Sierra Nevada Mixed-Conifer Species Response to Gap Openings

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Abstract Canopy openings have been used for years as a means of improving tree growth and health. However, little information exists about particular species' responses to the size of the gap opening, and in comparison to each other. Given that the Sierra Nevada has been experiencing a radical change in ratio between shade-tolerant and shade-intolerant species due to fire suppression, such information could help forest managers correct the imbalance through selective encouragement of shade-intolerant stands. White fir, a shade-tolerant tree species, and Ponderosa pine, a shade-intolerant species, were sampled from a research station in the Sierra Nevada. Core samples were taken from three replicates of four different gap sizes (0.1, 0.3, 0.6, 1.0 ha) opened in 1996. Core samples were used to measure growth rings and calculate relative growth rates over the five post-gap years and ten pre-gap years. Relative growth rate was calculated as the percentage of the tree's total basal area added that year. Ponderosa pine's response to gap creation (measured by the change in relative growth rate) was about 9% higher than white fir's. That difference was not a significant factor in the whole-model tests. Likewise, changes in gap size did not significantly affect either species' growth rate.

Introduction

The use of canopy openings has been explored for years as a means of improving tree growth and health. Canopy openings are created either through natural means such as fire and windfall, or artificially by removing trees to create a "gap" in the forest. The trees surrounding the gap then have greater access to sunlight, and suffer less from competition. Gap models have been developed for many different kinds of forest habitat, including some of those present in the Sierra Nevada, as well as the Appalachians of the eastern United States, northwestern Canada, Scandanavia, and Great Britain (Miller and Urban 1999, Mailly and Kimmons 2000). From a forest management standpoint, however, these studies have been little used. Actual relationships between species, gap size, and competitors are much less common than general studies of gap size and stand growth as a whole, and the potential for matching species to appropriate gap size and orientation has yet to be realized (Coates 2000).

While canopy openings are generally recognized to benefit all edge trees to some degree, many past experiments have focused on seedling performance after a gap is opened (Gray and Spies 1997, Oliver and Dolph 1992). Furthermore, many of these studies have taken place in other parts of the world, on species other than those found in the Sierra Nevada (Kneeshaw *et al.* 1998, Sundkvist 1994). The question of whether shade-tolerant or shade-intolerant species benefit more, and in what size opening, still remains.

Answering this question could lead to changes in forest management practices. The forests of the Sierra Nevada are currently experiencing a shift from shade-intolerants to shade-tolerants, due mainly to decades of fire suppression (Minnich *et al*. 1995). White fir in particular is overtaking stands formerly dominated by species such as Ponderosa pine and giant sequoia, resulting in dense understories and a corresponding increase in risk of severe wildfires (Roy and Vankat 1999). More knowledge about species performance in relation to gap size could give forest managers a useful tool for correcting this growing imbalance, as an alternative or complement to prescribed burning and understory thinning.

This project focused on a shade-tolerant species, *Abies concolor* (white fir), and a shade-intolerant species, *Pinus ponderosa* (Ponderosa pine) (Burns and Honkala 1990). Two hypotheses were tested. The first was that Ponderosa pine's response to gap opening would be greater, given that Ponderosa pine prefers less shade than white fir and would therefore respond more when released from shade. The second hypothesis was the smaller gaps would favor the shade-tolerant species, and that as gap size increased, the more shade-intolerant species would be favored, due to the increased availability of light in the larger gaps.

Methods

This study was carried out at Blodgett Forest Research Station (BFRS). BFRS is at about 4000' elevation, near the towns of Cool and Georgetown in the Sierra Nevada. The forest is primarily composed of mixed conifer species, as well as some tan and black oak. Core samples were taken with a hollow core drill approximately 1/4" in diameter. There were four discrete gap sizes: 0.1 ha, 0.3 ha, 0.6 ha, and 1.0 ha. Each gap size was replicated in three different places, for a total of 12 gap openings. All gaps were within a few hundred yards of each other. The cores were taken at regular intervals around the edge of each gap, using a compass to determine even spacing between samples. Samples were also drawn from an approximately equal number of trees in the "matrix" (the forest proper, or areas where no gaps were opened), to compare growth rates with the trees sampled from the gaps.

A total of 84 trees were sampled. White fir was far more prevalent than Ponderosa pine—there were a total of 188 white firs available for sampling as edge trees, but only 49 Ponderosa pines. Of those trees, 18 Ponderosa pines and 35 white firs were sampled as edge trees. Within the 0.1 ha gaps, 2 Ponderosa pines and 14 white firs were sampled; within the 0.3 ha gaps, 5 and 5, respectively; within the 0.6 ha gaps, 7 and 7, respectively; within the 1.0 ha gaps, 4 and 9, respectively. Within the matrix, 13 Ponderosa pines and 18 white firs were sampled.

Relevant growth factors were controlled for. The trees were all at about the same elevation, and used the same watershed and soil type. The side of the mountain where the gaps were cut had a northward orientation, with little variation. The slope was likewise relatively constant. In one part of the forest, trees were thinned (approximately 20% by basal area) some years before any gaps were cut. One gap of each size (4 total) was located within this area, while the other two of each size (8 total) were opened in unthinned areas. This was taken into account (see Results). Trees that showed signs of disease (flagging, bleeding, etc.) were avoided. Only trees with crown classes of codominant or dominant were sampled. Each tree's height and azimuth (from center of gap) were also taken.

Each core sample was mounted, leveled, and sanded before the growth rings were measured. A sliding scale with a digital readout was connected to a computer for the measurements, taken to the nearest .01 mm. A microscope was used to determine where each growth ring ended and the next began. Relative annual growth was calculated by considering that year's added basal area as a percent of the tree's total basal area (previous to that year). The relative annual growth data was averaged over the five post-cut years (1997-2001) and the ten pre-cut years (1987-1996). A ratio of post-cut growth to pre-cut growth was then determined for each tree for data analysis. This is also referred to as the "response" in the Results and Discussion sections below.

Results

Standard least squares whole-model tests were run on all samples taken, as well as on edge trees only. The results are tabled below.

Factor	DF	Sum of Squares	F Ratio	P Value	Power
Thinned area or unthinned	1	0.3435	3.3693	0.0702	0.4416
Edge tree or matrix	1	1.9177	18.8106	<0.0001	0.9899
Species	1	0.2838	2.7842	0.0992	0.3777

Table 1. Standard least squares whole-model test results from all trees (edge and matrix) of BFRS gap size study. Several of the sample areas were in a part of the forest previously thinned by 20% of basal area. The two species studied were *Pinus ponderosa* (Ponderosa pine) and *Abies concolor* (white fir).

Factor	DF	Sum of Squares	F Ratio	P Value	Power
Thinned area or unthinned	1	0.5277	4.3681	0.0423	0.5340
Gap size	3	0.0678	0.1872	0.9046	0.0822
Species	1	0.1344	1.1128	0.2971	0.1782

Table 2. Standard least squares whole-model test results from edge trees only of BFRS gap size study. As noted above, several of the sample areas were in a part of the forest previously thinned by 20% of basal area. The two species studied were *Pinus ponderosa* (Ponderosa pine) and *Abies concolor* (white fir). Four discrete gap sizes were sampled: 0.1 ha, 0.3 ha, 0.6 ha, 1.0 ha.

Species	All trees, before gap opening (1987-1996)	Matrix trees, after gap opening (1997-2001)	Edge trees, after gap opening (1997-2001)
White fir	3.011 ± 0.198	2.790 ± 0.258	3.306 ± 0.267
Ponderosa pine	1.515 ± 0.260	1.541 ± 0.304	1.800 ± 0.378

Table 3. Relative growth rates for two tree species in BFRS gap size study. Relative growth was calculated as the percentage of total basal area added per year. Matrix trees are those within the forest proper, while edge trees are located around the edges of the different gap sizes. Data is based on measurements of growth for ten years before the gaps were cut, and five years after the cutting. Error is given as growth rate ± standard error. The two species studied were *Pinus ponderosa* (Ponderosa pine) and *Abies concolor* (white fir).

Species	Edge trees in thinned area	Edge trees in unthinned area
White fir	1.318 ± 0.105	1.159 ± 0.070
Ponderosa pine	1.553 ± 0.100	1.192 ± 0.140

Table 4. Response in thinned vs. unthinned edge trees for two species in BFRS gap size study. Thinning took place before gaps were cut, with about 20% of basal area removed. "Response" is a ratio between the average relative annual growth rates of the ten pre-cut years (1987-1996) and the five post-cut years (1997-2001). Relative annual growth was calculated as the percentage of basal area added that year. Error is given as response ± standard error. The two species studied were *Pinus ponderosa* (Ponderosa pine) and *Abies concolor* (white fir).

The most significant effect that showed in the results was the change in relative growth rates between edge trees and matrix trees in the five post-cut years. In the whole-model test involving all trees, this factor was by far the most significant (Table 1). Both species showed significantly higher growth rates when located on the edge of a gap than when growing within the matrix (Table 3). Ponderosa pine averaged an increase of 0.285 percent basal area added per year, a jump of approximately 19%. White fir averaged an increase of 0.295 percent basal area added per year. This is a larger total increase than that of Ponderosa pine, but when examined in ratio to its average growth rate while within the matrix (1987-1996), it is actually a smaller improvement, increasing by approximately 10%. Therefore, while white fir showed a higher average relative growth rate in both pre-cut and post-cut years, it was Ponderosa pine that experienced the greatest difference between pre-cut and post-cut growth rates.

The next most significant factor found was being located in a thinned or an unthinned area of the forest. In the whole-model test with all trees, this had a P value of 0.07 (Table 1); in the test with edge trees only, it had a P value of 0.04 (Table 2). Table 4 shows the difference in response between the edge trees in a thinned area and an unthinned area for both species. White firs as edge trees in a thinned area showed about 14% higher response than those in an unthinned area.

For Ponderosa pine, edge trees in a thinned area showed an increase in response of 30% over those in an unthinned area.

The two factors that did not show statistical significance were the species effect and the gap size effect. While the species effect on relative growth rates in the all trees whole-model test is approaching significance (P value ≈ 0.10, Table 1), it is much less significant in the edge trees whole-model test (P value ≈ 0.30, Table 2). The effect of gap size on relative growth rates was much less important (P value ≈ 0.90, Table 2), and no preference for a particular gap size for either species emerged.

Discussion

The difference in growth rates between edge trees and matrix trees is by far the clearest result of this study. Both species experienced some degree of release as edge trees after the gaps were opened. It is interesting to note that during the five post-cut years, white firs still within the matrix actually showed a lower relative growth rate than during the ten pre-cut years, while Ponderosa pines remained at nearly the same level of growth (Table 3). It is hard to say whether this could be caused by some variable not accounted for, or whether it is due to the relatively small sample size of matrix white firs (18, compared to 35 white firs sampled as edge trees).

The effect of the thinning that took place before the gaps were cut was also very apparent. Again, both species benefited from the reduced competition with increased growth rates. Ponderosa pine's increase of 30% was considerably higher than white fir's 14%. This might be attributed to Ponderosa pine's higher preference for sunlight—as basal area was reduced, more light was available to both matrix and edge trees. Ponderosa pine might have been able to respond faster or more vigorously than its shade-tolerant counterpart, similar to the hypothesized difference in response within the larger gap sizes (see Introduction). However, a low sample size might also account for this difference in response to thinning—as noted above, there was only one replicate of each gap size within the thinned area, while two replicates of each in the unthinned areas.

A species effect was not clearly observed, despite the difference in edge tree response between Ponderosa pine (19% increase in relative growth rates) and white fir (10% increase). It is unclear whether this difference is another result of low sample size, or whether there was a difference and it was not well detected. In the whole-model test where the species effect was approaching significance (Table 1), the power of the test was only about 38%.

Likewise, a significant effect from gap size was not found. Neither species' relative growth rates indicated a preference for a particular gap size, or even an observable trend as gap size increased. It is possible that the gaps were too close in size, and that a greater difference between them might be a better basis for study. However, there was an order of magnitude between the smallest and largest gap sizes (0.1 and 1.0 ha), so it is also possible that the gap sizes were well selected. The insignificance could well be due to the fact that, in the 0.1 ha and 1.0 ha gap sizes, many more white firs were sampled than Ponderosa pines, due to the limited number of Ponderosa pines available there (see Methods). Sampling in the other two gap sizes (0.3 and 0.6 ha) was equally balanced.

Overall, while some significant factors in improving growth were found, the two factors which were the focus of this study did not show as significant. Time was somewhat of a sampling constraint, as there was a limited amount of time available between the winter snows melting and the due date of this project. The limited availability of Ponderosa pine was much more important as a constraint, as evidenced by the fact that standard errors throughout the statistics were almost always higher for Ponderosa pine. Further research that used appropriate sample populations could gather more information as to the relevance of species and gap size, and whether gap openings might play an effective role in reversing the increasing dominance of Sierra Nevada mixed-conifer stands by shade-tolerant species such as white fir.

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