	187	0	n/a	53.4	0.0	n/a
	Ceanothus intergerimis	7	26	n/a	2.0	7.4	n/a
	Chamaebatia foliolosa	0	2	n/a	0.0	0.6	n/a
	Gayophytum diffusum	0	6	n/a	0.0	1.7	n/a
	Litter	90	228	n/a	25.7	65.1	n/a
	Lotus nevadensis	0	48	n/a	0.0	13.7	n/a
	Phacelia egena spp. virgata	0	5	n/a	0.0	1.4	n/a
	Prunus virginiana	37	0	n/a	10.6	0.0	n/a
	Pteridium aquilinum var. pubescens	6	6	n/a	1.7	1.7	n/a
	Quercus kelloggii	0	1	n/a	0.0	0.3	n/a
	Ribes roezlii	0	8	n/a	0.0	2.3	n/a
	Rock	0	1	n/a	0.0	0.3	n/a
	Symphoricarpos mollis	1	6	n/a	0.3	1.7	n/a
5-89	*Achnatherum occidentale*	17	27	n/a	4.9	7.7	n/a
	Arctostaphylos patula	64	21	n/a	18.3	6.0	n/a
	Bare ground	28	26	n/a	8.0	7.4	n/a
	Bromus tectorum	1	9	n/a	0.3	2.6	n/a
	Ceanothus cordulatus	22	6	n/a	6.3	1.7	n/a
	Ceanothus intergerimis	2	23	n/a	0.6	6.6	n/a
	Chamaebatia foliolosa	1	3	n/a	0.3	0.9	n/a
	Cistanthe umbellata var. umbellata	8	2	n/a	2.3	0.6	n/a
	Elymus elymoides spp. Californica	0	2	n/a	0.0	0.6	n/a
	Eriogonum nudum var. nudum	0	2	n/a	0.0	0.6	n/a
	Gayophytum diffusum	0	5	n/a	0.0	1.4	n/a
	Kelloggia galiodes	0	2	n/a	0.0	0.6	n/a
	Linanthus ciliatus	0	8	n/a	0.0	2.3	n/a
	Litter	201	202	n/a	57.4	57.7	n/a
	Lotus nevadensis	0	10	n/a	0.0	2.9	n/a
	Lupinis breweri var. breweri	0	2	n/a	0.0	0.6	n/a
	Madia glomerata	1	0	n/a	0.3	0.0	n/a
	Rock	5	0	n/a	1.4	0.0	n/a
5-106	*Achnatherum occidentale*	2	0	0	0.6	0.0	0.0
	Bare ground	28	30	23	8.0	8.6	6.6
	Ceanothus intergerimis	24	0	0	6.9	0.0	0.0
	Ceanouthus cordulatus	67	16	12	19.1	4.6	3.4
	Claytonia perfoliata	2	0	0	0.6	0.0	0.0
	Gayophytum diffusm	2	0	13	0.6	0.0	3.7
	Horkelia tridentata spp. Tridentata	0	0	4	0.0	0.0	1.1
	Litter	183	252	199	52.3	72.0	56.9
	Lotus micranthus	3	1	32	0.9	0.3	9.1
	Lotus nevadensis	0	1	2	0.0	0.3	0.6
	Madia minima	0	0	2	0.0	0.0	0.6
	Pteridium aquilenium	24	30	40	6.9	8.6	11.4
	Ribes roezlii	5	6	12	1.4	1.7	3.4
	Rock	6	12	5	1.7	3.4	1.4
	Rumex acetosella	1	0	6	0.3	0.0	1.7
	Unknown grass	3	0	0	0.9	0.0	0.0
	Unknown *Poa* spp.	0	2	0	0.0	0.6	0.0
5-132	*Achnatherum occidentale*	20	n/a	2	5.7	n/a	0.6
	Arctostaphylos patula	5	n/a	1	1.4	n/a	0.3
	Bare ground	16	n/a	14	4.6	n/a	4.0
	Ceanothus cordulatus	6	n/a	0	1.7	n/a	0.0
	Gayophytum diffusum	0	n/a	1	0.0	n/a	0.3
	Litter	272	n/a	294	77.7	n/a	84.0
	Lotus micranthus	0	n/a	3	0.0	n/a	0.9
	Lotus nevadensis	6	n/a	8	1.7	n/a	2.3
	Ribes roezlii	21	n/a	15	6.0	n/a	4.3
	Rumex acetosella	4	n/a	0	1.1	n/a	0.0
	Symphoricarpos albus	0	n/a	7	0.0	n/a	2.0
	Unknown forb	0	n/a	4	0.0	n/a	1.1
	Viola lobata spp. lobata	0	n/a	1	0.0	n/a	0.3