Project Title: Fuel Reduction treatment longevity and crown response in interior ponderosa pine forests of northern California

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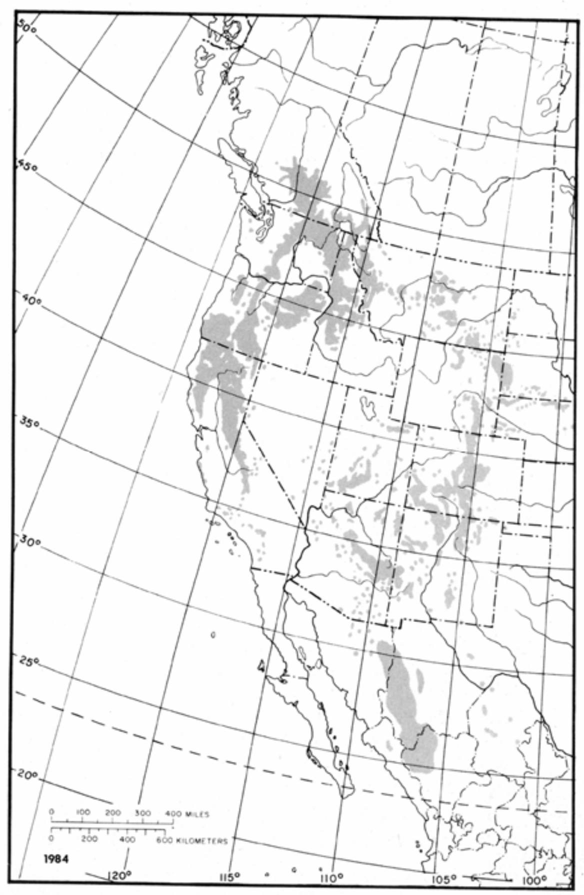
Abstract

With increasing interest in fuels treatments to address the high risk of severe fires in the western United States, there is an attendant need to quantify the effectiveness of such treatments. In addition to the immediate effect of reducing levels of combustible material and the attendant impact on fire intensity, resource managers also need to quantify or forecast the longevity of such treatments. Treatments that produce significant, but short-lived reductions in risk of severe wildfire may not be meeting the goals and objectives of managers. This temporal component needs further study and is the subject of this proposal.

There are three components to the project: (1) Quantify the change in fuels in the first five years following combinations of thinning and prescribed fire treatments in ponderosa pine stands. This will be done using data obtained from the Blacks Mountain Ecological Research Project (Oliver 2000). The second portion of the study will involve a destructive sample from three sites on the Experimental Forest. We will estimate the crown weight (foliage biomass) for trees in stands at Blacks Mountain thinned in 1996, 1998, 2004, and an untreated stand. Using the derived biomass relationships, we will quantified the temporal change in stand-level foliage biomass.

Background and Purpose

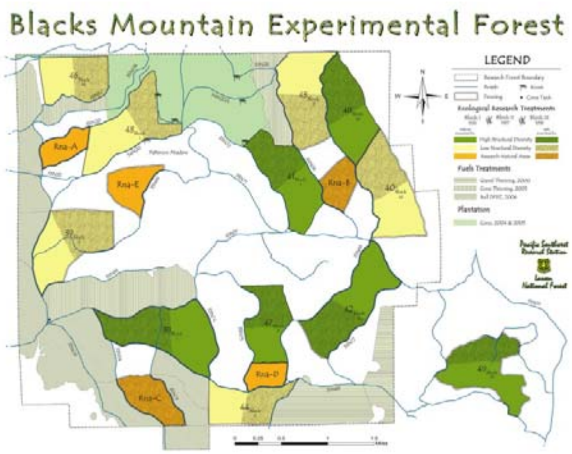
Ponderosa pine is widely distributed throughout the western United States (Figure 1) and is a major component of three different forest cover types (Eyre 1980). The most widespread of these types is the Interior Ponderosa Pine Type (SAF Type 237), which extends from Canada to Mexico, through the western Plains states to the eastern Cascades and Sierra Nevada. The forests of this type typically experience long, dry summers and cold winters with a significant proportion of precipitation falling as snow during the winter months. Studies of fire history in the interior pine type reveal variation in fire return interval, but in general the long-term pattern before settlement can be characterized by frequent low-intensity fire (e.g. Brown and Sieg 1996, Norman and Taylor 2003).



ure 1. Range of ponderosa pine (Burns and Honkala 1990).

Study Description and Location

This study was conducted at Blacks Mountain Experimental Forest in northeastern California. Trees were selected in thinned stands (Unit 39, Cone Thinning, and Gravel Thinning) as well as untreated stands in the vicinity of RNA C in the southern part of the experimental forest. A total of 82 trees were sampled. Of these 79 were kept and three were subsequently rejected as exhibiting old growth characteristics. The sampling of old-growth trees at Blacks was avoided for two reasons. First, we have a limited amount of older trees that are not already in some established experiments. Second, the variability in crown structure of such trees would require extensive sampling at great expense. In all likelihood this would have doubled the time and effort (and cost) of this project.



Blacks Mountain Experimental Forest treatments.

Treat. ID	Sample Size	DBH (cm)	H (m)	Crown Ratio	% BA Removed
U	21	32.8	17.3	0.542	0
T_2	29	33.3	15.2	0.592	80
T_8	21	33.3	14.8	0.621	80
T_{10}	8	30.1	14.8	0.608	69

Biomass Sample Trees at Blacks Mountain

Sampling

Trees were selected to fill a range of diameters between 10 and 50 cm breast height diameter within each treatment area (T_0=unthinned control, T_2=2 years since thinning, T_8=8 years since thinning, T_{10}=10 years since thinning). We targeted two trees in each 5cm diameter class in this range. Fewer were selected from the T_{10} treatment due to restrictions imposed by an existing experimental design for that treatment area. We avoided trees with one-sided crowns or visible signs of damage. The diameters for selected trees ranged from 11.9 to 52.3 cm. Trees were felled and the crown divided into five sections. Section 1 being at the base of the crown, section 5 at the top. Diameters were obtained for all branches using a caliper. One mid range branch was selected from sections 1, 4, and 5 and two branches (largest and smallest in the section) from sections 2 and 3.

Sampled branches were then stripped of foliage and current years foliage was bagged separately. For the terminal leader of the branch, foliage was separated by year for years 0 to 9 with 0 being the current years foliage and 1-9 were from each successive year retained by the branch. We found 9 to be the maximum number of years worth of foliage maintained at Blacks Mountain but the average was around 3, so often the years 4-9 were unrepresented for a given leader. The terminal leader for the tree (top of section 5) was removed in it's entirety and all needles separated and bagged separately for each year 0-9. Wood for each branch was bagged and removed.

The bole of the tree was sectioned at the stump, dbh, base of the live crown, the mid-point between dbh and crown base, and at the base of each successive crown section 2-5. All wood, branches and foliage were dried at 80º C for two weeks prior to weighing. The foliage was weighed in small batches to avoid any rehydration of the material.

Analysis

The first stage of analysis required the development of branch-level equations. The individual branch foliage biomass was fit using weighted nonlinear regression:

$$fw = k_{1t} bdob^{k_{2t}}, \quad [1]$$

where *fw* is foliage biomass (g), *bdob* is branch basal diameter outside bark (mm), *t* is treatment, and error variance was assumed proportional to the square of the predicted value.

The individual branch woody biomass was fit using weighted nonlinear regression:

$$bw = [q_{1t} + q_{2t} cp^2] bdob^{q_{3t}}, \quad [2]$$

Where *bw* is branch woody biomass in grams, *cp* is branch crown position (ranging from 0.1 to 0.9 using the center point of the section. Variance was assumed to be proportional to the predicted value.

We estimated the annual allocation of foliage by proportioning annual foliage for the terminal in each sampled branch. Then we fit last full year's foliage as a function of the sum of all foliage for the terminal. This effectively gives a proportional estimator that we then use to estimate the amount of foliage in any given tree in current year's foliage. We tried models with slope adjustments for thinning, for section, for both section and thinning, and with no adjustments. We employed a nonlinear, mixed-model with a random (tree-level) effect for the slope obtain the following predictive model for annual branch foliage (*af*):

$$af = [r_{1t} i_{1t} + r_{2t} i_{2t} + r_{3t} i_{3t}] \widehat{fw} \quad [3]$$

Where *af* is the current annual foliage biomass (g) and $\widehat{fw}$ is the predicted total. The variance is assumed proportional to predicted foliage weight. Indicator variables were used for sections and treatment: $i_{1t} = 1$ for sections 1-3, 0 otherwise, $i_{2t} = 1$ for section 4, 0 otherwise, $i_{3t} = 1$ for section 5, 0 otherwise, *t* indicates treatment area. This function was then used to estimate amount of annual foliage production for the entire tree by summing over all branches.

Using iterative seemingly unrelated regression (SUR) (Greene 2003), we fit a system of equations with three response variables: foliage, branch wood and bole biomass. The simultaneous fit allows for improvements in efficiency due to cross-equation correlations in the errors of the system. Branch wood and bole biomass values include bark. A final model selected was specified as:

$$foliage = \exp\left(a_{01} + a_{02}(It_2 + It_{10}) + a_{03}It_8 + a_{04}cr\right) dbh^{a_1} + e_1$$
$$branch = \exp\left(b_{01} + b_{02}(It_2 + It_8) + b_{03}cr\right) dbh^{b_1} + e_2$$
$$bole = \exp\left(c_{01}\right) height^{c_2} dbh^{c_1} + e_3$$

Where the response variable is biomass (g), It_x is an indicator for *x* years since thinning, *cr* is live crown length divided by total height, *dbh* is breast height diameter (cm) and *height* is total height (cm). Foliage weight does not include weight of current year's foliage if the tree was sampled during the growing season.

These analyses were then applied to a recently treated stand at Blacks Mountain Experimental Forest. We obtained estimates for pre-thin, post-thin and post-thin plus 5 years.

Key Findings

1. Trees in thinned areas had much higher levels of foliage after accounting for variability in tree size (*dbh*) and crown ratio. Thus the allometric relationship for foliage biomass in ponderosa pine is not stationary; the relationship changes with respect to thinning treatment. The dependence on treatment for foliage biomass implies that reliance on stationary allometric equations may result in substantial error when estimating crown biomass in ponderosa pine stands.
2. It appears that site productivity may have a larger effect on foliage mass per tree than we first anticipated. Although the evidence is somewhat anecdotal (all from one Experimental Forest), trees on a slightly higher site (the Gravel thinning T8) maintained much higher levels of foliage per tree. A closer examination of the Blacks Mountain Ecological Unit Inventory indicated that this area of the forest represented slightly higher levels of productivity.

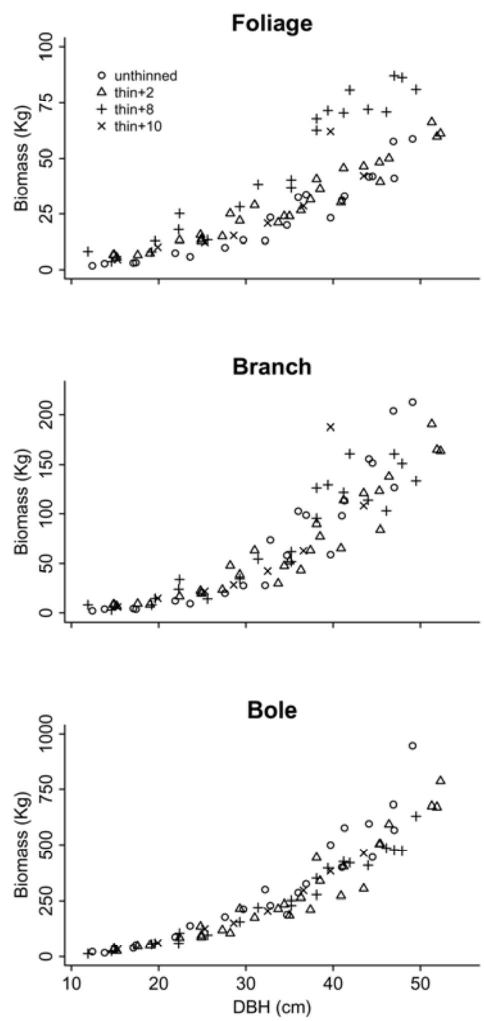
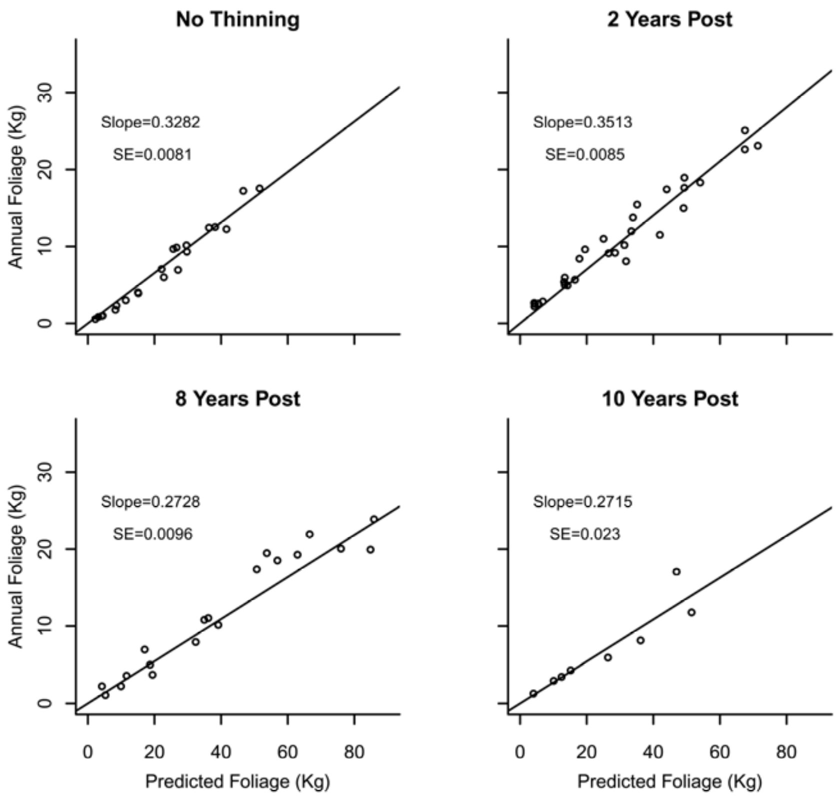


Figure 1. Foliage, branch and bole biomass in sampled ponderosa pine trees at Blacks Mountain.

3. Eight and ten years after thinning, annual foliage production is approximately 27 percent of the total. Since stands appear stable at this point, this also may be considered an approximate level of needle cast after stands have rebuilt crown.

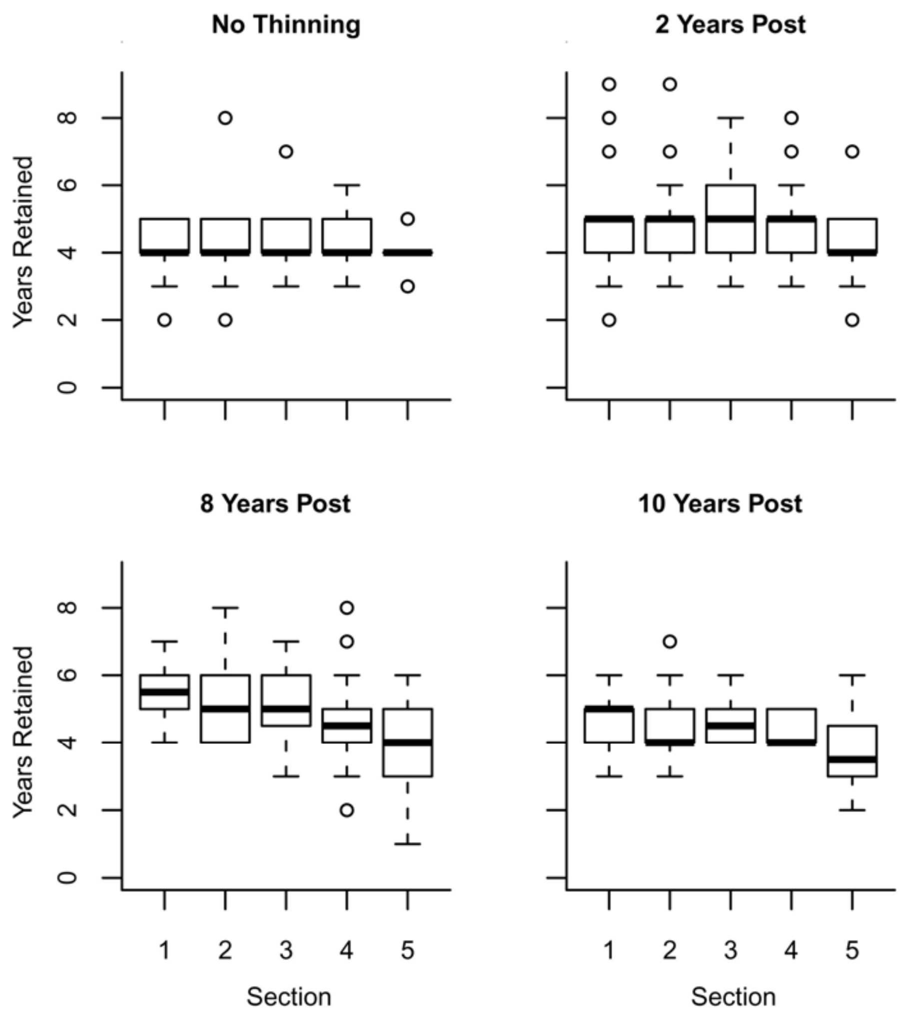
Figure 2. Tree-level annual foliage productivity estimated from total foliage.



The higher rate per unit of foliage two years following treatment is to be expected since during that period, the trees are rebuilding crown and increasing the amount of foliage in retained trees. By years 8 and 10 the trees appear to have fully responded and foliage production per unit of biomass has decreased. However rates per tree have actually increased as total foliage for a tree of given dimensions has increased in response to thinning.

4. Foliage is maintained in unthinned areas for about 4 years usually with needle retention extended for a year or two post thinning in the base of the crown. This extension of needle retention implies a short-term drop in litterfall in the years immediately following thinning resulting from both the overall reduction in crown mass in the stand combined with the increased retention.

Figure 3. Box and whisker plot of years of needle retention by crown section (1= base of crown, 5= top 20% of crown) for branches sampled in unthinned and thinned areas by years since treatment.



5. In a referenced fuel reduction thinning at Blacks Mountain Experimental Forest, these equations indicate that five years after thinning, foliage biomass at the stand level has already recovered to pre-treatment levels. Thus the crown foliage removed from the understory appears to simply have been shifted up into the crown, and this process happens very quickly.

Foliage and annual production estimates (kg ha^{-1}) for a thinned ponderosa pine stand at Blacks Mountain Experimental Forest.

	Pre-thin	Post-thin	Post-thin+5 years
Total Foliage	4174	3220	4428
Annual Foliage	1377	1062	1328

This stand was thinned from below. Before treatment, the stand had a basal area of 16.5 m^2ha^{-1}, (s.e. = 1.02 m^2ha^{-1}) and the quadratic mean diameter was 10.3 cm. After thinning from below, the number of stems was approximately 112 ha^{-1} and basal area was reduced to 10.6 (s.e. = 0.89). This thinning increased quadratic mean diameter to 35 cm. Five years post-thinning, basal area was 12.1 (s.e.=1.01), well below the pre-treatment level yet, the foliage biomass has recovered completely.

Thus after thinning, total foliage biomass and the amount of foliage created (and produced as litter) at the stand-level appears to recovers quickly. The long term fire-hazard benefit to this thinning comes from the re-arrangement of fuels: the reduction in ladder fuels. Litterfall rates, even in a heavily thinned stand such as this where stems per ha was reduced from 2000 to 112, are still going to produce needle cast for surface fuels at or near pre-treatment levels over the long term and these widely spaced stands may still carry frequent surface fires.

Management Implications

In practice, biomass estimation often relies upon extrapolated equations. The working assumption being that a single allometric equation for a given species should be sufficient, or at least any errors due to extrapolation are irrelevant. Unfortunately, the allometric biomass relationships are not likely to be stationary over space, or even over time within a given locale. This analysis suggests that changes in stand structure due to thinning will change the allometric relationship in ponderosa pine. We also found some evidence that for foliage, site productivity may be an even greater concern. If we were to mistakenly use the foliage equation from the T8 (Gravel Thinning) in an unthinned stand on the west side of Blacks Mountain Experimental Forest, we could obtain foliage biomass estimates that were off by nearly 100 percent. If there is that much variability within a fairly uniform 4,000 ha forest, imagine what errors might be created by applying these same equations in, say, the west side of the Sierra Nevada.

For ponderosa pine, at least, treatment regime and site productivity should be considered when developing estimates of biomass, particularly crown biomass. And equations should only be applied for similar sites and treatments. Branch and bole biomass appear to be much more stable and equations may be more reliably extrapolated for these components of biomass.

Deliverables Crosswalk

Deliverable	**Description**	**Status**
Manuscript	Crown response in thinned interior ponderosa pine *Thinning Effects Above-Ground Biomass Equations for Pinus ponderosa Trees in Northeastern California.* Ritchie, M.W., Zhang, J., and Hamilton, T.A. Submitted to Canadian Journal of Forest Research.	In Review
Manuscript	Evaluation of application of the FVS/FFE *Forecasting effects of thinning on fuel levels in interior ponderosa pine stands.*Ritchie, M.W., Coltrin, R., Zhang, J., and Skinner, C.N.	Incomplete, in draft form.
Web Site	Development of project web site http://www.fs.fed.us/psw/programs/ecology_of_western_forests/projects/biomass/	Completed, testing on template server
Manuscript	Analysis of Observed vegetation/fuels after treatment *Vegetation responses to stand structure and prescribed fire in an interior ponderosa pine ecosystem.* Zhang, J.; M.W. Ritchie, and W.W. Oliver. Can J. For Res. 38:909-918.	Completed

Ongoing Work

We are also now completing the FVS/FFE evaluation of biomass modifications. We are currently employing LiDar in these same treated areas at Blacks Mountain to refine estimates for both surface and crown fuels. This work is being funded by USFS Region 5. The long-term study is now nearing the ten-year post treatment point at which time we will be able to evaluate longer-term response to treatment and fuel accumulations.

References

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