Forest Research
Open Access

Walker, et al., Forest Res 2016, 5:1
DOI: 10.4172/2168-9776.1000167

Research Article Open Access

Responses of a Sierran Mixed Conifer Understory Plant Community to Cover Story Thinning, Slash Mastication, and Prescribed Fire Restoration Treatments

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Received date: Nov 18, 2015; **Accepted date:** Jan 19, 2016; **Published date:** Jan 21, 2016

Abstract

Thinning implemented with a cut-to-length harvesting system coupled with on-site slash mastication and redistribution and followed by prescribed under burning were assessed for their impacts on the shrub understory and natural regeneration in an uneven-aged Sierra Nevada mixed conifer stand. Initial suppression of the cover and weight of huckleberry oak, the most prevalent ground cover species, by the combined thinning and mastication operations and those of prostrate ceanothus by the under burn were followed by a pronounced resurgence in abundance for both species in burned stand portions, particularly where thinning had preceded the fire. White fir was most prevalent initially among species represented in the seedling size class of natural regeneration and became predominant thereafter while this species dominated the sapling class throughout the study. White fir seedling establishment was enhanced where the mechanized operations were excluded, and especially so where fire was as well, and such was also the case for incense-cedar initially but its seedling abundance declined precipitously as the study progressed. White fir saplings were most numerous in the unthinned stand subunit but the under burn proved lethal to many of them therein. Jeffrey and sugar pine were little represented among seedlings and absent altogether among saplings.

Keywords: Understory vegetation; Natural regeneration; Sierra nevada mixed conifer; Stand density management; Slash mastication; Prescribed fire

Introduction

Although not the primary focus of forest vegetation research historically, which has been largely concerned with the attributes of the over story and its commercial potential, understory plant communities provide important ecosystem functions. Among them, they often constitute critical wildlife habitat providing both cover and forage for varied fauna, act as a protective cover that serves to minimize soil erosion, contribute to soil organic matter budgets and therefore its overall fertility, and in cases where leguminous and/or actinorhizal species reside, supply N additions that can measurably enhance site productivity [1-4]. In the Sierra Nevada of the western USA, a shift in the composition of understory communities from grass dominated ones to those in which shrubs are preponderant, a result of century-long fire exclusion [5,6] has been deemed cause for concern because many native shrubs are highly flammable and constitute ladder fuels permitting vertical extension of ground fires [4,7], and their abundance has exacerbated a wildfire risk that is increasingly elevated [8,9]. Among the remedies being assessed is the reintroduction of fire in the form of controlled under burning, which after some early trials in otherwise untreated stands has largely been confined to those previously thinned, an approach that is perceived to ameliorate undesirable impacts on over story health [5,10,11]. For several combinations of forest cover type and understory plant community, however, the pace of recovery regarding the latter and the form it takes in terms of resemblance to, or deviation from, that extant pretreatment is at present largely a matter of conjecture.

Conceptually, there has been a proclivity for forest regeneration to be viewed as a separate entity from understory vegetation, perhaps reflecting that the former consists of seedling and sapling progeny of over story constituents while the shrub, grass, and forb species of the latter share no genetic commonalities with them. Furthering the distinction is that shrubs, grasses, and forbs often compete with tree seedlings and saplings for vital resources so intensely that forest regeneration is inhibited, if not precluded altogether [4,12]. Silvicultural practices implemented for forest restoration purposes can also exert profound influences on natural regeneration establishment, with the consequences of particular importance in uneven-aged stands where such regeneration is usually relied upon to insure that replacements are present as mortality occurs in the older age classes. Although not considered a reproduction method per se, thinnings in uneven-aged stands often create the disturbance required for natural regeneration to become established by opening the canopy for greater light penetration to the forest floor and the harvesting involved in their implementation commonly exposes the mineral soil that facilitates seed germination and seedling establishment [13], but some portion of preexisting regeneration encompassing both seedlings and saplings is almost assuredly to be destroyed in the process by the trafficking of workers and equipment over the site. A similar mix of outcomes is conceivable regarding prescribed under burning, as among principal purposes for the use of this treatment is to reduce thick duff and debris layers, and therefore prepare a seedbed, plus it has the potential to at least temporarily suppress competing vegetation thereby releasing new regeneration, but it is probable that a substantial portion of any regeneration in place at implementation, including that of sapling size, will not survive to augment new seedlings that originate post treatment [10,14,15]. Thus, both thinning and controlled burning offer benefits conducive to the establishment and perpetuation of forest regeneration, but they also have potentially detrimental aspects, so on balance there is considerable uncertainty concerning the ultimate outcome in each case.

The study presented here entailed an assessment of changes occurring over a span of multiple years in the understory plant community of an eastern Sierran mixed conifer stand as influenced by prior mechanized thinning of the over story with mastication and dispersal of the resulting slash and by prescriptive under burning. Included in the investigation were both ground cover species and natural forest regeneration, and regression analysis was utilized to discern possible linkages between these two understory components as well as between them and parameters specific to both the over story and the site. These results provide land managers insight regarding probable ground cover and natural regeneration responses to restoration treatments used to enhance forest health and fire resilience in this and similar forest cover types.

Materials and Methods

Study site

The subject stand is naturally regenerated, second growth, uneven-aged Sierra Nevada mixed conifer and is located on the USDA Forest Service Lake Tahoe Basin Management Unit (39.22°N, 120.10°W). The site upon which it resides is approximately 8.1 ha in size, the elevation is 2050 m, the aspect is generally east, the slope averages 7%, and the average annual precipitation is 80 cm with snowfall predominating [16]. The soils are of the Jorge-Tahoma Association, derived from volcanic parent material, and exceedingly rocky [17]. Based on dominant crown class trees averaging 162 years in age [18], the site quality is class IV according to the Dunning site classification system for Sierra Nevada mixed conifer [19].

Treatment installation

The study site was divided into paired subunits of equal proportion with one of two thinning treatments randomly assigned to each subunit, specifically a cut-to-length harvest accompanied by slash mastication or an unthinned control without any surface debris treatment. The harvesting and slash treatments were implemented in June 2003, with the former entailing the use of a Rottne SMV Rapid EGS 6WD single-grip harvester coupled with a Rottne SMV Rapid RK-90 6WD self-loading forwarder (Rottne Industri AB, Rottne, Sweden). The cut-to-length system retains residual organic materials in the stand as slash mats created by the harvester through its limbing and topping functions that both the harvester and forwarder subsequently travel over and is designed to minimize mineral soil impacts [18]. Other than a contractual stipulation that harvested trees not exceed 50.8 cm DBH, preferentially consist of white fir as available, and exclude sugar pine, operator choice was exercised in the selection of those to be removed to achieve a target residual basal area of 30 m^2 ha^{-1}. Immediately following the thinning, the resulting slash mats were masticated and redistributed using a Morbark 30/36 Mountain Goat self-propelled chipper (Morbark, Inc., Winn, MI, USA) with the directive to also treat preexisting coarse woody debris where it was deemed to be excessive and to distribute chipped materials evenly over the thinned subunit.

A controlled under burn was implemented on one-half of each of the two subunits dedicated to the individual thinning treatments in early June of 2004, with the portion to be treated randomly chosen. Partitioning of each subunit was accomplished using 1.0-m-wide hand lines accompanied by the manual felling of trees with crowns overtopping the fuel breaks as needed for containment. A strip head fire ignition pattern was employed starting at 0800 hrs and the under burn was completed at 1400 hrs with the designated portions of both subunits treated in a single day. At ignition, the air temperature was 10°C, relative humidity was 45%, the wind speed was 4.8 km hr^{-1}, and 10-hr time lag fuel moisture was 18%. The rate of spread averaged approximately 57 m hr^{-1} over the entire burn period, and at the close of ignition, the air temperature was 16°C, relative humidity was 23%, and the wind speed was 9.6 km hr^{-1}.

Data collection

For assessing its influence on the understory, over story stand attributes were quantified by measuring trees of pole size and larger, specifically those ≥ 10.2 cm DBH, within 20 permanent 0.04-ha circular plots, with 10 of them located within each of the two subunits divided equally between the burned and unburned portions therein. Every tree in these plots was measured for total height, DBH, and lives crown length and then tallied by species, and included were free standing dead trees, defined as those with no live crown. Subsequently, tree counts were summed by plot as were dead stems and the percentage of the latter was calculated as well. Also, tree heights and live crown lengths were used to calculate live crown percentages, DBH values were used to derive their quadratic mean by plot according to the Curtis and Marshall [20] formula, and basal area by plot was derived from plot stem counts and quadratic mean DBH using the Davis et al. [21] formula. Ultimately, the stem counts and basal area for each plot were expanded to reflect equivalent 1.0-ha values. The initial over story inventory was conducted at the conclusion of the first growing season following that during which the under burn was implemented, while a final one identical to the first in all respects was completed at the end of the seventh growing season thereafter.

Downed and dead fuels inventories by time lag category [11] were also conducted to assess the impacts of fine and coarse forest floor debris on the understory. For combined 1+10-hr (≤ 2.5 cm diameter) fuels, duff, litter, and fine woody materials from five randomly located circular plots of 0.093 m^2 each within each of the 0.04-ha plots were collected, dried to a constant weight, and weighed. Dry weights of each group of five samples were then averaged and the samples were returned to their respective collection points within the study site. For 100-hr (> 2.5 to ≤ 7.6 cm diameter) and 1000-hr (> 7.6 cm diameter) fuels, a single 4-m^2 and single 54-m2 circular plot, respectively, was established with the same plot center as that of each of the 0.04-ha plots. Collection of the 100-hr fuels from the 4-m^2 plots permitted a dry weight determination by direct measurement as well, and these samples were also returned to the plots afterward. For 1000-hr fuels, however, lengths and diameters at the midpoint were measured for use in estimating volume according to the Huber formula [22], and collection of 10 log segments from random locations outside the plots, measuring their dimensions, and then drying and weighing them provided a density constant for use in converting volume to dry weight by plot. To determine total loading, individual time lag category dry weights were summed, and all fuel weights were ultimately expanded to reflect equivalent 1.0-ha values. Downed and dead fuels were initially quantified at the conclusion of the growing season during which the under burn was implemented with the final inventory undertaken at the end of the eighth season thereafter.

Centered within each of the 0.04-ha plots used in the over story inventories was a 54-m^2 circular plot established for the purpose of grid mapping the understory species encountered on the site, which permitted expression of the prevalence of such species on a percent ground cover basis. In order to express their prevalence on a dry weight basis as well, 10 samples of known ground cover area were collected of each species from random locations outside of the measurements plots, dried to a constant weight, and weighed. Each sample consisted of all tissues occupying a ground area of 0.093 m^2, with the species-specific weight constants derived from them permitting the conversion of percent cover to dry weight by plot. In addition to the determination of the cover and weights by individual species, those of all species in total were determined, and all ground cover weights were ultimately expanded to equivalent 1.0-ha values. Initially conducted at the close of the third growing season following that during which the under burn was implemented, a second and final understory inventory was done at the close of the fifth season thereafter, and the cover and weights specific to their initial and final determination were used in the calculation of the changes in these abundance measures over the five-season interim.

Inventories specific to the natural regeneration component of the understory were subdivided into those for the seedling (≤ 1.37 m tall) and sapling (> 1.37 m tall and ≤ 10.1 cm DBH) size classes, and in each case encompassed counts by species within the two classes. However, saplings were also tallied as either alive or standing dead, thus permitting calculation of proportions by mortality status. Seedling inventories were performed using 40-m2 circular plots established with the same centers as those for the 0.04-ha plots used in the over story measurements, while the sapling inventories relied upon the aforementioned 54-m^2 plots involved with the 1000-hr fuel and ground cover measurements. Ultimately, both the seedling and sapling counts were expressed on a 1.0-ha basis. The scheduling of the forest regeneration inventories coincided exactly with those of the over story, which permitted the calculation of the changes in the seedling and sapling counts occurring over a seven-season period.

Statistical analysis

For cover and weight variables related to the two inventories of ground cover vegetation and seedling and sapling counts derived from the two involving forest regeneration, a repeated measures, mixed model analysis of variance (ANOVA) was used to assess effects of the mechanized and prescribed fire treatments, the time of inventory, and all possible interactions. This analysis incorporated both the compound symmetry covariance structure and the first-order autoregressive structure, and for a given variable, the covariance structure relied upon was that providing the lowest value for Akaike's Information Criterion (bias-corrected version, AICC). Changes between inventories pertaining to the various study components were subjected to two-way ANOVA for purposes of testing for main treatment effects and their interaction. For each form of ANOVA, effects were considered to be significant only when $p \leq 0.05$ according to the F test. Subsequently, differences among means for each variable were evaluated using the least significant difference (LSD) test with $\alpha = 0.05$. Percentage data were subjected to arcsine transformation prior to all of the analyses indicated above.

To investigate possible linkages between variables, two series of simple linear regression models were computed that paired those variables considered to be plausibly related. For the first series, hereafter denoted as the ground cover series, over story tree height, DBH, live crown length and percentage, basal area, and total stem count plus the percentage by species along with downed and dead fuel loading by time lag category and in total constituted the independent variables with percent cover by individual understory species and in total along with their changes serving as dependent variables. These were configured such that values of the independent variables based on the initial inventories were matched with those derived from the initial and final inventories plus the changes regarding the dependent variables while values of the former based on the final inventories were paired exclusively with those derived from the same regarding the latter. Additional models in the first series featured the initial values for understory cover as the independent variables while those from the final inventory, along with the changes, were the dependent variables, all matched within species and within the total. In the natural regeneration series, the second of the two, seedling and sapling counts by species plus their respective totals, and with the sapling counts further segregated by mortality status, replaced ground cover variables as the dependent components, while the array of independent variables noted above regarding the first series was repeated largely verbatim as were the inventory pairings. However, in the second series ground cover values serving as the independent variables included those derived from both the initial and final inventories, with those from the final one matched exclusively with regeneration values from the same. For both series, ground cover species prevalence was expressed on a percent cover basis exclusively regardless of whether its inclusion in any model was as an independent or a dependent variable, and models were considered to be significant only when $p \leq 0.05$ according to the F test. All statistical analyses were performed using the Statistical Analysis System (SAS Institute, Inc., Cary, NC).

Results

Over story and fuels characteristics

At the initial inventory, the stand consisted of 76.4% California white fir (*Abies concolor var. lowiana* [Gord.] Lemm.), 7.9% Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), 7.5% sugar pine (*Pinus lambertiana* Dougl.), 5.9% incense-cedar (*Libocedrus decurrens* Torr.), and 2.3% California red fir (*Abies magnifica* A. Murr.). Overall mean height and DBH were 16.9 m and 45.7 cm, respectively, with the largest trees occurring in the burned portion of the thinned subunit and the smallest in the burned portion of the unthinned subunit regarding both dimensions. Live crown length averaged 7.0 m and the live percentage was 41.4%, with the greatest length and percentage found in the thinned but unburned treatment combination while the former was shortest in the burned but unthinned combination and the latter was lowest in the thinned and burned combination. Mean basal area at the initial inventory was 46.3 m^2ha^{-1} distributed over an average of 315 stems ha-1, and for both density measures the highest and lowest values presided in the unthinned and unburned combination and in the thinned and burned combination, respectively. Mortality amounted to 43 stems ha-1 on average, or 13.6% of all trees, with the highest standing dead count occurring in the unthinned but burned combination, the highest percentage residing in the thinned and burned combination, and the lowest for both prevailing in the thinned but unburned combination. At the final inventory, over story composition was 76.6% white fir, 8.1% Jeffrey pine, 6.9% sugar pine, 6.0% incense-cedar, and 2.4% red fir. For height, DBH, and live crown length and percentage, overall means were then 17.8 m, 47.9 cm, 7.3 m, and 41.0%, respectively, with the highest and lowest values for each again residing as noted above regarding the initial inventory. As for final density, an overall mean basal area of 49.0 m^2ha^{-1} was distributed over an average of 308 stems ha-1 of which 40 stems ha-1, amounting to 13.0%, were dead, and here also the final high and low values for each density and mortality measure did not deviate from those disclosed above.

Downed and dead fuel loading at the initial inventory averaged 97908 kg ha^{-1} for the 1+10-hr time lag categories, 2253 kg ha^{-1} for the 100-hr category, 11529 kg ha^{-1} for the 1000-hr category, and 111690 kg ha^{-1} for the total. For the 1+10-hr, 100-hr, and total fuels, the loading was highest overall in the unburned portion of the thinned subunit while the lowest occurred in the burned but unthinned combination. Specific to the 1000-hr category, however, the highest value was found in the stand portion that was neither thinned nor burned with the lowest residing in the thinned but unburned portion. At the final fuels inventory, average loading across treatments was 33858 kg ha-1 for the 1+10-hr categories, 1501 kg ha^{-1} for the 100-hr category, 28765 kg ha^{-1} for the 1000-hr category, and 64124 kg ha-1 in total, and only for the 1000-hr category did the highest and lowest loads occur as they had initially. Otherwise, final 1+10-hr fuels were greatest in the thinned and burned treatment combination and least in the unthinned and unburned combination, 100-hr loading was greatest and least in the unburned and burned portions, respectively, of the thinned subunit, and total loading was greatest in the unthinned and unburned treatment and least in the thinned but unburned treatment.

Ground cover

Shrub species encountered on the study site consisted of huckleberry oak (*Quercus vaccinifolia* Kellogg), bush chinquapin (*Chrysolepis sempervirens* [Kellogg] Hjelmqvist), prostrate ceanothus (*Ceanothus prostratus* Benth.), whitethorn ceanothus (*Ceanothus cordulatus* Kellogg), snowbrush ceanothus (*Ceanothus velutinus* Douglas ex Hook.), pinemat manzanita (*Arctostaphylos nevadensis* A. Gray), creeping snowberry (*Symphoricarpos mollis* Nutt.), wax currant (*Ribes cereum* Douglas), and bitter cherry (*Prunus emarginata* [Douglas ex Hook.] D. Dietr.). No forb or grass species were encountered at either of the two understory inventories conducted during the study.

As the most prevalent shrub residing on the study site overall, percent cover of huckleberry oak was significantly influenced by the thinning treatment ($p = 0.0496$) and the prescribed fire × year of inventory interaction ($p = 0.0411$) according to ANOVA, while the sole influence on the change in its percentage between the initial and final inventories was the fire treatment ($p = 0.0411$) in and of itself (Table 1). The LSD test provided some confirmation of the above effects on cover, as it discerned a significant difference between treatments at the initial inventory that did not persist through the final one, but the distinction it revealed amounted to that between a higher cover in the unburned portion of the unthinned subunit compared to none by this species in the unburned portion of the thinned treatment. As for the change in huckleberry oak cover, this test distinguished substantial increases in its abundance within the burned portions of the thinned and unthinned subunits from a loss in the unburned and unthinned combination. Regarding bush chinquapin, ANOVA detected no influences on its abundance or in the change thereof and the LSD test discerned no differences among the various treatment combinations in either as well.

Inventory	Mechanized and fire treatments	Ground cover (%)									
		HO	BCQ	PC	WT	SC	PM	CS	WC	BCR	Total
Initial	Thinned/ masticated										
	Burned	1.98ab	0.01a	0.16b	0.00a	0.36a	0.01b	0.67a	0.00a	0.08a	3.27b
	Unburned	0.00b	2.03a	5.31a	0.20a	0.00b	3.48a	3.71a	0.05a	0.00a	14.78ab
	Unthinned										
	Burned	8.65ab	0.00a	0.45b	0.00a	0.00b	0.00b	1.10a	1.04a	0.00a	11.24ab
	Unburned	11.31a	10.19a	0.82ab	0.00a	0.00b	0.00b	1.18a	0.59a	0.00a	24.09a
Final	Thinned/ masticated										
	Burned	9.40a	0.00a	2.83a	0.71a	4.14a	0.00b	3.20a	0.00a	0.46a	20.74a
	Unburned	0.00a	1.98a	5.14a	0.18a	0.00b	3.47a	5.82a	0.04a	0.00b	16.63a
	Unthinned										
	Burned	13.28a	0.00a	2.16a	0.00a	0.00b	0.00b	1.52a	1.11a	0.00b	18.07a
	Unburned	10.27a	9.73a	0.86a	0.00a	0.00b	0.00b	1.19a	0.55a	0.00b	22.60a

Change in cover3	Thinned/ masticated										
	Burned	+7.42a	–0.01a	+2.67a	+0.71a	+3.78a	–0.01a	+2.53a	0.00ab	+0.38a	+17.47a
	Unburned	0.00ab	–0.05a	–0.17b	–0.02b	0.00b	–0.01a	+2.11a	–0.01ab	0.00b	+1.85b
	Unthinned										
	Burned	+4.63a	0.00a	+1.71ab	0.00b	0.00b	0.00a	+0.42a	+0.07a	0.00b	+6.83ab
	Unburned	–1.04b	–0.46a	+0.04b	0.00b	0.00b	0.00a	+0.01a	–0.04b	0.00b	–1.49b

Table 1: Percent Ground Cover by Species and in Total in the Understory of an Uneven-Aged Sierran Mixed Conifer Stand as Influenced by Thinning, Slash Mastication, and Prescribed Fire.[1, 2] ([1]Within each table component, means sharing a common letter do not differ significantly at α = 0.05 according to the LSD test; each mean is based on values from five plots (n = 5). [2]HO = huckleberry oak, BCQ = bush chinquapin, PC = prostrate ceanothus, WT = whitethorn ceanothus, SC = snowbrush ceanothus, PM = pinemat manzanita, CS = creeping snowberry, WC = wax currant, BCR = bitter cherry. [3]Means preceeded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.)

Of the three ceanothus species found on the site, prostrate ceanothus was the only one for which ANOVA discerned significant effects (Table 1), amounting to a fire treatment × year influence on its percent cover and one of fire treatment alone on the change thereof (both p = 0.0500). The LSD test denoted as significant differences in the prevalence of this species between a higher cover in the unburned portion of the thinned subunit than those in burned stand portions regardless of thinning treatment, disparities confined to the initial inventory, and it deemed significant the disparities between a large increase in its abundance within the burned portion of the thinned subunit compared to a decrease in the unburned portion of this subunit and a modest increase in the unthinned and unburned combination. Despite the lack of significant effects on either whitethorn or snowbrush ceanothus according to ANOVA, the LSD test distinguished an increase in the former from the initial to the final inventory within the thinned and burned treatment from the other treatment combinations, which in part simply reflected that this species was absent from the unthinned subunit in its entirety throughout the study, and it distinguished the cover by the latter in the burned portion of the thinned subunit as well as an increase between inventories therein from the respective values of all other treatments, largely a reflection that this shrub resided solely in the thinned and burned treatment combination for the duration of the study.

For the remaining species encountered on the site, namely pinemat manzanita, creeping snowberry, wax currant, and bitter cherry, significant influences as discerned by ANOVA on both their cover percentages and the changes thereof were absent as well (Table 1). Nevertheless, except for creeping snowberry, the LSD test disclosed one treatment combination as disparate from one or more of the others at one or both of the inventories and/or specific to the change between them. Regarding pinemat manzanita, its cover percentage in the unburned but thinned treatment differed from the remaining combinations at both inventories, mainly reflecting the absence or near absence of it in three of the four stand portions, while an inter-inventory increase in wax currant cover in the burned portion of the unthinned treatment differed from a decrease in its unburned portion. As for bitter cherry, the distinction belonged to the thinned and burned combination, the only stand portion where this species resided throughout the study, with the differences deemed significant at both the final inventory and regarding a cover increase between the inventories.

Unlike the case with most of the individual species, ANOVA disclosed significant influences on total ground cover, specifically year of inventory (p = 0.0130) and fire treatment × inventory year interaction (p = 0.0155) effects on overall percent cover along with a fire treatment effect (p = 0.0155) on the change in total cover (Table 1). These were accompanied by significant differences among treatments as discerned by the LSD test amounting to a greater total cover in the stand portion that was neither thinned nor burned than that existing in the burned portion of the thinned subunit at the initial inventory as well as a substantial cover increase between inventories in the latter treatment combination that differed from a small one in its unburned counterpart and from a cover reduction in the unthinned and unburned stand portion. Regarding the inventory year influence detected by ANOVA for total cover, an increase was evident from the initial to the final inventories in every treatment combination except the stand portion where neither thinning nor burning was implemented.

Within species, all individual and interactive effects on ground cover dry weight were identical in every respect to those identified by ANOVA for percent cover because the dry weights were a function of the percentages transformed through the use of species-specific weight constants. For the same reason, differences among means disclosed by the LSD test are also identical within each species (Table 2). Consequently, influences of all main and interaction effects on the individual species based on ANOVA and the LSD test are not reiterated here. For total ground cover abundance, however, ANOVA disclosed discrepancies in significance levels between the dry weight and percent cover measures, specifically concerning the year of inventory (p = 0.0170 versus p = 0.0130) and fire treatment × inventory year interaction (p = 0.0073 versus p = 0.0155) effects on overall abundance and the fire treatment effect (p = 0.0073 versus p = 0.0155) on its change between inventories. These discrepancies reflect that the two cumulative abundance measures consist of disparate proportions of each constituent species when the unique weight constants are factored into the calculation of the dry weight measure. Nevertheless, given the threshold level adopted to indicate significant influences in this study, they were not of sufficient magnitude to alter the interpretation of these results, and the outcomes of the LSD test were consistent between the two measures in every respect as well. However, the change in total weight over the course of the study perhaps best illustrates the magnitude of the effect that the under burn eventually exerted on overall ground cover abundance, most apparently in the thinned subunit where the increase amounted to one of 534%, which far surpassed the next largest increase of 64% in the burned portion of the unthinned subunit. To a substantial degree, these reflected increases in huckleberry oak biomass, which amounted to 375% in the thinned and burned treatment and 53% in the unthinned but burned one, plus especially large increases in that of prostrate ceanothus, specifically 1724% and 378% in the former and latter treatment combinations, respectively.

Inventory	Mechanized and fire treatments	Ground cover (kg ha^{-1})									
		HO	BCQ	PC	WT	SC	PM	CS	WC	BCR	Total
Initial	Thinned/ masticated										
	Burned	193.7ab	0.8a	11.8b	0.0a	29.5a	0.8b	12.6a	0.0a	8.0a	257.2b
	Unburned	0.0b	278.5a	403.1a	15.6a	0.0b	245.7a	69.9a	0.8a	0.0a	1013.6ab
	Unthinned										
	Burned	846.9ab	0.0a	34.3b	0.0a	0.0b	0.0b	20.8a	15.0a	0.0a	917.0ab
	Unburned	1107.5a	1400.3a	61.9ab	0.0a	0.0b	0.0b	22.2a	8.5a	0.0a	2600.4a
Final	Thinned/ masticated										
	Burned	919.8a	0.0a	215.2a	53.9a	337.7a	0.0b	60.3a	0.0a	43.6a	1630.5a
	Unburned	0.0a	272.6a	390.2a	14.1a	0.0b	245.3a	109.7a	0.5a	0.0b	1032.4a
	Unthinned										
	Burned	1299.7a	0.0a	163.9a	0.0a	0.0b	0.0b	28.6a	16.0a	0.0b	1508.2a
	Unburned	1005.4a	1336.9a	64.9a	0.0a	0.0b	0.0b	22.4a	7.9a	0.0b	2437.5a
Change in cover[3]	**Thinned/ masticated**										
	Burned	–0.8a	+203.4a	+53.9a	+308.2a	–0.8a	+47.7a	0.0ab	+35.6a	+1373.3a	+726.1a
	Unburned	0.0ab	–5.9a	–12.9b	–1.5b	0.0b	–0.4a	+39.8a	–0.3ab	0.0b	+18.8b
	Unthinned										
	Burned	+452.8a	0.0a	+129.6ab	0.0b	0.0b	0.0a	+7.8a	+1.0a	0.0b	+591.2ab
	Unburned	–102.1b	–63.4a	+3.0b	0.0b	0.0b	0.0a	+0.2a	–0.6b	0.0b	–162.9b

Table 2: Dry Weight of Ground Cover by Species and in Total in the Understory of an Uneven-Aged Sierran Mixed Conifer Stand as Influenced by Thinning, Slash Mastication, and Prescribed Fire.[1, 2] ([1]Within each table component, means sharing a common letter do not differ significantly at α = 0.05 according to the LSD test; each mean is based on values from five plots (n = 5). [2]HO = huckleberry oak, BCQ = bush chinquapin, PC = prostrate ceanothus, WT = whitethorn ceanothus, SC = snowbrush ceanothus, PM = pinemat manzanita, CS = creeping snowberry, WC = wax currant, BCR = bitter cherry. [3]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.)

Natural regeneration

At the initial inventory, 49.4% of all seedlings were white fir, 3.5% were Jeffrey pine, 4.7% were sugar pine, 34.2% were incense-cedar, and 8.2% were red fir (Table 3). Representation of Jeffrey pine within the seedling size class at the final inventory was completely lacking, while that of white fir had risen to 74.3% with incense-cedar representation declining to 8.6%. Of the remainder, 11.4% were sugar pine and 5.7% were red fir.

According to ANOVA, white fir seedling counts were influenced by thinning treatment (p = 0.0152) along with the year of inventory (p = 0.0223) effect noted above (Table 3). Specific to this species, the LSD test revealed a significantly higher count in the unburned portion of the unthinned subunit than that in the thinned subunit irrespective of fire treatment at the initial inventory, and a higher one in the former than that in the burned portion of the thinned subunit, where this species no longer resided, at the final inventory. Although unaccompanied by a significant effect as designated by ANOVA, the LSD test also discerned disparities among treatment combinations for the change in quantities of white fir, where a loss in the unthinned and unburned combination significantly exceeded smaller losses in the remaining treatments. As for Jeffrey and sugar pine seedlings, ANOVA detected no influences on their abundance or in the change thereof and the LSD test discerned no differences among the various treatment combinations for either as well.

Inventory	Mechanized and fire treatments	Seedling counts (# ha^{-1})					
		WF	JP	SP	IC	RF	Total
Initial	Thinned/masticated						
	Burned	49b	49a	49a	0b	0a	147b
	Unburned	296b	49a	49a	99b	247a	740b
	Unthinned						
	Burned	494ab	49a	49a	49b	0a	641b
	Unburned	1235a	0a	49a	1285a	99a	2668a
Final	Thinned/masticated						
	Burned	0b	0	49a	0a	0b	49b
	Unburned	247ab	0	99a	0a	99a	445ab
	Unthinned						
	Burned	395ab	0	0a	49a	0b	444ab
	Unburned	642a	0	49a	99a	0b	790a
Change in cover[3]	Thinned/masticated						
	Burned	–49a	–49a	0a	0a	0a	–98a
	Unburned	–49a	–49a	+50a	–99a	–148a	–295a
	Unthinned						
	Burned	–99a	–49a	–49a	0a	0a	–197a
	Unburned	–593b	0a	0a	–1186b	–99a	–1878b

Table 3: Seedling Counts by Species and in Total in the Understory of an Uneven-Aged Sierran Mixed Conifer Stand as Influenced by Thinning, Slash Mastication, and Prescribed Fire.[1, 2] ([1]Within each table component, means sharing a common letter do not differ significantly at $\alpha = 0.05$ according to the LSD test; each mean is based on values from five plots (n = 5). [2]WF = white fir, JP = Jeffrey pine, SP = sugar pine, IC = incense-cedar, RF = red fir. [3]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.)

Counts of incense-cedar seedlings were influenced by the thinning and fire treatments (both p = 0.0186) and the thinning × fire treatment (p = 0.0393), thinning treatment × inventory year (p = 0.0498), fire treatment × inventory year (p = 0.0233), and thinning × fire treatment × inventory year (p = 0.498) interactions in addition to the inventory year (p = 0.0223) effect in and of itself noted previously, with ANOVA also disclosing thinning and fire treatment influences (p = 0.0498 and p = 0.0233, respectively) along with a thinning × fire treatment interaction effect (p = 0.498) concerning the change in counts for this species (Table 3). Nevertheless, the LSD test distinguished only a higher count in the unburned portion of the unthinned subunit from lower ones in the remaining stand portions that was limited to the initial inventory, although these disparities were of considerable magnitude and reflected a complete absence of this species in the thinned and burned combination, along with a large reduction in the count within the unthinned and unburned stand portion from the changes in the other three treatment combinations, which in actuality amounted to a lack thereof in the burned portions of both subunits. Absent any significant influences as discerned by ANOVA for seedlings of red fir, the LSD test distinguished a higher count in the unburned portion of the thinned subunit from the ones in the remaining stand portions at the final inventory, which in fact simply reflected the absence of this species in all except the former at the conclusion of the study.

As for the total seedling count, ANOVA designated the effects of the thinning (p = 0.0240) and fire (p = 0.0175) treatments, the year of inventory (p = 0.0075), and the fire treatment × inventory year interaction (p = 0.0337) as significant, while for the change in the total it did so for fire treatment (p = 0.0337) alone (Table 3). According to the LSD test, the total count in the unthinned and unburned treatment combination surpassed those of every other combination at the initial inventory and surpassed that of the thinned and burned combination again at the final one. However, despite losses between inventories extending across all treatments, that in the unthinned and unburned combination significantly exceeded the others and by substantial margins. In part reflecting the large total count present in this treatment initially when it exceeded that elsewhere by ≥260%, seedling losses therein amounted to 70% over the course of the study. These disparities were essentially explained by such specific to white fir and incense-cedar for which large initial counts in the unthinned and unburned combination that exceeded the ones in the other treatments by ≥ 150% and ≥ 1198%, respectively, were ultimately diminished by 48% for the former and 92% for the latter.

In the sapling size class, only two species were represented at the initial inventory whether alive or dead, namely white fir and incense-cedar which constituted 89.8% and 10.2%, respectively, of the overall sapling total (Table 4). At the final inventory, white fir was still predominant at 82.8% of the overall total while incense-cedar constituted 13.8%, but a small contingent of red fir, amounting to 3.4% of the total, was present as well.

Inventory	Mechanized and fire treatments	Seedling counts (# ha^{-1})											
		WF		JP		SP		IC		RF		Total	
		L	D	L	D	L	D	L	D	L	D	L	D
Initial	Thinned/masticated												
	Burned	0b	37b	0	0	0	0	0b	0	0	0	0b	37b
	Unburned	148ab	0b	0	0	0	0	0b	0	0	0	148ab	0b
	Unthinned												
	Burned	408a	334a	0	0	0	0	0b	0	0	0	408a	334a
	Unburned	334a	37b	0	0	0	0	148a	0	0	0	482a	37b
Final	Thinned/masticated												
	Burned	0b	0a	0	0	0	0	0b	0a	0a	0	0b	0a
	Unburned	74b	74a	0	0	0	0	0b	0a	37a	0	111ab	74a
	Unthinned												
	Burned	371a	37a	0	0	0	0	0b	0a	0a	0	371a	37a
	Unburned	334a	0a	0	0	0	0	111a	37a	0a	0	445a	37a
Change in cover[3]	Thinned/masticated												
	Burned	0a	–37a	0	0	0	0	0a	0a	0a	0	0a	–37a
	Unburned	–74a	+74a	0	0	0	0	0a	0a	+37a		0	–37a
	Unthinned												
	Burned	–37a	–297b	0	0	0	0	0a	0a	0a	0	–37a	–297b
	Unburned	0a	–37a	0	0	0	0	–37a	+37a		0a		0

Table 4: Live and Dead Sapling Counts by Species and in Total in the Understory of an Uneven-Aged Sierran Mixed Conifer Stand as Influenced by Thinning, Slash Mastication, and Prescribed Fire.[1, 2, 3] ([1]Within each table component, means sharing a common letter do not differ significantly at α = 0.05 according to the LSD test; each mean is based on values from five plots (n = 5). [2]WF = white fir, JP = Jeffrey pine, SP = sugar pine, IC = incense-cedar, RF = red fir. [3]L = live, D = dead. [4]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.)

Among saplings, the only species for which ANOVA disclosed significant effects was white fir, and among live ones, only the thinning treatment ($p = 0.0465$) influence on their counts proved so (Table 4). As for the LSD test, it distinguished higher live counts in the unthinned subunit irrespective of fire treatment from none extant in the burned portion of the thinned subunit at the initial inventory and those in the former from the live counts in either portion of the thinned subunit at the final inventory, with live white fir again absent in the thinned and burned combination. For dead white fir, ANOVA discerned significant influences of the thinning and fire treatments (both $p = 0.0143$), the year of inventory ($p = 0.100$), plus the thinning × fire treatment interaction ($p = 0.0034$) along with those of thinning treatment × inventory year and fire treatment × inventory year (both $p = 0.0021$) on the quantities thereof. Additionally, it revealed significant thinning and fire treatment effects (both $p = 0.0021$) on the change in dead white fir counts. Regarding the dead counts, the LSD test denoted as significant disparities between a higher quantity in the burned portion of the unthinned treatment and lower ones in all other treatment combinations, but only at the initial inventory, while for the change between inventories, it distinguished a large loss in the former from far less pronounced changes in the remaining treatments. Although unaccompanied by significant influences as discerned by ANOVA, the LSD test nonetheless distinguished the unthinned and unburned treatment from the others at both inventories concerning live incense-cedar, which essentially reflected that saplings of this species resided in only this one stand portion for the duration of the study.

Across species, live sapling counts were significantly affected by thinning treatment alone (p = 0.0448) according to ANOVA, with total live counts in the unthinned subunit exceeding those in the thinned stand portions by ≥ 176% at the first inventory and ≥ 234% at the last one (Table 4). This influence was rendered most apparent by the LSD test in regards to the burned portion of the thinned subunit which it distinguished from either portion of the unthinned treatment, likely a reflection in large part of the complete absence of any live saplings of any species in the thinned and burned treatment combination at both inventories. In general, the pattern of treatment responses displayed by live saplings overall paralleled that specific to white fir, for which the quantities in the unthinned stand portions exceeded those in thinned ones by ≥ 126% initially and by ≥ 351% at the conclusion of the study. Influences discerned as significant by ANOVA for total dead counts in the sapling size class consisted of the thinning treatment (p = 0.0094) and year of inventory (p = 0.0376) along with the thinning × fire treatment interaction (p = 0.0311) plus those of thinning treatment × inventory year and fire treatment × inventory year (both p = 0.0119), and it also disclosed significant thinning and fire treatment effects (both p = 0.0120) on the change in dead saplings counts across species. However, disparities deemed significant by the LSD test were limited to a higher quantity in the burned portion of the unthinned subunit than elsewhere at the initial inventory and a greater loss between inventories in this treatment combination than that occurring in any other stand portion. The magnitude of these disparities strongly reflected the influence of the white fir responses, as both the total dead and dead white fir sapling counts in the unthinned but burned combination exceeded those in any other treatment by ≥803% and the losses between inventories in the unthinned but burned combination regarding both the total dead count and that specific to this fir amounted to 89% of the quantity present initially.

Relationships of ground cover variables

The first series of simple linear regressions, which dealt with factors potentially influential in ground cover development, yielded a total of 54 significant models (Table 5). Two of these featured initial tree height as the independent variable to which wax currant cover at both the initial and final inventories was negatively related, and a third negatively related the abundance of this species at the latter inventory to final tree height. A single model incorporated live crown length, specifically that at the initial inventory, as the independent variable to which initial snowbrush ceanothus cover was negatively related, but more often represented among independent variables was initial live crown percentage to which final whitethorn ceanothus, initial and final snowbrush ceanothus, and final bitter cherry abundance values along with the change between inventories for the latter species were all negatively related. For the remaining models incorporating a measure of tree crown development as the independent component, final whitethorn and snowbrush ceanothus cover was negatively correlated with final live crown percentage which was also true for final bitter cherry cover.

Only a single significant model featured a stand density measure as the independent variable, specifically one in which a positive correlation was demonstrated between final bush chinquapin cover and final tree count (Table 5). However, when segregated by species, models correlating ground cover with the prevalence of specific over story species were numerous, including ones coupling initial and final pinemat manzanita and creeping snowberry cover with the proportion of white fir at the initial inventory plus the final values for each of these shrubs with the final white fir proportion, all negative relationships. With Jeffrey pine replacing white fir and with positive correlations replacing negative ones, an otherwise identical array of relationships to those noted above were revealed as well. With initial sugar pine proportion serving as the independent variable, the initial, final, and change in snowbrush ceanothus and bitter cherry cover comprised the dependent counterparts, while with the final proportion of this over story constituent constituting the former the latter consisted of the final cover for each of these shrubs, all again positive relationships. Only a single significant model involved incense-cedar, specifically its proportion initially with which initial huckleberry oak cover was positively correlated, and only two involved red fir for which the initial proportion served as the independent variable to which initial cover of prostrate and whitethorn ceanothus was positively related.

Of models incorporating downed and dead fuel weights as the independent variables, only those based upon such from the initial inventory proved to be significant (Table 5). Of these, initial and final pinemat manzanita abundance was positively correlated with both the 1+10-hr fuels and with total loading. Also, that of creeping snowberry at each inventory was positively related to the former while the initial snowberry cover was positively related to total fuels as well.

Somewhat more numerous were models featuring the initial values for understory cover as the independent variables while those from the final inventory, along with the changes, constituted the dependent counterparts (Table 5). Matched within species in all cases, those for which the dependent variable consisted of final cover involved huckleberry oak, bush chinquapin, prostrate and snowbrush ceanothus, pinemat manzanita, creeping snowberry, wax currant, and bitter cherry, with positive relationships prevailing in each. For those models in which the dependent component involved a change between inventories, one specific to bush chinquapin featured a negative correlation while two others concerning snowbrush ceanothus and bitter cherry revealed positive relationships.

Independent variable	Dependent variable	Correlation	Model F test p-value	Model r^2
Height, initial	Wax currant, initial	Negative	0.0432	0.2082
Height, initial	Wax currant, final	Negative	0.0458	0.2036
Height, final	Wax currant, final	Negative	0.0381	0.2177
Live crown length, initial	Snowbrush ceanothus, initial	Negative	0.006	0.3501
Live crown percent, initial	Whitethorn ceanothus, final	Negative	0.0393	0.2154
Live crown percent, initial	Snowbrush ceanothus, initial	Negative	<0.0001	0.6
Live crown percent, initial	Snowbrush ceanothus, final	Negative	0.0015	0.4391
Live crown percent, initial	Bitter cherry, final	Negative	0.0025	0.4066
Live crown percent, initial	Bitter cherry, change	Negative	0.0005	0.4986
Live crown percent, final	Whitethorn ceanothus, final	Negative	0.0471	0.2015

Citation: Walker R, Swim SL, Fecko RM, Johnson DW, Miller WW (2016) Responses of a Sierran Mixed Conifer Understory Plant Community to Cover Story Thinning, Slash Mastication, and Prescribed Fire Restoration Treatments. Forest Res 5: 167. doi: 10.4172/2168-9776.1000167

Live crown percent, final	Snowbrush ceanothus, final	Negative	0.0058	0.3525
Live crown percent, final	Bitter cherry, final	Negative	0.0095	0.3188
Tree count, final	Bush chinquapin, final	Positive	0.0269	0.244
White fir proportion, initial	Pinemat manzanita, initial	Negative	0.0169	0.2781
White fir proportion, initial	Pinemat manzanita, final	Negative	0.0183	0.2721
White fir proportion, initial	Creeping snowberry, initial	Negative	0.0097	0.3171
White fir proportion, initial	Creeping snowberry, final	Negative	0.0235	0.254
White fir proportion, final	Pinemat manzanita, final	Negative	0.0245	0.2508
White fir proportion, final	Creeping snowberry, final	Negative	0.0436	0.2073
Jeffrey pine proportion, initial	Pinemat manzanita, initial	Positive	0.0013	0.4448
Jeffrey pine proportion, initial	Pinemat manzanita, final	Positive	0.0015	0.4383
Jeffrey pine proportion, initial	Creeping snowberry, initial	Positive	0.0019	0.4247
Jeffrey pine proportion, initial	Creeping snowberry, final	Positive	0.0149	0.2872
Jeffrey pine proportion, final	Pinemat manzanita, final	Positive	0.0032	0.3913
Jeffrey pine proportion, final	Creeping snowberry, final	Positive	0.017	0.2776
Sugar pine proportion, initial	Snowbrush ceanothus, initial	Positive	0.02	0.2658
Sugar pine proportion, initial	Snowbrush ceanothus, final	Positive	<0.0001	0.7077
Sugar pine proportion, initial	Snowbrush ceanothus, change	Positive	<0.0001	0.7383
Sugar pine proportion, initial	Bitter cherry, initial	Positive	<0.0001	0.6677
Sugar pine proportion, initial	Bitter cherry, final	Positive	<0.0001	0.7284
Sugar pine proportion, initial	Bitter cherry, change	Positive	<0.0001	0.6185
Sugar pine proportion, final	Snowbrush ceanothus, final	Positive	0.0001	0.5771
Sugar pine proportion, final	Bitter cherry, final	Positive	<0.0001	0.5975
Incense-cedar proportion, initial	Huckleberry oak, initial	Positive	0.0383	0.2173
Red fir proportion, initial	Prostrate ceanothus, initial	Positive	0.0155	0.2841
Red fir proportion, initial	Whitethorn ceanothus, initial	Positive	<0.0001	0.6455
1+10-hr fuels, initial	Pinemat manzanita, initial	Positive	0.011	0.3086
1+10-hr fuels, initial	Pinemat manzanita, final	Positive	0.0111	0.3078
1+10-hr fuels, initial	Creeping snowberry, initial	Positive	0.0133	0.295
1+10-hr fuels, initial	Creeping snowberry, final	Positive	0.0418	0.2106
Total fuels, initial	Pinemat manzanita, initial	Positive	0.0221	0.2584
Total fuels, initial	Pinemat manzanita, final	Positive	0.0223	0.2578
Total fuels, initial	Creeping snowberry, initial	Positive	0.0209	0.2624
Huckleberry oak, initial	Huckleberry oak, final	Positive	0.0001	0.5747
Bush chinquapin, initial	Bush chinquapin, final	Positive	<0.0001	0.9997
Bush chinquapin, initial	Bush chinquapin, change	Negative	<0.0001	0.9852
Prostrate ceanothus, initial	Prostrate ceanothus, final	Positive	<0.0001	0.6609
Snowbrush ceanothus, initial	Snowbrush ceanothus, final	Positive	<0.0001	0.6685
Snowbrush ceanothus, initial	Snowbrush ceanothus, change	Positive	<0.0001	0.6048
Pinemat manzanita, initial	Pinemat manzanita, final	Positive	<0.0001	0.9996
Creeping snowberry, initial	Creeping snowberry, final	Positive	<0.0001	0.7561
Wax currant, initial	Wax currant, final	Positive	<0.0001	0.9955
Bitter cherry, initial	Bitter cherry, final	Positive	<0.0001	0.6485
Bitter cherry, initial	Bitter cherry, change	Positive	0.0016	0.4343

Table 5: Significant simple linear regression models relating percent ground cover by species in the understory of an uneven-aged sierran mixed conifer stand to cover story, fuels, and ground cover variables.[1] ([1]All models incorporate 20 or fewer observations (n ≤ 20) depending upon the availability of pertinent values within the individual plots.)

Regarding the first regression series in total, the variation in the dependent variables of the significant models therein that was explained by such in the independent variables ranged from 20% to more than 99% (Table 5). The strongest of these were models pairing, within understory species, initial cover with final cover or with the change during the interim, of which four accounted for more than 90% while only one explained less than 50% of variation in the dependent components.

Relationships of natural regeneration

The second regression series, which dealt with factors potentially influential in seedling and sapling demography, including mortality regarding the latter, yielded a total of 87 significant models (Table 6). A substantial proportion of these featured the over story tree dimensions of height and DBH as the independent variables, and without exception, such models revealed negative correlations. With initial height serving as the independent component, dependent variables consisted of the final white fir seedling count along with the initial and final live sapling counts of this species, the initial dead white fir sapling count, the initial and final total live sapling counts, and that of total dead saplings initially. Coupled with final tree height were counts of final white fir and total seedlings plus those of live white fir and total live saplings at the final inventory. For models involving initial DBH of over story trees, the dependent components were limited to sapling counts, specifically those of initial and final live white fir, initial dead white fir, initial and final live totals across species, and the initial total dead. Nevertheless, final white fir and total seedling counts along with live white fir and total live sapling counts at the final inventory were related to the final over story DBH.

Independent variable	Dependent variable	Correlation	Model F test p-value	Model r^2
Height, initial	White fir seedlings, final	Negative	0.0466	0.2023
Height, initial	White fir live saplings, initial	Negative	0.0304	0.2347
Height, initial	White fir live saplings, final	Negative	0.013	0.2966
Height, initial	White fir dead saplings, initial	Negative	0.0031	0.3926
Height, initial	Total live saplings, initial	Negative	0.0291	0.2379
Height, initial	Total live saplings, final	Negative	0.0128	0.2976
Height, initial	Total dead saplings, initial	Negative	0.0018	0.4258
Height, final	White fir seedlings, final	Negative	0.0225	0.2572
Height, final	Total seedlings, final	Negative	0.0369	0.22
Height, final	White fir live saplings, final	Negative	0.0079	0.3318
Height, final	Total live saplings, final	Negative	0.0104	0.3125
DBH, initial	White fir live saplings, initial	Negative	0.0042	0.3742
DBH, initial	White fir live saplings, final	Negative	0.004	0.3758
DBH, initial	White fir dead saplings, initial	Negative	0.0075	0.3347
DBH, initial	Total live saplings, initial	Negative	0.0046	0.367
DBH, initial	Total live saplings, final	Negative	0.0052	0.3597
DBH, initial	Total dead saplings, initial	Negative	0.0112	0.3075
DBH, final	White fir seedlings, final	Negative	0.0285	0.2394
DBH, final	Total seedlings, final	Negative	0.0222	0.2582
DBH, final	White fir live saplings, final	Negative	0.0033	0.3882
DBH, final	Total live saplings, final	Negative	0.0043	0.3714
Basal area, initial	Incense-cedar dead saplings, final	Positive	0.0419	0.2105
Basal area, final	Incense-cedar dead saplings, final	Positive	0.0283	0.24
Tree count, initial	White fir seedlings, initial	Positive	0.0386	0.2166
Tree count, initial	White fir seedlings, final	Positive	0.0134	0.2946
Tree count, initial	Incense-cedar seedlings, final	Positive	0.0089	0.3234
Tree count, initial	Total seedlings, initial	Positive	0.0416	0.211
Tree count, initial	Total seedlings, final	Positive	0.0225	0.2572
Tree count, initial	White fir live saplings, initial	Positive	0.0063	0.3468

Tree count, initial	White fir live saplings, final	Positive	0.0039	0.3787
Tree count, initial	Incense-cedar live saplings, initial	Positive	0.0089	0.3234
Tree count, initial	Incense-cedar dead saplings, final	Positive	0.0337	0.227
Tree count, initial	Total live saplings, initial	Positive	0.0024	0.4084
Tree count, initial	Total live saplings, final	Positive	0.0068	0.3415
Tree count, final	White fir seedlings, final	Positive	0.0067	0.343
Tree count, final	Incense-cedar seedlings, final	Positive	0.0025	0.4074
Tree count, final	Total seedlings, final	Positive	0.01	0.3155
Tree count, final	White fir live saplings, final	Positive	0.0037	0.381
Tree count, final	Incense-cedar dead saplings, final	Positive	0.0204	0.2644
Tree count, final	Total live saplings, final	Positive	0.0058	0.352
White fir proportion, initial	Sugar pine seedlings, final	Negative	0.0316	0.2318
White fir proportion, initial	White fir dead saplings, initial	Positive	0.0128	0.298
White fir proportion, initial	Total dead saplings, initial	Positive	0.0256	0.2476
Incense-cedar proportion, initial	Incense-cedar seedlings, initial	Positive	0.0065	0.3445
Incense-cedar proportion, initial	Incense-cedar live saplings, initial	Positive	0.0304	0.2348
Incense-cedar proportion, initial	Incense-cedar live saplings, final	Positive	0.0026	0.4047
Incense-cedar proportion, initial	Incense-cedar dead saplings, initial	Positive	0.0003	0.5182
Incense-cedar proportion, final	Incense-cedar live saplings, final	Positive	0.0034	0.3866
Red fir proportion, initial	Red fir seedlings, initial	Positive	<0.0001	0.714
Red fir proportion, initial	Red fir seedlings, final	Positive	<0.0001	0.8252
Red fir proportion, initial	Red fir seedlings, change	Negative	0.0005	0.4979
Red fir proportion, initial	Red fir live saplings, final	Positive	<0.0001	0.6493
Red fir proportion, final	Red fir seedlings, final	Positive	<0.0001	0.802
Red fir proportion, final	Red fir live saplings, final	Positive	<0.0001	0.7269
1+10-hr fuels, initial	White fir dead saplings, initial	Negative	0.0117	0.3045
1+10-hr fuels, initial	Total dead saplings, initial	Negative	0.0161	0.2814
1,000-hr fuels, initial	White fir live saplings, initial	Positive	0.0026	0.4047
1,000-hr fuels, initial	White fir live saplings, final	Positive	0.0024	0.4077
1,000-hr fuels, initial	Total live saplings, initial	Positive	0.0026	0.4044
1,000-hr fuels, initial	Total live saplings, final	Positive	0.0008	0.4758
Total fuels, initial	White fir dead saplings, initial	Negative	0.0215	0.2606
Total fuels, initial	Total dead saplings, initial	Negative	0.0374	0.2191
Huckleberry oak, initial	Incense-cedar seedlings, initial	Positive	0.0416	0.2111
Huckleberry oak, initial	Incense-cedar live saplings, final	Positive	0.038	0.2179
Huckleberry oak, initial	Incense-cedar dead saplings, initial	Positive	0.007	0.34

Bush chinquapin, initial	White fir seedlings, initial	Positive	0.0101	0.3148
Bush chinquapin, initial	Incense-cedar seedlings, initial	Positive	0.0029	0.3973
Bush chinquapin, initial	Incense-cedar seedlings, final	Positive	0.0169	0.2778
Bush chinquapin, initial	Total seedlings, initial	Positive	0.0011	0.4534
Prostrate ceanothus, initial	Red fir seedlings, initial	Positive	0.0017	0.4289
Prostrate ceanothus, initial	Red fir seedlings, final	Positive	0.0425	0.2093
Prostrate ceanothus, initial	White fir dead saplings, final	Positive	0.0008	0.4725
Prostrate ceanothus, initial	Red fir live saplings, final	Positive	0.0002	0.5388
Prostrate ceanothus, initial	Total dead saplings, final	Positive	0.0039	0.3775
Prostrate ceanothus, final	White fir dead saplings, final	Positive	0.0004	0.5055
Prostrate ceanothus, final	Red fir live saplings, final	Positive	0.01	0.3154
Prostrate ceanothus, final	Total dead saplings, final	Positive	0.0039	0.3789
Whitethorn ceanothus, initial	Red fir seedlings, initial	Positive	<0.0001	0.8551
Whitethorn ceanothus, initial	Red fir seedlings, final	Positive	0.0008	0.4712
White thorn ceanothus, initial	White fir dead saplings, final	Positive	<0.0001	0.7902
Whitethorn ceanothus, initial	Red fir live saplings, final	Positive	<0.0001	0.9988
Whitethorn ceanothus, initial	Total dead saplings, final	Positive	<0.0001	0.6537
Creeping snowberry, initial	Sugar pine seedlings, final	Positive	0.003	0.394
Creeping snowberry, final	Sugar pine seedlings, final	Positive	<0.0001	0.6458
Wax currant, initial	White fir dead saplings, initial	Positive	0.0355	0.223
Wax currant, initial	Incense-cedar dead saplings, initial	Positive	0.0316	0.2317
Wax currant, initial	Total dead saplings, initial	Positive	0.0096	0.3177

Table 6: Significant simple linear regression models relating natural regeneration demography by species and in total in the understory of an uneven-aged sierran mixed conifer stand to cover story, fuels, and ground cover variables.[1] ([1]All models incorporate 20 or fewer observations ($n \leq 20$) depending upon the availability of pertinent values within the individual plots.)

Also numerous were significant models featuring stand density measures as the independent variables, but in these positive correlations prevailed without exception (Table 6). Basal area served as the independent variable in only two models, with one each specific to each of the inventories but with the final dead incense-cedar sapling count constituting the dependent variable in both. Much more prevalent were models in which initial over story tree count constituted the former, as it was paired with initial white fir and total seedling counts, the final white fir seedling count plus those of incense-cedar and the total across species, and live sapling counts at both inventories specific to white fir and the total as well as those of live incense-cedar saplings at the initial inventory and dead ones at the final inventory. With final tree count as the independent variable, the dependent counterparts consisted of the final counts of white fir, incense-cedar, and total seedlings plus those of white fir and total live saplings along with dead saplings of incense-cedar.

Of models in which the proportion of over story constituents by species served as independent variables, two revealed negative correlations, specifically one relates the final sugar pine seedling count to the initial white fir proportion and the second pairing the change in counts for red fir seedlings with the initial red fir proportion (Table 6). Portraying positive relationships were models coupling dead white fir and total sapling counts at the initial inventory to the initial proportion of the former in the over story. Additionally, specific to incense-cedar regarding the independent and dependent variables, the initial count of its seedlings, those of live and dead saplings, and the final live sapling count were positively related to its initial over story proportion while the final count of its live saplings was positively correlated with the final proportion. Furthermore, within-species pairings with exclusively positive correlations extended to red fir, relating initial and final seedling counts along with that of live saplings at the latter inventory to the initial proportion of this fir as well as the final seedling and live sapling counts to the final proportion.

For models in which downed and dead fuels provided the independent counterpart to natural regeneration variables, positive and negative correlations prevailed therein in equal proportion, the fuel loading in significant models was limited to that quantified at the initial inventory, and saplings alone were represented among the dependent variables but with live and dead counts of them equally so (Table 6). The negative relationships herein entailed pairings of dead white fir and of the total dead across species, each at the initial inventory, with both 1+10-hr and total fuels, while positive ones coupled initial and final live white fir and total live saplings with 1000-hr loading.

Especially numerous among significant models in this series were those revealing linkages between natural regeneration and ground cover species, with such linkages manifested in positive correlations in every case (Table 6). Among them, initial cover of huckleberry oak was the independent variable to which the initial incense-cedar seedling count, the final live incense-cedar sapling count, and the initial dead sapling count of this species were each related. Models involving bush chinquapin as the independent component were confined to those featuring seedling variables as the dependent counterpart, with their counts specific to white fir, incense-cedar, and the total across species at the initial inventory as well as that of incense-cedar at the final one related to initial chinquapin cover. More prevalent were significant models incorporating prostrate ceanothus in the independent variable, as the initial and final red fir seedling counts were correlated with the initial cover of this shrub while final counts specific to dead white fir saplings, total dead saplings, and live red fir in this size class were correlated with the its initial and final cover. Initial whitethorn ceanothus cover was another independent variable to which the same array of dependent counterparts as that noted above concerning initial cover of prostrate ceanothus was also related. The last of the models relating natural regeneration to ground cover prevalence involved creeping snowberry cover at the initial and final inventories, with which the final sugar pine seedling count was correlated, and the initial wax currant cover, with which the initial dead sapling counts of white fir, incense-cedar, and the overall total were correlated.

As proved true regarding the first regression series, the variation in the dependent variables of the significant models within the second series explained by that in the independent variables therein ranged from 20% to more than 99% (Table 6). Generally, the strongest of these were models featuring whitethorn ceanothus ground cover as the independent component along with those that paired red fir regeneration with the prevalence of this species among overatory constituents. Among such models, only one failed to account for at least 50% of the variation in the dependent components, and only two of them failed to explain at least 65% of such variation.

Discussion

Regarding the most prevalent shrub in the understory community of the study site, huckleberry oak, a possible vestige of the impact of the mechanized operations was evident at the initial inventory, with the interval between implementation and the first ground cover measurements encompassing nearly five full growing seasons. Ostensibly, reflected in the cover and weight disparities between the thinned and unthinned treatments were the combined influences of direct disturbance by the machine trafficking entailed in the harvesting and mastication processes coupled with burial beneath the slash mats and chipped materials that ensued. However, factors tempering this supposition are that the only statistically significant difference between treatments identified herein was that between the unburned portions of the two thinning treatments and that this species never had more than a minimal presence in the unburned portion of the thinned subunit even before treatment implementation [23]. However credible the evidence here is, a comparable study in a western USA pine stand, albeit one in which on-site slash mastication did not accompany a mechanized thinning, disclosed a recovery of the understory shrub community to the pretreatment abundance level within five post treatment years [24]. Regardless, over the course of this study the fire treatment proved to be of greater importance as manifested in considerable increases in huckleberry oak abundance in the burned portions of both thinning treatments during the interval between the initial and final inventories, a result that reflects the capacity of this species to vigorously reemerge from rootstocks following fire damage to aerial plant portions [7,25]. Somewhat reinforcing this interpretation was a regression model of some strength that positively related final huckleberry oak cover to that present initially. An obvious implication of this finding is that if long-term mitigation of wildfire risk is a management priority on sites where it has a substantial presence, it may be necessary to employ broadcast burning recurrently due to the extreme flammability of this species [7]. The other shrub for which the results here clearly indicated treatment effects was prostrate ceanothus, which was still exhibiting suppression by the under burn at the initial inventory but then recovered in burned stand portions over the course of the study. Similar to huckleberry oak, however, the recovery was especially pronounced in the burned portion of the thinned subunit although the interaction of the thinning and fire treatments was nonsignificant regarding both species. Nevertheless, the most readily apparent explanation for the greater increases in the thinned and burned treatment combination, specifically that diminished stocking extant in this treatment regarding the over story proved to be stimulatory, with thinnings generally considered to favor expansion of understory communities in western USA forests due to greater availability of light and water [4], is rendered somewhat questionable by the absence of any linkage demonstrated through the regression analysis between the abundance of either of these species and over story density. Specific to prostrate ceanothus, an alternative explanation related to its propensity to store seeds in the forest floor in close proximity to existing specimens that germinate profusely in response to fire [4] is rendered perhaps even less satisfactory, given a regression model here that disclosed a strong positive relationship between its initial and final abundance, by the fact that the initial abundance of this ceanothus in the thinned and burned stand portion was numerically lower than that in any other treatment combination, a scarcity that even extended back prior to treatment implementation [23]. Whether wholly explainable or not, the especially pronounced resurgence of both huckleberry oak and prostrate ceanothus on the portion of this site where thinning proceeded the under burn largely accounted for the exceptional increase in total ground cover therein.

As for the remainder of the shrubs residing on this site, namely bush chinquapin, whitethorn and snowbrush ceanothus, pinemat manzanita, creeping snowberry, wax currant, and bitter cherry, results revealed here did not provide much support for any assumption of pronounced treatment impacts on their prevalence or on the change in such during the interval between the two inventories given that no significant effects thereupon were demonstrated, and to the extent that any treatment influences could be discerned, they were limited to disparities as disclosed by the mean comparison test. Nevertheless, some such disparities were revealed for all of these species except chinquapin and snowberry, with increases in the abundance of the two ceanothus species and in bitter cherry over the course of the study within the burned portion of the thinned subunit perhaps most noteworthy, although this supposition is tempered by the fact that these three shrubs never resided in more than two of the four treatment combinations. A somewhat perplexing aspect of this study is that linkages between shrub species for which no specific treatment effects or interactions thereof were demonstrated, which was all but two of those in residence somewhere on the study site, and various over story variables, including three dimensions, density, and proportional species representation as well as those concerning downed and dead fuel loading, were revealed with far greater frequency than such relationships specific to huckleberry oak and prostrate ceanothus, which suggests that relatively subtle variation over the entirety of the study site with respect to the growing environment of most of the resident species assumed a greater role in their prevalence than the comparatively drastic modifications attributable to the imposed treatments. Cases in point include several negative correlations between the prevalence of some of these shrubs and both the live crown percentage of the over story and its proportion of white fir and several positive ones between such and the proportional representation of Jeffrey and sugar pine along with 1+10-hr and total fuel loading. Regardless, the strongest models specific to these species were generally those that related their final abundance to that present initially as was the case with huckleberry oak and prostrate ceanothus.

Even when disregarding the treatment influences, the transitory nature of natural regeneration of the seedling size class was much in evidence in this study, as in the interval between the initial and final inventories the representation of white fir transitioned from accounting for nearly one-half to nearly three-quarters of all seedlings, an initially meager presence of Jeffrey pine declined to total absence, sugar pine representation more than doubled but nevertheless remained modest, three-quarters of an initially substantial incense-cedar population was lost, and a small initial red fir presence became smaller yet. Given that species representation in the over story remained essentially static for the duration of the study, the changes in seedling composition undoubtedly reflect in part the vagaries of seed production among the various over story constituents, which in turn probably accounts for the fact that species-specific correlations between seedling counts and the relative proportions of their parent trees were confined to incense-cedar and red fir, although for the latter species the relationships were of pronounced strength. However, in the case of white fir, a factor confounding the relationship between the prevalence of the progeny and that of potential parents was that some of the latter may have been past prime seed-bearing age, as several regression models revealed a negative relationship between seedling abundance for this species, as well as for total seedlings of which white fir was predominant, and tree size, suggesting that its regeneration was enhanced where seed parents were smaller and therefore probably younger. As mentioned previously, dominant crown class trees on this site were, on average, approaching the end of their second century at the time of this study [18]. Aside from its prominence in the seedling population, white fir was one of only two species for which treatment influences proved to be definitive, which was manifested in persistently higher counts in the unthinned treatment and most especially where under burning was precluded as well even though its count there receded more than that in any other treatment combination over the course of the study. Two factors likely account for this outcome, the first and most obvious being the avoidance of seedling losses associated with the disturbance inherent in the imposed treatments, with mechanized thinning alone generally considered to impart substrate surface impacts on approximately one-fifth of the acreage of sites upon which it is practiced [13], which in the case here was compounded by the formation and later mastication of the slash mats, resulting in the burial of the preexisting forest floor in its entirety, with the resulting fuel bed then consumed in large part [18] where the under burn was implemented. Reflecting its shade tolerance, the second factor is the capacity of this species to regenerate under low light conditions such as those created by dense over stories and verdant shrub communities [26], and pertinent here is that the highest overall over story basal area and stem count and understory shrub cover resided in the unburned portion of the unthinned subunit throughout the study. Lending further weight to an assumption of the importance of the latter factor were multiple regression models that positively related white fir seedling abundance to cover story stem count and an additional one revealing such a relationship between the former and bush chinquapin cover, which was exceptionally plentiful in the unthinned and unburned stand portion. Considered in total, these findings substantiate the view that shade and an undisturbed forest floor generally favor the regeneration of white fir more so than that of associated species in Sierra Nevada mixed conifer forests [27]. An elevated quantity of incense-cedar seedlings, which was the other species in the regeneration of this size class for which treatment influences were clearly evident, were also found in the unthinned and unburned treatment, but unlike for white fir the facilitating effects imparted there were clearly negated sometime following the initial inventory because very few seedlings of this species persisted through the end of the study. Early seedling mortality in incense-cedar often results from its propensity toward slow primary root growth, which renders it prone to desiccation [28]. Regardless, considered to be of intermediate shade tolerance, incense-cedar is reputed to regenerate best under partial shade [29] but has also been found to endure dense shade in the seedling stage [30]. Support provided here for the latter finding includes the aforementioned high over story density and shrub cover in the unthinned and unburned treatment combination coupled with several regression models disclosing positive correlations between seedling quantity for this species and tree count plus the coverage of both huckleberry oak and bush chinquapin, the two shrubs accounting for most of the relatively abundant understory present therein. Perhaps equally notable to the two species for which definite treatment influences were disclosed here were two others for which they were not, specifically Jeffrey and sugar pine. Prescribed fire has usually been found to favor Jeffrey pine regeneration more so than that of its common associates, in particular white fir [31,32], but given the paucity of seedlings of this species initially and its disappearance altogether thereafter, none of the stand or site modifications imparted by the treatments investigated in this study were to its benefit. Likewise, none facilitated sugar pine establishment, with the findings here concerning this species limited to a regression model in which its abundance was negatively correlated with white fir prevalence in the over story and two others revealing positive relationships between its counts and ground coverage of creeping snowberry.

Regarding regeneration of the sapling size class, neither Jeffrey nor sugar pine resided within any stand portion for the duration of the study while red fir representation was limited to an extremely small quantity within a single treatment combination, and only at the final inventory at that. Incense-cedar saplings were also confined to a single treatment combination, which in fact was also the only one they had ever inhabited since before treatment implementation [33]. Beyond models disclosing positive correlations between counts of red fir and incense-cedar saplings and the respective proportions of these two species in the over story, their severely limited distribution over the site renders the connotations of the other significant regressions involving them questionable. Regardless, the apparent incapacity of either of the imposed treatments to expand the sapling populations of the two pine species here is of greater importance given the undesirable shifts occurring of late in species representation within the Sierran mixed conifer cover type generally [34] and in this stand specifically [35,36]. As for white fir, the influence of thinning treatment was readily evident in the elevated quantities of live saplings present at both inventories in the unthinned subunit where losses induced by the mechanized operations, including those killed outright as well as others that died in the aftermath due to the physical injuries they had sustained earlier, were precluded. However, it was also apparent that a substantial number of saplings in the unthinned subunit were killed by the under burn, either through heat girdling or crown loss or some combination, as attested to by the large number of dead saplings within this stand portion at the initial inventory. Such damage was severe enough that most of them did not remain upright through the end of the study, perhaps reflecting in combination the extreme flammability of white fir attributable to the resinous nature of its bark and foliage [37] and the lack of rot resistance in its wood [26]. Although negatively correlated with over story tree size in multiple regression models, a linkage of uncertain interpretation but extending to the dead sapling counts of this species in two models, live sapling counts were also positively correlated with over story tree count in three others, which is noteworthy because this density measure was nearly as high in the burned portion of the unthinned subunit as it was in its unburned portion. Thus, the relatively large numbers of its live saplings in the unthinned subunit overall probably reflects the capability of white fir to persist in the shade of dense overstories for prolonged time periods [38], another manifestation of its shade tolerance. A small number of regression models involving downed and dead fuels and ground cover would appear to provide some explanation for the elevated quantity of dead white fir saplings at the initial inventory in the burned but unthinned treatment combination, specifically one each negatively relating this count to 1+10-hr and to total fuels and another positively relating the former to wax currant cover, with the values for each of these independent variables also derived from the initial inventories. However, fuel loading of all time lag categories in the unthinned but burned stand portion was relatively low even before treatment implementation [18], which casts doubt on an assertion that a more intense and prolonged fuel combustion induced greater mortality there, and although wax currant was relatively abundant in this treatment combination it was still of modest coverage, which renders questionable the extent to which it competed with white fir saplings for critical resources. Ultimately, it is probable that the large loss in the unthinned but burned stand portion primarily reflects the availability of the many white fir saplings there to sustain damage sufficient to eventually prove lethal. Regardless, this mortality conforms to the findings of previous studies in various western USA forest types involving prescription fire in which the extent of its lethality in the sapling size class was readily evident [32,39,40]. Unlike seedlings for which populations may be largely replenished, subject to the seed crop availability, soon after broadcast under burning, sapling replenishment post-fire is dependent on the persistence of seedlings long enough to attain sapling size, which is far less certain, especially with periodic application. Overall, the treatments here did not enhance the presence of the sapling size class, which suggests that they would do little to maintain the regeneration component that is vital to the long-term maintenance of an uneven-aged stand structure.

In summary, over story thinning accomplished with a cut-to-length harvesting system coupled with on-site mastication and dispersal of slash and debris and followed by under burning were evaluated for their influences over a post-treatment span of several years on the shrub understory and natural regeneration within an uneven-aged, eastern Sierran mixed conifer stand. At the onset of the study, suppression of the cover and weight of huckleberry oak, the most prevalent ground cover species in residence, along with those of prostrate ceanothus possibly attributable to the detrimental impacts of disturbance by the combined thinning and mastication operations in the case of the former and perhaps more clearly by that of the under burn regarding the latter was followed by a pronounced resurgence in the abundance of both species in burned stand portions, and especially where thinning had preceded the fire. However, definitive treatment influences on the prevalence of other shrub species inhabiting the study site, of which there were several, were lacking. Of the tree species found on the site, white fir was most prevalent by a substantial margin among the regeneration of the seedling size class initially and was overwhelming predominant at the conclusion of the study. A lack of disturbance by the mechanized operations proved to be conducive to establishment of seedlings of this fir, and especially so where under burning was precluded as well, and although a decline in its abundance over the course of the study in the stand portion where neither the mechanized nor fire treatments were imposed exceeded those elsewhere, it remained in greatest abundance there nonetheless. That this treatment combination also facilitated the establishment of incense-cedar seedlings was evident initially, but their abundance therein receded so sharply that treatment influences were essentially absent by the final inventory. Other tree species present, most notably Jeffrey and sugar pine but also including red fir, had little representation among seedlings and were unaffected by treatment, with those of Jeffrey pine ultimately going undetected altogether. In sapling size regeneration, white fir was even more predominant than in the seedling component, minor quantities of incense-cedar and red fir saplings were limited to a single treatment combination each and to only one of the two inventories regarding the latter, while unrepresented in totality were Jeffrey and sugar pine saplings irrespective of treatment or inventory. Nevertheless, white fir saplings were especially numerous in the unthinned treatment as well, and persistently so, but many of them in its burned portion were dead with the number declining as the study progressed only because their state of decay did not permit them to remain erect. The silvicultural practices incorporated into this study are being increasingly viewed as restoration treatments appropriate for sensitive sites in western USA forests, and these results provide land managers insight into their probable impacts on the understory communities of such forests.

Acknowledgments

Support for this research was provided by the Nevada Agricultural Experiment Station, McIntire-Stennis Cooperative Forestry Research Program, and the USDA Forest Service. The authors are indebted to S. Belshaw, D. Boe, M. Clark, A. Coogan, G. Fernandez, W. Frederick, W. Mosley, J. Ray, C. Sarman, R. Wilson, CTL Enterprises Inc., and the USDA Forest Service Lake Tahoe Basin Management Unit for their assistance.

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