Estimation of Crown Cover in Interior Ponderosa Pine Stands: Effects of Thinning and Prescribed Fire

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ABSTRACT: *We evaluated the relationship between crown cover measured with a vertical sight tube and stand basal area per acre in treated (thinned, burned, and thinned and burned) and untreated interior ponderosa pine (*Pinus ponderosa *P. & C. Lawson) stands in northeastern California. Crown cover was significantly related to basal area at the plot level and stand level. In addition, the relationship was not affected by two extremely different thinning regimes. However, the predicted crown cover was generally lower, for a given level of basal area, in a recently thinned stand than in a stand that had not been recently thinned. Prescribed fire had no detectable effect on the relationship. The maximum measured value of stand level crown cover in untreated stands in this study was about 60 percent. West. J. Appl. For. 20(4): 240–246.*

Key Words: Sight tube, basal area, white fir.

Land managers frequently need to express the degree of crowding or occupancy of forested areas. Measures of stand density are relevant to the estimation of yield, the probability of mortality, and may be related to the incidence of disease and insect outbreaks. Within the context of operational forestry applications, most density measures are derived from the number and size of trees in a stand (Spurr 1952).

Stand occupancy has been quantified by such means as basal area per acre or stand density index (Reineke 1933). Among young plantations, spacing or trees per acre (TPA) are informative metrics. Other well-established measures are the crown competition factor (Krajicek et al. 1961) and the tree area ratio (Chisman and Schumacher 1940). All of these indices of stand occupancy are well defined, easily measured, and are, in fact, closely related (Curtis 1970).

More recently there has been some interest in crown cover—the proportion of ground area covered by the vertical projection of the crown—as a measure of occupancy. Methods for obtaining estimates of crown cover are direct or indirect. Direct methods include the use of instruments such as the spherical densitometer (Lemmon 1956), vertical sight tube (Stumpf 1993), or moosehorn (Robinson 1947) to quantify crown cover on the ground. Indirect methods include remote sensing (estimating crown cover from aerial photography) and prediction from tree conditions (Mitchell and Popovich 1997, Gill et al. 2000).

Crown cover is often viewed as a meaningful expression of stand conditions relating to habitat suitability (Schuster and Halls 1962, Reynolds et al. 1992). However, there is no true measure of crown cover because any definition of crown cover is inextricably linked to the angle of view. A wider angle of view relates to an increasing estimate of crown cover (Bunnel et al. 1989). An explanation for this is as a line of sight strays from true vertical (zero degrees), gaps in the canopy will appear smaller and the vertical structure of the vegetation canopy will appear larger. For example, the use of a spherical densitometer implies a different definition of crown cover than the use of a vertical sight tube (Ganey and Block 1994). It can be effectively argued that the expectation and the variance of any estimate of crown cover are not independent of the choice of the method. Hence, any evaluation cannot be considered independent of the method used to quantify crown cover.

In the process of evaluating two current large-scale ecological research projects at Blacks Mountain Experimental Forest (Oliver 2000) and at the Goosenest Adaptive Management Area (AMA) (Ritchie 2004), we have been frequently confronted with the issue of crown cover in relation to the treatments. Because of the costs and uncertainty associated with any measure of crown cover, it would be useful to have a function that can relate crown cover to a more readily obtainable measure of stand occupancy. In this

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article, we analyze the relationship between field-measured crown cover and basal area, as well as the potential impacts of thinning and prescribed fire on this relationship.

Data

We used data from a subset of the Blacks Mountain (Oliver 2000) and the Goosenest AMA (Ritchie 2004) research projects. Both study sites are located in northeastern California (Figure 1) and fit the description of the interior ponderosa pine forest type 237 (Eyre 1980). Elevations of our sample plots range from 5,600 to 6,900 ft at Blacks Mountain and from 4,900 to 5,700 at Goosenest AMA. Mean annual precipitation at Blacks Mountain ranges from 9 to 29 in. and averages 18 in. We have no reliable, long-term weather data at Goosenest AMA, however, the climate resembles that of Blacks Mountain. The combination of long, cold winters and warm, dry summers allows for only a short growing season.

Blacks Mountain Experimental Forest

In the Blacks Mountain experiment, stands have been manipulated to create two contrasting stand structures: high structural diversity and low structural diversity. The experiment also includes fire effects with two treatment levels: with and without prescribed fire. Treatments are applied in three blocks. Within each of these blocks, each of the two stand structures was created in two randomly selected units ranging from 200 and 350 ac in size. This yields a total of 12 units, each of which is split in half for the application of prescribed fire (Oliver 2000), yielding a total of 24 split units.

To create the low structural diversity stand structure, stands were thinned to maintain a single canopy layer. The goal was to simplify forest tree structure (Oliver 2000). The trees maintained were 40 to 100 ft tall, with crown ratios generally greater than 50%. Leave-tree crowns were full and pointed. Pine bark did not have the bark plates characteristic of older trees. All large trees in the highest canopy layer were removed. Tree spacing tended to be uniform at a density of around 100 TPA and range from 80 to 145 TPA.

All canopy layers were retained in the high structural diversity silvicultural treatment. The resulting stands feature multiple age classes and varying crown structures. Pockets of unthinned groups of trees and clumps of larger trees were left to create an uneven spacing as well. All of the large, old trees were maintained with smaller trees removed within a radius of approximately 33 ft. Within-stand densities average 190 TPA, and range from 145 to 235 TPA.

Included in the Blacks Mountain data are four Research Natural Areas (RNAs) on the Experimental Forest, each approximately 100 ac. The RNAs were set aside to serve as unmanaged, qualitative controls representative of the interior ponderosa pine type. They have had no previous history of management, but fire exclusion has affected their understory densities. Two of the four RNAs (RNA-B and RNA-C) have had one recent application of prescribed fire. Stand densities range from 445 to 1,270 TPA.

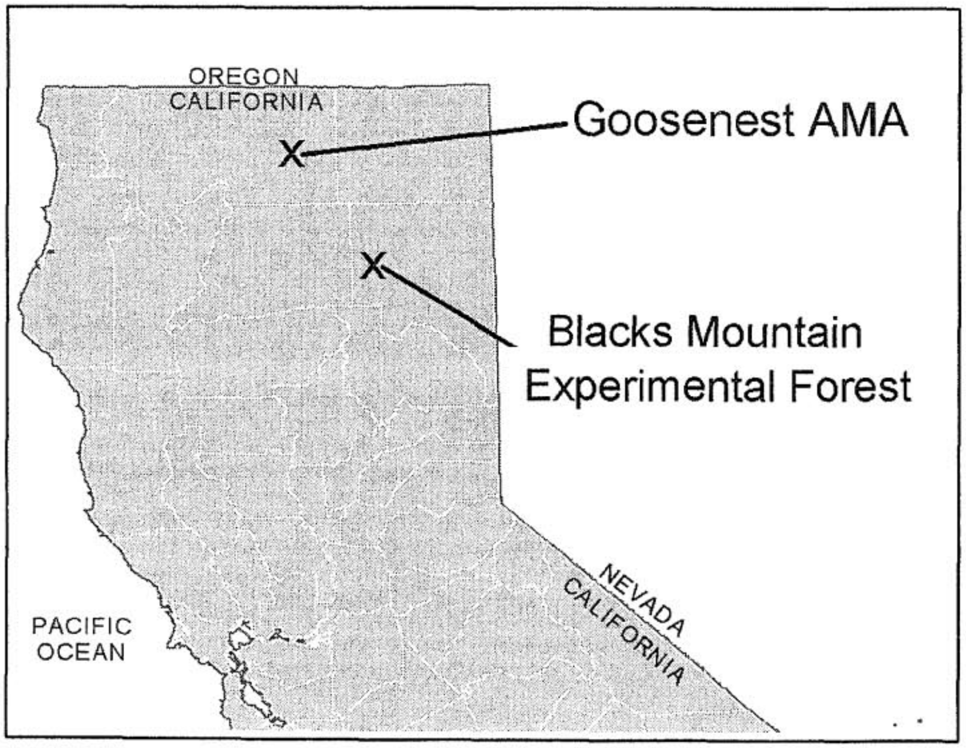

Figure 1. Map of northern California showing the locations of the Blacks Mountain Experimental Forest and the Goosenest Adaptive Management Area.

Crown cover measurements were taken in nine of the 12 thinned Blacks Mountain units. Five of these units were high structural diversity units (38, 41, 47, 48, and 49) and four were low structural diversity units (39, 40, 44, and 45). In addition, all four RNAs were measured as well.

Goosenest AMA

In the Goosenest AMA, an experiment was established to evaluate methods for accelerating late-successional stand development. Three thinned treatments and one unthinned treatment were applied in a completely randomized design. Twenty units of 100 ac each were selected, each receiving one of the four treatments (Ritchie 2004). There are five replicates for each treatment.

In the pine emphasis treatment, stands were thinned to favor the re-establishment of ponderosa pine dominance. Much of the white fir was thinned to initiate species conversion toward more historic proportions of pine and fir. Small openings of 1 to 3 ac in size were created in locations with a high proportion of fir and were subsequently planted with pine seedlings. Crown cover was evaluated in two of these units (units 7 and 12).

The pine-with-fire treatment combined a pine emphasis thinning with the application of prescribed fire. The prescribed fires took place between 1 and 3 years after the mechanical treatments were completed. Four of these units were chosen for crown cover observations (units 3, 6, 13, and 15).

The large tree treatment was simply a thinning from below, regardless of species. The largest dominant and co-dominant trees were left at 18- to 25-ft spacing. Four of these units were chosen for crown cover observations (units 1, 2, 11, and 14).

All five Goosenest control units were also selected for crown cover observations (units 4, 10, 16, 18, and 20). The control units have had no recent thinning activity.

Silvicultural treatments at Blacks Mountain were applied one block of four units at a time. Prescribed fire was applied in the fall, 1 to 2 years after thinning. One block was treated in 1996 and burned in 1997, another was treated in 1997 and burned in 1999, and the third block was treated in 1998 and burned in 2000. One RNA was burned in 1997 and another in 1998. Treatments at Goosenest were applied in summer and fall of 1998 to 2000 and prescribed fire was applied in the fall of 2001. Table 1 contains descriptive data for all treatment units used in this study.

Table 1. Summary statistics, including the 10th and 90th percentiles, for cover and basal area from nested fixed-area plots for each of the 37 sample areas, including four RNAs (R-A, R-B, R-C, and R-D).

Sample				Crown cover			Basal area			
Unit ID	Study	N	Treatment	10th	Mean	90th	10th	Mean	90th	Quadratic mean dbh
					%			sq. ft/acre		Inches
1	Goosenest	18	Thin	12.2	24.9	36.6	62.9	95.9	126.9	16.8
2	Goosenest	18	Thin	9.8	22.9	36.6	45.3	81.4	103.6	15.2
3	Goosenest	17	Thin	4.9	23.1	34.1	52.9	92.4	125.6	16.6
4	Goosenest	18	None	24.4	44.6	58.5	99.8	169.9	267.4	9.9
6	Goosenest	17	Thin	22.5	37.6	57.5	74.5	139.7	229.0	17.8
7	Goosenest	18	Thin	10.0	25.3	42.5	36.9	97.8	169.3	18.8
10	Goosenest	18	None	30.0	57.6	82.5	105.3	182.0	322.6	10.8
11	Goosenest	17	Thin	17.5	30.9	45.0	61.4	95.4	117.7	17.7
12	Goosenest	19	Thin	5.0	25.8	40.0	8.2	89.2	140.9	15.5
13	Goosenest	15	Thin	4.9	20.7	31.7	18.4	72.3	131.5	17.1
14	Goosenest	18	Thin	17.5	29.6	40.0	57.0	95.0	129.6	16.9
15	Goosenest	17	Thin	7.5	27.1	55.0	16.6	85.5	153.3	16.7
16	Goosenest	18	None	34.1	54.5	75.6	98.9	190.9	285.2	10.1
18	Goosenest	17	None	31.7	51.2	65.9	131.3	223.3	301.5	8.9
20	Goosenest	19	None	39.0	59.9	78.0	172.9	284.2	364.6	11.5
380	Blacks Mtn.	31	Thin	20.0	34.7	50.0	52.1	89.9	134.5	12.2
381	Blacks Mtn.	22	Thin + burn	12.5	30.0	50.0	61.9	104.5	147.4	11.9
390	Blacks Mtn.	21	Thin	5.0	17.3	30.0	18.4	35.1	59.0	9.1
391	Blacks Mtn.	28	Thin + burn	2.5	17.1	32.5	5.9	30.2	45.7	9.3
400	Blacks Mtn.	27	Thin	2.5	16.7	25.0	24.0	44.5	65.2	8.9
401	Blacks Mtn.	25	Thin + burn	5.0	15.6	25.0	26.7	51.9	83.4	8.9
410	Blacks Mtn.	24	Thin	12.5	28.0	42.5	50.9	96.9	159.0	10.0
411	Blacks Mtn.	23	Thin + burn	7.5	25.4	40.0	55.1	97.6	147.5	12.9
440	Blacks Mtn.	17	Thin	14.6	21.4	31.7	16.2	38.9	66.0	7.4
441	Blacks Mtn.	16	Thin + burn	4.9	16.5	26.8	25.1	44.9	66.3	8.2
450	Blacks Mtn.	24	Thin	12.2	19.8	31.7	30.5	45.3	61.6	9.8
451	Blacks Mtn.	28	Thin + burn	4.9	16.1	26.8	20.2	37.6	57.9	10.5
470	Blacks Mtn.	12	Thin	19.5	30.5	48.8	50.5	106.8	124.4	11.8
471	Blacks Mtn.	17	Thin + burn	17.1	31.7	43.9	39.8	110.2	214.5	15.2
480	Blacks Mtn.	22	Thin	15.0	26.6	42.5	37.5	97.9	158.8	14.3
481	Blacks Mtn.	26	Thin + burn	22.5	38.7	65.0	67.8	123.5	200.7	12.8
490	Blacks Mtn.	22	Thin	17.1	31.7	46.3	65.0	106.9	166.1	14.1
491	Blacks Mtn.	18	Thin + burn	9.8	26.6	39.0	55.2	115.2	193.6	15.3
RNA-A	Blacks Mtn.	16	None	26.8	48.5	70.7	102.9	180.1	255.5	6.5
RNA-B	Blacks Mtn.	19	Burn	24.4	38.4	58.5	97.7	171.2	233.6	6.8
RNA-C	Blacks Mtn.	24	Burn	35.0	48.5	70.0	84.9	137.2	213.1	8.5
RNA-D	Blacks Mtn.	12	None	45.0	61.7	75.0	137.3	184.7	236.2	5.6

In all treatment units, a permanently monumented grid system of 328 × 328 ft was established as a spatial reference for data collection. Every other one of the monumented points was selected for crown cover and tree dbh observations, resulting in a grid of sample points spaced about 464 ft apart.

In all treatment units, cover was measured in the field with a vertical sight tube (Stumpf 1993). The sight tube is used to derive a hit or miss observation; when tree crowns are intersected by the cross hairs, the observer records a hit (1), otherwise, a zero is recorded. The tube is held at eye-level and the angle is kept vertical by a pair of bubble levels integrated into the instrument. At each selected grid point, 41 readings were taken with the sight tube: one at the center, and 10 at 5-ft spacing in each of the four cardinal directions, thereby establishing sampling coverage for a 0.2 ac (52.7-foot radius) sample plot. A mean crown cover ratio was calculated for each grid point by dividing the number of hits by the number of observations (41). Sampling at both study sites was done in the summer and early fall of 2000 to 2003 (2–7 years after thinning).

On this same 0.2-ac plot, trees greater than or equal to 11.6 in. dbh were measured for dbh. On a smaller, 0.05-ac circular plot, centered on the same grid points, trees greater than 3.5 in. dbh but less than 11.6 in. dbh were measured. Yet another circular plot, 0.01 ac in size, was used to measure saplings from 1.6 to 3.5 in. dbh. Trees smaller than 1.5 in. dbh were not sampled. Basal area per acre was calculated from these data for each grid point.

Analysis

Because managers typically express crown cover for an entire unit or stand, we related the stand averages of basal area per acre to the stand averages of observed average percent crown cover. Using the values obtained over each stand, we fit a predictive model using basal area per acre as a predictor variable. In this analysis, we simply treated each split component of a unit as an independent treatment unit. Having measured nine whole units at Blacks Mountain, this yields 18 treatment units, nine burned, nine unburned. With this simplification, we were able to include the RNAs, which are not split, from Blacks Mountain in this analysis. Because the intent for model 1 is to derive a predictive function, we chose a nonlinear form to optimize the fit of the model,

$$\mathrm{cc}_i = \theta_0 + \theta_1 \cdot \exp(-\exp(\theta_2 - \theta_3 \mathrm{ba}_i)) + \varepsilon_i, \qquad (1)$$

where θ_n = coefficients estimated by non-linear regression, cc_i = mean crown cover percent for treatment unit i, ba_i = mean basal area per acre for treatment unit i, ε_i = random error.

Parameters were estimated using the NLIN procedure in SAS (SAS Institute, Cary, NC). We observed an apparent increase in variability over basal area. That is, stands with higher density (e.g., unthinned units) appeared to have a higher variance than those that had been heavily thinned. We corrected for this variance by deriving a weight as a function of stand basal area, ba_i, and the square of the SE ($\sigma^2_{\bar{X}i}$) of the cover estimate for each treatment unit, i, expressed as $\bar{\mathrm{X}}$ a percentage:

$$\mathrm{weight} = \frac{1.0}{0.08603 \times \mathrm{ba}_i + \sigma^2_{\bar{X}i}}.$$

Our next objective was to test for effects of thinning and burning within the context of our predictive crown cover/basal area. To do this, we looked at the data from the two study areas at the sample point (grid point) level. To analyze the data from two different study designs, we looked at each study area using a separate mixed-model analysis. The predictive equation from Model 1 was used to develop a predicted crown cover from the basal area at each sample point. This predicted crown cover was used as a covariate in the next two models to look at the effects of thinning and burning on the predictive relationship.

At Blacks Mountain, the split unit design allowed us to look at the effect of prescribed fire on the relationship. We were also able to study the difference between two types of thinning, high and low structural diversity. The RNAs were left out of this model because they are not split plots. Consequently, a test of thinned versus unthinned was not possible with the Blacks Mountain data. Analysis was conducted using the MIXED procedure in SAS for mixed-effects models. The random effects were assumed to have a mean of zero and constant variance. Model 2 is the final model fit for the Blacks Mountain data:

$$\mathrm{cc}_{ijkl} = \beta_0 + \beta_1 \cdot \hat{Y}_{ijkl} + \upsilon_l + \tau_j + \gamma_k + \tau_j \times \gamma_k + \varepsilon_{ijkl}, \qquad (2)$$

where cc_{ijkl} = crown cover percent, block i, treatment j, split k, sample point l, β_n = coefficients estimated by mixed model analysis, $\hat{Y}_{ijkl}$ = crown cover predicted from basal area using model 1, υ_l = random block effect, τ_j = treatment effect, γ_k = prescribed burn effect, $\tau_j \times \gamma_k$ = thinning by burning interaction, ε_{ijkl} = random error, i = block 1, 2, 3, j = treatment (high structural diversity, low structural diversity), k = split (burned, unburned), and l = sample point 1, 2, . . ., number of sample points per split.

At Goosenest, a completely randomized design with a control treatment allowed us to look at the effect of thinning compared with no thinning. Also, we looked at the difference between the pine emphasis treatment and the pine-with-fire treatment to ascertain the effect of prescribed fire. The Goosenest model has only one grouping variable to indicate which treatment was applied,

$$\mathrm{cc}_{ijk} = \beta_0 + \beta_1 \cdot \hat{Y}_{ijk} + \tau_i + \upsilon_j + \varepsilon_{ijk}, \qquad (3)$$

where cc_{ijk} = crown cover percent, treatment i, unit j, sample point k, β_n = coefficients estimated by mixed model analysis, $\hat{Y}_{ijk}$ = crown cover predicted from basal area using model 1, τ_i = treatment effect, υ_i = random unit effect, ε_{ijk} = random error, i = treatment (control, large tree, pine emphasis, pine-with-fire), k = unit 1, 2, . . ., number of units per treatment, and j = sample point 1, 2, . . ., number of sample points per unit. When the model was fit, contrasts were used to estimate the effects of thinning a stand and burning a thinned stand. In the first contrast, all three thinned treatments (large tree, pine emphasis, and pine-with-fire) were compared with the control treatment. In the second contrast, the pine emphasis treatment was compared with the pine-with-fire treatment.

Results

Not surprisingly, for predicting crown cover at the stand level, there is a strong relationship between estimated stand basal area and crown cover (Figure 2). Parameter estimates for the nonlinear fit to the stand level model (1) are shown in Table 2. The model explained about 90% of the variation, based on the corrected total sum of squares, in measured crown cover ($R^2 = 0.9039$). The error distribution is fairly symmetric, with tails slightly shorter than those of a normal distribution (Figure 3). Residual analysis of the stand level model (1) did not reveal any significant trends with respect to treatments or location of plots.

Table 3 shows the results of the mixed model analysis of the Blacks Mountain model (2). The effect of the predicted value of crown cover was significant ($P < 0.0001$). Neither the treatment effect, the burning effect, nor the effect of their interaction was significant (p all greater than 0.05).

However, running the analysis of the Goosenest model (3) gave slightly different results. The effect of the predicted value of crown cover was still significant ($P < 0.0001$; Table 4). The treatment effect was on the margin of being significant ($P = 0.0613$). The contrasts (Table 5) were run even though the treatment effect was not significant with alpha set at 0.05. Control stands had an estimated increase in crown cover percentage compared with thinned stands of 9.56, which was a significant difference ($P = 0.0187$). The small effect of prescribed fire was not significant ($P = 0.6649$).

Table 2. Parameter estimates and standard errors of model 1.

	Estimate	Approximate SE
θ_0	16.9210	1.4827
θ_1	43.710	6.9694
θ_2	2.2308	0.5161
θ_3	0.0196	0.00546

Discussion

Crown cover is time consuming to measure and difficult to standardize to obtain consistent results with different observers. Even the definition of the term is dependent on the method of measurement. We were able to relate observed crown cover to basal area, a clearly defined metric easily derived from most forest inventories. The resultant predictive equation provides a means to estimate crown cover in thinned interior pine stands of northern California.

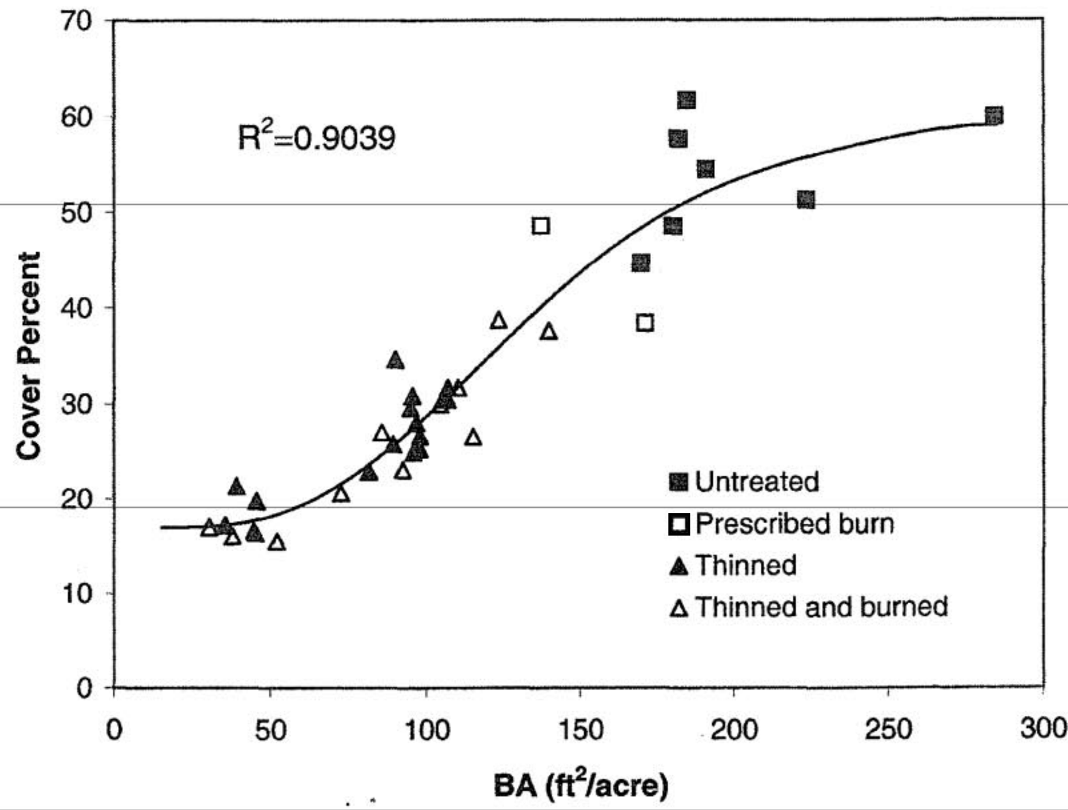

Figure 2. Nonlinear regression of basal area per acre against crown cover at the stand level from model 1. A four-parameter Gompertz equation was used for the regression. There are 37 stands treated with various levels of thinning and prescribed fire. *R*-squared was calculated using the corrected total sum of squares.

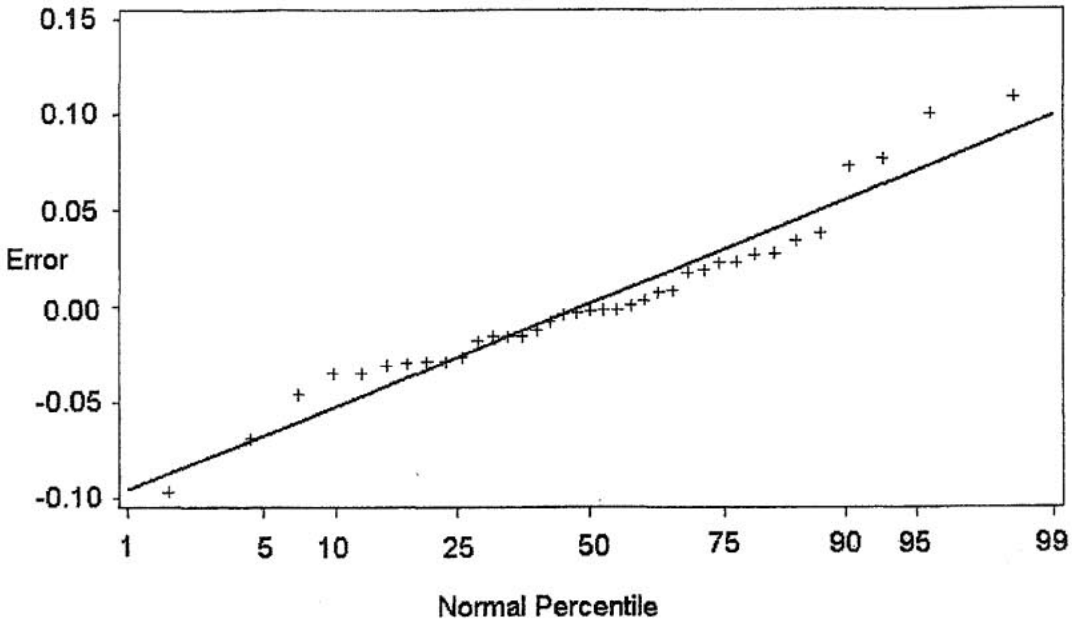

Figure 3. Normal probability plot of model 1 residuals.

Table 3. Single degree of freedom (numerator) *F* tests from the SAS mixed procedure (Type III) for Blacks Mountain (Model 2).

Factor	Effect	Denominator degrees of freedom	*F* statistic	Probability > *F*
Predicted crown cover	0.7479	394	134.36	<0.0001
Treatment		1	10.02	0.1948
High diversity	3.8398			
Low diversity	.			
Burn		1	4.07	0.2929
Burned	−2.3840			
Unburned	.			
Treatment*burn	0.5954	1	0.08	0.8214

Table 4. Type III *F* tests from the SAS mixed procedure for Goosenest (Model 3).

Factor	Effect	Denominator degrees of freedom	*F* statistic	Probability > *F*
Basal area	0.7923	258	134.93	<0.0001
Treatment		3	7.94	0.0613
Large tree	1.8811			
Pine emphasis	−1.0072			
Control	9.8527			
Pine with fire	.			

There was a strong relationship between stand basal area and crown cover in the sampled stands. These results are similar to the findings of Mitchell and Popovich (1997) in an earlier study of ponderosa pine in Colorado and Wyoming. These results are also consistent with the observation that individual tree vertical crown projection can be related to its dbh (Smith et al. 1992). Some factors, such as overlapping crowns and the differences between open-grown trees and trees grown under competition, probably weaken the relationship.

Table 5. Contrasts for Mixed Model Analysis of Model 3. "Treated" represents all three noncontrol treatments at Goosenest.

Contrast	Effect (%)	Denominator degrees of freedom.	*F* statistic	Probability > *F*
Control versus treated	9.5647	3	21.71	0.0187
Pine treatment versus pine with fire	−1.0172	3	0.21	0.6746

The relationship between crown cover and basal area at the stand level appeared very flat above basal areas of about 200 square ft per acre, and the asymptotic maximum cover for these interior pine stands is near 60% (Figure 2). This maximum corresponds closely with a plateau near 60% observed by Mitchell and Popovich (1997). However, Mitchell and Popovich (1997) observed this plateau with basal areas above 100 square ft per acre in the Rocky Mountains, whereas our data indicate that this plateau, if it exists, occurs at a higher level of basal area in northeastern California. One confounding factor is that our stands were measured with a vertical sight tube, whereas Mitchell and Popovich (1997) used a spherical densitometer. The spherical densitometer is known to give overestimates of vertical crown cover, sometimes by 30 to 40% (Cook et al. 1995).

Prescribed fire did not appear to have any effect on cover in the Blacks Mountain or the Goosenest model. We anticipated little fire-induced mortality because our prescribed fires were generally confined to surface fuels, and whole tree yarding of all treeless than 20 in. dbh minimized logging slash. Hence, mortality and corresponding changes in basal area or crown spacing were very minimal.

The results from the Blacks Mountain model indicate that there is little effect on the relationship of crown cover and basal area related to stand structure. In the Goosenest model, there was some evidence of a treatment effect, although it was not significant at $\alpha = 0.05$ ($P = 0.0613$; Table 4). A contrast of all treated plots compared with the control plots was significant ($P = 0.0187$; Table 5) with a difference of about 9% crown cover. This suggests that, although thinning itself could impact the basal area-crown cover relationship, we saw no evidence that the style of thinning performed substantially modified this relationship. The thinning response could conceivably be affected by such factors as time since thinning, species composition, site productivity, and original stand density, which were unaccounted for in this study. Including the length of time between thinning and when measurements were done as a covariate in these analyses would have been ideal. However, this was not done because the range of 2 to 7 years was insufficient.

Thinning intensity varied considerably within each stand and within each treatment. This is because our prescription targeted a given density, and different pretreatment stand conditions required different magnitudes of removal to meet this target. As thinning intensity decreases, the thinning effect must approach zero. Trees grown under competition will usually have shorter, sparser crowns than more open grown trees. Until crowns have had a chance to respond to thinning, crown structure will tend to be more open for a given level of basal area.

Expected reductions in crown cover because of thinning can be quantified in a way related to commonly used expressions of stand density. We were not able to quantify effects of burning or the type of thinning on the relationship between basal area and crown cover. However, at one site, we did find some evidence that, for a given level of basal area, recently treated stands may have a slightly lower level of crown cover. One would expect this effect to diminish over time as crowns expand.

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