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Long-Term Forest Floor Fuels Accumulations in Sierran Mixed Conifer Subjected to Forest Restoration Treatments

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Abstract

Long-term influences of mechanized thinning using a cut-to-length approach combined with on-site slash mastication along with those of prescription under burning on downed and dead fuel accumulations were evaluated in an uneven-aged eastern Sierra Nevada mixed conifer stand. Based on an initial inventory conducted soon after treatment implementation, accumulations in an unburned portion of the stand subunit subjected to thinning were elevated with respect to both 1+10 hr time lag and total fuel loads. In contrast, the near immediate effect of the under burn on these fuels was marked diminishment in their abundance. Nearly a decade later, however, effects of the mechanized and fire treatments had largely dissipated. In the interim between inventories, the thinned but unburned treatment combination exhibited the greatest reduction in 1+10 hr and total fuels while the unthinned and unburned combination also exhibited a large reduction in the former. Furthermore, diminished reductions in 1+10 hr fuels were apparent within the burned portions of the thinned and unthinned stand subunits, and the unthinned but burned combination was the only one to incur an increase in total fuels. These findings offer land managers insight regarding the persistence of fuel bed alterations induced by these increasingly common management practices in Sierran mixed conifer and similar forest cover types.

Keywords: Forest fire; Time lag fuels; Stand density management; Slash mastication; Prescribed fire; Sierra Nevada mixed conifer

Introduction

Increases in wildfire activity across western USA forests in recent decades have prompted extensive efforts to implement fuels reduction practices in order to mitigate the risk of catastrophic fire events [1-6]. A common approach has been the thinning of forest stands with the specific intent of diminishing aerial and ladder accumulations, but because this opens up the canopy it may coincidentally hasten the breakdown of surface and ground fuels due to a greater penetration of precipitation and sunlight to the forest floor, which can enhance conditions conducive to microbial activity and thus accelerate their decomposition [7-9]. However, some forms of mechanized thinning operations, specifically those that feature within-stand delimbing and topping functions, produce concentrated slash mats that persist unless further management activities are undertaken, and are also prone to damaging residual stems that can later succumb to their injuries, thereby eventually adding to downed and dead loading [10,11]. Prescription fire is another prominent fuels reduction practice, one perhaps most appropriate where the reintroduction of fire is ecologically desirable, that directly targets ground, surface, and ladder fuels while offering the ancillary benefits associated with the breakdown of duff and litter [7,12]. However, under burning that is not preceded by density management can elevate stand mortality [13-15] and even when accompanied by such management there is some risk of mortality in retained stems depending on several factors, including fire intensity and tree vigor prior to under burning along with the diameter class and species composition of the residual stand [16-18]. If extensive mortality in over story stems is induced, immediate reductions in surface fuels may be quickly offset by the descent of standing dead stems to the forest floor. To date, the majority of studies focused on the efficacy of these fuels reduction practices have primarily quantified immediate responses, but longer-term accounting is necessary to determine if outcomes endure for prolonged periods.

This study entailed an assessment of transitions in surface and ground fuel loading in the extended aftermath of fuels reduction practices commonly utilized on sensitive sites in the Sierra Nevada and elsewhere in the western USA. Specifically, influences on dead and downed loading of a cut-to-length harvesting system in tandem with slash mastication and of prescription under burning, plus those ensuing from the interaction of these mechanized and fire treatments, were assessed nine years after thinning and eight years subsequent to under burning. The implications of these findings may provide land managers some predictive capacity regarding the effectiveness of such practices in Sierran mixed conifer and similar forest cover types. This investigation is unique in that it entailed the long-term consequences regarding forest floor fuel loading of a combination of treatments and forest cover type that have not been previously documented.

Materials and Methods

Study site

The stand chosen for this study is naturally regenerated, second growth, uneven-aged eastern Sierra Nevada mixed conifer 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, and the slope averages 7%. The 50 year average annual precipitation has been 80 cm falling predominately as snow, but over the course of this study the annual average was 78 cm [19]. The soils are of the Jorge-Tahoma

Association, derived from volcanic parent material, and exceedingly rocky [20]. Based on dominant crown class trees averaging 162 years in age [21], the site quality is class IV according to the Dunning site classification system for Sierra Nevada mixed conifer [22]. Approximately two decades before this study commenced, ownership of this acreage was transferred from the private to the public sector, therefore this stand reflects a legacy of prolonged fire exclusion and periodic harvests that targeted its yellow and white pine components.

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 fuel treatment. Both 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 delimbing and topping functions that both the harvester and forwarder subsequently travel over and is designed to minimize mineral soil impacts [21]. Other than contractual stipulations 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 considered excessive and to distribute chipped materials evenly over the thinned subunit.

In June 2004, a controlled under burn was implemented on one-half of each of the two subunits dedicated to the individual thinning treatments, with the portion to be treated randomly chosen. The division 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

Prior to treatment implementation, 20 permanent 0.04 ha fixed-radius plots were established in a square pattern on the site divided equally between the two thinning treatments, with the 10 plots in each of the subunits further divided evenly between the portion to be burned and that to remain unburned for a total of five plots in each treatment combination. Specific to the mensurational and fire injury data reported here, an initial post-treatment inventory was conducted approximately one year after the application of the fire treatment. Regarding over story variables, within each plot all trees ≥ 10.2 cm DBH were measured for total height, DBH, and live crown length and then tallied by species. Subsequently, tree heights and live crown lengths were used to calculate live crown percentages, average DBH values by plot were calculated using the quadratic mean formula [23], basal area by plot was derived from quadratic mean DBH in combination with plot stem counts [24], and species specific above-ground biomass within each plot was determined using the formulas of Gholz et al. [25] and Ter-Mikaelian and Korzukhin [26], which were subsequently combined to obtain an overall total as well. This inventory also included standing dead trees, identified as those lacking any live crown, permitting the determination of dead tree count and the percentage of dead trees by and across species. Ultimately, the stem count, basal area, above-ground biomass, and dead tree counts for each plot were expanded to reflect equivalent 1.0 ha values. As an indicator of fire injury, height to live crown base was calculated from tree height and live crown length and was expressed on an absolute and proportional basis. Additionally, bole char height was measured and also expressed on an absolute and proportional basis, while the average charred percentage of the circumference of the bole extending throughout the char height was estimated with periodic calibration by direct measurement at a constant height interval on randomly selected trees.

For downed and dead fuels, an initial post-treatment inventory by time lag category [15] was conducted within each of the 20 permanent 0.04 ha circular plots soon after the completion of the under burn. Concerning the 1+10 hr fuels (≤ 2.5 cm diameter), duff, litter, and fine woody debris from five randomly located 0.061 m^2 circular plots within each of the 0.04 ha plots were collected, dried to a constant weight, and weighed. The dry weights of each group of five samples were averaged and then returned to their respective collection points. For the 100 hr (>2.5 to ≤ 7.6 cm diameter) and 1000 hr (>7.6 cm diameter) fuels, a single 4 m^2 and a single 54 m^2 circular plot, respectively, were established with the same plot center as each of the permanent 0.04-ha circular plots. The 100 hr fuels were collected from the 4 m^2 plots, dried to a constant weight, weighed, and also returned to their respective collection points. For the 1000 hr fuels, the length and diameter at mid-length of each segment were recorded for use in the calculation of an estimate of volume according to the Huber formula [27], and the volumes within each 54 m^2 circular plot were then summed. To obtain a density constant to allow for the conversion of plot volumes to dry weights, 10 log sections from random locations outside the plots were collected, measured as above, dried to a constant weight, and weighed. Ultimately, fuel load dry weights for all time lag classes and their total were expressed in kg ha^{-1}. Subsequently, the proportional representation of the individual time lag categories within total fuel loading was determined.

A final inventory was conducted nine years after thinning and eight years subsequent to under burning that incorporated the same measurements and extrapolated values as detailed above concerning the initial inventories except for those associated with fire injury, which were not remeasured. The availability of initial and final data for all other variables permitted the calculation of their changes over the course of the study.

Statistical analysis

Because field logistics involving the implementation of the thinning and prescribed fire treatments necessitated that the thinning treatments be assigned to individual subunits of the stand with the under burn then assigned to one-half of each subunit, it was necessary to test for the independence of the plots within each thinning and burning treatment combination using pretreatment data for variables germane to this study. The chosen variables were tree height, DBH, and basal area. For each variable, residual values were calculated, which were defined as the difference between the mean for a given variable of the five plots of each treatment combination and the values obtained from the individual plots for the selected variable. Subsequently, the residual value of one plot was designated as the independent variable and that of the immediately adjacent plot the dependent variable which was repeated sequentially within each treatment combination, yielding one value of each for each plot pair, four values of each for each of the four treatment combinations, and thus a total of 16 values of each for the entire stand. These values were then incorporated into simple linear regression models by variable. For each regression, models were considered to be significant, signifying a lack of independence among the plots within treatments, only when $p \leq 0.05$ according to the F test. None of the models proved to be significant, indicating that values from individual plots were not influenced by those from immediately adjacent plots for any of these variables.

Excluding the changes occurring between the initial and final inventories, data pertaining to tree dimensions, stand density, mortality, and fuels were analyzed using repeated measures, mixed model analysis of variance (ANOVA) to test for effects of thinning and prescribed fire treatments, the year of inventory, and all possible interactions. This analysis incorporated both the compound symmetry covariance structure and the first-order autoregressive structure. For each variable, the covariance structure relied upon was that providing the lowest value for Akaike's Information Criterion (bias-corrected version, AICC). For changes between the initial and final inventories pertaining to various study components as well as data involving fire injury, a two-way ANOVA was used to test for thinning and fire treatment effects plus their interaction. In every ANOVA indicated above, main effects and their interactions were considered significant only when $p \leq 0.05$ according to the F test. Subsequently, differences among means were evaluated using the least significant difference (LSD) test with $\alpha=0.05$.

Additional statistical analysis consisted of three series of simple linear regression models used to investigate relationships between an array of over story variables and downed and dead fuel loading, with the first series dedicated to unburned plots, the second to burned plots, and the last to unburned and burned plots combined. The unburned series contained models involving all possible combinations of tree height, DBH, live crown length and proportion, basal area, stem count, dead tree count and percentage overall as well as segregated by species plus species-specific and combined total biomass as independent variables with fuel weights by time lag category, specifically 1+10 hr, 100 hr and 1000 hr, along with total fuels, serving as dependent variables. Included in this series were models based on values representing the specified independent and dependent variables matched within inventories along with others in which values derived from the initial inventory serving as independent variables were paired with those from the final inventory regarding dependent variables accompanied by their change over the course of the study. Other than involving data derived from burned plots only, the second regression series replicated verbatim the independent and dependent variable couplings of the first series. The third series, which involved values from both unburned and burned plots, incorporated fire injury measures at the initial inventory as the independent variables. Specifically, height to live crown base expressed on an absolute and proportion basis, bole char height also expressed on an absolute and proportion basis, and bole char circumference were paired with the same suite of dependent variables indicated above for the first two series. For all three regression series, models were considered significant only when $p \leq 0.05$ according to the F test. All statistical analyses were performed using SAS (SAS Institute, Inc., Cary, NC).

Results

Stand attributes

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.). 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.

Following the implementation of the thinning and fire treatments, ANOVA revealed that total tree height was significantly influenced by the thinning treatment (p=0.0024) and the year of inventory (p=0.0029) but all effects on the change in this dimension were non-significant (Table 1). The LSD test indicated that the initial mean height in the thinned and burned combination exceeded that in the unthinned subunit irrespective of fire treatment while that in the unburned portion of the thinned subunit surpassed the mean in the unthinned but burned combination, and that these distinctions persisted verbatim through the final inventory. Although tree height increased within all treatment combinations over the course of the study, no significant disparities among treatments were detected by the LSD test for the change in this dimension. For DBH, ANOVA identified the thinning treatment (p=0.0371) and year of inventory (p=0.0001) effects, along with those of the thinning × fire treatment (p=0.0257) and fire treatment × inventory year (p=0.0295) interactions as significant, while the change in this dimension was influenced solely by fire treatment (p=0.0295). Regarding the differences in DBH among treatment combinations, the LSD test again disclosed identical discrepancies at the initial and final inventories, but for this dimension the trees in the burned portion of the thinned subunit were larger than those in the burned but unthinned combination only. As for the change in this dimension, increases were evident in all treatment combinations, while the LSD test revealed that the one in the thinned and burned combination exceeded those in unburned stand portions irrespective of thinning treatment.

Inventory	Thinning and burning treatment	Height	DBH	Live crown	Live crown	Basal area	Tree count
		(m)	(cm)	(m)	(%)	(m^2 ha^{-1})	(stems ha^{-1})
Initial	Thinned/chipped						
	Burned	20.3a	54.3a	6.7a	28.0b	28.2b	129b

	Unburned	18.5ab	45.7ab	8.8a	46.6a	31.7b	188b
	Unthinned						
	Burned	13.3c	36.0b	5.9a	39.4ab	40.5b	435a
	Unburned	15.3bc	46.7ab	6.6a	43.2a	84.6a	509a
Final	Thinned/chipped						
	Burned	21.8a	58.4a	6.8ab	27.2c	29.1b	114b
	Unburned	19.1ab	47.1ab	9.3a	51.4a	34.7b	193b
	Unthinned						
	Burned	14.0c	38.3b	5.8b	36.4bc	44.0b	405a
	Unburned	16.1bc	47.6ab	7.1ab	44.0ab	88.1a	519a
Change in values[2]	Thinned/chipped						
	Burned	+1.5a	+4.1a	+0.2a	-0.8ab	+0.9a	-15ab
	Unburned	+0.6a	+1.4b	+0.6a	+4.8a	+2.9a	+5ab
	Unthinned						
	Burned	+0.7a	+2.3ab	-0.1a	-3.0b	+3.4a	-30b
	Unburned	+0.8a	+0.9b	+0.4a	+0.8ab	+3.4a	+10a

Table 1: Mensurational characteristics in a mixed conifer stand of the Lake Tahoe Basin as influenced by thinning, chipping, and under burning[1].
[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]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.

For live crown variables, ANOVA indicated that all effects were non-significant for live crown length and the change therein, while significant differences among treatments according to the LSD test were limited to a single disparity between larger crowns within the unburned portion of the thinned subunit and smaller ones within the unthinned but burned combination at the final inventory (Table 1). Every treatment combination incurred an increase in live crown length over the course of the study except for the burned but unthinned combination where a slight decrease occurred. Concerning live crown proportion, ANOVA revealed the influences of the fire treatment (p=0.0042) and fire treatment × inventory year (p=0.0334) interaction to be significant along with a fire treatment (p=0.0334) influence on the change in proportion. At the initial inventory, the LSD test indicated that live proportion within both of the unburned stand portions was greater than those in the thinned and burned combination, while at the final inventory it was greater in the thinned but unburned treatment than in every other combination except for the unburned portion of the unthinned subunit, and that the proportion in the latter exceeded that within the thinned and burned treatment combination as well. As for the change, increases were evident in both of the unburned stand portions while decreases prevailed within both burned portions, and the LSD test revealed that the increase in the thinned but unburned combination differed significantly from the decrease within the burned but unthinned treatment.

Significant effects imposed on basal area according to ANOVA consisted of those of the thinning (p=0.0003) and fire (p=0.0043) treatments, their interaction (p=0.0155), and the year of inventory (p<0.0001), while all effects on the change in this density measure were non-significant (Table 1). At the initial inventory, the LSD test indicated that basal area was significantly greater in the unthinned and unburned combination than in all others, a response to treatment that persisted through the end of the study. Regarding the change in basal area, increases prevailed in all treatment combinations but in congruence with ANOVA, the LSD test did not divulge any significant disparities among treatments. For tree count, influences of the thinning treatment (p<0.0001) and the fire treatment × inventory year interaction (p=0.0368) were revealed as significant by ANOVA, while for the change in count the fire treatment (p=0.0368) proved to be influential. Significant distinctions disclosed by the LSD test were confined to those between thinning treatments at both inventories, specifically with the counts within the unthinned subunit exceeding those in the thinned subunit irrespective of fire treatment. Over the course of the study, increases in tree counts were exclusive to the unburned stand portions while decreases were so to burned portions. Nevertheless, the LSD test identified only a single disparity among treatments in which the increase in the unburned portion of the unthinned subunit differed significantly from the decrease in its burned counterpart.

Total white fir above-ground biomass was significantly influenced by the thinning treatment (p=0.0052), the year of inventory (p<0.0001), and their interaction (p=0.0376) according to ANOVA, while the thinning treatment (p=0.0288) was influential regarding the change in biomass (Table 2). The LSD test again disclosed identical discrepancies among treatments at the initial and final inventories but in the case here the total in the unthinned and unburned combination

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surpassed those in the thinned subunit in its entirety. As for the change in the total for white fir, increases prevailed in every treatment combination but the LSD test failed to detect any significant differences among them. For Jeffrey pine biomass, ANOVA revealed numerous significant influences, specifically those of the fire treatment (p=0.0351) and inventory year (p=0.0013) plus the thinning treatment × inventory year (p=0.0328), fire treatment × inventory year, and the thinning treatment × fire treatment × inventory year (p=0.0082) interactions. In somewhat of a departure from ANOVA, the LSD test did not divulge a single significant disparity among treatments for either the initial or final inventory. Nevertheless, ANOVA also revealed that all possible effects on the change in biomass for this species were significant, namely the thinning (p=0.0328) and fire (p=0.0082) treatments as well as their interaction (p=0.0162), with increases prevailing in every treatment combination and the LSD test indicating that the increase in the thinned but unburned combination surpassed that in all of the others. Regarding sugar pine, ANOVA indicated that all effects on its total biomass were non-significant and the LSD test did not disclose any significant differences among treatment combinations specific to this species. As for the change in sugar pine biomass, increases prevailed in all treatments except for the thinned and burned combination where a decrease did so. Total incense-cedar biomass was influenced by the thinning treatment (p=0.0415) and thinning × fire treatment interaction (p=0.0267) while all influences on its change were non-significant. Specific to the former, the LSD test indicated that its total within the unthinned and unburned combination surpassed every other treatment combination at both inventories. Over the course of the study, incense-cedar biomass increased in every treatment except the unthinned and unburned combination where a decrease occurred but significant differences among treatments were absent herein without exception. All effects for red fir biomass and its change between inventories were non-significant according to ANOVA and likewise all differences among treatments for the total and its change were as such according to the LSD test, but numerical increases in the unburned stand portions contrasted against a lack of change in the burned portions. As for the combined total biomass across species, ANOVA identified the thinning (p=0.0035) and fire (p=0.0231) treatments as well as their interaction (p=0.0427), the year of inventory (p<0.0001), and the thinning treatment × inventory year interaction (p=0.0473) as significant, while thinning treatment (p=0.0473) influenced the change in these values. With the LSD test indicating that the total in the unthinned and unburned combination surpassed that in every other treatment at both inventories, the change between inventories in the former only surpassed that of the burned portion of the thinned subunit, reflecting a difference in the magnitude of the increases that prevailed within every treatment combination.

		Biomass (kg ha^{-1})					
Inventory	**Thinning and burning treatment**	**WF**	**JP**	**SP**	**IC**	**RF**	**Combined total**
Initial	Thinned/chipped						
	Burned	108979b	2898a	65475a	10930b	0a	188282b
	Unburned	109033b	50765a	36136a	1416b	3681a	201031b
	Unthinned						
	Burned	194607ab	11778a	34624a	6513b	0a	247522b
	Unburned	332658a	43585a	50508a	75800a	4953a	507504a
Final	Thinned/chipped						
	Burned	121011b	3227a	62999a	11557b	0a	198794b
	Unburned	118161b	58462a	36485a	1670b	5510a	220288b
	Unthinned						
	Burned	217652ab	12561a	37638a	8936b	0a	276787b
	Unburned	359687a	44789a	51852a	74625a	5799a	536752a
Change in values[3]	Thinned/chipped						
	Burned	+12032a	+329b	-2476a	+627a	0a	+10512b
	Unburned	+9128a	+7697a	+349a	+254a	+1829a	+19257ab
	Unthinned						

	Burned	+23045a	+783b	+3014a	+2423a	0a	+29265ab
	Unburned	+27029a	+1204b	+1344a	-1175a	+846a	+29248a

Table 2: Above-ground biomass by and across species in a mixed conifer stand of the Lake Tahoe Basin as influenced by thinning, chipping, and under burning[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]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.

Of the variables employed to assess species-specific mortality, namely those of dead tree count and the percentage of dead trees, ANOVA revealed that all effects on both measures and their changes for white fir were non-significant, and the LSD test did not disclose any significant disparities among means regarding either (Table 3). Nevertheless, over the course of the study the number of dead white fir increased in the burned portion of the unthinned subunit and decreased in its unburned counterpart while those in both portions of the unthinned subunit remained unchanged. When expressed as percentages, however, increases prevailed in both burned stand portions while decreases did so in unburned portions. In contrast, Jeffrey pine did not incur any mortality whatsoever for the duration of the study. Similar to white fir, ANOVA did not assign any significance to any effects on sugar pine mortality regarding either measure or the changes therein and all differences among means were again disclosed as non-significant by the LSD test. For both the count and percentage measures in sugar pine, a decrease between inventories in the burned portion of the thinned subunit occurred whereas both measures remained unchanged elsewhere. Significant influences on incense-cedar mortality and its changes were also absent according to ANOVA, but the LSD test did disclose identical disparities among treatments at the initial and final inventories where mortality in the unthinned but burned combination exceeded that in all other treatments for both the dead count and its percentage. Regardless, mortality in this species by either measure remained consistent between the two inventories. All effects imposed on red fir mortality and associated changes were also revealed by ANOVA to be non-significant, a status also extending to all disparities among treatments for this species according to the LSD test. For both the count and its percentage, red fir mortality decreased in the thinned but unburned combination while no change occurred in the unthinned and unburned combination. Assessed across species, no influences on either dead count or its change were detected by ANOVA, and while a fire treatment (p=0.0459) effect on dead percentage was detected none materialized regarding the change in the latter. Despite the lack of influences on dead count discerned by ANOVA, the LSD test indicated that the final count within the unthinned but burned combination surpassed that within the thinned but unburned combination. It also disclosed a significant disparity in initial dead tree percentage involving a higher one in the thinned and burned treatment than in all other combinations as well as a final percentage in the former that exceeded all but that within the unthinned but burned treatment. Over the course of the study, overall dead count and its percentage decreased within every stand portion except for that entailing the unthinned but burned combination where an increase was detected.

Inventory	Thinning and burning treatment	Dead trees (stem ha^{-1})						Dead trees (%)					
		WF	JP	SP	IC	RF	Total	WF	JP	SP	IC	RF	Total
Initial	Thinned/chipped												
	Burned	35a	0	19a	-	-	54a	27.0a	0	33.3a	-	-	41.8a
	Unburned	13a	0	0a	0b	13a	26a	10.5a	0	0.0a	0.0b	25.0a	6.9b
	Unthinned												
	Burned	45a	0	8a	25a	-	78a	8.3a	0	33.3a	100.0a	-	17.9b
	Unburned	45a	0	0a	0b	0a	45a	12.5a	0	0.0a	0.0b	0.0a	8.8b
Final	Thinned/chipped												
	Burned	35a	0	12a	0b	-	47ab	29.0a	0	37.5a	0.0b	-	41.2a
	Unburned	13a	0	0a	0b	0a	13b	8.6a	0	0.0a	0.0b	0.0a	6.7b
	Unthinned												
	Burned	55a	0	8a	25a	-	88a	12.1a	0	33.3a	100.0a	-	21.7ab
	Unburned	40a	0	0a	0b	0a	40ab	12.0a	0	0.0a	0.0b	0.0a	7.7b

Change in values[4]	Thinned/chipped												
	Burned	0a	0	-7a	-	-	-7a	+2.0a	0	+4.2a	-	-	-0.6a
	Unburned	0a	0	0a	0a	-13a	-13a	-1.9a	0	0.0a	0	-25.0a	-0.2a
	Unthinned												
	Burned	+10a	0	0a	0a	-	+10a	+3.8a	0	0.0a	0	-	+3.8a
	Unburned	-5a	0	0a	0a	0a	-5a	-0.5a	0	0.0a	0	0.0a	-1.1a

Table 3: Mortality by and across species in a mixed conifer stand of the Lake Tahoe Basin as influenced by thinning, chipping, and under burning[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 or fewer plots (n ≤ 5) depending on the presence of a given species within pertinent plots.
[2]WF=white fir, JP=Jeffrey pine, SP=sugar pine, IC=incense-cedar, RF=red fir.
[3]When not associated with a mean, "–" indicates an absence of trees within treatment combination.
[4]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.

Pertaining to the variables involved in the assessment of fire injury, ANOVA indicated that the thinning treatment (p=0.0055) and the thinning × fire treatment (p=0.0357) interaction significantly influenced height to live crown base while the fire treatment (p=0.0250) alone influenced the proportional height to live base (Table 4). As for the LSD test, it indicated that the former was significantly greater in the thinned and burned combination than in all other treatments while for the latter measure the value in this combination surpassed all others except for the unthinned but burned treatment. Concerning bole char variables, all possible effects on absolute and proportional char height were identified by ANOVA as significant, specifically, the thinning (p<0.0001 and p=0.0006, respectively) and fire (both p<0.0001) treatments as well as their interaction (p<0.0001 and p=0.0006, respectively), while the fire treatment (p<0.0001) was the sole influence on char circumference. For all three char measures, the LSD test indicated that the thinned and burned combination was transcendent relative to all other stand portions and that the unthinned but burned combination was so relative to the two unburned stand portions.

	Height to live crown base		Bole char		
			Height		Circumference
	(m)	(%)	(m)	(%)	(%)
Thinning and burning treatment					
Thinned/chipped					
Burned	13.6a	71.9a	3.3a	19.8a	40.0a
Unburned	9.7b	53.4b	0.0c	0.0c	0.0c
Unthinned					
Burned	7.5b	60.6ab	0.7b	7.7b	25.6b
Unburned	8.7b	56.7b	0.0c	0.0c	0.0c

Table 4: Fire injury characteristics in a mixed conifer stand of the Lake Tahoe Basin as influenced by thinning, chipping, and under burning[1,2].
[1]Within each variable, 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]Data based on initial inventory only.

Downed and dead fuels

With respect to downed and dead fuel weights, ANOVA divulged that the thinning (p=0.0127) and fire (p<0.0001) treatments, year of inventory (p<0.0001), and the fire treatment × inventory year (p<0.0001) interaction significantly influenced that of the combined 1+10 hr time lag category (Table 5). Initially, the LSD test identified significantly greater accumulations in the unburned portion of the thinned subunit than in any other treatment combination while accumulations within the unburned portion of the unthinned subunit surpassed those in the remaining treatments. By the conclusion of the study, however, these differences had largely dissipated. Despite decreases prevailing in all treatments in 1+10 hr loading, ANOVA identified the fire treatment (p<0.0001) as influential regarding this change. The LSD test indicated that the thinned but unburned combination displayed a significantly greater reduction than those in all remaining treatment combinations while the unburned portion of the unthinned subunit exhibited reductions that exceeded those in the two burned portions as well. When averaged across thinning treatments, the unburned stand portions displayed reductions in 1+10 hr fuels averaging 4.8 × those in the burned portions. Furthermore, the reduction in the thinned but unburned portion was 57% greater than that in the unburned portion of the unthinned subunit.

	Dry weight (kg ha^{-1})				Dry weight (%)		
	1+10 hr	100 hr	1000 hr	Total	1+10 hr	100 hr	1000 hr

Inventory	Thinning and burning treatment							
Initial	Thinned/chipped							
	Burned	62398c	1861a	11350a	75609c	82.5a	2.5a	15.0a
	Unburned	165508a	3454a	8361a	177323a	93.3a	2.0a	4.7a
	Unthinned							
	Burned	52414c	1661a	12565a	66640c	78.6a	2.5a	18.9a
	Unburned	111310b	2034a	13841a	127185b	87.5a	1.6a	10.9a
Final	Thinned/chipped							
	Burned	40244a	1143a	20961a	62348a	64.5a	1.8a	33.7a
	Unburned	36119a	2250a	11300a	49669a	72.7a	4.5a	22.8a
	Unthinned							
	Burned	30235a	1453a	36828a	68516a	44.1a	2.1a	53.8a
	Unburned	28834a	1157a	45969a	75960a	38.0a	1.5a	60.5a
Change in values[2]	Thinned/chipped							
	Burned	–22154a	–718a	+9611a	–13261a	–18.0a	–0.7a	+18.7a
	Unburned	–129389c	–1204a	+2939a	–127654b	–20.6a	+2.5a	+18.1a
	Unthinned							
	Burned	–22179a	–208a	+24263a	+1876a	–34.5a	–0.4a	+34.9a
	Unburned	–82476b	–877a	+32128a	–51225a	–49.5a	–0.1a	+49.6a

Table 5: Dry weight by time lag category and in total as well as their proportional representation of the total for downed and dead fuels in a Sierra Nevada mixed conifer stand as influenced by thinning, chipping, and prescribed fire[1].
[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]Means preceded by "+" indicate increases while those preceded by "–" indicate reductions in mean values.

No significant effects were discerned by ANOVA regarding the 100-hr category or the change therein, and correspondingly the LSD test did not assign significance to any of the disparities among the treatment means (Table 5). Changes between inventories for this fuel category were uniformly negative but in a strictly numerical comparison the reductions in the unburned stand portions averaged approximately 2.2 × those in burned stand portions, a finding generally aligned with that noted above regarding 1+10 hr loading.

As for the 1000 hr time lag category, ANOVA indicated that the year of inventory (p=0.0207) was the only significant influence on these fuels and their change over the course of the study (Table 5). This designation by ANOVA was manifested primarily in increases occurring in the unthinned treatment which numerically exceeded smaller ones in the thinned subunit by an average of 349%, although the LSD test did not disclose any significant disparities regarding either absolute weight or its change for this time lag category.

An array of influences on the total fuel loading across time lag categories proved to be significant, with ANOVA specifying those of the fire treatment (p=0.0043) and year of inventory (p<0.0001) along with the thinning treatment × inventory year (p=0.0213) and fire treatment × inventory year (p=0.0003) interactions to be so (Table 5). Initially, the LSD test divulged numerous disparities among the various treatment combinations that replicated those of the 1+10 hr fuels verbatim. Specifically, it revealed that total fuels were significantly greater in the thinned but unburned combination than in all other treatments and that accumulations within the unthinned and unburned combination surpassed those in the remaining two treatments. Numerically, the magnitude of these disparities amounted to a total weight in the thinned but unburned combination that exceeded those in the burned stand portions irrespective of thinning treatment by 149%, while total loading in the unthinned and unburned combination exceeded them by 79%. At the conclusion of the study, however, all disparities among treatments for total fuels were disclosed to be non-significant by the LSD test without exception. As for significant influences on the change in total fuels over the course of the study, the thinning (p=0.0213) and fire (p=0.0003) treatments were revealed to be as such by ANOVA. With decreases prevailing in all except the unthinned but burned combination which incurred a small increase, the LSD test indicated that the reduction within the thinned but unburned combination differed significantly from the changes in the other treatments, and its exceptionally large reduction amounted to 72% between the initial and final inventories.

Imposed treatment influences on the proportional representation of the individual time lag categories within the total fuel loads disclosed here were not designated by ANOVA to be significant for any of these categories regarding either the percentages themselves or their change between inventories (Table 5). Furthermore, none of the disparities among the various treatment combinations in either the percentages or their changes were specified as significant by the LSD test. However, a year of inventory effect was discerned by ANOVA to be significant on the 1+10 hr ($p<0.0001$) and 1000 hr ($p=0.0001$) percentages. Initially, 1+10 hr loading constituted 86% of the total when averaged across the four treatment combinations, while 100-hr fuels were 2% and those in the 1000 hr category were 12%. By the end of the study, however, the average 1+10 hr weight had decreased considerably to 55% of total loading, and although 100 hr fuels persisted at 2%, the 1000 hr category had increased substantially to 43%.

Relationships of downed and dead fuels to over story variables

The first simple regression series, which related downed and dead fuel loading to an array of over story characteristics within the unburned portions of the two subunits, produced 22 significant models (Table 6). For those involving tree dimensions, each featured independent variables derived from the initial inventory and positive relationships prevailed in models incorporating initial fuels values while negative ones did so for those involving their change between inventories. Specifically, the initial 1+10 hr category and total fuels were each related to height and to live crown length as was the change in the former, and additionally the change in total fuels was related to crown length also. When biomass measures were utilized as independent variables only one significant model prevailed which conveyed a negative relationship between the initial values for total fuels and white fir biomass. These models explained from approximately 45% to 75% of the variation in the dependent variables, collectively constituting some of the strongest computed in the study with all but one explaining more than one-half of it. Models incorporating mortality measures as the independent component conveyed positive relationships exclusively. Of those involving species-specific mortality, final 1000 hr and total fuels were correlated with both the initial and final white fir dead tree count, while the change in the 1000 hr time lag category was so with the initial white fir dead count and its percentage. For models concerning a cross-species stand mortality, final 1000 hr and total fuels were related to initial total dead tree count and its percentage as well as to the final dead count, while the change in 1000 hr fuels was so to both of the former mortality measures. The variation in the dependent variables explained in the models involving stand mortality ranged from nearly 45% to slightly over 60%, with those pertaining to initial dead tree count across species each explaining at least 60%.

Independent variable	Dependent variable	Correlation	F test p-value	Model r^2
Unburned series[1]:				
Height, initial	1+10 hr fuels, initial	Positive	0.001	0.7587
Height, initial	1+10 hr fuels, change	Negative	0.0088	0.5969
Height, initial	Total fuels, initial	Positive	0.0104	0.5807
Live crown length, initial	1+10 hr fuels, initial	Positive	0.0173	0.5277
Live crown length, initial	1+10 hr fuels, change	Negative	0.0316	0.4582
Live crown length, initial	Total fuels, initial	Positive	0.0112	0.5735
Live crown length, initial	Total fuels, change	Negative	0.0052	0.644
White fir total biomass, initial	Total fuels, initial	Negative	0.017	0.5299
White fir dead tree count, initial	1000 hr fuels, final	Positive	0.024	0.5403
White fir dead tree count, initial	1000 hr fuels, change	Positive	0.0159	0.588
White fir dead tree count, initial	Total fuels, final	Positive	0.032	0.5045
White fir dead tree count, final	1000 hr fuels, final	Positive	0.0369	0.4857
White fir dead tree count, final	Total fuels, final	Positive	0.05	0.4437
White fir dead tree percentage, initial	1000 hr fuels, change	Positive	0.0427	0.466
Total dead tree count, initial	1000 hr fuels, final	Positive	0.0068	0.6201
Total dead tree count, initial	1000 hr fuels, change	Positive	0.0081	0.6044
Total dead tree count, initial	Total fuels, final	Positive	0.0081	0.6045
Total dead tree count, final	1000 hr fuels, final	Positive	0.0235	0.4932
Total dead tree count, final	Total fuels, final	Positive	0.0328	0.4536

Total dead tree percentage, initial	1000 hr fuels, final	Positive	0.0187	0.5194
Total dead tree percentage, initial	1000 hr fuels, change	Positive	0.0166	0.5322
Total dead tree percentage, initial	Total fuels, final	Positive	0.0122	0.5645
Burned series[1]:				
White fir total biomass, initial	100 hr fuels, final	Positive	0.0134	0.5552
White fir total biomass, final	100 hr fuels, final	Positive	0.0109	0.5764
Jeffrey pine total biomass, initial	100 hr fuels, final	Positive	0.0416	0.4235
Jeffrey pine total biomass, final	100 hr fuels, final	Positive	0.0434	0.418
White fir dead tree percentage, initial	1+10 hr fuels, initial	Positive	0.0231	0.4953
White fir dead tree percentage, initial	1+10 hr fuels, change	Negative	0.0287	0.4698
White fir dead tree percentage, initial	Total fuels, initial	Positive	0.0367	0.4394
Combined series[2]:				
Bole char height	1+10 hr fuels, initial	Negative	0.0139	0.292
Bole char height	Total fuels, initial	Negative	0.0128	0.2976
Bole char height percentage	1+10 hr fuels, initial	Negative	0.007	0.3393
Bole char height percentage	Total fuels, initial	Negative	0.0072	0.3381
Bole char circumference	1+10 hr fuels, initial	Negative	0.0037	0.382
Bole char circumference	Total fuels, initial	Negative	0.0037	0.3821

Table 6: Significant simple linear regression models relating downed and dead fuels to an array of mensurational and mortality variables segregated by burning treatment and across treatments in a Sierra Nevada mixed conifer stand.
[1]Models are based on values from 10 plots (n=10) except for those involving species specific mortality where n ≤ 10 depending on the presence of a given species within pertinent plots.
[2]Models are based on values from 20 plots (n=20).

The second regression series, which was concerned with the relationships between downed and dead fuels and various over story characteristics within the burned portions of the two subunits, yielded seven significant models (Table 6). Of these, four involved biomass while the other three incorporated mortality measures as the independent variables. Concerning the former, final 100 hr fuels were positively correlated with the initial and final white fir and Jeffrey pine biomass. As for the latter three models, initial 1+10 hr and total fuels were positively related to initial white fir dead percentage while the change in the former was negatively so. Most of the models in this series were of moderate strength, although two of them explained 55% or more of the variation in the dependent component, specifically those that involved white fir biomass.

The third and final regression series, which related fuel weights to fire injury characteristics across all treatments, generated six significant models (Table 6). These involved the 1+10 hr category and total fuels as determined at the initial inventory with each negatively correlated with each of the three bole char measures, namely height, height percentage, and circumference. Collectively, these models were the weakest generated in this study, with all explaining less than 40% of the variation in the dependent variables.

Discussion

The mechanized and fire treatments investigated in this study, with the former consisting of thinning accomplished using cut-to-length harvesting coupled with on-site mastication of the resulting slash and the latter entailing prescribed under burning, exerted readily apparent effects on 1+10 hr time lag fuels in the near-term aftermath of their implementation. Furthermore, since the combined 1+10 hr categories constituted the preponderance of the initial overall downed and dead dry weights reported here these effects extended essentially verbatim to total fuel loading. Influences of the thinning treatment were perhaps best exemplified by initial loading in the thinned but unburned combination which exhibited numerically elevated accumulations in 1+10 hr, 100 hr, and total fuels when juxtaposed against every other treatment combination, with the distinctions regarding the former and latter statistically significant as well. Additionally, total accumulations within this treatment combination were approximately 90% higher than what would be expected based on documented loads associated with a similar array of species residing on unmanaged Sierran sites [28]. As an aside, the comparatively low 1000 hr loading in the thinned but unburned combination may in part reflect the impacts of mastication which converted the coarse activity fuels generated by the thinning operation as well as some preexisting ones to fine fuels [21]. Overall, the on-site slash retention inherent in the harvesting approach employed here, perhaps modified by the slash mastication and redistribution that ensued, had pronounced influences on surface fuel accumulation. In contrast, the near immediate effect of the under burn on downed and dead fuels was a diminishment in their abundance in burned stand portions irrespective of thinning treatment, with that in the 1+10 hr categories and total fuels again statistically distinctive. Several regression models disclosing negative relationships between these two fuel weights and the three bole char measures quantified in this study also indirectly attested to the prominent effect of the fire treatment, with these models likely reflecting the differences between the burned and unburned stand portions more so than that within the former as suggested by the fact that the unthinned subunit exhibited some evidence of lower fire intensities as indicated by less bole char while also displaying some of the lowest fuel weights, which ostensibly would suggest the greater combustion usually associated with higher intensities. Two additional regression models, but in this case based on data derived from burned stand portions only, depicted positive relationships between the initial 1+10 hr and total loading and the percentage of dead white fir. These may offer some insight into why fuel loading in the thinned and burned combination was numerically higher than that in the unthinned but burned combination, as the white fir dead percentage was numerically higher in the former which may have produced additional post-fire litter deposition and therefore masked a greater combustion due to the higher fire intensity suggested by the statistically elevated bole char in this treatment combination. Regardless, the short-term effectiveness of the under burn in diminishing fine fuel abundance in this study mirrors the findings of other investigations conducted on Sierran sites [10,12,29,30]. As for the 100 hr and 1000 hr categories, no statistical inference could be drawn concerning a fire influence on either, as was the case noted above regarding thinning effects even though the former followed the pattern previously indicated for the 1+10 hr and total fuels. Nevertheless, no discernable pattern was evident regarding 1000 hr loading and the lack of a fire effect on it here may simply reflect the customary failure of sound fuels of this size to markedly combust due to their small surface area to volume ratios and relatively high moisture contents [31-33].

Nearly a decade after treatment implementation, the effects of the thinning and under burning had largely dissipated as all fuel weights in every treatment combination were then statistically equivalent, and given that treatment effects were most pronounced in 1+10-hr and total fuels initially, the lack of significant distinctions therein at the final inventory were rendered especially notable and perhaps best illustrated a clear moderation of initial treatment impacts. Specific to the 1+10 hr categories, the thinned but unburned combination no longer constituted the numerical apex among treatments, and in somewhat of a reversal from the initial inventory their abundance in burned stand portions numerically exceeded that in their unburned counterparts, albeit by exceedingly small margins. Furthermore, for total fuels, the lowest overall weight at the final inventory resided in the thinned but unburned combination, representing a stark transition from the initial response. Despite the lack of obvious treatment effects at the final inventory, the regression analysis provided some insight into possible contributors to final downed and dead loading, with numerous models in the unburned series disclosing positive relationships between the initial and final white fir and total dead tree counts and the final 1000 hr and total loading. Of these, the ones involving initial dead counts may collectively demonstrate that the linkage between stand mortality and fuel accruals, coarse and otherwise, persists over extended time periods. By way of further reasoning, influences of the natural self-thinning that results from intense between-tree competition for resources in higher stocked stands [34,35] was in evidence here given that density and mortality were higher overall in the unthinned and unburned combination as was the 1000 hr fuel dry weight. When utilizing biomass as a surrogate for stand density, two additional models provided more evidence of the potential influence of density on downed and dead fuels but in this case within burned stand portions and pertaining to final 100 hr loading, which was positively related to final white fir and Jeffrey pine biomass. Higher stand density has been previously associated with heightened annual litter fall [36] but in the case here this supposition should be interpreted with caution as the difference in 100 hr fuels between the two burned portions was not especially pronounced.

The changes in downed and dead fuel accumulations incurred between the two inventories as influenced by the thinning and under burning treatments were considered to be of critical importance because of their informational value regarding those that may extend over even longer time periods. As was the case noted above regarding treatment influences on initial fine fuel loading, those on the changes thereafter were also most apparent in the 1+10 hr categories, which again clearly affected the changes in total loading. Concerning the former, decreases were evident in every treatment combination, indicating that post-treatment decomposition in the forest floor exceeded litter fall across the entire stand despite the slightly below average precipitation this site received over the course of the study. Nevertheless, such a reduction was most apparent within the unburned portion of the thinned subunit. This finding is similar to that of Stephens, Collins, and Roller [37] who noted a substantial decrease in fine woody fuels seven years after a thinning followed by mastication in a western Sierra Nevada mixed conifer stand, although a direct comparison is difficult because the fuel categorical divisions were not completely analogous to those used here. In another study with identical fuel categories as those utilized here, but in a pure eastern Sierran Jeffrey pine stand not subjected to subsequent mastication, Swim et al. [11] also observed considerable decreases in 1+10 hr fuels approximately a decade after the implementation of a thinning accomplished through cut-to-length harvesting. One possible explanation for the large decrease in 1+10 hr fuels exhibited in the thinned but unburned combination of the present study is that when thinning diminished the canopy cover it may have hastened the breakdown of these fuels due to a greater penetration of precipitation and sunlight to the forest floor, which is often conducive to microbial activity [7-9], ultimately heightening N mineralization that largely governs decomposition rates [9]. Furthermore, the thick mulch layers created by the thinning treatment coupled with slash mastication may have enhanced soil moisture retention and buffered the soil against temperature extremes, both of which can also aid decomposition [38-42]. This may have been the case in the unthinned and unburned combination as well except with an unaugmented but nevertheless thick forest floor exerting a mulching effect, as this combination also exhibited large reductions in 1+10 hr fuels and had elevated amounts of them initially. Alternatively, the substantial reductions in the two unburned stand portions may not only reflect the benefits of abundant organic material to decomposition but also potentially a lack of detrimental fire treatment impacts thereupon. Typically, low intensity prescribed fire enhances fine fuel decomposition due to its propensity to also promote conditions that are advantageous to microbial activity, including a brief pulse of N release [40,43] but generally this effect quickly subsides [31,40,44-46]. The influence of prescribed fire on decomposition over longer time periods has not been as extensively investigated, but one such study conducted by Monleon and Cromack [47] noted depressed litter decay rates in ponderosa pine (*Pinus ponderosa* Laws.) 12 years after a prescription fire, and another conducted by Swim et al. [11] reported diminished reductions of fine fuels in a Jeffrey pine stand 10 years after under burning. On the Jeffrey pine site just noted, Roaldson et al. [48] postulated that their finding of lower levels of mineral N in burned stand portions nine years after prescribed fire resulted from an immediate but short-term effect of it diminishing the mineralizable N pool coupled with its inhibition of N-fixing shrubs in the understory, possibly explaining why prescribed fire may hinder decomposition in some instances given the aforementioned influence of N availability on the breakdown of organic debris. However, the latter was not likely the case here because the three N-fixing shrubs on this site, namely prostrate, whitethorn, and snowbrush ceanothus (*Ceanothus prostratus* Benth., *C. cordulatus* Kellogg and *C. velutinus* Douglas ex Hook., respectively) all increased in abundance after the prescribed fire in stand portions where they initially resided [49]. Another possible explanation for the diminished decomposition in the burned stand portions here is that prescribed fire may have altered the amount and composition of the saprophytic component of soil microbial biomass, thus impeding this process [39,45,50]. As an aside, the 100-hr fuels followed a pattern similar to that of the 1+10 hr categories in that they exhibited larger reductions in the two unburned stand portions than in their burned counterparts, possibly resulting from the same array of suppositions noted above, although these distinctions among treatments were statistically non-significant.

Regarding the change in total loading, the influences of the thinning and fire treatments were again most evident in the thinned and unburned combination, which exhibited a statistically pronounced reduction. This decrease undoubtedly reflects the considerable diminishment of 1+10 hr fuels previously noted, but a further contributor to this outcome was that this treatment combination incurred the smallest numerical increase in 1000 hr loading as well. Although no statistical distinctions prevailed for the largest time lag category, accruals of them across the stand were apparent over the course of the study, which was rendered even more obvious by the increase in their proportional prevalence, especially in the unthinned subunit. As was previously discussed, stands with elevated densities, such as the two portions in the unthinned subunit here, often undergo natural self-thinning from intense between-tree competition [34,35] inevitably culminating in additional 1000-hr loading. Furthermore, self-pruning of lower branches is often heightened in dense stands due to intensified side pressure from neighboring trees [51-53] which may have also contributed to the numerical, but substantial, increases in 1000-hr accruals within the unthinned subunit. Possibly pertinent here is that the stand was dominated by white fir, a species with the propensity to delay self-pruning thus producing thick branches before abscission [54]. Although not substantiated statistically, but perhaps notable nonetheless, the unthinned but burned combination was the only one to incur an increase in total fuels, albeit marginal, during the interval between inventories. This likely reflects the diminished decrease in the 1+10 hr categories as well as the numerically large increase in 1000 hr loading, with the latter potentially stemming from prescribed fire exacerbating mortality when it is not preceded by density management [13-15] which was somewhat in evidence here.

Conclusion

In summary, mechanized thinning implemented through cut-to-length harvesting coupled with on-site slash mastication and a fire treatment entailing a prescription under burn were evaluated for their long-term influences on downed and dead fuel accumulations in an uneven-aged eastern Sierra Nevada mixed conifer stand. Quantified as individual time lag dry weights plus their total, fuel loading in the thinned but unburned combination was elevated in the combined 1+10 hr categories following treatment implementation, and given that these fuels proportionally dominated overall loading initially, total fuels were elevated as well. In contrast, the near immediate effect of the under burn on these fuels was a pronounced diminishment in their abundance. However, nearly a decade after treatment implementation the effects of thinning and under burning had largely dissipated, as all time lag categories in every treatment combination were statistically equivalent at the final inventory. As for the changes in loading over the course of the study, the thinned but unburned combination exhibited the greatest reduction in 1+10 hr and total fuels while the unthinned and unburned combination also exhibited a large reduction in the former. Diminished reductions in 1+10 hr loading within the two burned stand portions were apparent and the unthinned but burned combination was the only one to incur an increase in total loading, reflecting not only significantly smaller reductions in fine fuels but also a numerically large increase in those of the 1000 hr category. The overarching interpretation of these findings is that the initial desirable effects of under burning and the negative ones attributable to the mechanized treatments examined here on fuel bed accumulations may not persist indefinitely. These findings provide land managers some predictive capacity regarding the effectiveness of these increasingly common fuel reduction practices in Sierran mixed conifer and similar forest cover types.

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