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Initial changes in forest structure and understory plant communities following fuel reduction activities in a Sierra Nevada mixed conifer forest

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Abstract

The widespread attention that has been devoted to wildfires by the public, as well as by state and federal governments, over the last several years in the United States has created a demand for fuel reduction activities aimed at alleviating wildfire hazard. While the appropriateness of these fuel reduction activities has been discussed in detail in previous studies, only a few studies have experimentally examined the effects of fuel reduction on forests. This paper investigates the initial effects of three different fuel reduction strategies on forest structure and understory plant communities using replicated treatments, which are compared to untreated controls. Understory plants are grouped by plant growth form (shrub, forb, graminoid) and by plant origin (native, exotic). The effects of each treatment alternative: mechanical, prescribed fire, mechanical followed by prescribed fire, and untreated control, are reported for each plant group. Each fuel treatment modified forest structure such that growing space increased and allowed for rapid reestablishment of forbs and graminoids, which did not differ in abundance from pre-treatment levels. The mechanical only treatments (thinning from below and rotary mastication) significantly reduced shrub cover relative to the control, however mechanical plus fire and fire only treatments did not. Mechanical plus fire treatments altered forest structure most substantially, which may explain the observed increases in richness and cover of exotic species. However, the magnitude of these differences was small. Both treatments involving fire decreased native species richness significantly, but differences in native species cover were insignificant for any of the active treatments. These results demonstrate a relatively high degree of resilience in these Sierra Nevada mixed conifer understory communities, at least initially, to fuel reduction activities.

Keywords: Fuel treatments; Alien species; Prescribed fire; National Fire and Fire Surrogate study

1. Introduction

A common management strategy to alleviate adverse effects from wildfires in forests is to reduce the vertical and horizontal loading and continuity of live and dead forest fuels (Agee and Skinner, 2005). In recent years this strategy has been ubiquitously adopted as the foremost objective in managing forests throughout the western United States (U.S.) (HFRA, 2003; Stephens and Ruth, 2005). Some have argued that fuel reduction strategies are being uncritically applied to all forest types in attempting to avoid uncharacteristically severe wildfires (Veblen, 2003; Schoennagel et al., 2004). In forest types historically typified by high severity fire regimes (e.g., Rocky Mountain subalpine forests) such strategies may not be ecologically congruent with historical patterns of fire severity and regeneration dynamics (Schoennagel et al., 2004). However, in drier mid- to low-elevation forests numerous tree-ring based studies have shown the preponderance of moderate- to low-intensity fires throughout the western U.S. prior to Euro-American settlement (Skinner and Chang, 1996; Swetnam and Baisan, 1996; Brown et al., 1999; Taylor, 2000; Veblen et al., 2000; Stephens and Collins, 2004; Moody et al., 2006). As a result of the dramatic changes in forest structure and composition brought about by fire exclusion and past harvesting practices, many advocate active fuel management (Covington and Moore, 1994; Allen et al., 2002; Agee and Skinner, 2005). In these forests, objectives aimed at mitigating wildfire hazard and objectives that intend to restore more natural forest conditions converge.

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Recent studies have demonstrated the efficacy of fuel treatments in reducing fire severity in actual wildfires (Agee and Skinner, 2005; Finney et al., 2005) and in modeled wildfires (Stephens and Moghaddas, 2005a). The fuel treatments evaluated in these studies include prescribed fire, various thinning strategies, including mastication, as well as combinations of the strategies. Tradeoffs exist among the treatment types with respect to manipulating forest structure and reducing surface fuels. These tradeoffs lead to differential resource availability in forest understory communities based on the biomass removed and the extent of the soil disturbance. In the Sierran mixed conifer forest Battles et al. (2001) found stands managed under even-aged systems tended to have higher numbers of understory species, or species richness. Additionally, Metlen and Fiedler (2006) reported that restoration/fuel reduction treatments in *Pinus ponderosa*/*Pseudotsuga menziesii* forests in western Montana led to increases in understory species richness and plant cover.

Historically, fire played a critical role in shaping the structure and composition in both forest types referenced (Arno, 1980; Stephens and Collins, 2004; Moody et al., 2006). Periodic, moderate- to low-intensity fires maintained relatively low tree densities and low ground/surface fuel loads. These fires sustained higher light levels, higher water availability, and increased nutrient cycling in forest understory communities, relative to current conditions (Biswell, 1989). As such, it is hypothesized that species associated with these forest types possess traits that allow for persistence, and even proliferation, following periodic fires (Whelan, 1995). Despite the extended period of fire suppression over the last century it appears that understory plants in historically fire-maintained forests continue to demonstrate resilience to fire and fire-surrogate treatments (Metlen et al., 2004; Metlen and Fiedler, 2006).

This resilience to fire and fire-surrogate treatments may be threatened by the invasion of exotic species. Often, exotic species have a competitive advantage in colonizing disturbed sites due to prolific seed production and rapid establishment/growth (D'Antonio and Vitousek, 1992; Levine et al., 2003). Once established, exotic invaders can drastically change plant community composition and ultimately change fundamental ecosystem processes, such as water and nutrient availability, as well as fuel/fire dynamics. While changes in fire regimes due to invasive grasses have been noted in the interior western U.S. grasslands/shrublands (Knapp, 1995; Humphrey and Schupp, 2001) and other areas (Brooks et al., 2004), forests throughout the West appear to be somewhat resistant to major exotic plant invasions at present (Keeley et al., 2003; Keeley, 2006). However, for the same reasons that more intensive forest management and fuel reduction/restoration activities lead to increases in understory plant richness and cover, these activities have been shown to correspond with increases in exotic plant species (Battles et al., 2001; Fiedler et al., 2006). Given the extent to which current forest managers goals in the western U.S. aim to reduce fuels and restore a more natural or resilient range of forest conditions, managers may face an increased risk of exotic plant invasion when implementing fuel reduction projects (Keeley, 2006). Scientific evaluation of fuel treatment effects on understory plant communities is needed to ensure managers make informed decisions.

Until recently the effects of fuel reduction activities on understory plant communities have seldom been studied. Metlen et al. (2004), Metlen and Fiedler (2006), and Knapp et al. (in press) present results on understory vegetation from controlled empirical experiments designed to assess the ecological effects of fuel treatments. These studies are part of the National Fire and Fire Surrogate (FFS) study, and are from three of the 13 locations across the continental U.S. (Weatherspoon and McIver, 2000). In this paper, we present results from the Blodgett Forest FFS study site in the north-central Sierra Nevada, California. This paper adds to the recent suite of studies examining fuel treatment effects on forest understory plant communities by expanding the range of forest types studied, as well as comparing and contrasting fuel treatment effects among the different forest types.

The objective of this study is to determine how three different fuel treatment strategies affect understory plant richness and abundance relative to untreated controls. The strategies include: (1) moderate to heavy thinning from below (Graham et al., 1999) of trees greater than 25 cm diameter at breast height (DBH) followed by rotary mastication of trees less than 25 cm, (2) prescribed fire only, (3) the sequential combination of thinning from below, rotary mastication, then prescribed fire. We compare treatments effects by looking at three broad categories based on potential changes in (a) forest structural attributes, (b) plant abundance by plant growth form, and (c) species richness and abundance of native versus exotic plant species. The null hypothesis is that there will be no significant ($p < 0.05$) difference between treatment strategies within each of these categories.

2. Methods

2.1. Study area

This study was performed at the University of California Blodgett Forest Research Station (Blodgett Forest), approximately 20 km east of Georgetown, California. Blodgett Forest is located in the mixed conifer zone of the north-central Sierra Nevada at latitude 38°54′45″N, longitude 120°39′27″W, between 1100 and 1410 m above sea level, and encompasses an area of 1780 ha (Fig. 1). Tree species in this area include sugar pine (*Pinus lambertiana* Dougl.), ponderosa pine (*Pinus ponderosa* Laws), white fir (*Abies concolor* Gord. & Glend), incense-cedar (*Calocedrus decurrens* [Torr.] Floren.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), California black oak (*Quercus kelloggii* Newb.), tan oak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehder), and Pacific madrone (*Arbutus menziezii* Pursh). The average overstory species composition for the treatment units prior to the treatments was approximately 11% sugar pine, 14% ponderosa pine, 23% white fir, 22% incense cedar, 18% Douglas-fir, 10% black oak, and 2% mixed hardwood (tan oak, chinkapin, and madrone). There were no significant differences in species composition among the treatment types prior to the treatments (Stephens and

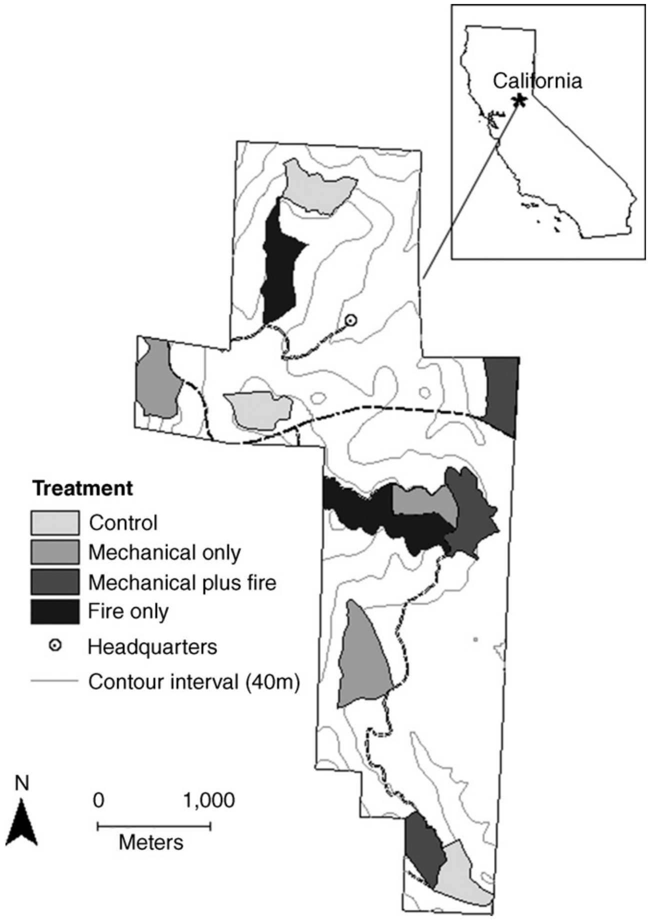

Fig. 1. Treatment unit locations (3 replicates per treatment) in Blodgett Forest Research Station, Georgetown, CA, USA.

Moghaddas, 2005a). Common understory shrubs in the treatment units include *Ceanothus integerrimus*, *Ribes roezlii*, *Rosa gymnocarpa*, and *Chrysolepis sempervirens*. Some of the most common understory forbs are *Galium* sp., *Iris hartwegii*, *Viola lobata*, and *Goodyera oblongifolia*. Such mixed conifer forests cover 3.2 million ha (7.8%) of California's total land base (CDF, 2003).

Soils at Blodgett Forest are well-developed, well-drained, and derived from either andesitic mudflow or granitic/granodiorite parent materials (Hart et al., 1992). Soils within the treatment units are mostly fine-loamy, mixed, semiactive, mesic Ultic Haploxeralfs, with a smaller component of coarse-loamy, mixed, superactive, mesic Humic Dystroxerepts. Cohasset, Bighill, Holland, and Musick are common soil series within the treatment units. Soils are deep, weathered, and generally overlain by an organic forest floor horizon. Common soil depths range from 85 to 115 cm. Slopes of the treatment units in Blodgett Forest range from 0 to 42%, with an average just over 18%.

Climate at Blodgett Forest is Mediterranean with a summer drought period that extends into the fall. Winter and spring receive the majority of precipitation that averages 160 cm (Stephens and Collins, 2004). Average temperatures in January range between 0 and 8 °C. June, July, and August are generally mild with average August temperatures between 10 and 29 °C, with infrequent precipitation from thunderstorms (averaging 4 cm over June, July, and August from 1960 to 2000) (Stephens and Collins, 2004).

Fire was a common ecosystem process in the mixed conifer forests of Blodgett Forest before the policy of fire suppression began early in the 20th century. Between 1750 and 1900, median composite fire intervals at the 9–15 ha spatial scale were 4.7 years with a fire interval range of 4–28 years (Stephens and Collins, 2004). Forested areas at Blodgett Forest have been repeatedly harvested and subjected to fire suppression for the last 90 years reflecting a management history common to many forests in California (Laudenslayer and Darr, 1990; Stephens, 2000) and elsewhere in the western U.S. (Graham et al., 2004).

2.2. Treatments

The primary objective of the treatments was to modify stand structure such that 80% of the dominant and co-dominant trees in the post-treatment stand would survive a wildfire modeled under 80th percentile weather conditions (Weatherspoon and Skinner, 2002). The secondary objective was to create a stand structure that maintained or restored several forest attributes and processes including, but not limited to, snag and coarse woody debris recruitment, floral and faunal species diversity, and seedling establishment. To meet these objectives, three different treatments: (1) thinning from below and mastication (mechanical only), (2) thinning from below and mastication, followed by prescribed fire (mechanical plus fire), (3) prescribed fire only, as well as untreated control were each randomly applied (complete randomized design) to 3 of 12 experimental units that varied in size from 14 to 29 ha. Total area for the 12 experimental units was 225 ha. To reduce edge effects from adjoining areas, data collection was restricted to a 10 ha core area in the center of each treatment unit.

Control units received no treatment during the study period (2000–2005). Mechanical only treatment units had a two-stage prescription; in June–August 2001 stands were moderately to heavily thinned from below (Graham et al., 1999) to maximize crown spacing while retaining 28 to 34 m^2 ha^{-1} of basal area. The thin from below mechanical treatment included the removal of intermediate and some co-dominant conifers at least 25 cm DBH, with relatively larger dominant and co-dominant trees in the stand given overall preference for retention. The harvest treatment favored the removal of trees showing disease or physical damage first, followed by relatively smaller trees then larger diameter trees to achieve vertical and horizontal crown separation. Marking prescriptions favored retention of conifer species such that a relatively even proportion of each species would be represented by the five conifer species present on the study site after treatment (Stephens and Moghaddas, 2005a). Individual trees were felled, limbed, and cut into specified saw log lengths using a chainsaw, and removed with either a rubber tired or track laying skidder for eventual processing at a sawmill. All limbwood and tops were left in the treatment unit after removal from harvested trees. During harvests, hardwoods, primarily California black oak, were coppiced to facilitate their regeneration (McDonald and

Tappeiner, 1996). All residual trees were well spaced with little overlap of live crowns in dominant and co-dominant trees. Following the harvest (06–08/2002) approximately 90% of understory conifers and hardwoods between 2 and 25 cm DBH were masticated in place using an excavator mounted rotary masticator. Mastication shreds and chips standing small diameter (2–25 cm DBH in this case) live and dead trees in place. Masticated material was not removed from the experimental units. The remaining unmasticated understory trees were left in scattered clumps of 0.04–0.20 ha in size.

Mechanical plus fire experimental units underwent the same treatment as mechanical only units, but in addition, they were prescribed burned using a backing fire (Martin and Dell, 1978). Fire only units were burned with no pre-treatment using strip head-fires (Martin and Dell, 1978). All prescribed burning was conducted during a short period (10/23/2002 to 11/6/2002) with the majority of burning being done at night because relative humidity, temperature, wind speed, and fuel moistures were within pre-determined levels to produce the desired fire effects (Knapp et al., 2004). Prescribed fire prescription parameters for temperature, relative humidity, and wind speed were 0–10 °C, >35%, and 0.0–5 km h^{-1}, respectively. Fuel moisture was monitored using a standard 10-h fuel stick. The desired moisture content was 7–10%.

2.3. Vegetation measurements

Overstory and understory vegetation were measured in 20 0.04 ha circular plots, installed in each of the 12 treatment units (240 plots total). Individual plots were placed on a systematic 60 m grid (5 columns, 4 rows) with a random starting point. Plot centers were permanently marked with a pipe and by tagging witness trees to facilitate plot relocation after treatments. Tree species, DBH, total height, height to live crown base, and crown position (dominant, co-dominant, intermediate, and suppressed) were recorded for all trees greater than 10 cm DBH. Similar information was also recorded for all saplings (trees >1.37 m tall and <10 cm DBH) on 0.004 ha subplots nested in each plot. In addition, all tree species seedlings (<1.37 m tall) were tallied in each subplot. Canopy cover was measured using a 25 point grid in each 0.04 ha plot with a site tube (Jennings et al., 1999). Using 9700 individual pre and post-treatment tree measurements, total live and dead standing volume (m^3 ha^{-1}) was calculated using published equations for Sierra Nevada conifer (Wensel and Olson, 1995) and hardwood (McDonald, 1983) species.

At each 0.04 ha plot understory plant species were recorded for presence/absence, as well as for abundance over the entire 400 m^2. Abundance was estimated using three categories based on percent ground surface area cover for each species: (1) 0.1–5% cover-midpoint 2.5%; (2) 5.1–25%-midpoint 15%; (3) >25.1%-midpoint 62.5%. Species richness (the number of species present) and abundance (using category midpoint) of individual species was summed by plant growth form (graminoid, forb, shrub) and by plant origin (native or exotic) for each 0.04 ha plot. Species richness and abundance (percent cover) are the only measures of understory plant diversity presented in this paper. These measures are simple to interpret and easy to compare among studies because they are widely reported (Battles et al., 2001). Identification of plant species and origin were based on Hickman (1993). In addition to the understory plants, the percent mineral soil exposed was ocularly estimated to the nearest 5% over the entire ground surface for each plot. Each of these measurements was taken prior to treatment (June–August 2001) and following the treatments (June–August 2003).

Table 1 summarizes the pre-treatment averages for each of the forest structural attributes measured, as well as understory plant abundance and richness by plant growth form and plant origin. Overall, pre-treatment means for forest structure and understory plant abundance and richness were similar among treatment alternatives (Table 1). However, there are a few

Table 1
Average (standard error) pre-treatment forest structure and understory plant abundance and richness at Blodgett Forest Research Station, CA

	Control	Mechanical only	Mechanical plus fire	Fire only
Forest structural attributes				
Basal area (m^2 ha^{-1})	50.7 (2.2)	47.8 (1.6)	50.7 (2.0)	45.5 (1.7)
Trees (stems ha^{-1})	1578.6 (210.9)	1342.6 (208.3)	1152.7 (185.7)	1261.9 (166.0)
Live tree volume (m^3 ha^{-1})	498.4 (32.5) AB	489.7 (20.3) AB	547.4 (27.9) A	436.3 (22.8) B
Canopy cover (%)	68.9 (2.5)	66.3 (2.5)	63.3 (2.2)	68.1 (2.0)
Seedling density (ha^{-1})	533.7 (92.2)	470.6 (105.1)	578.8 (107.8)	578.0 (96.0)
Mineral soil exposed (%)	4.7 (1.3) AB	6.6 (1.4) AB	2.6 (0.7) A	5.4 (0.9) B
Cover by plant growth form				
Shrub (%)	9.0 (2.2)	15.8 (3.1)	10.7 (2.3)	4.9 (0.7)
Forb (%)	5.4 (0.7)	9.2 (1.4)	6.2 (1.2)	5.5 (0.7)
Graminoid (%)	0.9 (0.2) AB	1.3 (0.3) AB	1.4 (0.2) A	0.5 (0.13) B
Native vs. exotic species				
Total native species cover (%)	16.1 (2.8) AB	27.2 (4.3) B	19.4 (3.2) AB	11.2 (1.3) A
Total exotic species cover (%)	0.04 (0.04)	0.34 (0.16)	0.29 (0.12)	0.25 (0.13)
Native species richness (400 m^2)	6.1 (0.4)	8.3 (0.6)	6.8 (0.5)	5.9 (0.4)
Exotic species richness (400 m^2)	0.06 (0.03)	0.20 (0.07)	0.15 (0.05)	0.12 (0.05)

Basal area and tree density is calculated for trees > 2.5 cm DBH. Mean values in a row not followed by the same letter are not significantly different ($p < 0.0083$—Bonferroni correction, $\alpha = 0.05$).

exceptions. The pre-treatment percent mineral soil exposed in mechanical plus fire units was significantly lower than that of fire only units. The opposite was true for graminoid cover. Additionally, total pre-treatment native species cover in mechanical only units was significantly higher than that of fire only units. For all other pre-treatment variables, no significant differences among the four treatment alternatives were evident using a Bonferroni-adjusted α level ($p < 0.0083$).

2.4. Data analysis

Species accumulation curves were constructed for each treatment alternative to insure that understory plants were sampled adequately (Fig. 2). The curves represent the average number of species recorded as a function of the number of plots sampled. The averages were calculated from 100 permutations, in which plots were added in random order up to the total number of plots per treatment alternative ($n = 60$). Michaelis–Menton saturating functions were fit to each curve to estimate the asymptote, or total number of species present, for each alternative (Battles et al., 2001). Species accumulation curves for each treatment alternative indicate that understory plants were sampled more than adequately given the 60 plots per alternative (Fig. 2). The rate at which new species are added appears to decline substantially at just under 20 plots for each curve. This indicates that in the 20 plots for each replicate (3 replicates/treatment alternative) understory plants were adequately sampled. The asymptotes for each of the curves demonstrate that units treated with fire only have fewer species overall, relative to the other treatment alternatives. However, the pre-treatment means for native and exotic species richness were not significantly different among treatment alternatives (Table 1).

Treatment effects were investigated by using the difference between post-treatment and pre-treatment variables describing forest structure (basal area, tree density, canopy cover, total live tree biomass, seedling density, and mineral soil exposed) cover by plant growth form (shrub, forb, graminoid) and cover and richness by plant origin (native, exotic) (Metlen and Fiedler, 2006). Summing plant abundance by growth form and plant origin using the three rather broad categories of cover mentioned previously potentially results in an additive error that could overestimate plant cover. We had to use the three broad categories because we wanted to maintain the 0.04 ha plot size typical for forest managers in the western U.S., which is larger than ideal for estimating abundance of understory species. By using post–pre-treatment differences we get rather conservative estimates for changes in plant abundance, which would result in the identification of significant differences that are real rather than spurious.

Diagnostic plots for both pre-treatment variables and treatment differences for each of the variables were inspected for normality. For most variables the diagnostic plots indicated distributions were either skewed or heavy-tailed. Square root and log transformations did little to improve the distributions. Due to the inability to meet normality assumptions, we chose to perform all comparisons among treatment alternatives (pre-treatment and treatment differences) using non-parametric methods. Kruskal–Wallis tests (Ott and Longnecker, 2001) were performed among the four treatment alternatives for each of the variables mentioned. If Kruskal–Wallis tests indicated significance ($p < 0.05$), pairwise Wilcoxon Signed-Rank tests were performed on all six possible comparisons. A Bonferroni-adjusted α level (0.00833) was used to identify significant differences in pairwise comparisons (Schwilk et al., 1997).

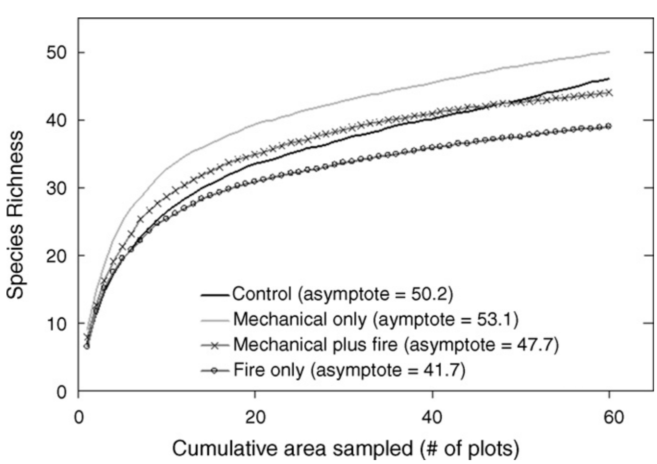

Fig. 2. Species accumulation curves for forest understory vegetation sampled prior to treatment (2001). Curves show the average number of species identified in relation to the number of plots sampled. The averages were computed from 100 permutations, in which plots were added randomly. The asymptote for each treatment curve was estimated by fitting a Michaelis–Menton model, which resulted in an estimated $R^2 > 0.99$ for each treatment alternative.

3. Results

It is worth restating that the treatment effects reported are first-year responses to mastication and prescribed fire, but second-year responses to the thinning from below done in both mechanical treatments. All three fuel reduction treatments substantially altered forest structure. Basal area, tree density, live tree volume, canopy cover, and tree seedling density were all significantly reduced relative to untreated controls (Fig. 3). Both mechanical treatments reduced basal area and live tree volume relative to fire only, as well. Both treatments involving prescribed fire significantly reduced tree seedling density, while mineral soil exposed increased for both, relative to mechanical only and control alternatives (Fig. 3). The mineral soil exposed in the mechanical treatments was not different from that in the control units. Additionally, canopy cover in the mechanical plus fire units was significantly lower than that in fire units, while no differences were significant between mechanical only and fire only, nor between mechanical only and mechanical plus fire units. The reductions in tree density for each of the three fuel treatments were mostly among trees below 25 cm DBH (Fig. 4). The two treatments involving thinning and mastication also substantially reduced trees in the 25.3–45.5 cm diameter class, and to a lesser extent, trees in the 45.6–76.2 cm diameter class. The number of trees >76.2 cm DBH remains relatively constant throughout each of the treatment alternatives.

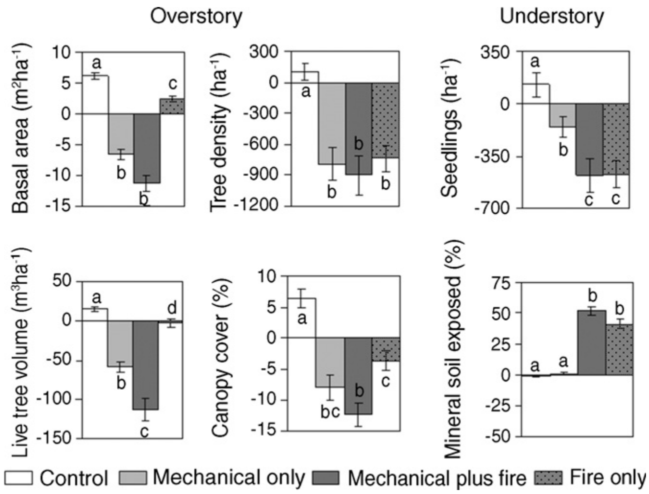

Fig. 3. Averaged differences (2003 post-treatment – 2001 pre-treatment) in forest overstory and understory characteristics with the standard error of the mean represented by the narrow bars. If Kruskal–Wallis tests were significant ($p = 0.05$), treatment differences were compared using multiple non-parametric pairwise comparisons between treatments. Bonferroni correction ($p < 0.0083$) was used to identify significance for pairwise comparisons. Mean differences with the same letter, or no letter at all, are not significantly different.

The fuel reduction treatments had a less consistent effect on understory plants. Mechanical only treatments significantly reduced shrub cover relative to control units (Fig. 5). This reduction in shrub cover for mechanical only units was not significantly different from mechanical plus fire or fire only units. Additionally, the reductions in shrub cover observed in mechanical plus fire and fire only units were not significantly different from the untreated controls. Cover of forb and graminoid species showed no difference in response to any of the active treatment relative to control units, and relative to each of the other treatments (Fig. 5).

Total cover of native species was reduced in both mechanical treatments, but these reductions were marginally insignificant giving the Bonferroni-adjusted α level (Fig. 6). Native species cover slightly increased in fire only units, but was not statistically different from control units, or either mechanical treatment. The decreases in native species richness in both treatments involving fire were significant relative to the increase in native richness for control units. Total cover and richness of exotic species did significantly increase in both mechanical treatments relative to control units (Fig. 6). In fire

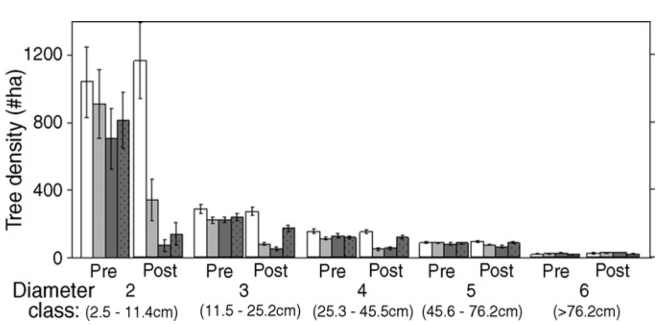

Fig. 4. Averaged pre-treatment and post-treatment tree density by diameter class with the standard error of the mean represented by the narrow bars.

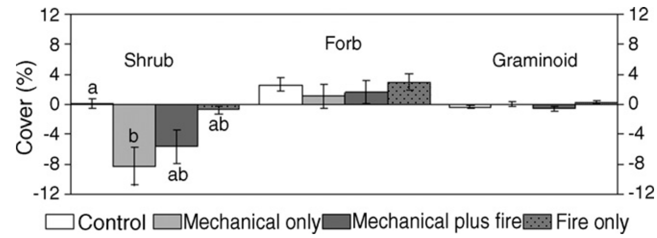

Fig. 5. Averaged differences (2003 post-treatment – 2001 pre-treatment) in plant abundance by growth form with the standard error of the mean represented by the narrow bars. Mean differences with the same letter, or no letter at all, are not significantly different.

only units exotic species richness and cover did not change significantly compared to the control. The increases in both exotic cover and richness in mechanical plus fire units were significantly higher than that in fire only units (Fig. 6). Table 2 shows the responses of the most common (pre-treatment) shrubs, forbs, and exotic species to each of the treatment alternatives, and suggests mechanisms driving the responses.

4. Discussion

The primary goal for each of the three treatments was to reduce vertical and horizontal continuity of live and dead fuels in forest stands such that potential wildfire severity would decrease. This goal was achieved with all of the treatments, but was most obvious for both treatments involving fire (Stephens and Moghaddas, 2005a). The mechanical plus fire and mechanical only treatments resulted in the highest disturbance severity, using the change in live tree volume as a proxy for treatment severity (Fig. 3). In forests that were historically maintained by frequent surface fires, as Blodgett Forest was (Stephens and Collins, 2004), the fuel reduction treatments studied in this paper also created forest structure that more closely resembles the historical forest structure (Stephens, 2000) (i.e. prior to cultural practices of large scale harvesting

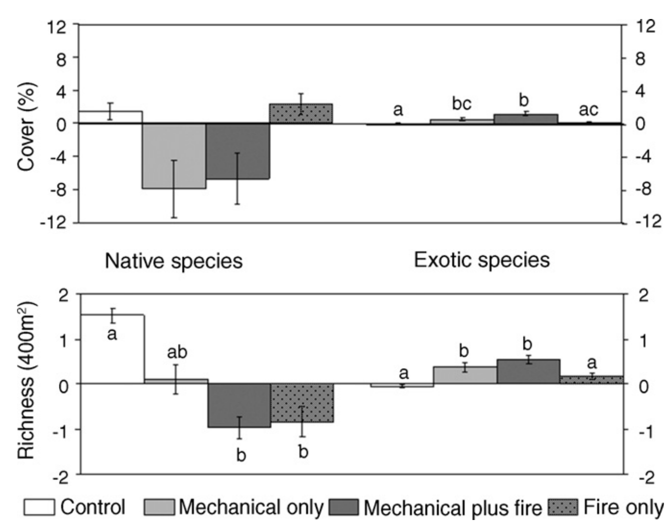

Fig. 6. Averaged differences (2003 post-treatment – 2001 pre-treatment) in abundance and richness by plant origin with the standard error of the mean represented by the narrow bars. Mean differences with the same letter, or no letter at all, are not significantly different.

Table 2
Responses to treatment alternatives and characteristics of the most common (pre-treatment) shrubs, forbs, and exotic species at Blodgett Forest Research Station, CA

	Control	Mechanical only	Mechanical plus fire	Fire only	Response following disturbance—mechanism
Shrubs					
Ceanothus integerrimus	+	~	+	+	Colonizer—seed and resprout
Ribes roezlii	+	~	++	~	Survivor—resprout and seed
Rosa gymnocarpa	++	~	+	−−	Survivor—seed and resprout
Chamaebatia foliolosa	~	++	−−	+	Colonizer—root resprout
Symphoricarpos mollis	~	−	−−	−−	Evader
Forbs					
Galium sp.	+	~	−−	−	Evader
Iris hartwegii	~	~	−	−	Evader
Viola lobata	~	−−	−−	~	Evader
Goodyera oblongifolia	+	−−	−−	−−	Evader
Trientalis latifolia	++	~	~	++	Survivor—seed
Pyrola picta	−	−−	−−	−−	Evader
Exotic species					
Cirsium vulgare	−−	++	++	++	Colonizer—seed
Verbascum thapsus	~	++	++	−−	Colonizer—seed

Responses are based on differences in the total number of plots each species was found between post- and pre-treatment, and are symbolized as follows: ~ for differences within −10 to 10% of the pre-treatment levels, − or + for differences within −11 to −40% or 11 to 40% of pre-treatment levels, and −− or ++ for differences <−40% or >40% of pre-treatment levels.

and fire suppression). For at least 200 years prior to ca. 1850 fires occurred on average every 5–10 years at the spatial scale of the individual treatment units in this study (14–28 ha) (Stephens and Collins, 2004). Given the long association that species in Sierra Nevada mixed conifer forests have had with fire it is not surprising that native understory plant communities showed a moderate degree of resilience to the fire and fire-surrogate treatments implemented in this study (Knapp et al., in press).

Each of the fuel reduction treatments reduced overstory trees and ultimately increased potential growing space in the understory. Decreases in basal area, tree density, canopy cover, and seedling density would lead to increased light reaching the forest floor. This increase in light combined with increased mineral soil exposed in both treatments involving fire, most likely caused by the consumption of litter and duff layers during burning, improved conditions for seed germination and vegetative resprouting on the forest floor. These improved conditions allowed for rapid recovery of understory plants, and most likely explain the lack of significant treatment effects on forb and graminoid cover for any of the three alternatives. The fact that mineral soil exposed did not change in the mechanical only units apparently did not affect the recovery of forbs or graminoids. However, the combined effect of no change in mineral soil exposed and lack of fire-cued germination and stimulation of sprouting may have impacted shrub recovery in the mechanical only units, thus explaining why these units experienced significant reductions in shrub cover while mechanical plus fire units did not.

The mechanical plus fire treatments resulted in the greatest changes in all of the six forest structural attributes, and highest disturbance severity (Fig. 3). This is not surprising given the relatively intensive treatment in these units with intermediate sized trees removed, smaller trees and large shrubs reduced to chips by mastication, and follow up under burning (Fig. 4). Given the degree to which forest stands in these units were altered we expected to see more change in understory vegetation, which was not evident when examining changes in abundance by plant growth forms. However, changes in the relative abundance and richness of native species versus exotic species were evident. Exotic species cover and richness increased significantly, while native species richness decreased significantly, in mechanical plus fire units. Metlen and Fiedler (2006) also found that areas treated by mechanical thinning followed by burning had the highest richness and cover of exotic species. Apparently, the extent of the disturbance, as well as the multi-phase nature of the disturbance (thinning: 06–08/2001, mastication 06–08/2002, and burning: 10–11/2002) created by mechanical plus fire treatments allowed sufficient time and increased growing space for the rapid establishment of the colonizing exotic species (Table 2).

The findings from this study are similar to those reported by Battles et al. (2001) in which the more severely disturbed forest stands that were managed using clearcutting and shelterwood systems had higher proportions of exotic species compared to both unmanaged stands and stands that were managed using single-tree or small group selection systems. The lack of any significant change in exotic richness or cover in fire only units suggests that moderate to low-intensity burning alone may not provide the magnitude of disturbance necessary for exotic species to successfully establish. The study by Knapp et al. (in press) in the southern Sierra Nevada, which reported that prescribed burning had no effect on exotic species, further supports this hypothesis. More intense wildfire, however, has been shown to lead to increases in exotic species in Sierran conifer forests (Keeley et al., 2003).

It is important to note that although the initial changes in exotic species reported are significant, the magnitudes of theses changes are low. Exotic cover increases by an average of 1.3%, with an addition on average of 0.5 exotic species per 400 m^2 in the mechanical plus fire units. In the mechanical only units 0.4 exotic species are added per 400 m^2. Furthermore, these increases in exotics are primarily driven by increased abundance of one species, *Cirsium vulgare*, or bull thistle (Table 2). This species accounts for over 90% of the total exotic abundance throughout all the treatment units at Blodgett Forest. The low pre-treatment levels of exotic richness and abundance throughout all treatment units in Blodgett Forest most likely explain the relatively small change in exotic species following the two mechanical treatments. If there were greater richness and abundance of exotics initially results could be very different.

The fact that the number of native species observed decreases as a result of the two treatments involving fire, while for mechanical only units no change is evident, suggests that burning excludes, or at least delays the recovery of some understory species. The two species that showed the most substantial reduction following the prescribed fire treatments were *Goodyera oblongifolia* (rattlesnake orchid) and *Pyrola picta* (white-veined wintergreen) (Table 2). Both of these species are considered late-seral species, meaning they are associated with more closed canopy stands characteristic of later successional stages. The increase in the number of native species observed in control units is more difficult to explain. Perhaps interannual variability in the timing and amount of precipitation and/or changes in temperature patterns affected how conspicuous certain species were. If this were the case, the reductions in native species for the two fire treatments may be especially significant.

5. Conclusion

The current emphasis in forest management on public lands is to reduce live and dead fuels over extensive areas in order to decrease potential fire severity to forest vegetation or damage to infrastructure and other human development. While various fuel treatments have been shown to reduce fire severity under real wildfire conditions (Martinson and Omi, 2002; Graham, 2003; Finney et al., 2005), information on the short and long-term effects of fuel treatments on various ecosystem components (e.g., understory plants, wildlife, soils, and insects) and ecological processes (e.g., fuel addition/consumption, nutrient cycling, and water availability) is still needed. The results presented in this paper provide insight on the initial effects of three different fuel reduction treatments on understory vegetation using a robust experimental design. These results demonstrate that although each of the treatments (mechanical only, mechanical plus fire, and fire only) modified overstory forest structure significantly, the total abundance of native understory plant species was not significantly affected when compared to untreated controls. Additionally, forb and graminoid abundance were not significantly changed by the active treatments relative to untreated controls. Both treatments involving fire did decrease native species richness significantly. However, results from a similar study (Metlen and Fiedler, 2006) suggest that decreases in understory species richness may be short-term phenomena, and should be interpreted accordingly.

The response of native understory plants to fuel reduction treatments suggest a fair degree of resilience in Sierran mixed conifer understory communities, despite over a century of tree harvesting and fire suppression (Stephens and Collins, 2004). However, exotic species do pose a real threat to this resilience (Keeley, 2006). The mechanical plus fire treatment did increase the richness and abundance of exotic species. These increases were small, but significant; and may become larger given time (Metlen and Fiedler, 2006). With respect to exotic plant species, managers will need to assess the potential risk for colonization and spread of exotic species, which as our results show may follow fuel reduction activities. Managers should determine if these risks outweigh the benefits of potentially modifying fire behavior and reducing fire severity by implementing fuel treatments.

This paper, along with other recent papers from the Fire and Fire Surrogate (FFS) study at Blodgett Forest (Stephens and Moghaddas, 2005a,b; Apigian et al., 2006), presents results and analysis on the effectiveness of fuel treatments, and the effects they have on Sierran mixed conifer forest ecosystems. This information is intended to help mangers make knowledgeable decisions in planning and implementing fuel reduction activities. As the other components of the FFS study are added to the existing literature (e.g., wildlife and bark beetle effects) both at Blodgett Forest, and for the other National FFS sites, these studies will provide managers with scientific information for better understanding the ecological effects of fuel treatments for a range of forested ecosystems.

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