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Ten-year Diameter and Basal Area Growth of Trees Surrounding Small Group Selection Openings

Abstract

The effects of small openings in forest stands has interested silviculturists and ecologists for years. Interest generally has centered on the vegetation in the openings, not on that immediately outside of them. Quantitative information on the growth of trees adjacent to group-selection openings, although often mentioned in forestry textbooks as contributing to cost effectiveness, is scant. Five conifer and three hardwood species bordering 9-, 18-, and 27-m diameter openings in the northern Sierra Nevada of California were examined for diameter growth 10 years before and 10 years after an initial group selection cutting. Ten-year diameter growth at breast height of various combinations of species and diameter classes did not differ significantly ($P > 0.05$) among opening sizes 10 years after cutting. But mean basal area growth of pines (ponderosa and sugar) 10 years after cutting was significantly greater ($P < 0.05$) than that before cutting in 18- and 27-m openings. This difference also was found for shade-tolerant conifers (Douglas-fir, incense-cedar, and California white fir) bordering all opening sizes. Mean basal area growth of hardwoods (California black oak, tanoak, Pacific madrone) did not differ before and after cutting for any opening size.

Introduction

Today, as never before, sentiment is shifting toward forest management systems that are perceived as being more gentle on the land, its vegetation, and its creatures. Sustaining ecosystems and not chronically disrupting ecosystem processes are the watchwords of modern forestry. Smith (1962) noted that "The group selection method is more readily adapted to a wide variety of conditions than any other because the ecological requirements of most species can be met within its framework." Furthermore, the small, scattered openings created by timber harvest suggest small-scale natural disturbances such as those created by small hot fires.

The group-selection cutting method, which is part of an uneven-aged silvicultural regeneration system, involves the removal of groups of trees to create small openings that range from 0.01 to 0.8 ha. The upper size limit of openings is governed primarily by the environment in them. Openings should not be so large as to lose the site protection of the surrounding trees (Daniel et al. 1979). Thus, slope, aspect, and height of surrounding trees influence opening size. Several openings, scattered throughout a stand, usually are harvested together on a cyclical basis. The cycle often is 10 to 20 years. There is no rotation and cutting continues in perpetuity, usually removing clusters of mature trees. Initial and early entries into the stand, however, usually have an element of "improvement" in them, whereby trees of younger ages are removed. Indeed, the necessity for cutting small trees "is felt especially in making a first cutting in previously unmanaged stands" (Hawley 1946). This gives opportunity to lower the proportion of less desirable species, trees with poor growth, those that interfere with the growth of better trees, and poorly formed, slow-growing, and diseased individuals.

Increased growth of residual trees after cutting is generally considered to be beneficial. But for group selection, the growth of trees surrounding the openings is seldom quantified and its amount has not been reported for mixed conifer and hardwood species in the western United States. The minimum opening size required to influence tree growth and the distance into the stand beyond which the openings will have little or no effect are equally unreported. This paper presents results on these subjects from a study that quantified 10-year diameter and basal area growth of various sizes and species of trees before and after group-selection cutting in three sizes of small openings.

Methods

Site and Species

The study was located on the Challenge Experimental Forest in north central California. Here, site quality is high and the dominant species, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), will average 34 m in height in 50 years (Powers and Oliver 1978). Summers on the Experimental Forest are hot and dry; winters cool and moist. The average midsummer maximum temperature, based on 43 years of record, is 32 °C; the midwinter minimum is -1 °C. The growing season is about 200 days. Precipitation averages 1727 mm with 94 percent falling between October and May. Moisture is the limiting factor for growth, and drought often predisposes less vigorous trees to attack by insects and disease. Aspects are mostly northeast and southwest and slopes vary from 3 to 30 percent. Texture of the soils is clay loam grading with depth to clay. Soils tend to be deep, moderately well drained, and quite fertile.

In addition to ponderosa pine, other tree species on the Forest are Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), sugar pine (*Pinus lambertiana* Dougl.), California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), and incense-cedar (*Libocedrus decurrens* Torr.) (Little 1979). Hardwoods, principally California black oak (*Quercus kelloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific madrone (*Arbutus menziesii* Pursh) are scattered throughout as individual trees, clumps, or groves. The Forest consists of a broad mosaic of even-aged stands resulting from past logging and fires. The oldest dominant and codominant conifers in the study area were about 100 years old when the study began and averaged about 77 per ha, 70 percent of which were ponderosa pines. Typical of stands in the northern Sierra Nevada, a few overmature hardwoods were present along with a large component of younger trees of shade-tolerant species (Douglas-fir, California white fir, incense-cedar, and tanoak) (Rundel et al. 1977). Altogether, trees larger than 8.9 cm in diameter at breast height (d.b.h.) numbered 613 per ha and contained about 62 m^2 per ha of basal area.

Location and Environment

Groups of large and small trees, which were located in two units located within 1.5 km of each other on relatively homogeneous ground having similar soil and growth potential, were logged in the fall of 1963 to form circular openings of about 9, 18, and 27 m in diameter (crown dripline to crown dripline). There were 27 openings in one unit and 21 in the other. The smallest size opening was created by removal of several medium- to small-sized trees; the largest by removal of several large, medium, and small trees. Surrounding trees were of all sizes. Each opening size was replicated 16 times. Location of openings was random with the restriction that they be within 60 m of skid roads. In May 1964 unmerchantable conifers and hardwoods were removed and the ground scarified by a bulldozer. As a result, each opening was free of vegetation, at least above ground. Below ground, roots of border trees probably had room to expand into area formerly occupied by cut trees.

Measurements and Analysis

In spring 1964, shortly after harvest, trees surrounding the 48 group-selection openings were visually evaluated to determine the distance from the opening edge where they no longer received additional light from the opening or where their roots most likely would not be able to extend into it. Altogether, 677 conifer and hardwood trees in the breast-height diameter range of 10 to 106 cm comprised the after-logging sample (Table 1). No trees beyond 6 m were judged to be affected by creation of the openings. All trees were remeasured in August 1973 or after 10 complete growing seasons.

The before-logging sample was done retrospectively by boring trees at breast height and calculating radial growth from 1954-1963, which was doubled to arrive at diameter growth. Because the prelogging measurements were inside bark and the after-logging measurements were outside bark, they needed to be reconciled. Specifically, the after-logging data needed to be corrected for bark growth during the 10-year period. This task was accomplished by using the corrections formulated by Dolph (1981) for the five conifer species. No corrections were available for the hardwood species.

For the before-logging sample, we randomly chose one of the two units. It had 27 openings in it, 9 of each size. To check the previously determined opening-influence limit of 6 m, we measured additional trees 6 to 13 m from the opening. Altogether, 372 trees, located 0.5 to 13 m from the opening edge comprised the prelogging sample (Table 1). The distance of each tree from the opening edge was recorded.

TABLE 1. Number of sample trees bordering openings after logging (48 openings) and in prelogging (27 openings) period by diameter, class and species.

Diameter class (cm)	Species	After logging opening diameter (m) 9	18	27	Before logging
		No. of trees			
10 to 30	Ponderosa pine	4	7	5	15
	Sugar pine	—	1	1	1
	Douglas-fir	24	28	30	52
	Calif. white fir	1	7	4	3
	Incense-cedar	24	34	43	68
	Hardwoods	18	11	33	14
31 to 60	Ponderosa pine	35	53	46	86
	Sugar pine	1	—	1	—
	Douglas-fir	14	23	22	38
	Calif. white fir	—	1	3	2
	Incense-cedar	13	11	12	24
	Hardwoods	5	2	5	3
>61	Ponderosa pine	32	35	61	53
	Sugar pine	4	—	2	—
	Douglas-fir	5	5	7	11
	Calif. white fir	—			—
	Incense-cedar	—	—	—	—
	Hardwoods	2	—	2	2

To determine tree growth and distance relationships, data were analyzed by regression and the analysis of variance (ANOVA) therefrom, and paired t tests (Wilkinson 1989). Statistical significance in all tests was at $\alpha = 0.05$. Both d.b.h. and basal area were considered to evaluate growth, and many transformations of both were examined for normal distribution of residuals, constancy of variance, and trend of residuals relative to predicted values. The model in this paper best met the assumptions of normality and provided the best fit.

Steps in the analysis were first to determine the distance into the adjacent stand where trees were influenced by the openings. The next step was to analyze for possible differences in before- and after-logging stand growth. The third step was to examine the after-logging data to determine possible differences in 10-year diameter growth among species and tree size classes for the different opening sizes. Because the first analysis indicated no significant effect beyond 6 m, we used data from the 48 openings in the after-logging analysis.

Results

Tree Growth and Distance from Opening Edge

We found the best expression to document the influence of the openings to be a linear equation of the difference in 10-year basal area growth before and after logging. Based on this difference, little growth occurred on trees farther than 6 m into the forest (Figure 1). The equation was of the form:

$$Y = \beta_i + \alpha_1 D + \alpha_2 \ln(D) + \varepsilon$$

in which:

$Y = dba_1 - dba_0$

D = distance from opening edge (m)

dba_0 = inside bark basal area growth for 10-year period before harvest (cm^2)

dba_1 = inside bark basal area growth for 10-year period after harvest (cm^2)

β = intercept term for the *i*th opening size

α = coefficients, and

ε = random error.

We found a weak relationship between the difference in before- and after-logging basal area growth and distance from opening edge. The highest r-squared values, which were for trees adjacent to the largest opening size, were 0.11 for pines, and 0.06 for tolerant conifers. Both values were significant at P = 0.05, but are of no practical significance. Although the difference in growth for the 10-year period tended to decrease as distance from the opening increased (Figure 2), we were unable to objectively define a specific distance from the opening edge where the opening ceased to have an influence. An exception to the decreasing growth trend was that some trees on

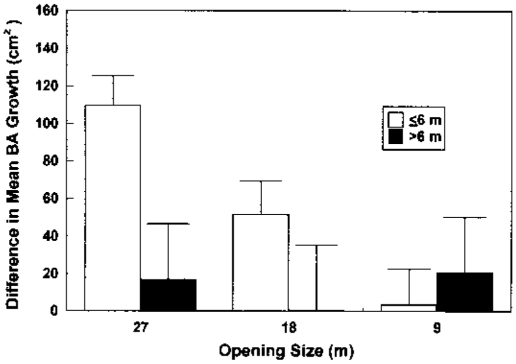

Figure 1. The difference in mean before- and after-logging inside bark basal area (with standard errors) suggests that little growth accrues to trees farther than 6 m into the forest, at least for 18- and 27-m diameter openings.

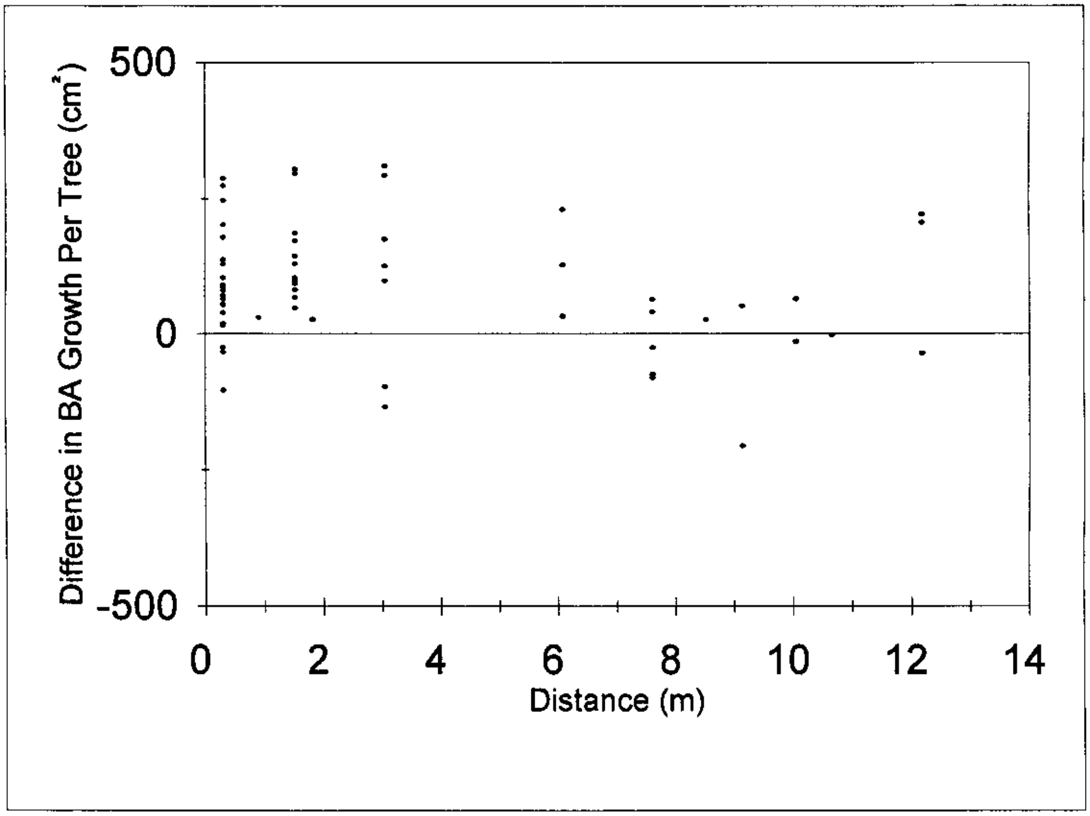

Figure 2. Example of the difference in before- and after-logging 10-year basal area growth per tree relative to distance from opening for pines in 27-m openings, Challenge Experimental Forest, north central California, 1973.

the edge of openings appeared to grow less than those farther back in the forest (Figure 2). This difference may be the result of shock caused by opening up the stand or possible damage to roots from logging.

Before and After Logging Comparison

Mean 10-year basal area growth after logging differed significantly from mean 10-year basal area growth before logging for pines bordering 18- and 27-m diameter openings, and for shade-tolerant conifers adjacent to 9-m, 18-m, and 27-m diameter openings (Table 2). The difference in 10-year basal area growth of hardwoods before and after logging did not differ significantly among opening sizes. And in one instance (27-m diameter openings), hardwoods actually grew 52 percent slower. We believe, however, that this negative response has little practical importance and no statistical significance ($P = 0.23$).

For those species and opening sizes where growth increased after logging, the basal area growth increase ranged from 9 percent for pines adjacent to 18-m openings and for tolerant conifers next to 9-m opening to 87 percent for hardwoods adjacent to 18-m diameter openings (Table 2). When all species and opening sizes were combined, the average net 10-year basal area growth increase resulting from logging was 24 percent.

Diameter Growth and Opening Size

Average 10-year diameter and basal area growth after logging were examined statistically to determine which variable explained the most variation. Based on ANOVA, no statistically significant differences in breast-height diameter were found among species or diameter classes among opening sizes (Table 3). Overall (but not significant) trends in mean values were: diameter growth was greater for large trees than small trees; growth

TABLE 2. Average 10-year basal area growth of trees in group selection openings by species class and size of opening before and after logging.

Species class	Opening diameter (m)	Before logging (cm^2/10 yrs)	After logging (cm^2/10 yrs)	Increase (decrease) (pct)	Standard error of difference (cm^2)	P[a]
Pines	9	436	439	0	17	0.43
	18	370	405	9	18	0.05
	27	408	516	26	20	0.01
Tolerant conifers	9	215	234	9	10	0.04
	18	191	226	18	6	0.01
	27	160	224	40	14	0.01
Hardwoods	9	53	83	57	12	0.06
	18	60	112	87	23	0.07
	27	279	183	(52)	120	0.23
Average				24		

[a] Tail probability (P-value) of the paired t-statistic between the before and after logging values on each line. P values < 0.05 are considered significant for individual tests. If simultaneous tests for the three openings are desired, then $P < 0.05/3 = 0.016$ are considered significant (Bonferroni t-test).

TABLE 3. Average ten-year diameter growth of various combinations of tree species and sizes bordering group selection openings, 1964-1973.

Species combination	Diameter class (cm)	Opening diameter (m)	Diameter growth (cm/10 yrs)	Increase (pct)	Root mean square error (cm)	F	P
Pines	10 to 30	9	2.8[a]	9	2.9	0.34	0.72
		18	2.8	14			
		27	4.1	19			
	31 to 60	9	3.8	8	2.0	2.80	0.07
		18	4.3	8			
		27	5.1	10			
	>61	9	4.8	6	2.0	0.58	0.56
		18	4.8	7			
		27	5.3	7			
Tolerant conifers	10 to 30	9	3.0	16	2.2	0.57	0.57
		18	3.3	16			
		27	3.6	19			
	31 to 60	9	4.6	11	2.1	0.53	0.59
		18	4.8	12			
		27	5.1	12			
	>61	9	5.6	8	2.5	0.69	0.52
		18	7.4	9			
		27	7.4	10			
Hardwoods	10 to 30	9	3.6	21	2.5	0.54	0.59
		18	4.3	28			
		27	4.3	25			
	31 to 60	9	4.6	11	2.3	1.16	0.36
		18	5.8	18			
		27	3.0	6			

[a] No significant differences in diameter growth at the 5-percent level were found among opening sizes for each diameter class and species, based on ANOVA.

was greater for trees adjacent to the largest opening size; and shade-tolerant conifers grew better than less tolerant pines. Hardwoods grew better than conifers in the smallest diameter class.

Discussion and Conclusions

The juxtaposition of trees of many sizes relative to each other and to distance from the edge of small openings is such that the amount of light and soil moisture that each tree gains from new group-selection openings is highly variable. Large trees, well back from the opening, have an advantage over small trees because their large crowns and root mass enable them to exploit the typically small spaces where light filters through and where roots can extend into new openings. And large trees, located near the opening boundary, may deny site resources from the opening to trees behind them. Smaller trees, in general, need to be closer to the openings to gain additional resources from them. Consequently, growth of trees adjacent to openings is influenced by tree size, distance from opening, and position of other trees. Because of this combination of factors, we found it difficult to regress tree growth to distance from opening edges. McCreary and Perry (1983) also found it difficult to regress basal area increment to distance for 35-year-old Douglas-fir trees adjacent to strip thinnings near Corvallis, Oregon.

The adjacent tree root/opening size interaction also is a factor affecting tree response. In a separate study on a nearby area on the Experimental Forest, Ziemer (1968) measured soil moisture around a forest-grown but completely released (all other trees removed) 70-cm diameter sugar pine. He found that "soil moisture depletion extended outward to a distance of slightly over 6 m from the base of the tree and somewhat deeper than 5 m under the tree." Presumably, this zone of depletion was caused by moisture-absorbing tree roots. Consequently, at least some roots of adjacent trees probably were already present throughout the 9-m wide openings. And because only a few trees were removed to create this size of opening, most of the opening already was occupied by tree roots. The combination of already-present roots, little new area free of roots, and probable rapid expansion of existing roots tended to mitigate the response from adjacent trees.

Basal area growth of trees adjacent to 9-m diameter openings, in general, was not any better than that of trees farther back in the stand. But pines and shade-tolerant conifers near 18-m openings grew significantly better. These findings suggest that the minimum opening size required to enhance tree growth lies between 9- and 18-m in diameter.

In this study, we visually surveyed hundreds of trees adjacent to openings and judged that no tree beyond 6 m was influenced by the openings. This finding, Ziemer's work, and our graphical results (Figure 1), indicate that 6 m is about the limit of influence from these small sizes of openings in the conifer and hardwood stands on the Experimental Forest. McCreary and Perry (1983) found that increases in basal area growth of Douglas-fir trees in western Oregon extended 3.1 m into the uncut forest. They also cited a Swedish study with Scotch pine (*Pinus sylvestris*) where diameter growth "greatly increased," but only on trees up to 3.0 m in the unthinned stand. Based on these studies, it appears that the influence of small openings and thinnings on adjacent trees is limited in terms of distance into the uncut stand, but within this affected zone, stem growth of trees is significantly increased. These findings may be of interest to ecologists (Sousa 1984, for example) who have long been intrigued by the effect of gaps in the forest canopy.

In our study, pines and tolerant conifers grew significantly better after logging than before logging in the larger openings. When considering the group selection cutting method, forest managers can now ascribe a modest amount of basal area growth (24 percent in 10 years) to trees bordering small-sized openings on sites typical of this study. This growth, as well as the abundant conifer and hardwood regeneration noted in these openings (McDonald and Abbott 1994), add to the applicability of this cutting method.

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