Examination of the relationship between fuel loads and forest characteristics in the northern Sierra Nevada mixed conifer

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Abstract

In the past 100 years, the Sierra Nevada mixed conifer ecosystem has changed substantially due to fire suppression, logging, and cattle grazing (Belsky and Blumenthal, 1997; Mckelvey, 1996). One of the most important changes is the accumulation of fuel. This study focuses on the relationship between surface fuel loads and the forest characteristics of species composition/abundance and slope and aspect. In order to understanding the relationship between fuel loads and species composition/abundance and slope and aspect, predictive equations for all surface fuel types(duff, litter, 1-hour, 10-hour, 100-hour and 1000-hour fuels) were made. The components of the equations were varied across the fuel classifications as were their significance levels. The models did show a relationship between fuel loads and the aforementioned environmental characteristics; however the relationships are complex and most likely indirect. Although my results are interesting and in many cases, significant, more research would need to be done to understand the relationships and to make more accurate predictive equations and thus conclusions about these relationships.

Introduction

The Sierra Nevada is a large mountain range in eastern California and western Nevada, stretching 400 miles (650 km), from Fredonyer Pass in the north to Tehachapi Pass in the south. The mixed conifer forest covers 10% of the vegetated area in the Sierra Nevada of California (The Sierra Nevada Ecosystem Project, 1996). Over the past 100 years, the ecosystem structure of this region has changed substantially. Within the California Sierra Nevada mixed conifer, the canopy tree density and basal area have increased, by 10% and 39%, respectively, form 1956 to 1998 (Ansley and Battles, 1998). This increase is mostly attributed to the increase of shade tolerant species, especially *Abies concolor* (White fir), and *Pseudotsuga menziesii* (Douglas fir) (Ansley and Battles, 1998). In addition, forest surface fuels have accumulated to unprecedented amounts (Mckelvey Et Al, 1996). Currently, in the Northern Sierra Nevada mixed conifer, the average total surface fuel load is about 120-150 tonns/hectare: litter and duff: 103 tonns/hectare, 1, 10, 100 hour: 12.7tonns/hectare, 1000 hour: 33.8 tons/hectare) (Knapp, E.E, 2004 and Stephen and Moghaddas, 2005) Fire suppression, cattle grazing, and logging have all had a role in facilitating these changes in forest structure and composition. (Belsky and Blumenthal, 1997; Mckelvey, 1996).

Although all these changes in the Sierra Nevada mixed conifer ecosystem are important and interrelated, this study focuses on surface fuel loads. Surface fuels are any dead organic material containing carbon. This includes dead and down logs, branches, twigs, leaves, needles, litter, and duff. Fuel loads are a concern for forest health and management. Fuel loading is related to forest health and the occurrence of insects and disease. Areas with high fuel loads are attacked more often by harmful insects and diseases (McCullough et al, 1998). Furthermore, fire behavior is, in part, determined by fuel loads and stand structure. The combined effect of fuel loading, increased basal area, and stand density, increase fire size and intensity (Stephens, 1997).

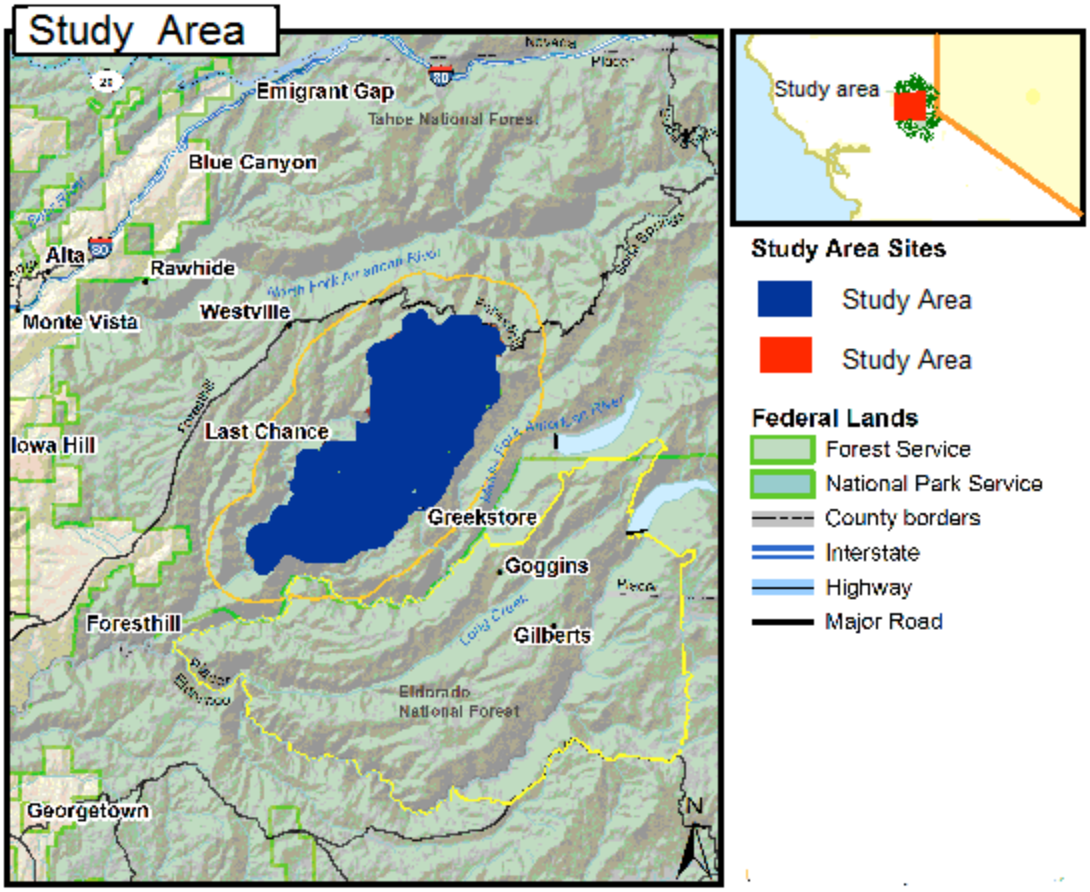
Because fuel loading is a great concern for forest health and fire regimes, much research has been done on fuels across many different forests. Most of the research has focused either on quantifying the changes in fuel loads (Ansley and Battles, 1998), examining how fuel loads effect fire behavior (Bessie W.C and Johnson E.A., 1995) or on how different disturbance regimes effect fuel loading (Stephens, 1997; Stephens 1995 Et Al) However, not much research has been done to understand fuels in terms of their relationship to their immediate environment. Studying the effect that certain environmental factors have on fuel loads would be significant for a few reasons. First, it will expand our knowledge of the current conditions and dynamics of the studied ecosystem. Furthermore, understanding relationships between environmental conditions and fuels would be important for future forest management. Restoring forest health and preventing unmanaged forest fires, will include fuels management and regulations (Stephens, 1997). Knowing how environmental factors affect fuel loading could potentially help managers simplify the task of fuel regulation. For instance, if we could predict fuel loads based on species composition we could implement a wide scale yet micro-ecosystem tailored fuel management plan

The research that has been done to understand fuel loading in terms of environmental conditions was conducted in the Rocky Mountains. Glacier National Park, in Montana, used gradient modeling to model fuel loads among other forest characteristics. Gradient modeling uses environmental gradients to model the occurrence of natural phenomena. (Keane et al, 2000). Glacier National Park used the gradients or environmental conditions of elevation, slope and years since the last burn in order to model or predict fuel loads. This study found that all three environmental characteristics had a significant effect on fuel loads. Elevation and slope generally had negative relationship with fuel loads, although it the degree of negativity varied amongst the fuel types, and years since burn had a consistently positive relationship with fuel loads. (Kessel, 1979) Although their have been gradient modeling studies done in the sierra Nevada these studies focused on modeling vegetation types and fire behavior. Studies of the relationship between fuel loads other environmental factors (or gradients) in the northern Sierra Nevada mixed conifer have been overlooked.

Much like gradient modeling, this paper will explore how different environmental characteristics influence fuel loading in the northern Sierra Nevada mixed conifer. This study focuses on the relationship between fuel loads and the forest characteristics of species composition/abundance and slope and aspect. I will answer the question; is there a relationship or correlation between fuel loads and species composition/abundance and slope and aspect, and if so, how strong is that correlation. With this information I will make a predictive model for fuel loads based on species composition/ abundance and slope and aspect. I hypothesize that there will be a strong correlations between species composition/abundance and fuel loading. I expect that certain tree species will contribute more biomass to fuel loads than other species. I expect that slope and aspect will also be important factors influencing fuel loading.

Methods

Study area In order to determine the influence of species composition/abundance and slope and aspect on fuel loading in the northen Sierra Nevada mixed conifer, data was collected in the Upper Manilia Canyon between the north and middle fork of the American river in Tahoe National Forest, California (39.10’31”N, 120.32’23”W). (Map 1) The site was chosen because it is a northern Sierra Nevada mixed conifer area, without much urban development. The site is within the range of variation present within its respective region (SNAMP proposal). This means that, statistically, this area is not different from other regions in the northern Californian mixed conifer Sierra Nevada.



Map 1. Map of the study site. Adapted from the SNAMP website: http://snamp.cnr.berkeley.edu/documents/

The tree species in this area include *Abies concolor* (White fir) , *Abies magnifica* (Red fir), *Calocedrus decurrens* (Incense cedar), *Pinus lambertiana* (Sugar pine), *Pinus ponderosa*

(Ponderosa pine), *Pseudotsuga menziesii (Douglas fir),* Tan oak(*Lithocarpus densiflorus),* California black oak(*Quercus Kelloggii)* (SNAMP Proposal, 2007). *A. concolor*, *C. decurrens, P. lamberitana, P. ponderosa, P. menziesii* are the species being used in this study, because they are the most abundant species in this site. (Throughout this paper, the tress species will be referred to in an abbreviation of its scientific name. *A. concolor* (ABCO), *C. decurrens (CADE), P. lamberitana (PILA), P. ponderosa(PIPO), P. menziesii(PSME).)*

The site encounters a Mediterranean climate; most of the 160cm of annual precipitation occurs during the winter and spring months and average temperatures range from 0-8 degrees C and 10-29 degrees C during the winter and summer, respectively (Stephens and Collins, 2004).

Over the summer months (May-September 2007), I inventoried 198 plots throughout the site. The plots were established using UTM coordinates off of a USGS topographic map in the computer program, TOPO!(National Geographic Interactive Maps Topo! 2007. for windows, version 3.4.2. Evergreen, Colorado, USA) Using the program TOPO, the first plot was randomly chosen by the program, and the following plots were placed on a 500 meter grid, radiating from the first plot, at equal distances from each other. Each plot is circular .05 hectare with 12.62m radius.

Surface and ground fuels were sampled according to the procedures in the handbook for inventorying downed and woody material (Brown, 1974). This method uses transects to sample fuels. Using a compass, a random bearing was spun to establish the first transect. The following transects were generated by adding 120 to the initial bearing and 120 to the second bearing. A measuring tape was run 12.62m, from plot center, along each bearing. These are the sampling transects. Using a go/no go with .64cm, 2.54cm, and 7.62cm openings, the number of downed woody particle intersecting the transect were counted. Samples were taken in the following manor:

Fuels less than .64cm in diameter were counted when they intersected the transect between 3 and 5 meters. These are 1-hour fuels.

Fuels between .64cm and 2.54cm in diameter were counted when they intersected the transect between 3 and 5 meters. These are 10-hour fuels

Fuels between 2.54cm and 7.62 cm in diameter were counted when they intersected the transect between 3 and 6 meters. These are 100-hour fuels.

Fuels larger than 7.62 cm were counted when they intersected the transect at any point. In this case the diameter of the piece was recorded. These are 1000-hour fuels.

Litter and duff were sampled at 3 and 10 meters on each transect. In this case, the measurement taken is the depth, in cm, of the litter(freshly fallen needles, leaves bark cones) and the duff(organic materials, partially decomposed, original state unrecognizable). Fuel data sets used in this paper includes: duff, litter, 1-hour, 10-hour, 100-hour, and 1000-hour fuels.

All fuels loads were calculated from this raw data, using the equations developed for Sierra Nevada forests (van Wagtendonk et al. 1996, van Wagtendonk et al. 1998). Coefficients required in calculating all surface and ground fuels were weighted by the basal area fraction of each .05 hectare plot. This methodology produces accurate estimates of fuel loads (van Wagtendonk et al. 1996; van Wagtendonk et al. 1998).

In order to obtain an estimate for species composition/abundance, the basal area of each species/acre needs to be determined. All trees above 5cm in diameter that fell within the plot were inventoried. After noting the species, the tree's diameter at breast height(4.5 ft) was taken with a DBH tape. The total height of each tree was taken using a vertex hypsometer (Haglof Laser Vertex Hypsometer 2007, Construction Safety Products, INC. Shreveport, LA, USA)

The basal area of each tree was calculated using the following equation which translates the DBH of a tree to basal area. **BA = .005454 * d2** Then the basal area of each species/ plot was calculated by adding all the individual trees of one species together. This number was then multiplied by 20 to get the basal area of each species per hectare then divided by 2.47 to get basal area of each species per acre. My final estimate for species composition/abundance is in the units, BA/acre (ft^2/acre).

Slope and Aspect were determined from plot center using a compass and a clinometer.

Statistical analysis To explore the relationship between fuels and the chosen environmental characteristics I used a generalized linear model. The generalized linear model was used, instead of the standard least squares model because my data does not meet the criteria for a standard least squares model, as it is non-normal and the response variable is binomial(a density which is a ratio). In addition I have both numerical and categorical data. The standard least squares model only works with numerical data, whereas the generalized linear model works with both types. The generalized linear model fits an observed dependent variable data set, in this case, fuels, using a linear combination of independent variables, in this case: Basal Area of each species, slope and aspect. It makes a model or a predictive linear equation for the dependent variable by combining the values of the independent data sets with coefficients establish by their regressions with the dependent variable and a link function which is based on the distribution of the independent data sets. I used the link function for a binomial distribution. The binomial link function is:

$$XB = \ln(u/(1-u))$$

In order to determine which independent variables had a significant effect on a dependent variable, which independent variables to use in the generalized linear model, I used the stepwise option on JMP. (JMP student edition 7.0 for windows. publisher: SAS/JMP) In the stepwise platform, the user can interact with the output model and select the variables used in the model. It allows one to add and subtract different variables to and from the model equation in order to make the best fitting equation, one step at a time (JMP guild). In order to enter the predictive equation, the variable had to have a prob>F of .25 or less. The variables that satisfied that significance level could be used, but were not necessarily used in the predictive equation. The two factors I looked at when choosing the model were AIC, a measure of goodness of fit, and r^2. R^2 describes how much of the variation in the fuel load is explained by the model, in other words, the combined effects of the terms or predictor variables. By adding and subtracting different variables, I tried to minimize the AIC, and maximize the R-square.

After determining which factors to include in the model I input these factors into a generalized linear model. The statistical accuracy of the models was explored using the chi-squared test for the whole model and the term estimates.

Results

Generalized Linear Models Using the stepwise platform on JMP, I was able to look at each fuel type (duff, litter, 1-hour, 10-hour, 100-hour and 1000-hour) and determine the extent of the influence of each independent predictor variable. The model that most accurately predicted the amount of duff included: *A. concolor, P. ponderosa, P menziesii* and aspect (west) as predictor variables (ACI= 32.4, r^2= .82). The model that most accurately predicted litter included: *A. concolor, C. decurrens P. lambertiana, P menziesii* and slope as predictor variables (ACI= 12.6,

r^2= .93). The Model that most accurately predicted 1-hour fuels included: Aspect (north and west) (ACI= -46.6, r^2=.73). The model that most accurately predicted 10-hour fuels included: *A. Concolor* and aspect (north) (ACI= -6.7, r^2=.31 .) in its predictor equation. The model that most accurately predicted 100-hour fuels included: *P. ponderosa* aspect (west and south) (ACI= -4.3, r^2= .72) and the most accurate model for 1000-hour fuels included: *A. concolor*, *P. lambertiana and P menziesii* and slope (ACI= -.8, r^2= .58) .

The r^2 values vary but are generally high, thus the models, especially for duff and litter, explain the much of variation in the fuel loads. Duff and litter also have high AICs which suggest that there is multi-collinearity between the predictor variables. Multi-collinearity does not reduce the predictive power or reliability of the model as a whole; it only affects calculations regarding individual predictors by changing the estimate and/or underestimating the significance of their predictor variable estimates. (Table 2a-2b)

With the exception of the model made for 1 hour fuels, The models are statically significant according the chi-squared whole model test.(table 1) One would be able to estimate the amount of a fuel type (tons/acre) , if one knew the measurements for the term estimates for that model.

Table 1 Whole model statistics for each fuel load

Fuel type	Whole model Chi-Sqrd	Prob>chi	R^2
duff	126.1	<.0001*	.81
litter	21.1	.0492*	.93
1hour	.5	.7755	.73
10-hour	19.0	<.0001*	.31
100hour	13.1	.0011*	.72
1000-hour	26.7	<.0001*	.58

Duff is the strongest model, as it has high chi-squared and r^2 values and all of its terms are significant.(Table1 and Table 2a) Litter is also a strong model. It has the highest r^2 value, and a large chi-squared value. Had I corrected for the multi-collinearity, litter's term estimates probably would have had higher significance levels as well.

Overall there is a large amount of variation in the predictor variable, or terms, that make the models.(Tables 2a-f) While some fuel loads are most accurately described by fewer terms(environmental factors), such as 1 hour fuel, some models, such as duff and litter, use 4 or 5 terms to accurately describe the fuel load. Furthermore, no term is constantly used in all the models, and terms often vary in the degree of their effect and sign (positive/negative). (Tables 2a-2f)

Table 2a-f Term estimates and their significance for the models

Table 2a. Duff

Term	**Estimate**	**Chi square**	**Prob>ChiSqr**
Intercept	-4.02(+/- .157)	441.440	<.0001*
ABCO	-.25(+/- .04)	56.173	<.0001*
PIPO	.06(+/- .014)	3.923	<.0001*
PSME	.09 (+/- .02)	30.671	<.0001*
Aspect(W)	.56(+/- .12)	58.160	<.0001

Table 2b. Litter

Term	**Estimate**	**Chi square**	**Prob>ChiSqr**
Intercept	-4.063 (+/- .340)	179.102	<.0001*
ABCO	-.071 (+/- .036)	4.081	.0434*
CADE	.010 (+/- .065)	.0229	.8795
PILA	.058(+/- .014)	17.501	<.0001*
PSME	-.025(+/-.040)	.421	.5167
Slope	.007(+/- .008)	.713	.3985

Table 2c 1-hour

Term	**Estimate (+/- SE)**	**Chi square**	**Prob>ChiSqr**
Intercept	-7.63(+/-.30)	20946.64	<.0001*
Aspect(N)	.24 (+/- ..50)	.30	.5984
Aspect (W)	-.10(+/- .50)	.05	.8298

Table 2d 10-hour

Term	**Estimate (+/- SE)**	**Chi square**	**Prob>ChiSqr**
Intercept	-5.75(+/-.10)	12275.54	<.0001*
ABCO	.028 (+/- .006)	15.68	<.0001
Aspect (N)	-.242 (+/- .154)	2.41	.1205

Table 2e 100-hour

Term	**Estimate (+/- SE)**	**Chi square**	**Prob>ChiSqr**
Intercept	-5.14(+/-.15)	2617.84	<.0001*
Slope	-.01 (+/- .004)	7.68	<.0001
Aspect (S)	.19(+/- .15)	1.47	.2243
Aspect (W)	.3072(+/- .15)	4.76	.0291*

Table 2f 1000-hour

Term	**Estimate**	**Chi square**	**Prob>ChiSqr**
Intercept	-5.58(+/- .35)	425.90	<.0001*
ABCO	-.06(+/- .04)	2.0	.1594
PILA	.06(+/- .015)	13.88	.0002*
PSME	-.13 (+/- .05)	10.76	<.0001*
Slope	-.0067(+/- .009)	.69	.4057

(Note: interpretation of the tables

The estimates are the coefficients for each term in the predictor equation. It is important to note that the estimates or coefficients have been transformed by the link function.
Predictive equations:

General model: $g(p)=\ln(p/1-p)= \text{term}_{0} + \text{term}_1 \times \text{estimate} + \text{term}_2 \times \text{estimate}\ldots\ldots$

p=fuel type, $\text{term}_{0=}$ intercept

When an estimate is positive it has a positive effect on the fuel, and when an estimate is negative it has a negative effect on the fuel. The fuel load will never go below zero; as the combination of terms gets smaller the fuel load approaches zero.)

Although there is overall a large amount of variation in the components of each model, there are a few notable trends. *A. concolor* is used in 4 of the 6 models, were as other species average inclusion in about 2 models. *A. concolor* is also significant in 3of its 4 models and has a negative sign of 3 of the 4 fuel types. Thus, according to my models, as *A. concolor* abundance increases, duff, litter and 1000-hour fuels decrease. Aspect is also used in 4 of the 6 predictor equations. Aspect has consistently larger(either positive or negative) coefficients, meaning that whenever aspect's effect on a fuel load is significant, and used to predict a fuel load, it has a much more larger impact on the fuel load than any other environmental variable. Also *P. lamberitana* was the only environmental factor used more than once, in which the sign of the coefficient did not change. *P. lamberitana* had a consistently positive relationship with fuel loads meaning that as *P. lamberitana* abundance increases, litter and 1000hour fuels increase as well.

D**iscussion**

Generalized linear models have allowed me to investigate the impact that species composition/abundance, slope and aspect have on fuel loading. My research suggests that there is a relationship between these environmental characteristics and fuel loads but that this relationship is indirect and complex. The models I made were multifaceted, using many variables to predict fuel loading. In addition the variables used to model fuels changed from fuel type to fuel type. These results suggest that fuel loads cannot be reduced to one tree species or environmental gradient. These findings are in agreement with Brown and Blevins, (1986), who found fuel loading to be highly variable and difficult to predict; as well as Keane et. al. (2001), who suggests that fuel loading was highly dependent on many factors, including vegetation, disturbance regime, and stand history.

My research is also in agreement with Pyne (1996) who suggested that fuel loads were not often directly related to vegetation type. Although I found significant correlations between vegetation, in this case, tree species, the correlations were inconsistent throughout fuel types. Furthermore, tree species generally had very small coefficients (especially compared to aspect), suggesting that even though their effect is statistically significant, they're effect is also very small. (However, multicollinearity could be effecting the estimates for tree species.) My research suggests that aspect is a much more important factor in determining fuel loads than species composition/abundance.

This study in Glacier National Park in Montana found slope to be a significant factor in determining fuel loading (Kessel, 1979). In my study slope was used in three predictor equation. Its effect was usually small and in 2 of the 3 models, statistically insignificant. Slope had a moderate influence in fuel lauding. Unlike the research done in Glacier National Park, my research suggests that slope is not a key factor influencing fuel loading. However, in order to further investigate slope's influence, I made models completely ignoring aspect data. In these models, slope was used more often and was more significant. This suggests that Aspect's strong influence on fuel loads overshadowed slopes influence.

Of tree species studied, *A. concolor* is the most influential species determining fuel loading, as *A. concolor* is the tree species most often used and significant in my models. However this conclusion might be too simple minded. According to my research, A. *concolor* is the most prevalent species in the northern Sierra Nevada. (Within my plots, *A. concolor* was found present in more plots than any other species (174 of 198 plots: next was *P. Lamberitana* at 110 plots). *A. concolor* also contributes the most basal area, over all of the plots (BA: *A. concolor*= 1392, *P. lamberitana*= 528, *P. menziesii*=350, *P. ponderosa* =263, *C. decurrens* = 258).) This is mostly due to the large numbers of trees and not due the occurrence of large *A. concolor* trees. The reason for the statistical significance of *A. concolor,* and the lack of statistical significance for any of the other species might be due to the smaller sample sizes of all other species.

Although my models were statistically significant, they were also complex and varied such that the relationships between fuel loads and slope, aspect and species abundance, are still unclear. However, from my research we can pull away a few solid conclusions. Aspect has the most influence of all the in environmental factors studied. Also, *A. concolor* is the most prevalent species in the northern Sierra Nevada and, is the most influential tree species (of the species studied) on fuel loads. Furthermore, I found that relationships do exist between fuel loads and the studied environmental factors; however, these relationships seem to be complex and indirect and cannot be explained using one environmental factor.

In spite of these finding, my results are not conclusive enough to have implications for forest management. However my findings do have implications for future research. My research indicates that the relationship between aspect and fuel loads should be studied more thoroughly. Further analysis of the all relationships I studied should include corrections for multi-collinearity. In addition other forest characteristics should be studied to find more direct, clear, relationships between environmental characteristics, for instance elevation and shrub cover, and fuel loads.

In conclusion I have found interesting results that have lead to a better understanding of the Sierra Nevada forest ecosystem. Fuels should continue to be studied because of their importance in the forest ecosystem. Fuel mapping and modeling is feasible and could potentially guild future forest management.

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