

EFFECTS OF MECHANICAL THINNING, FIRE, AND MASTICATION ON THE SPATIAL STRUCTURE OF THE FOREST FLOOR

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SUMMARY OF POINTS

- Vegetation cover by species was collected in 400 1m² plots, 100 in each of four treatment sites: control, mechanical thinning, mastication, and fire. In addition, downed fuels and soil nutrients, moisture, and temperature were monitored at each site.
- Mastication sites had a greater quantity of downed woody debris as well as duff compared to control sites.
- Soil nutrient levels in mastication sites were no different than control sites; only the fire site showed different (higher) levels.
- The spatial structure of the understory was not greatly different than the control site, but was slightly more patchy.
- Composition on mastication site was different than control sites due to the dominance of certain species and an overall greater cover.
- **The data do not suggest mastication has greater negative effects than other treatments.**

Abstract: Mastication has become a common and cost-effective means for fuel reduction and restoration of open ponderosa pine forest, but mastication effects on the understory are still unknown. This study examined the spatial structure of fuels, soil and vegetation at Heil Valley Ranch in areas masticated and compared it to a control area and two other management techniques: thinning and fire (prescribed burn). The objectives were to determine to what extent mastication alters forest floor fuels, soil structure, and vegetation composition and diversity. Further, the spatial structure of these understory components were examined to help understand the impacts of mastication and influences on understory heterogeneity. Data were collected from a stratified random placement of 1m² plots in each treatment type. Vegetation cover was collected from each plot. Soil cores were extracted within the top 20 cm of the soil surface from 15 plots in each site, and fuel data were collected from five locations within each site. Results show an increased level of available fuels in the mastication site when compared to thinning, but not when compared to the fire site, especially class 3 and class 4 woody biomass. Mastication also had greater levels of duff present at the site (>600g m²) while not significantly changing the soil composition, which could be due to the lack of time needed for proper decay and return of the nutrients to the soil. The fire site on the other hand had much greater levels of K, Ca, Mg. The mastication site did have slightly more spatial heterogeneity than the fire site and the control site, but less than the thinning site; however, the diversity within the fire site was much greater than that within the mastication site. Overall cover was also lower in the mastication site when compared to fire (>100% - due to abundance of species and overlap in shade cover), but slightly more compared to the thinning and control sites (<50% total cover). The data do not suggest major differences on fuel loads, soil chemistry, or spatial heterogeneity among the thinning treatments, but do elucidate an increase in cover and richness; thus, mastication may be just as effective of a technique for maintaining ponderosa pine ecosystems. The data further suggest that fire should not be excluded from management consideration.

Introduction

Recent large-scale fires and insect outbreaks presenting the increased possibility of large-scale fires in western forests have led to a fuel reduction program especially in the wildland-urban interface (Harrod et al. 2009). In addition, restoration of dry conifer forests is an important endeavor due to the loss of the natural disturbance regime (Arno 1996). Mastication (shredding, chopping, or chipping small trees and/or shrubs into small chunks and leaving the material on site) has been touted as a cost-effective means for fuel reduction, but mastication effects on the understory are still unknown (Wolk et al. 2008). To date, little research has been compiled on the effects of mastication on the forest floor. This lack of knowledge impedes our ability to assess the efficacy of mastication as a management tool. If there are short or long-term

negative impacts of mastication on Ponderosa pine ecosystem structure or function, then other stewardship techniques should be used.

Mastication is a mechanical fuel treatment targeting non-commercial timber (Harrod et al. 2009). The treatment includes shredding, chopping, or chipping small trees from dense stands and spreading the wood chips throughout the cleared site. The procedure was found to be cost-effective means of forest restoration and fuel reduction and had negligible effects regarding subsequent fire behavior on overstory trees (Harrod et al. 2008). However, this relatively new treatment has had little research regarding forest floor (vegetation and soil) response to mastication.

A few studies have examined the effects of mastication on understory flora. Wolk et al. (2008) in their final report to Boulder County suggested that thinning increased vegetation density but had no effect on diversity of native or exotic species. However, their study only examined three plots at each site location and did not examine spatial structure except in relevance to trails. Several studies suggest thinning enhances understory vegetation but potentially enhances exotic invasion as well (Metlen et al. 2004, Laughlin et al. 2006). Wayman and North (2007) suggest fire, thinning, and the combination of fire and thinning all differentially impact understory flora.

Two studies suggest negative impacts of mastication on soil. Busse et al. (2008) showed clear negative impacts with mulch depths greater than 7.5 cm. Following fire on mastication sites, soils reached lethal temperatures for microorganisms essentially sterilizing the soil; especially in dry soils. Contrarily, Harrod et al. (2008) found that mastication did not lead to excessive soil heating. Hatchett et al. (2006) examined erosion in the Tahoe Basin and found sediment output four times greater in mastication areas versus control sites. However, they found no differences in soil compaction or infiltration, suggesting the erosional differences may only occur during significant rainfall events.

The efficacy of mastication to reduce fire severity is also in question. Fire behavior modeling showed that mastication was detrimental, compared to prescribed fire techniques, in that it did not reduce extreme fire behavior at moderate to extreme weather conditions (Kobziar et al. 2009). The reason was increased landscape heterogeneity in the patchy use of mastication and the inability of current fire models to accurately depict fire behavior in the modified landscape. Contrarily, Glitzensein et al. (2006) found fire behavior models to correctly predict slow-moving, low intensity fires in a southeastern mixed forest. Disturbance, or lack thereof, has been linked to landscape structure in numerous situations (Lindenmayer and Fischer 2006) and such structure at many scales has been shown to impact ecosystem function (Hernández-Stefanoni and Dupuy 2008; Buchanan et al. 2008).

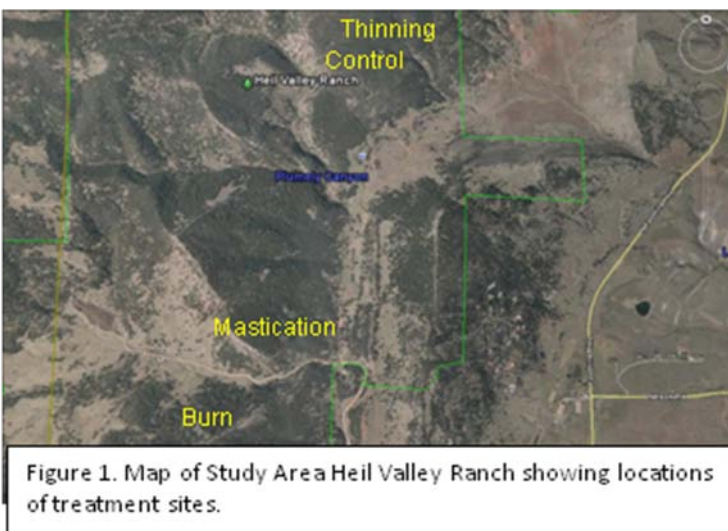
Spatial structure has become an increasingly important factor controlling community composition at small (Franklin et al. 1997) and landscape scales (Kupfer et al. 2004), especially due to the fragmented

nature in how land stewardship is performed and the problems of exotic species when disturbance is used as a management technique. The effects on vegetation are governed by island biogeographic theory, in that small populations are more likely to go extinct and isolated populations less likely to be colonized. Thus, dispersal is a major factor in disturbed landscapes and exotic species tend to be ruderal with high dispersal rates (Kupfer and Franklin 2009). Knowledge of the spatial structure of the management and the resulting vegetation response is vital to understanding the full impacts of stewardship activities.

Currently, the literature lacks adequate studies assessing the effects of mastication on understory vegetation and soil structure and function. What little research exists is also confounded by inconsistent results. Here we report on a place-based research project to determine the effects of mastication on the spatial structure and function of the Ponderosa Pine forest floor.

Objectives: The objective of the proposed research was to determine the effects of fire, thinning and mastication on the forest floor spatial structure, and specifically compare the differences in the less-studied mastication to other management strategies. A further objective was integrative knowledge. This study integrates with Dr. Rick Adam's study concerning bat foraging activity within these sites. Our goal was to understand the effects of forest thinning treatments from both a bottom-up (autotrophic) and top-down (bats as predator response) perspective using insects (primary consumers) at the intermediate trophic link. Dr. Adams and Franklin will be comparing their data in January.

Hypotheses: We hypothesized that mastication would increase fuels and increase soil organic matter more than thinning or fire. We further hypothesized that mastication would increase vegetation cover and diversity compared to control sites, but less than other treatment sites. Finally, we hypothesized that mastication would decrease understory heterogeneity compared to all other treatments.



Methods

Treatments

The research examined four management methods at Heil Valley Ranch (Fig. 1): control, mechanical thinning, mastication, and prescribed fire. Thinning is intended to promote biological diversity and structural heterogeneity characteristic of old-growth forests (Aukema and Carey 2008). Thinning reduces the overall

density of trees, which in turn increases light availability, and an increase in light availability also increases the overall cover and biomass of the forest understory vegetation. Removing the trees also may increase the levels of available resources and may allow a greater number of understory species to persist in the ecosystem (Dodson et al. 2007). The thinning and mastication sites in this study resulted in canopy removal of 60-80%. The thinning site had debris gathered into piles while the mastication site debris was scattered as discussed above.

Busse et al. (2000) suggested that a generally greater reduction in woody biomass by fire leads to higher diversity in the understory of both native and exotic flora. Metlen et al. (2006) specifically suggested that burning alone can result in increased forb abundance, graminoid abundance, and overall species diversity. Wayman and North (2007) suggest fire, thinning, and the combination of fire and thinning all differentially impact understory flora. The prescribed fire on this site, while not witnessed, was apparently fairly hot due to the loss of overstory (~80% of the canopy). All sites received their treatments in either 2007 or 2008, so all disturbances were recent and reflect similar recovery time for the understory.

Description of research

One site was chosen for each treatment; control, thinning, mastication, and prescribed burn (fire). Every effort was made to maintain similar characteristics among sites, especially regarding soil and aspect. All management treatments were less than three years old so age should not be a major factor in differences of fuels and vegetation. Within each site, a 0.25 ha site for each treatment (mastication, fire, thinning, and control) was examined. A 50 m X 50 m grid was established and 1 plot (1m²) randomly located within each 5 m² section (n=100 plots/site). Percent cover was examined for each site using a modified Daubenmire cover scale (Franklin et al. 2003). Richness, diversity, and evenness values were calculated for each plot by species.

Four small soil cores were extracted from 15 randomly selected plots at each site. Extractions were from 0-10 cm (topsoil) and mixed thoroughly. Samples were air-dried, sieved, and sent to A&L Analytical Laboratories, Inc., for analysis. Fuel data were collected and analyzed using a modified Brown technique following Kane et al. (2009); five locations were randomly chosen within each site. Soil temperature and moisture data were collected from July 13, 2010 to September 26, 2010 with temperature buttons and Watermark soil moisture sensors, respectively.

Data analysis

Due to lack of true replication, only descriptive statistics were used to compare among treatments. Vegetation differences were assessed using nonmetric multidimensional scaling (MNS) with a two-axis ordination, followed by a multi-response permutation procedure (MRPP) and species indicator analysis (McCune and Mefford 2006). Spatial autocorrelation, standardized to a 25 m active lag and 1.5 m lag distance, was assessed for diversity values and composition using variograms and krigging in the GS+ program. Models were isotropic and model type was based on the R^2 ; the model that accounted for the most variance. Heterogeneity was calculated following Li and Reynolds (1995). Vegetation composition data were reduced to one value using a one-dimensional NMS ordination; the first axis ordination values were used for spatial analysis (Franklin et al. 2003).

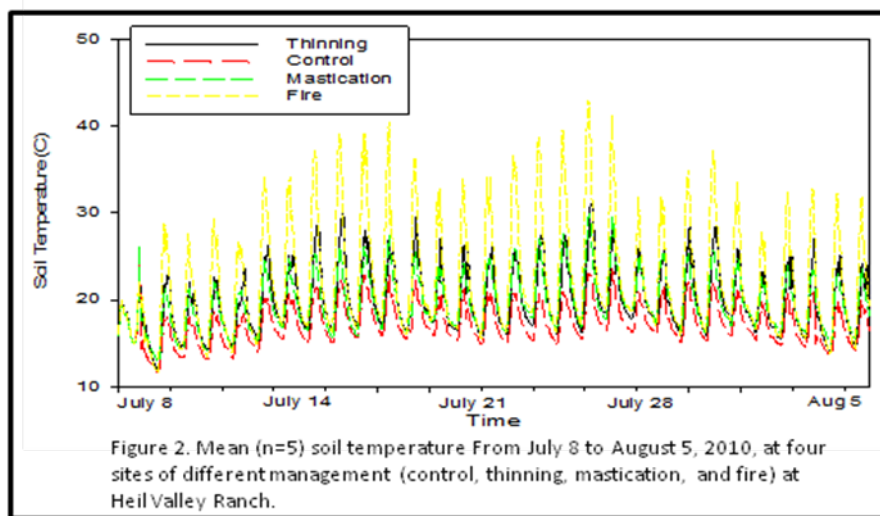
Table 1. Site characteristics for four ponderosa pine forest treatments (control, thinning, mastication, and fire) at Heil Valley Ranch.

SITE	Elevation (km)	Aspect	% Slope	Average Soil Temp (C)
Control	6.850	86 E	27	19.08
Thinning	6.780	114 ESE	11	21.69
Mastication	6.100	114 ESE	40	20.71
Fire	6.645	66 NE	61	22.76

Results

Site Characteristics

Sites were similar in elevation, aspect, and percent slope (Table 1). Temperature varied among sites (Fig. 2) with the fire site showing the highest temperatures (~54 C high and an average high on July 26-27);

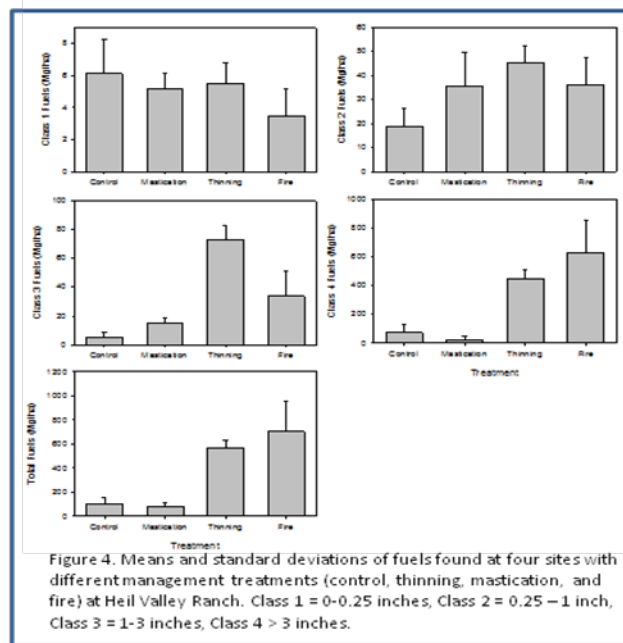
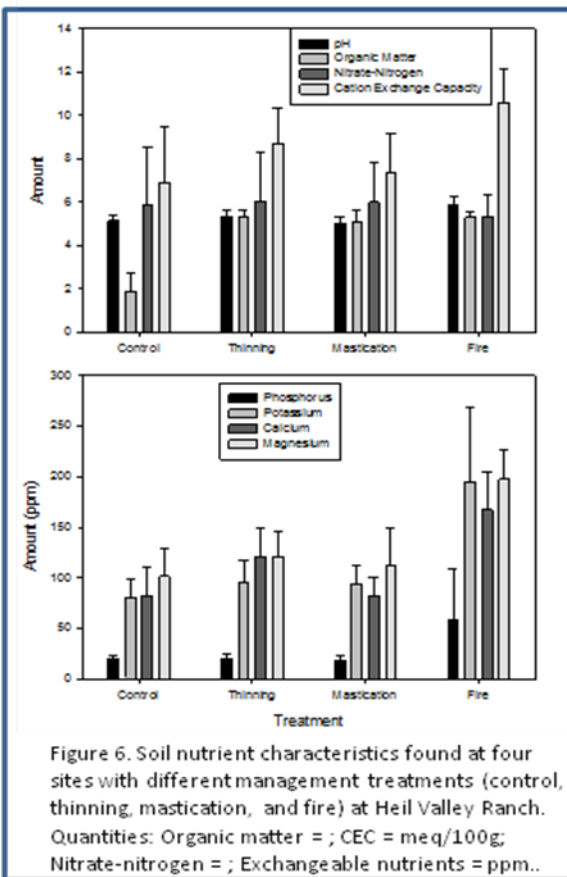
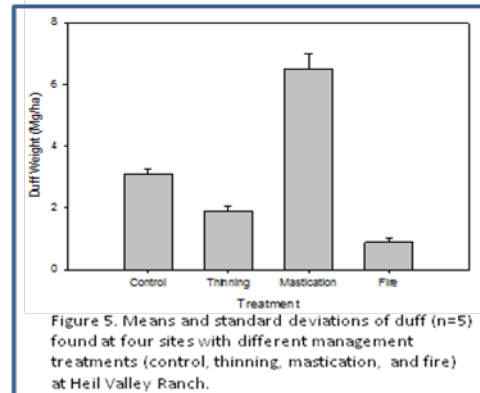
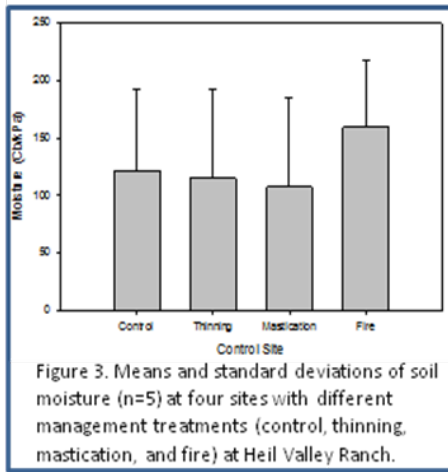


the lowest temperatures occurred in the control site, and the mastication and thinning sites had relatively similar soil temperatures. Soil moisture was relatively constant among sites (Fig. 3); the least soil moisture was found within the fire plots and the greatest soil moisture within the mastication plots.

Dead and down fuels were noticeably different among sites

(Fig. 4). The control site had the most Class 1 fuels, the least Class 2 and 3 fuels, and the second to least

class 4 fuels. Because the thinning site had the least Class 4 fuel load, it had the least total fuels of all treatments but was similar to the control site. The mastication site and fire site had much greater Class 3 and Class 4 fuels and thus total fuel load. Duff was greater in the mastication site than all other sites (Fig. 5).



Soil nutrients were also noticeably different among sites (Fig. 6). Organic matter was lower in control sites compared to all other sites and soil exchangeable nutrients

were greater in the fire sites compared to all other sites.

Vegetation Characteristics

Vegetation composition among the sites was different. Ordination analyses clearly (significant based on MRPP) separated thinning, mastication and fire treatments as compositionally different, but the control sites overlapped with all treatments (Fig. 7). Species indicator analysis suggested that the fire site had the greatest number of characteristic species that distinguish it from the other treatments (Table 2). The thinning

group was discriminated by the presence of, e.g., *Poa pratensis* L. and *Danthonia spicata* (L.) Beauvois, the mastication site was discriminated by *Phacelia hastata* Douglas and *Silene antirrhina* L., and the fire site was discriminated by *Ceanothus fendleri* Gray, *Bromus japonicus* Thunberg, and *Grindelia squarrosa* (Pursh) Dunal. The control site was not as clearly discriminated and had only weak indicators: *Hieracium fendleri* L., and *Polytrichum piliferum* Hedw.

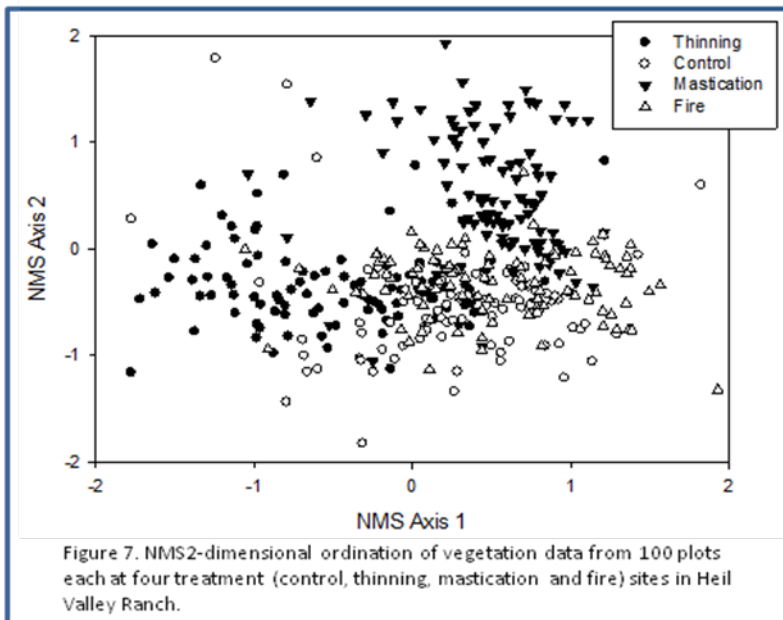
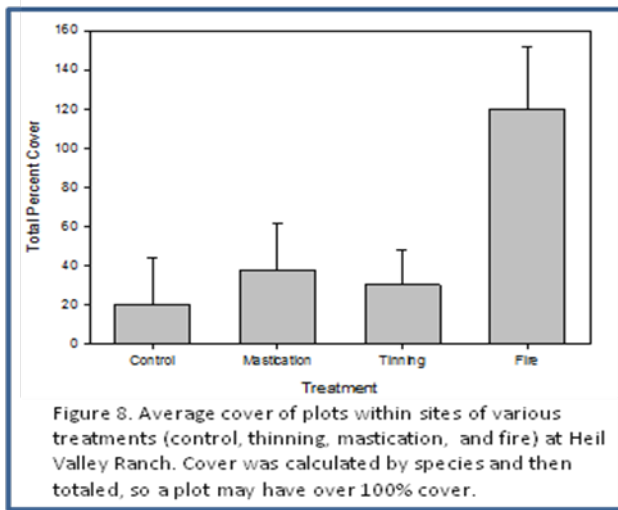


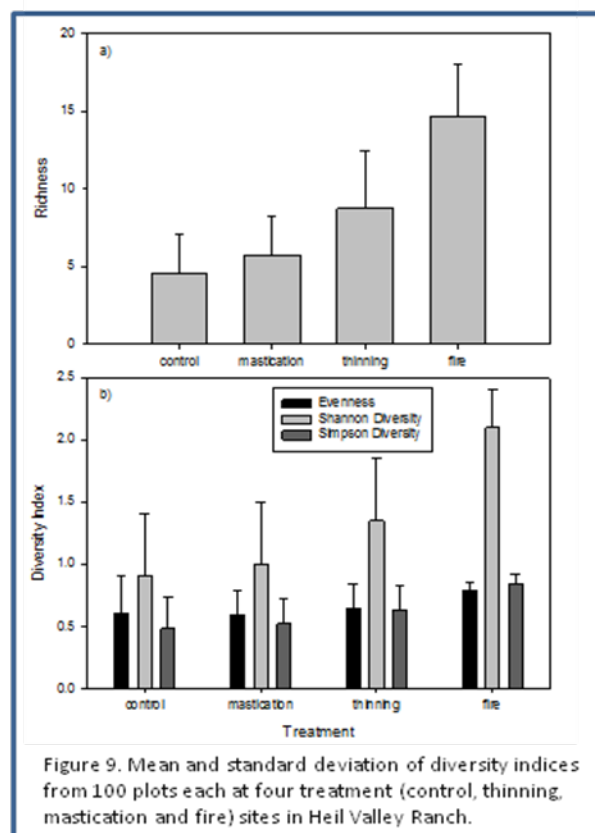
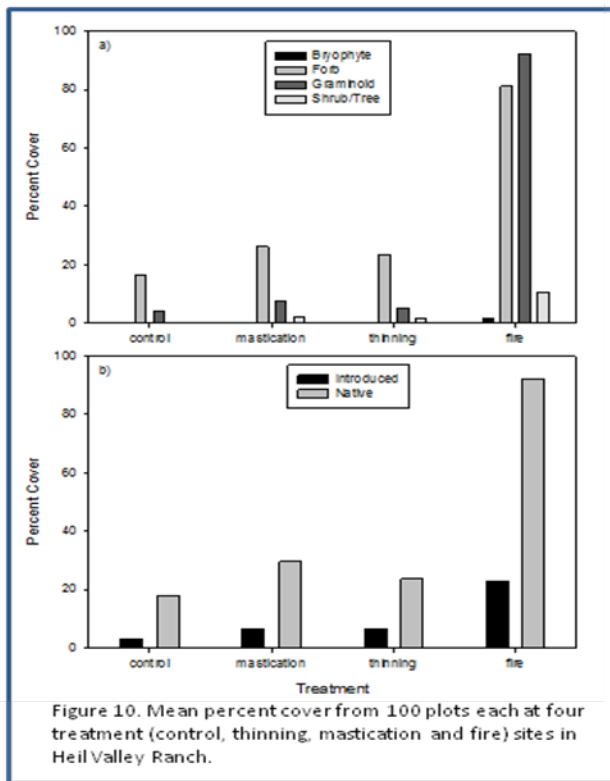
Table 2. Indicator species by treatment based on significant species analysis of 100 plots from each treatment type.

TREATMENT			
Control	Thinning	Mastication	Fire
<i>Hieracium fendleri</i>	<i>Arnica fulgens</i>	<i>Elymus trachycaulus</i>	<i>Ambrosia psilostachya</i>
<i>Pinus ponderosa</i>	<i>Danthonia spicata</i>	<i>Phacelia hastata</i>	<i>Anisantha tectorum</i>
<i>Polytrichum piliferum</i>	<i>Geranium caespitosum</i>	<i>Silene antirrhina</i>	<i>Bromus japonicus</i>
	<i>Poa pratensis</i>	<i>Verbascum thapsus</i>	<i>Ceanothus fendleri</i>
	<i>Ranunculus ranunculinus</i>		<i>Cirsium arvense</i>
			<i>Epilobium brachycarpum</i>
			<i>Grindelia squarrosa</i>
			<i>Lactuca tatarica</i>
			<i>Remux(sp?) acetosella</i>
			<i>Symphyotrichum porteri</i>
			<i>Tragopogon dubius</i>

Overall cover of sites averaged 20-40% and was similar among treatments except for fire which averaged over 100% cover (Fig. 8). The high cover of fire was due to multiple and overlapping layers. Species richness was greatest at the fire site, followed by mastication, thinning, and control (Fig. 9). For all other diversity indices, fire>thinning>mastication>control.



Growth form cover appeared to be increased by disturbance. Fire had the greatest cover for all growth forms, especially forbs and graminoids (Fig. 10a), and was the only site where bryophytes were found in plots. While forbs dominated all other treatment sites, graminoids dominated fire sites. Both exotic and native cover were higher in the thinned and mastication site compared to the control, but the fire site had the highest cover of both (Fig. 10b). Relative to the control site, fire sites had much greater native cover.



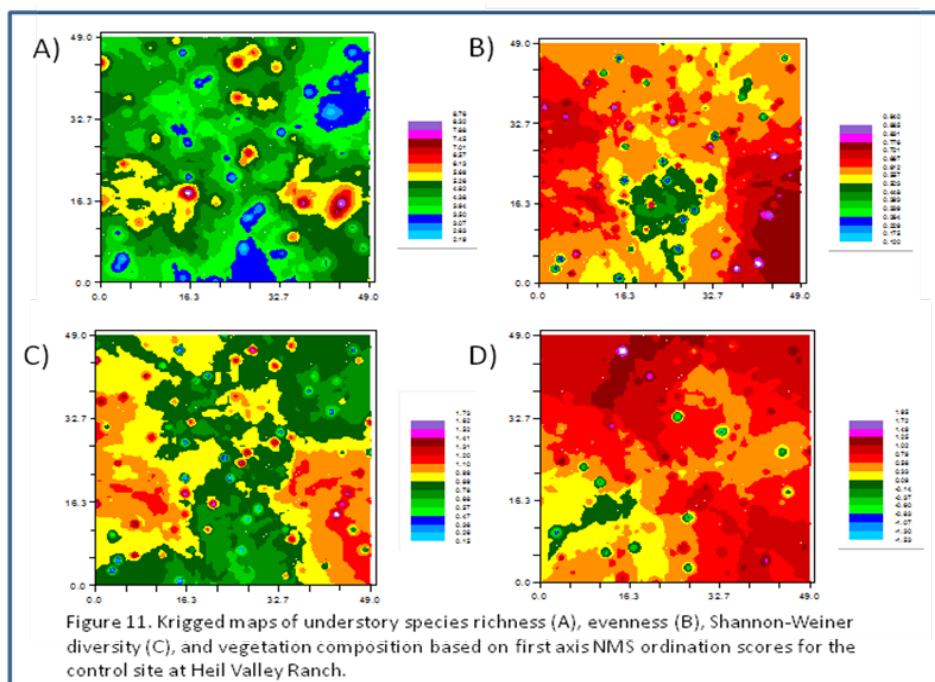
Spatial Characteristics (Mastication & Fire Sites)

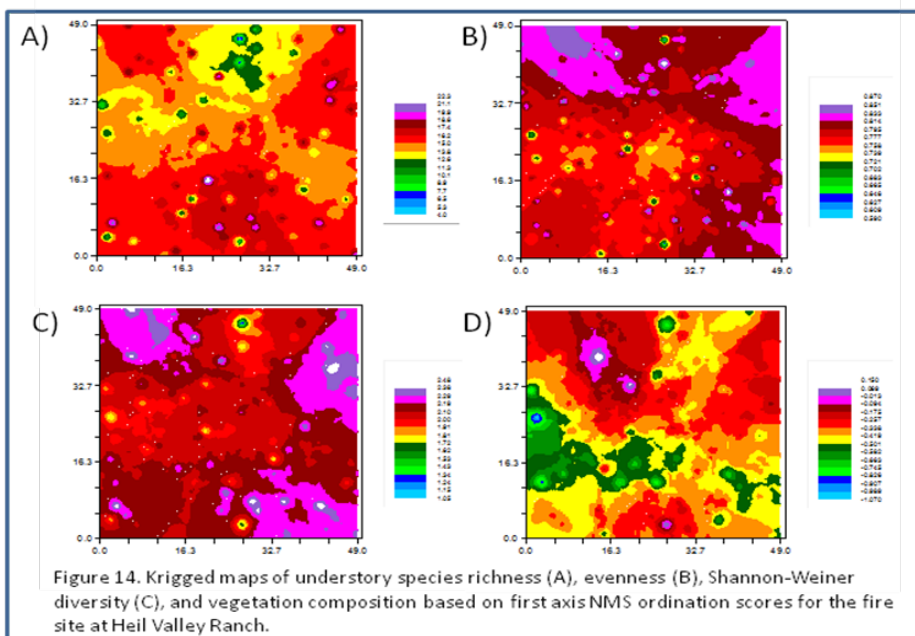
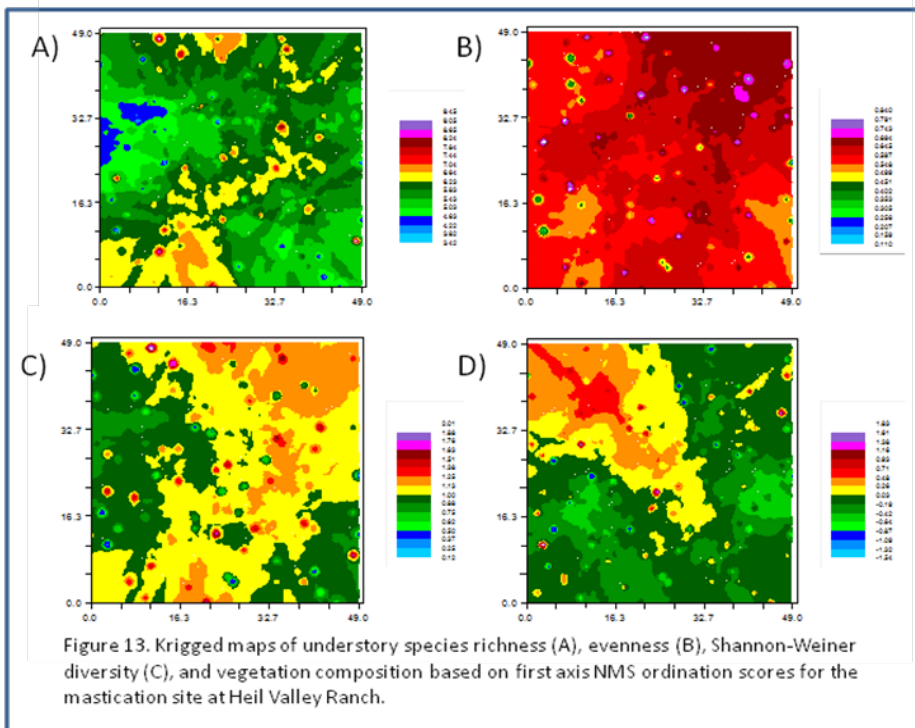
Axis 1 of the NMS ordination of vegetation data was significant ($p=0.0099$) based on a randomization test. Semivariance analysis suggested strong heterogeneity for diversity values and community composition (all above 0.7), although model R^2 values were sometimes low or nonexistent (Table 3). Spatial heterogeneity was generally the highest for diversity and composition in the mastication site and thinning compared to the fire site and control site. The patch size (i.e., range) for diversity values

ranged from 1.2 m in the thinning site to 9.5 m in the control site (Table 3), suggesting small-scale patchiness in all sites. The thinning site seemed to have the smallest scale of spatial structure, due to very high semivariance values at the lowest spatial scale (1.5.m); the lack of model fit ($R^2 = 0$) is due to this fact. Composition patch size was around 2 m (1.2 to 2.37 m) except in the fire site where it was much greater; 10 m. Krigging results elucidate spatial comparisons among the diversity values and composition. Richness, for example, is noticeably least patchy in the control site (Fig. 11a) and most patchy in the thinning site (Fig. 12a). Species diversity was least patchy in fire site (Fig. 14c) and again most patchy in the thinning site (Fig. 12c). Species composition was least patchy in the fire site (Fig. 14d).

Table 3. Spatial autocorrelation (semivariance) of diversity values and vegetation composition (NMS Ordination axis 1) of Mastication and Fire sites at Heil Valley Ranch.

Site	Data Type	Model Used	Nugget	Sill	Range	R^2	Spatial Heterogeneity
Control	Richness	Exponential	2.15	7.18	9.48	0.73	0.70
	Evenness	Gaussian	0.0001	0.087	2.82	0.64	0.99
	Shannon	Gaussian	0.0001	0.295	3.19	0.74	1.00
	NMS	Spherical	0.167	0.995	1.57	0.01	0.83
Thinning	Richness	Spherical	1.43	14.23	1.2	0.00	0.90
	Evenness	Spherical	0.0004	0.036	1.2	0.00	0.89
	Shannon	Spherical	0.05	0.27	1.2	0.00	0.82
	NMS	Spherical	0.001	0.84	1.2	0.00	0.99
Mastication	Richness	Exponential	0.43	6.2	3.27	0.45	0.93
	Evenness	Gaussian	0.0001	0.037	2.75	0.00	0.99
	Shannon	Gaussian	0.0001	0.204	3.53	0.52	1.00
	NMS	Gaussian	0.001	1.008	2.37	0.48	0.99
Fire	Richness	Gaussian	0.01	12.45	4.35	0.78	0.99
	Evenness	Spherical	0.0004	0.006	1.41	0.00	0.94
	Shannon	Exponential	0.014	0.107	7.77	0.52	0.87
	NMS	Exponential	0.117	0.234	10.11	0.48	0.50





Discussion

While mastication is an efficient method to reduce fuels and restore ponderosa pine forest, its effects on understory communities is only partially understood. We compared vegetation on a mastication site, thinning site, prescribed fire site, and control site to determine effects of mastication in relation to other management techniques. Our basic findings were that mastication sites had substantially more fuels, especially Class 3 and duff, noticeably different composition and slightly greater diversity, but were

otherwise similar to thinning and control sites. In addition, mastication sites were not different from thinning and control sites in regard to soil temperature or soil moisture.

Our first hypothesis, that mastication would increase fuels and soil organic matter more than thinning or fire, is only partly supported. The mastication site and the fire site both had high levels of dead and down woody fuels, with the fire site having slightly more total fuels than the mastication site. Fuel loads from this study were substantially higher for thinning and fire treatments than other studies have shown, but comparable for the mastication treatment to studies in the east (approximately 160 Mg/ha; Glitzenstein et al. 2006) and the west (20-60 Mg/ha; Vaillant et al. (Final Report)). Control site fuel loads were greater by a magnitude of ten from those reported by Robertson and Hall (1999), but we don't have an explanation for the difference. It is possible that the density of the control site was greater in our study.

Glitzenstein et al. (2006) and Busse et al. (2009) found similar results in that mastication significantly increased woody biomass in the understory, but the amounts vary with location and class sizes. Both previous studies, however, found that fire actually decreased the relative amounts of woody biomass in the understory, especially in regards to rotten fuels. The differences could be that the trees at Heil Valley Ranch were not entirely burned in the fire and thus remained in the environment (became dead and down), whereas the smaller size classes that were present in the understory prior to the burn, as in previous studies, were reduced with the fire. Both the thinning and control sites had much lower fuel loads, especially for class 3 and class 4 fuels, which were mostly removed during the thinning and cleaning stage of the thinning site. Wolk and Rocco (2008) also found much lower fuels and duff in thinning and control sites compared to mastication treatments.

Soil organic matter was greater in all three treatment sites (thinning, mastication, and fire) compared to the control but not different among treatments. However, the duff layer was much greater on mastication sites and that may lead to increased soil organic matter after a year or two of decomposition. Soil nutrients showed no negative impact of mastication and were essentially the same as control and thinning sites. Contrarily, Miesel et al. (2009) found that thinning treatments impacted soil nutrients - increased soil N and pH - differently and suggested such changes would affect forest growth rates. Fire, acting as a fast decomposer, resulted in substantially higher available nutrient concentrations as has been shown by numerous other studies (Kutiel and Naveh 1987), although fire can also reduce volatile nutrients (Covington and Sackett 1984). Supporting our thinning site and mastication site data but contrary to our fire site data, Kaye et al. (1999) found no differences in the effects of ponderosa pine restoration strategies on soil nutrient losses.

Our second hypothesis, that mastication would increase vegetation cover and diversity compared to the control site but less than the other treatment types was also only partly supported. Total cover was

approximately twice as high in the mastication site as the control site, but only about a third of cover in the fire site. Studies have confounding results regarding the increase or decrease of cover following thinning and fire (Busse et al. 2000). Increases in cover were related to increases in diversity as well. The data clearly showed differences in understory community composition, as was also found by Wolk and Rocca (2008) who compared thinning and thinning & chipping treatments along the Front Range of Colorado. Indeed, Wolk and Rocca (2008) also had *Phacelia* as an indicator of mastication treatment sites. Also as with Wolk and Rocca (2008), much of the diversity in treatment sites was due to exotic species. However, it appeared that the cover of exotics and natives was similarly higher in the mastication and thinning treatments compared to the control; in other words, the disturbance did not give a greater advantage to exotics as has been found in some studies (Dodson et al. 2007). In fact, the fire site had much greater cover of native species than exotic species compared to control sites, suggesting fire gives an advantage to natives.

Richness was greatest in the fire site, followed by mastication, then thinning, and finally control. Shannon and Simpson diversity indices followed the same trend, but evenness was similar among the control, mastication, and thinning sites; the fire site had greater evenness. Therefore, mastication did impact vegetation cover and diversity, but was certainly more similar to the thinning and control sites than the fire site. This is consistent with Abella et al. (2004) in that increasing intensity of disturbance (fire in our case) increased overall understory diversity, especially native diversity, while lower levels of disturbance (mastication and thinning in our case) had limited impacts on vegetation diversity with respect to undisturbed sites. Abella et al. (2004) also found an increase in exotic species diversity in medium intensity disturbances, which was similar to our results in that the mastication site had a significantly higher amount of *Verbascum thapsus* L. (an exotic disturbance-loving species) than any of the other three sites. One reason for higher levels of vegetation cover within the fire site could be due to the lower levels of duff found within the site. Fire removed most of the duff layer and that removal promoted more favorable conditions for germination and growth. The seed bank and colonizers were able to flourish, especially with greater available soil nutrient pools. Lack of disturbance generally leads to ponderosa pine understory herbaceous communities being replaced by needles (Wienk et al. 2004).

Our third hypothesis was that mastication would decrease understory heterogeneity compared to all other treatments. This hypothesis was not supported, as all diversity metrics and the vegetation composition had strong spatial structure and small patch sizes (<3.5 m). The evidence suggests even smaller spatial structure in the understory of thinning treatments (in fact, smaller than our study design could examine), suggesting neither thinning treatment had a negative effect on small-scale heterogeneity. Indeed, fire has been found previously to increase small-scale spatial structure (Franklin et al. 1993, Bonnet et al. 2005). Because spatial heterogeneity is tied to several ecological theories, including succession, maintenance of

species diversity, competition, and multi-trophic interactions (Takeshita et al. 2009), it is important to understand the effects of management on spatial structure (North et al. 2007).

Overall, it appears that mastication increases fuel loads and vegetation cover, as well as spatial heterogeneity, and results in higher diversity than unmanaged sites. While duff and Class 3 fuels were higher in mastication sites, neither appeared to have a negative impact on abiotic conditions or biota. Based on the data presented above, there seems no reason not to include mastication in stewardship decisions regarding ponderosa pine ecosystems. That being said, fire may be an additional component to increase native species and overall diversity on sites that have been thinned.

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ADDENDUM 2011

Integration of Year 1 Data from Mastication and Burn Sites on Heil Valley Ranch

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Results from the Year 1 analysis of PA2 mastication and Overland Burn areas showed an inverse relationship between diversity of plants and diversity of bat species using these sites. The PA2 site was low in plant species richness, but high in bat abundance species richness, whereas the burn area was high in plant species richness and low in bat abundance and species richness. While plant composition was clearly different, plant diversity and cover were only slightly greater in the mastication sites compared to a control site (i.e., forested); richness of bats was also similar between open and forested habitats. Overall cover was also much greater for both native and exotic species in the burn site. Duff and small fuels were much greater on mastication sites than control sites, while fire sites were greater yet, except for duff.

Analysis of bat use of the Overland Burn area was only for two nights and therefore was not an exhaustive analysis, whereas the PA2 Mastication Area was equally sampled by both Adams and Franklin. More sonar sampling for bats in the Overland Burn is planned for summer 2011. In addition, the spatial relation of the mastication site to known bat roosts (i.e., closer than the burn site) may be a factor.

That being said, the case of low bat use of the burn area is consistent with what Adams found in the back-burn area in Geer Canyon. For the first two years, bat activity in the burn was nonexistent, whereas in a later census year, bat activity was higher and fairly diverse. Several factors may play a role in these patterns. Because intensive burns break down plant material and quickly recycle minerals back into the soil, secondary succession of plants would be strongly stimulated. However, burns also sterilize habitats and reduce the amount of duff (downed woody material was not more than other treatments but was more than the control site) that insects would use to provide microhabitats for reproduction. Thus, mastication and thinned areas provide the foundational structure for insects to use thereby attracting bats to the area. Intensively burned sites should over time provide the structure for insect reproduction and once succession reaches such a stage; bat would again be foraging in these areas, such as we have seen in the Geer Canyon back-burn site. The take-home message is that plant cover and diversity are not the most important factors that lead to insect diversity, and subsequently to bat foraging activity. Another factor may be the spatial structure of the overstory. While data were not collected, the size of canopy openings was noticeably greater for the fire site than the mastication or thinning site where several single trees or groups of trees remained standing in close proximity. Bat foraging in wide open areas may be inhibited more by predators.

Further study will be necessary to understand such integrated and complex interactions between abiotic and biotic components within ponderosa pine woodlands.