# Precommercial Stocking Control of Coast Redwood at Caspar Creek, Jackson Demonstration State Forest[1,2]

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**Abstract**

Regeneration of coast redwood by stump sprouting often results in a stand condition that is very dense. A precommercial thinning of redwood sprouts allows managers to select trees and spacing that can best utilize the productivity of the site. The study of five thinning treatments with an unthinned control was initiated on a 19-year old third growth stand. Treatments were 100, 150, 200, 250, and 300 trees per acre plus an unthinned control. All 18 plots were measured in 1981 immediately after precommercial thinning, again in 1986 (5-year growth), and again in 1998 (12-year growth). Results indicated that despite the range of thinning, the 38-year-old stand showed no statistical differences in volume growth or yield between the thinning treatments. Heavily thinned treatments concentrated more growth on fewer trees to match the stand volume growth in the lightly thinned treatments. A trend appears to be developing that indicates a drop in stand productivity for the heaviest thinning and the control. More time is needed to determine if the trend will continue.

*Key words: precommercial, redwood, stocking, thin*

## Introduction

This report documents the growth response of 18 precommercially thinned and control plots in the coast redwood *(Sequoia sempervirens)* forest type on the Jackson Demonstration State Forest (JDSF). These plots are located in a unit that had been clearcut as part of the 1961 Caspar Creek Cutting Trials (CCCT). This study originated in 1981 as a cooperative effort by the California Department of Forestry and Fire Protection (CDF) and the USDA Forest Service - Redwood Sciences Lab. CDF has since continued the study with a 1986 measurement and report that detailed the first five years of growth following the precommercial thinning (Lindquist 1988a). This paper is a summary of the update of the study, incorporating the 1998 measurement.

Improving the productive capacity of forest stands is the primary reason why forest managers invest in timber stand improvement work. Site preparation, planting, thinning, and other cultural operations are designed to produce a positive return when considering operational and capital costs. This study is designed to determine the growth response of coast redwoods to a variety of stocking levels following precommercial thinning.

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The optimal stand density for young coast redwoods is currently unknown and a complex question. Thinning too heavily may result in inefficient use of the site's productive capacity. In addition, the sprouting ability of coast redwood can result in excessive stocking and spacing problems that are not common to other conifer species. A single redwood stump may often produce more than 20 stems as the result of sprouting. The intense competition among these sprouts may eventually produce one or two codominant trees over the course of many years. Thinning is designed to accelerate this natural process.

Another characteristic of coast redwood is to produce dense, wide crowns if given abundant space, where a low density stand will expend much of its growth capacity on limbs and development of stems with a large amount of taper. Stem selection early in stand development is an important and reasonable option for the forest manager.

## Methods

The study is a complete random block design with three blocks. Each block contains six treatments including an unthinned control plot. Blocks 1 and 2 are located in the unburned portion of the clearcut and block 3 is located in the burned portion. The block design allows for the identification of effects due to treatments while controlling for block effects and providing replication. Eighteen plots were established in the study area as shown in *figure 1*. Each plot is 0.4-acres in size. Trees were tagged and measured in the central 0.2-acre area of each plot, while leaving the trees in the 0.2-acre perimeter area as a treatment buffer. The designated treatment was applied to the entire 0.4-acre plot. In addition, there is an unthinned control in each of the three blocks. Trees were selected to retain an equal number of stems in each quadrant of the central plot and in each of the four buffer areas. Redwood was designated as the highest priority for retention, with Douglas-fir *(Pseudotsuga menziesii)*, retained where suitable redwood were not available.

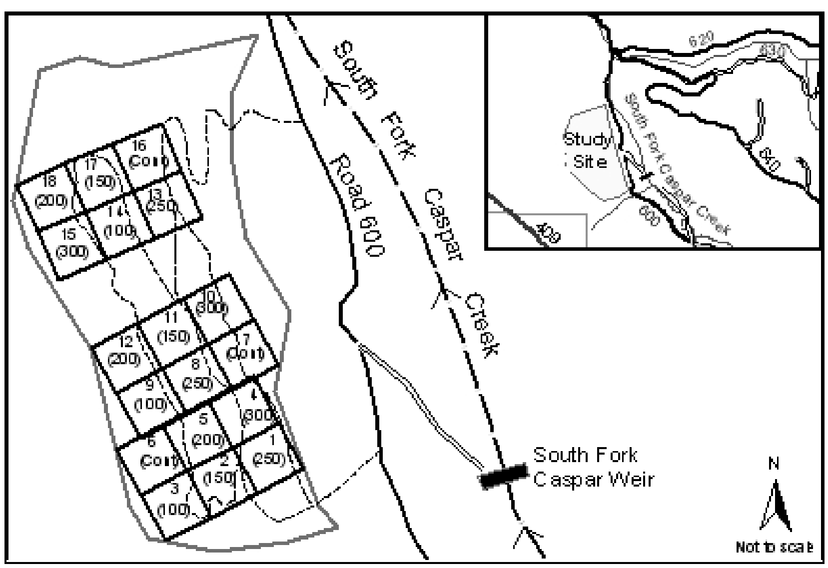


**Figure 1**—Study design layout for the pre-commercial thinning study.

*Figure 2* summarizes the sequence of events in the life of the stand and for the study. Block 3 was burned during site preparation in 1962, which resulted in a dense growth of blue blossom *(Ceonothus thyrsiflorus)* that has since declined in site occupancy. Redwood sprouts, in contrast to natural seedlings, represent 91 percent of all of the redwood regeneration prior to thinning in 1981.

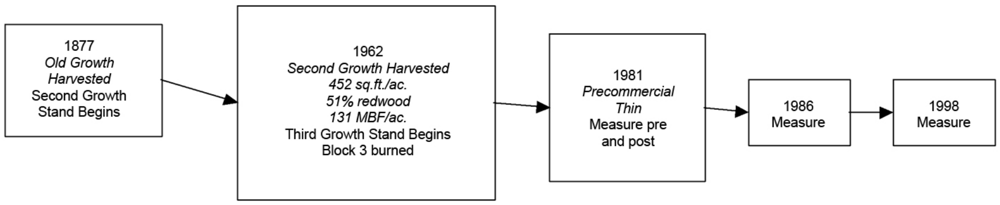


**Figure 2**—Sequence of events for the stand and the study.

Redwood sprout clumps were thinned to at least a 24-inch stem spacing within a single stump due to the need to distribute the trees as uniformly as possible. Trees as small as 1.5 inches in diameter were selected for retention. The primary objective in thinning redwood clumps was to achieve average spacing targets. Where spacing was adequate, thrifty trees were retained and the remaining stems were thinned from below.

Sample cores for the determination of age and site index (Lindquist and Palley 1961) were taken at each point in time. Local volume equations were developed to account for local conditions and allow for predictions that did not require a total height measurement for each tree. These equations were structured to predict total volume per plot. Individual tree volume was computed for each redwood and Douglas-fir tree with a height measurement, using the Krumland and Wensel (1979) equations for cubic (four inch top) and Scribner board foot (six inch top). A full description is available in Lindquist (2004).

Treatments in this study are the reduction of stand density, as measured by the number of trees per acre. Response to treatments may be exhibited in the average standing volume, periodic growth, mean annual growth as a function of basal area, average diameters, ingrowth, and mortality. Simply identifying differences between treatments is not the only intent of this study. Identification of a suitable stocking level to either maximize yield or accelerate the production of larger trees may be of practical use to forest landowners and managers. The statistical analysis relies upon the use of Analysis of Variance (ANOVA) to determine differences in response as the result of various levels of treatment. Blocks are included as a factor in the ANOVA to account for block effects. Other factors are considered and, where appropriate and not influenced by treatment effects, are accounted for using analysis of covariance (Gomez and Gomez 1984). Specific treatment differences are identified by the Scheffe test of multiple contrasts (SMC). SMC is only appropriate when the ANOVA indicates a significant difference in treatments overall (Neter and others 1985).

## Results

Results are presented for diameter, basal area, and cubic and board foot volume response. Mortality was primarily limited to the smallest trees. Ingrowth was still occurring in 1998, particularly for the 10.5-inch dbh threshold. Less Douglas-fir ingrowth occurred as the overstory density increased.

## Diameter

Average stand diameter is expressed as quadratic mean diameter (QMD), the diameter of the tree of average basal area. The average stem diameter for trees greater than 1.5 inches immediately after thinning in 1981, ranged from 5.6 inches (control) to 10.7 inches (T150); a range of 5.1 inches *(fig .3).* This exhibited a highly significant difference between treatments, due partially to removal of most of the smallest trees in the heavily thinned plots. This difference remained significant in 1986 and 1998, due to the greater number of slow-growing small stems in the control and higher residual-density treatments. Changes in average stand diameter were also affected by increased mortality of suppressed Douglas-fir. The range of average diameters in 1998 increased to 9.3 inches, partially due to the rapid radial growth in the T100 and T150 treatments.

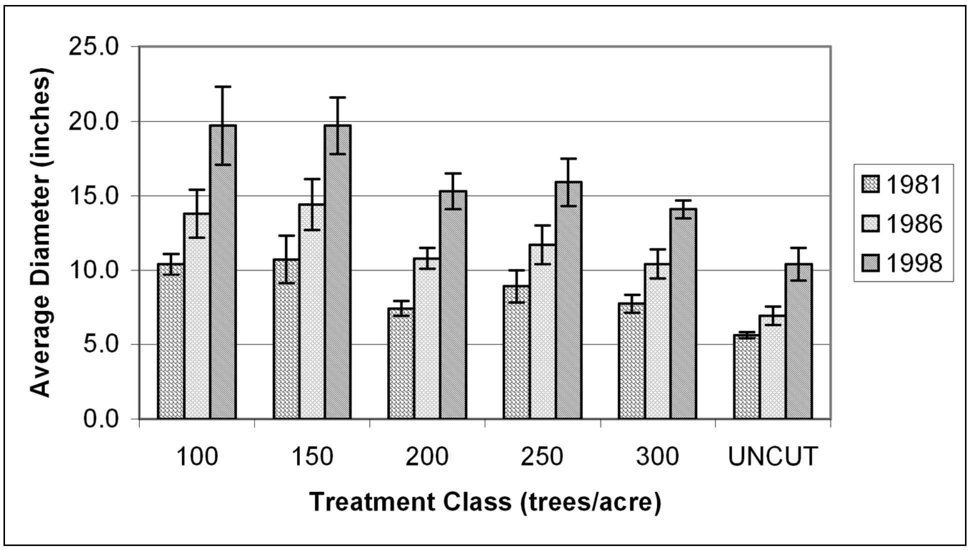


**Figure 3**—Average stand diameter for trees greater than 1.5 inch dbh. Error bars are one standard deviation.

## Basal Area

Stand basal area is a useful variable to consider in the evaluation of growth because it is highly correlated to stand volume. In 1981, immediately after thinning, the differences between treatments were highly significant for stands greater than 1.5 inches. The basal area of trees greater than 10.5 inches *(fig. 4)* was not significantly different between treatments in 1981, in spite of the fact that thinning changed the number of stems in each treatment. These values ranged from a low of 16.9 to 65.3 square feet per acre, with an average of 44.2 square feet per acre. The 1986 inventory also showed no significant differences between treatments despite the fact that the average basal area in thinned stands increased by a factor of 4.3. By 1986, an average of 67.8 trees per acre passed the 10.5-inch threshold. Average stand basal area in 1998 again showed no significant difference between treatments.

Despite the highly significant differences in the number of trees retained in the stands after treatment, the basal area was not significantly different after 17 years. The trees have adjusted to the space provided by thinning. However, there is an apparent response trend developing when both block and pre-treatment large tree inventory are considered *(fig. 5)*. *Table 1* shows that pre-harvest basal area in trees greater than 10.5 inches is an important covariate. Pre-harvest basal area is correlated to 1998 basal area (0.66), cubic volume (0.66), and board foot volume (0.78).

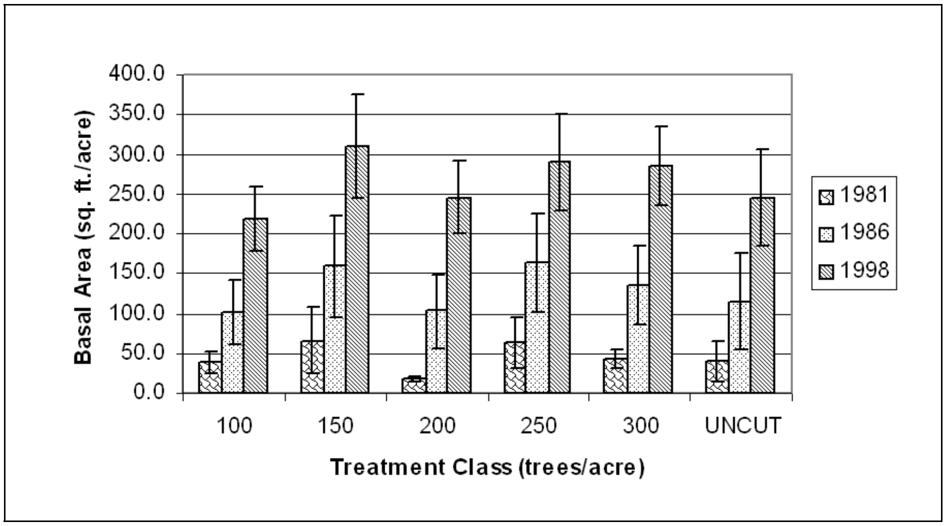


**Figure 4**—Average basal area for trees greater than 10.5″ dbh. Error bars are one standard deviation.

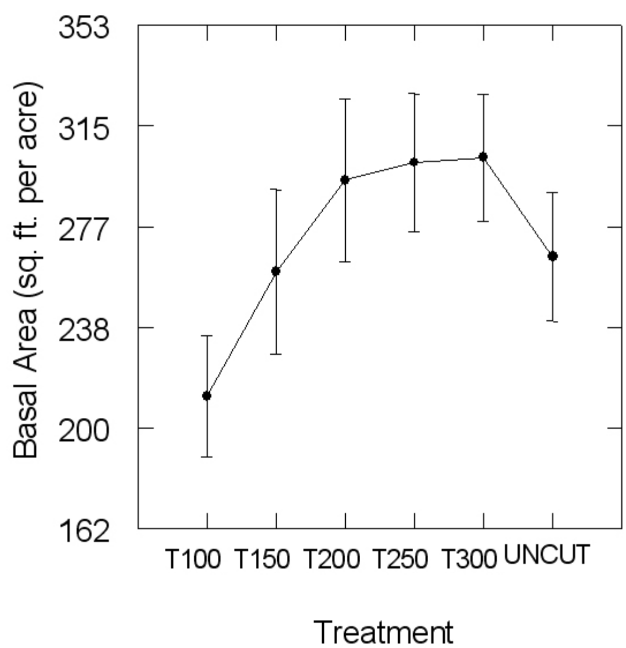


**Figure 5**—Basal area treatment means for trees greater than 10.5 inches for 1998. ANOVA includes block factor and pre-harvest basal area (>10.5″) as concomitant variable.

**Table 1**—*Analysis of variance for basal area (ft² per acre, trees >10.5 inches) inventory in 1998.*

N: 18 Multiple R: 0.860

| *Source* | *Sum-of-Squares* | *d* | *Mean-Square* | *F-ratio* | *P* |
|---|---|---|---|---|---|
| Block | 2068.578 | 1 | 2068.578 | 1.221 | 0.295 |
| Treatment | 18915.927 | 5 | 3783.185 | 2.233 | 0.131 |
| Pre-BA10 | 18871.893 | 1 | 18871.893 | 11.141 | 0.008 |
| Error | 16939.214 | 10 | 1693.921 | | |

The most recent periodic basal area growth in all treatments except T100 was greater than the control, but not statistically significant. Periodic basal area growth for the 17-year period shows no significant differences but all thinned treatments have higher basal area growth than the uncut plots.

## Cubic Foot Volume

Cubic volume was computed for all trees greater than 1.5 inches at breast height. Except for the unthinned plots, there were very few stems smaller than 4.5 inches diameter. No ingrowth was observed in terms of cubic volume (trees greater than 1.5 inches). Average cubic-foot inventory was not statistically different between treatments within the 1981, 1986, or 1998 *(table 2)* inventories. Plot variation within treatments was large (*fig. 6* error bars). *Figure 6* illustrates that a trend is developing, similar to basal area *(fig. 5)*, where although not statistically significant yet, the two least-stocked treatments appear to exhibit lower cubic foot productivity. The cubic volume response to thinning in terms of the five, 12, and 17-year periodic growth rate showed no difference between treatments.

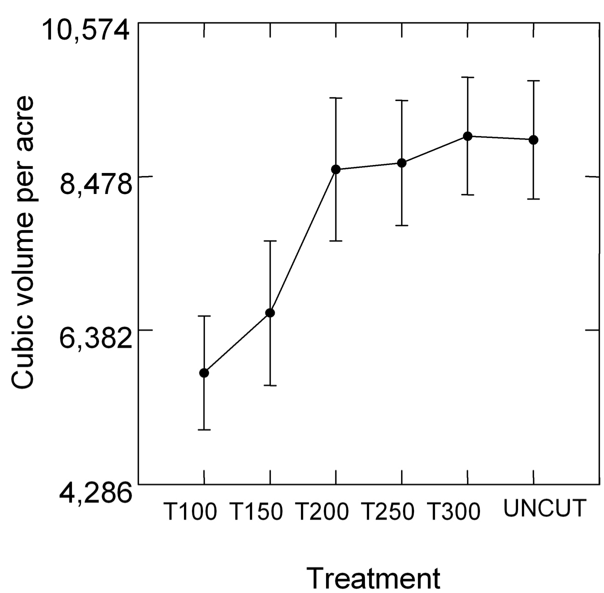


**Figure 6**—Cubic volume treatment means for 1998. ANOVA includes block factor and pre-harvest basal area (>10.5 inch) as concomitant variable.

**Table 2**—*Analysis of variance for cubic volume per acre inventory in 1998.*

N: 18 Multiple R: 0.759

| *Source* | *Sum-of-Squares* | *df* | *Mean-Square* | *F-ratio* | *P* |
|---|---|---|---|---|---|
| Treatment | 2.36960E+07 | 5 | 4739194.722 | 2.676 | 0.087 |
| Block | 274960.137 | 1 | 274960.137 | 0.155 | 0.702 |
| Pre-BA10 | 2.01839E+07 | 1 | 2.01839E+07 | 11.398 | 0.007 |
| Error | 1.77090E+07 | 10 | 1770896.300 | | |

## Board Foot Volume

Board-foot volumes were computed for trees greater than 10.5 inches dbh *(fig. 7)*. Over time, board-foot inventories were affected somewhat by in-growth of smaller trees into the 10.5-inch class. This effect was greatest in the lower density treatments. The board-foot values for each of the three inventory dates indicated no significant differences between treatments *(table 3)*. Adjusting the average treatment means for block and starting inventory effects *(fig. 8)*, the relationship, although not statistically significant, appears to be that T250 has produced the maximum board foot volume after seventeen years.

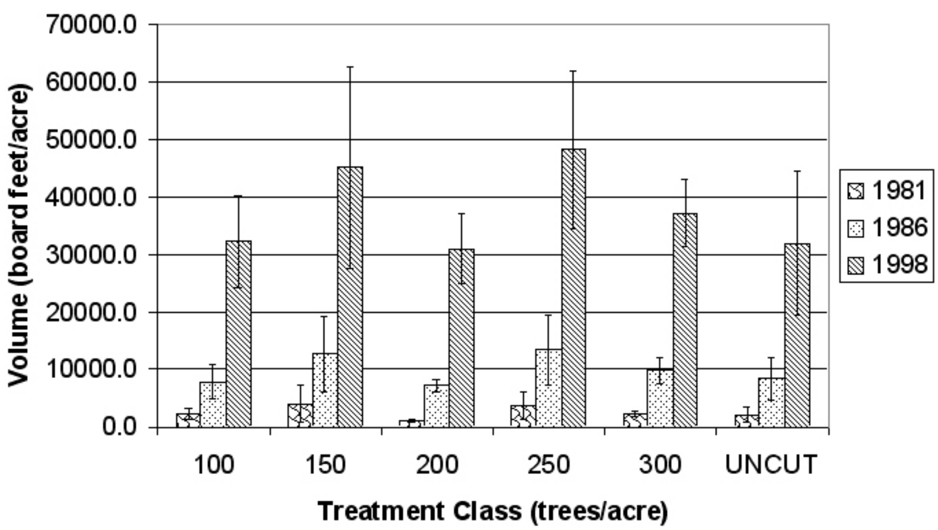


**Figure 7**—Average board foot per acre volumes (Scribner). Error bars are one standard deviation.

**Table 3**—*Analysis of variance for board foot volume inventory in 1998.*

N: 18 Multiple R: 0.903

| *Source* | *Sum-of-Squares* | *df* | *Mean-Square* | *F-ratio* | *P* |
|---|---|---|---|---|---|
| Treatment | 2.70464E+08 | 5 | 5.40928E+07 | 1.087 | 0.429 |
| Block | 1.71297E+08 | 2 | 8.56487E+07 | 1.722 | 0.233 |
| Pre-BA10 | 2.94656E+08 | 1 | 2.94656E+08 | 5.923 | 0.038 |
| Error | 4.47759E+08 | 9 | 4.97510E+07 | | |

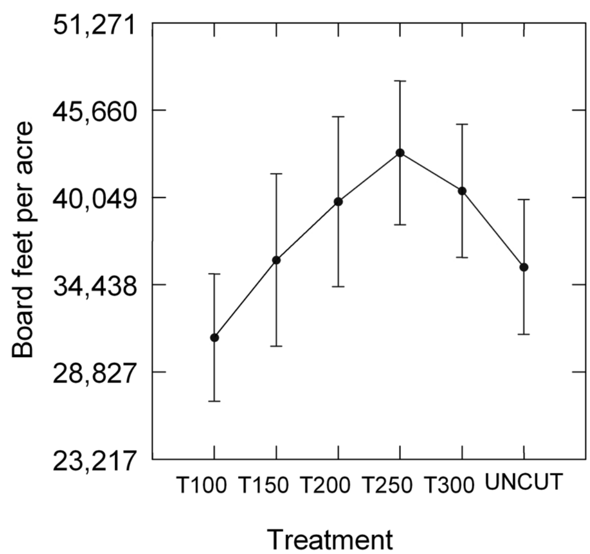


**Figure 8**—Board foot volume treatment means for 1998. ANOVA includes block factor and pre-harvest basal area (>10.5 inch) as concomitant variable.

The rapid diameter growth increase in the more heavily thinned plots has allowed them to keep pace with total volume growth in the more heavily stocked treatments. The process of thinning has left a stand comprised of vigorous redwood sprouts larger than 10.5 inches dbh. These trees, primarily in the T100 and T150, have responded by growing an average of 7.25 inches between 1981 and 1998. The result was that the thinning treatments to date have not shown statistically significant volume growth differences between treatments. The relative seventeen-year growth trend was the same pattern as that for standing volume shown in *figure 8*, with T250 exhibiting the maximum annual growth.

## Discussion

This study provides some valuable insight into the effective use of precommercial thinning in young robust redwood stands. Most of the results related to inventory and growth measures do not exhibit a statistically significant difference between treatments. Variability within treatments, while common in the redwood forest type, results in finding more subtle differences between treatments problematic.

The treatments appear equal due to the ability of redwood to take advantage of space created by thinning. *Figures 6* and *8* demonstrate that volume as a function of treatment resulted in a highly variable result that is not statistically significant at age 38. There are apparent trends in the graphs that suggest a thinning level of 250 or more trees per acre for cubic foot volume and 250 trees per acre for board foot volumes to maximize site utilization.

Maximum diameter growth occurs in the most heavily thinned plots that have a high percentage of redwood. Volume growth in the large diameter trees of the T100 and T150 treatments is keeping these plots growing at a rate that is equal to the more heavily stocked plots. For a short rotation strategy of 60 years, thinning to these levels while retaining mostly redwood sprouts in the stand structure seems to be a reasonable strategy for increasing the size of crop trees. However, *Figures 6* and *8* suggest that as the stand develops there may be a drop in productivity for T100 and T150.

Production of redwood heartwood is a prime economic consideration. Allowing the crop trees to increase in diameter at an optimum rate may be most profitable from the standpoint of volume and lumber grade. The lightly stocked treatments can achieve maximum diameter growth, but may also produce stems with large, wide and spreading branches. In addition, the relationship between branches and heartwood production is unclear (Gartner and others 2002). The plots were thinned at 19 years of age, which may be older than desired. Earlier thinning would result in a stand of small crowns that may take longer to close. Allowing redwood to develop as an open grown stem may result in the production of a highly tapered stem with an over abundance of growth dedicated to branch wood.

In the current third growth stand, there has been an abrupt change in the species composition of the stand. The number of trees in species other than redwood has dropped sharply. The first inventory of the current stand was 19 years after the clearcut and Douglas-fir stems accounted for about 25 percent of the stand. Other conifers are virtually eliminated from the stand composition. This is in contrast to partially logged stands of the Caspar Creek Cutting Trials where about 75 percent of the regeneration was grand fir (Lindquist 1988b). The full sunlight in the clearcut provided the level of light that Douglas-fir requires for growth and regeneration. However, the large number of redwood stump sprouts and heavy brush growth in the burned portion of the study (block 3) resulted in heavy competition for the Douglas-fir and many did not get the height growth necessary to survive in the overstory. However, this is a high Douglas-fir site and Douglas-fir will be an increasing percentage of the stand volume as the stand matures. If rotations are longer than 60 years, Douglas-fir will have adequate time to make an important contribution to the stand yield.

## Conclusion

The ANOVA results indicate that despite the range of thinning, the 38-year old stand shows no statistical differences in volume yield or growth between the thinning treatments. However, the decline in volume yield for the unthinned plots seems to indicate the need to reduce the density of regeneration early in the rotation. While this study provides some insight into production at various levels of stocking, the optimum stocking level is still an open question. More time will be required to see if growth rates can be maintained. In time, if smaller codominant and intermediate trees can continue to exhibit good radial growth, the more heavily stocked treatment may yield total greater volume than the lighter stocked treatments.

## References

Gartner, B.L.; North, E.M.; Johnson, G.R.; Singleton, R. 2002. **Effects of live crown on vertical patterns of wood density and growth in Douglas-fir.** Canadian Journal of Forest Research 32: 439-447.

Gomez, K.A.; Gomez, A.A. 1984. **Statistical procedures for agricultural research.** 2d ed. New York: John Wiley and Sons; 680 p.

Krumland, B.; Wensel, L. 1979. **Volume and taper relationships for redwood, Douglas-fir, and other conifers in the north coast of California**. Res. Note 9. Berkeley, CA: Coop. Redwood Yield Research Project; 66 p.

Lindquist, J.L. 1988a. **Third growth precommercial thinning at Caspar Creek.** Unpublished report. Calif. Dept. Forestry, Fort Bragg, CA.

Lindquist, J.L. 1988b. **The Caspar Creek cutting trials**. Forestry Note 99. Sacramento, CA: Calif. Dept. of Forestry; 25 p.

Lindquist, J.L. 2004. **Precommercial stocking control of coast redwood: a seventeen-year status report (1981-1998).** California Department of Forestry and Fire Protection. California Forestry Report No. 2. 26p.

Lindquist, J.L.; Palley, M.N. 1961. **Site curves for young-growth coastal redwood.** Calif. Forestry and Forest Products 29. Berkeley, CA: Univ. of Calif.; 4 p.

Lindquist, J.L.; Palley, M.N. 1963. **Empirical yield tables for young-growth redwood.** Calif. Ag. Exp. Sta. Bull. 796; 42 p.

Lindquist, J.L.; Palley, M.N. 1967. **Prediction of stand growth of young redwood.** Calif. Ag. Exp. Sta. Bull. 831; 62 p.

Malain, R.J.; Burns, D.M. 1962. **Young growth redwood and Douglas-fir cutting trials, a preliminary report.** Unpublished report. Calif. Div. Forestry, Fort Bragg, CA.

Neter, J.; Wasserman, W.; Kutner, M. 1985. **Applied linear statistical models.** 2nd ed. Homewood, IL: Irwin; 1127 p.

Smith, D.M. 1962. **The practice of silviculture.** New York: John Wiley and Sons; 578 p.