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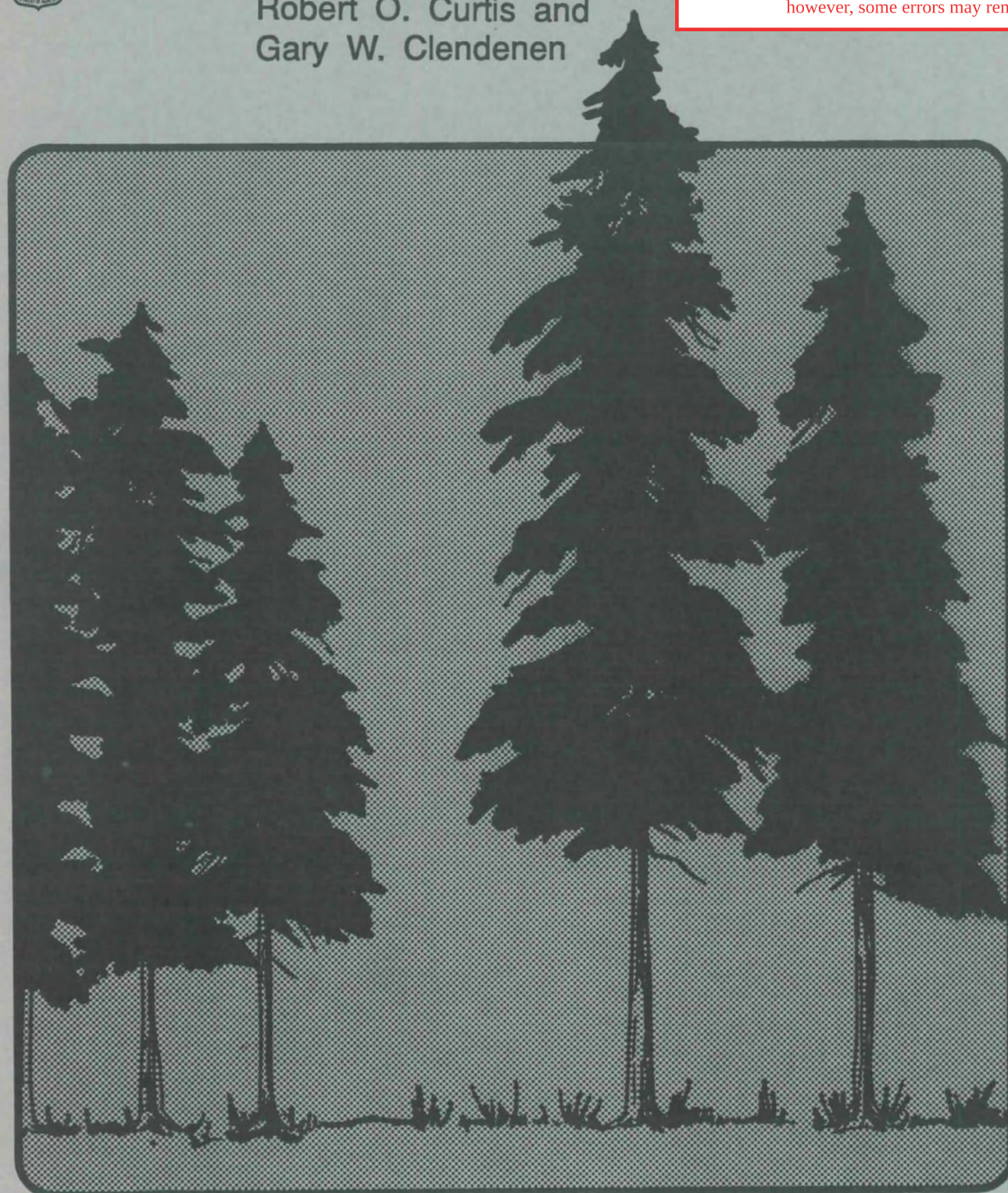
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Levels-of-Growing-Stock Cooperative Study in Douglas-Fir: Report No. 12--the Iron Creek Study: 1966-89

Robert O. Curtis and
Gary W. Clendenen

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Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plots to be retained in growing stock

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Background

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level of growing stock established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and on Vancouver Island, British Columbia, Canada. Site quality of these areas varies from I through IV.

This is a progress report on this cooperative study.

Levels-of-Growing-Stock Cooperative Study in Douglas-Fir:

Report No.12—The Iron Creek Study: 1966-89.

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Abstract

Curtis, Robert O.; Clendenen, Gary W. 1994. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 12—the Iron Creek study: 1966-89. Res. Pap. PNW-RP-475. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 67 p.

Results of the Iron Creek installation of the levels-of-growing-stock study in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) are summarized. To age 42 (planned completion of the experiment) volume growth in this site II Douglas-fir plantation has been strongly related to level of growing stock, partially offsetting the decrease in volume growth percent expected with increasing growing stock. Basal area growth-growing stock relations were much weaker than those for volume. Marked differences in tree size distributions have resulted from thinning. Periodic annual volume increments are two to three times greater than mean annual increments at age 42; this stand is far from culmination. Results in general are similar to those reported for other installations in the series on medium to good sites.

Keywords: Thinning, growing stock, growth and yield, stand density, Douglas-fir, *Pseudotsuga menziesii*, series—Douglas-fir LOGS.

Summary

Results of the Iron Creek installation of the cooperative levels-of-growing-stock study in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), located in the Randle District of the Gifford Pinchot National Forest in southern Washington, are summarized through age 42 (completion of 60 feet of height growth, comprising the planned course of the experiment).

Estimated site index (50-year base) of this plantation is 126 (mid-site II). Contrary to expectations when the study was established, volume growth has been strongly related to growing stock; basal area growth much less so. There is a substantial trade-off between increased individual tree size and value and total cubic volume production. Volume growth percentages have been considerably higher than those for basal area growth. At age 42, growth percentages in merchantable cubic volume are not strongly related to growing stock. Different growing stock levels have produced marked differences in tree size distributions and crown dimensions. Periodic annual cubic volume increments are two to three times greater than mean annual increments at age 42; the stand is far from culmination. Results have been generally comparable to those reported from other installations in the study on medium to good sites.

Other LOGS (Levels-of-Growing- Stock) Reports

Williamson, Richard L.; Staebler, George R. 1965. A cooperative level-of-growing-stock study in Douglas-fir. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Describes purpose and scope of a cooperative study investigating the relative merits of eight different thinning regimes. Main features of six study areas installed between 1961 and 1965 in young stands also are summarized.

Williamson, Richard L.; Staebler, George R. 1971. Levels-of-growing-stock cooperative study on Douglas-fir: report no. 1—description of study and existing study areas. Res. Pap. PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

Bell, John F.; Berg, Alan B. 1972. Levels-of-growing-stock cooperative study on Douglas-fir: report no. 2—the Hoskins study, 1963-1970. Res. Pap. PNW-130. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.

A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P.K. 1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (report no. 3, cooperative L.O.G.S. study series). Inf. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 46 p.

Williamson, Richard L. 1976. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 4—Rocky Brook, Stampede Creek, and Iron Creek. Res. Pap. PNW-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 39 p.

The USDA Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

Berg, Alan B.; Bell, John F. 1979. Levels-of-growing-stock cooperative study on Douglas-fir: report no. 5—the Hoskins study, 1963-1975. Res. Pap. PNW-257. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.

The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

Arnott, J.T.; Beddows, D. 1981. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 6—Sayward Forest, Shawnigan Lake. Inf. Rep. BC-X-223. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 54 p.

Data are presented for the first 8 and 6 years at Sayward Forest and Shawnigan Lake, respectively. The effects of the calibration thinnings are described for these two installations on Vancouver Island, British Columbia. Results of the first treatment thinning at Sayward Forest for a 4-year response period also are included.

Williamson, Richard L.; Curtis, Robert O. 1984. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 7—preliminary results; Stampede Creek, and some comparisons with Iron Creek and Hoskins. Res. Pap. PNW-323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 42 p.

Results of the Stampede Creek LOGS study in southwest Oregon are summarized through the first treatment period, and results are compared with two more advanced LOGS studies and are generally similar.

Curtis, Robert O.; Marshall, David D. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 8—the LOGS study: twenty-year results. Res. Pap. PNW-356. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 113 p.

Reviews history and status of LOGS study and provides new analyses of data, primarily from the site II installations. Growth is strongly related to growing stock. Thinning treatments have produced marked differences in volume distribution by tree size. At the fourth treatment period, current annual increment is still about double mean annual increment. Differences among treatments are increasing rapidly. There are considerable differences in productivity among installations, beyond those accounted for by site differences. The LOGS study design is evaluated.

Curtis, Robert O. 1987. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 9—some comparisons of DFSIM estimates with growth in the levels-of-growing-stock study. Res. Pap. PNW-RP-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Initial stand statistics for the LOGS study installations were projected by the DFSIM simulation program over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revisions in the DFSIM program.

Marshall, David D.; Bell, John F.; Tappeiner, John C. 1992. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 10—the Hoskins study, 1963-83. Res. Pap. PNW-RP-448. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p.

Results of the Hoskins study are summarized through the fifth and final planned treatment period. To age 40, thinnings in this low site I stand resulted in large increases in diameter growth with reductions in basal area and cubic volume growth and yield. Growth was strongly related to level of growing stock. All treatments are still far from culmination of mean annual increment in cubic feet.

Curtis, Robert O. 1992. Levels-of-growing stock cooperative study in Douglas-fir: report no. 11—Stampede Creek: a 20-year progress report. Res. Pap. PNW-RP-442. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 47 p.

Results of the first 20 years of the Stampede Creek study in southwest Oregon are summarized. To age 53, growth in this site III Douglas-fir stand has been strongly related to level of growing stock. Marked differences in volume distribution by tree sizes are developing as a result of thinning. Periodic annual increment is about twice mean annual increment in all treatments, indicating that the stand is still far from culmination.

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Introduction

The Iron Creek levels-of-growing-stock (LOGS) installation is one of nine installations in a regional thinning study established in young even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands according to a common work plan (report no. 1—Williamson and Staebler 1971; appendix 1 in this report; fig. 1).¹ This study is a cooperative effort involving Canadian Forest Service, Oregon State University, USDA Forest Service, Washington State Department of Natural Resources, and Weyerhaeuser Company. The objective is to compare growth-growing stock relations, cumulative wood production, and tree size development under eight different thinning regimes begun before the onset of severe competition. The original study plan was developed at Weyerhaeuser Company, Centralia, Washington. Procedural details were developed by the Pacific Northwest Research Station, USDA Forest Service, Portland, Oregon.

Detailed progress reports on individual installations are contained in the series of LOGS publications listed at the beginning of this report. Curtis and Marshall (1986) give an overall summary of results for the first 20 years of the program. Since 1986, several of the higher site installations, of which Iron Creek is one, have completed the full course of the experiment as originally planned.

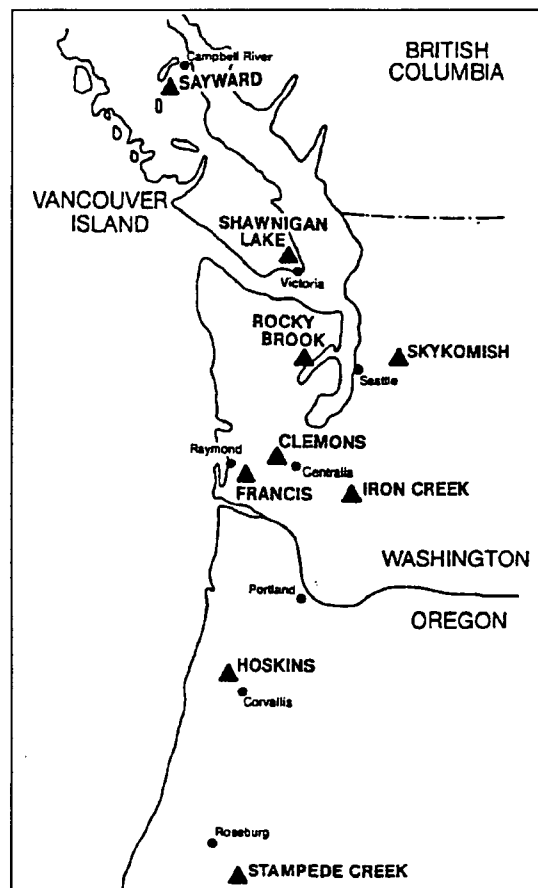


Figure 1—Locations of the nine installations of the levels-of-growing-stock cooperative study in Douglas-fir.

¹ Staebler, George R; Williamson, Richard L. 1962. Plan for a level-of-growing-stock study in Douglas-fir. Unpublished study plan. On file with: Forestry Sciences Laboratory, 3625—93d Avenue SW, Olympia, WA 98512.

The Iron Creek LOGS installation was established in 1966 by the Pacific Northwest Research Station and the Pacific Northwest Region (Region 6) of the USDA Forest Service. Some preliminary data were given by Williamson (report no. 4—1976) and by Williamson and Curtis (report no. 7—1984). At the end of the 1989 growing season, Iron Creek had completed the fifth and final treatment period of the experiment as originally planned.

The purposes of this report are to document the quantitative results obtained and to present and discuss the implications of results through the final treatment period.

Objectives

The LOGS cooperative studies evolved from work in the late 1950s by George Staebler (1959, 1960). Staebler argued that thinning would transfer increment to the remaining faster growing trees and increase growth percent through reduction in growing stock, while largely eliminating mortality losses. He also recognized that the implied assumption of near-constant gross increment over a wide range of stocking had not been tested. The objectives of the LOGS studies, as stated in the 1962 plan, were "to determine how the amount of growing stock retained in repeatedly thinned stands of Douglas-fir affects cumulative wood production, tree size, and growth-growing stock ratios." Treatments were designed to include a wide range of growing stock so that the results would show "how to produce any combination of factors deemed optimum from a management standpoint." The study was not designed as a test of specific operational thinning regimes but was intended to define the quantitative relations between growth and growing stock for a closely controlled initial stand condition and kind of thinning.

Methods

Description of Study Area

The Iron Creek LOGS installation was established in 1966 in a Douglas-fir plantation located in section 30, T. 11 N., R. 7 E., Randle Ranger District, Gifford Pinchot National Forest. Stand age was 17 years since planting in 1949; 19 years from seed. Composition at time of establishment was recorded as nearly pure Douglas-fir; however, there evidently was abundant natural seeding of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and redcedar (*Thuja plicata* Donn ex D. Donn) that had not yet reached sufficient size to be retained in the calibration cut, as shown by large numbers in an understory position now present on the control plots.

The stand is in a midslope position at an elevation of about 2,500 feet. Aspect is easterly, with slopes averaging about 25 percent. The plant association (Topik and others 1986) is western hemlock/swordfern (TSHE/POMU, *Tsuga heterophylla*/*Polystichum munitum*). Estimated site index as of 1989 (King 1966) was 126 (base age 50 years breast height [b.h.]), or mid-site II.

The deep, well-drained soil (series undetermined) is derived from volcanic ash and lapilli overlying a residual soil developed on fractured volcanic rock. Surface soils range from sandy loam to loam, with interbedded pumice.

At the time the study was established, many trees had been damaged by bear. About 20 percent of the trees remaining after the calibration thinning had some injury. The area was then fenced, and further injury was limited to one episode after damage to the fence in 1975. By 1989, few of the remaining trees showed noticeable evidence of bear damage, although butt scars still could be found.

The May 1980 eruption of Mount St. Helens deposited about 1 inch of ash on the study area. Foliage was still ash covered the following September.

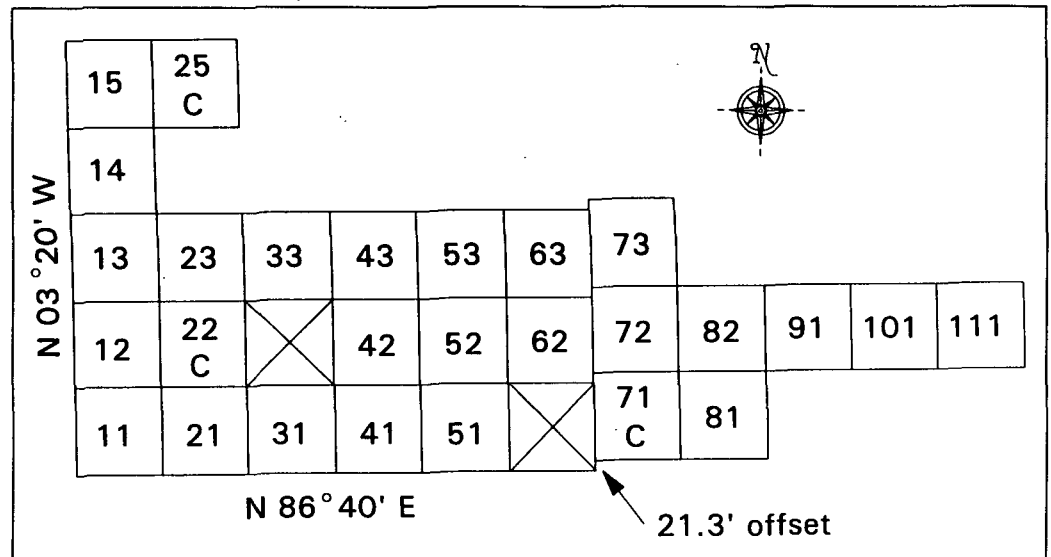


Figure 2—Arrangement of plots in the Iron Creek LOGS installation.

Several plots have had substantial damage from root rot. One plot (plot 51 in treatment 1) has been virtually destroyed by *Phellinus weirii* and has been excluded from analyses. Redcedar and hemlock reproduction is now abundant in the openings created by root rot and as a developing understory in the more heavily thinned treatments.

Experimental Design

The experiment is a completely randomized design having three replications of eight thinning treatments, plus control. The 27 plots are one-fifth of an acre, square, without buffers except that a 30-foot isolation strip was provided around the outer margins of the experimental area. Physical arrangement is shown in figure 2. Detailed criteria (appendix 1) for area and plot selection provided a high degree of uniformity in initial conditions.

Stand Treatments

Treatments were rigidly controlled to provide compatibility among installations on different sites.

Selection of crop trees—Crop trees were selected at the rate of 16 per plot (80 per acre), distributed to provide 4 well-spaced crop trees in each quarter of a plot. Crop trees were identified with white paint bands.

Calibration thinning—An initial calibration thinning was made on the 24 plots assigned to thinning treatments and was intended to reduce all to as nearly comparable condition as possible. All trees less than one-half the initial stand quadratic mean diameter (QMD) were cut. Additional noncrop trees were cut as needed to meet the study plan specifications, which called for the stand to be thinned to an initial spacing based on the equation,

$$S = 0.6167 \times QMD + 8,$$

where S is the average spacing in feet and QMD is quadratic mean diameter of the leave trees. Marking was controlled by the specifications that QMD of the leave trees should be within 15 percent of the installation mean, and leave tree basal areas should be within 3 percent. All leave trees on thinned plots were identified with permanent numbered tags. Trees 1.6 inches diameter at breast height (d.b.h.) and larger were tagged on the control plots.

Treatment thinnings—Treatment thinnings were made in 1970, 1973, 1977, 1980, and 1984 (ages 23, 26, 30, 33, and 37, respectively), which corresponded to about 10-foot increments in crop tree height. Thinning intensity was determined as percentages of gross basal area growth on the control plots, as defined in the table on the inside front cover. Gross basal area growth of controls was assumed to represent the productive potential of the site at full stocking. Basal areas after thinning were calculated from the equation,

$$BA_n = BA_{(n-1)} + p \times GBAG ,$$

where

BA_n = basal area retained after thinning,

$BA_{(n-1)}$ = basal area at beginning of preceding treatment period,

p = prespecified percentage of gross basal area growth of controls to be retained, and

$GBAG$ = average gross basal area growth on controls.

The expected trends in basal area created by these specifications are shown in figure 3.

Kind of thinning was further specified by the following requirements:

1. No crop trees were to be cut until all noncrop trees had been removed.
2. Average diameter of trees removed in thinning should approximate the average diameter of trees available for thinning (that is, noncrop trees only until all noncrop trees had been removed). This resulted in a d/D ratio (ratio of diameter of trees cut to diameter of stand before thinning) of less than 1.0 for the stand.
3. Trees removed in thinning were to be distributed across the range of diameters of trees available for thinning.

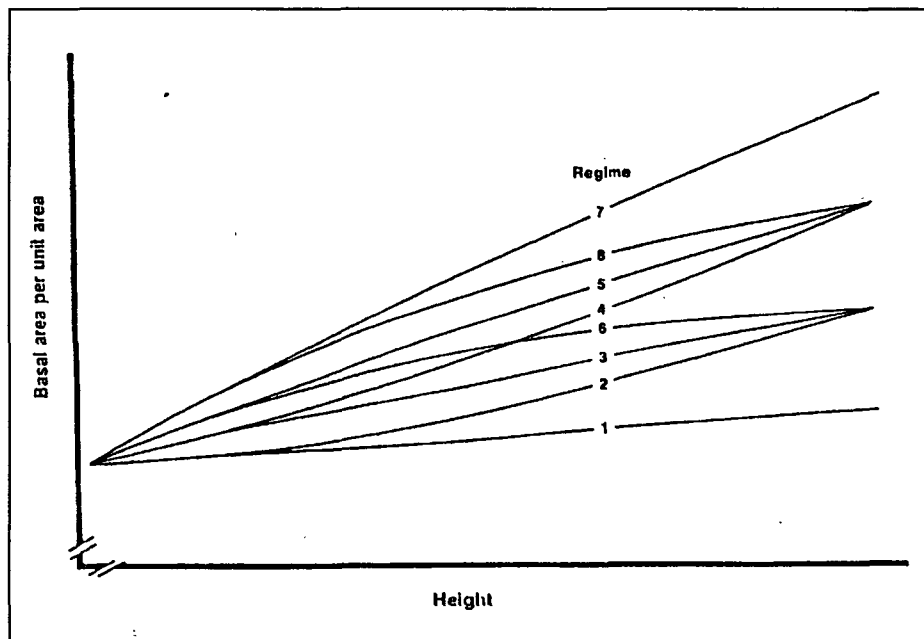


Figure 3—Idealized trends in basal area for the eight thinning regimes in the LOGS study.

Data Collection and Summarization

The thinning specifications of the study plan were expected to result in a crown thinning. The d/D ratios were calculated for each of the five treatment thinnings. Overall means were about 0.90 with no clear trends over time or treatment.

Immediately after the calibration thinning, and at all subsequent measurement dates (that is, 1966, 1970, 1973, 1977, 1980, 1984, 1989), diameters of all tagged trees were measured to the nearest 0.1 inch. Ingrowth was tagged and measured on the control plots only. Heights were measured on a sample of these trees; sample size differed but was not less than 12 trees per plot, and usually more, distributed across the range of diameters. Beginning with the 1973 measurement, heights to base of live crown also were measured.

Constrained height-diameter curves were fit to each measurement on each plot with an adaptation² of Hyink and others' (1988) procedure. Tree volumes in total cubic feet inside bark (CVTS) were calculated by the Bruce and DeMars (1974) equation, from actual measured heights when available and from heights predicted by the Clendenen equations for trees not having measured heights. These were converted to merchantable cubic volumes to a 6-inch top (CV6) by using equations from Brackett (1973).

Stand heights were characterized as average height (H40) of the largest 40 trees (by d.b.h.) per acre for each plot and were calculated as the mean of the measured or estimated heights of all trees in this category.

Analyses

The original study plan specified analysis of variance as the method of analysis. Many aspects of the experiment are more meaningfully presented and interpreted, however, through simple graphic comparisons of means and by regressions of periodic annual increment in basal area and in volume on basal area at period midpoints, by treatments. Regressions were of the form,

$$\ln Y = a + b \ln X + cX,$$

as used previously by Curtis and Marshall (report no. 8—1986). The underlying numerical values are summarized in a series of tables given in appendix 2.

Results

Analysis of Variance

The analysis of variance is presented in tables 1 and 2 (all tables are in appendix 2). This follows the procedure outlined in the original study plan and used in previous LOGS reports (report no. 8—Curtis and Marshall 1986; report no. 10—Marshall and others 1992), except for changes made necessary by loss of one plot. This is a repeated-measures experiment that is computationally similar to a split-plot design (Snedecor and Cochran 1980), in which the periodic remeasurements correspond to subplots. Computations were done with the GLM procedure of SAS (SAS Institute 1988) and used as successive response variables periodic annual gross increment in cubic volume and corresponding growth percent, periodic annual gross increment in basal area and corresponding growth percent, and periodic annual net increment in quadratic mean diameter.

The interactions period x (fixed vs. variable), period x (between increasing), and period x (between decreasing) were in general nonsignificant. The corresponding main effect fixed vs. variable treatments was nonsignificant, thereby indicating no difference in overall means. Differences in means between increasing treatments, and those between decreasing treatments, are significant or nearly so for all variables.

² Developed by Gary W. Clendenen and David D. Marshall.

Trends in Live Stand Statistics

The interactions period x fixed (linear) and period x (increasing vs. decreasing treatments) were significant in most cases. This indicates that, as would be expected, the relations differ over time. Consequently, the corresponding main effects, though statistically significant, are not meaningful. Interpretations are therefore made in terms of the graphic comparisons and regressions of growth on growing stock, by treatments, presented below.

Height of largest 40 trees per acre (H40)—H40, defined as the average of the heights of the largest (by d.b.h.) 40 trees per acre, is a useful measure of height development. This can be calculated objectively for all plots from the data available, is little affected by thinning, and is now quite commonly used as the basis for site index estimates in the region.

Excluding plot 51 (severely damaged by root rot), the range in 1989 heights (age 42) was from 95 to 106 feet. There appeared to be no relation to thinning treatment. Mean of the thinned plots differed by only 0.2 foot from the mean of the controls (table 3).

Figure 4 compares development of H40 over the life of the installation with that predicted by King (1966) for site index 126. The curves are nearly identical.

Number of trees—Trends over time in trees per acre by thinning treatments are shown in figure 5. Corresponding numerical values, including those for the controls (omitted in fig. 5), are given in table 4.

Basal area—Corresponding values of basal area per acre, by treatments, are shown in figure 6 and in table 5.

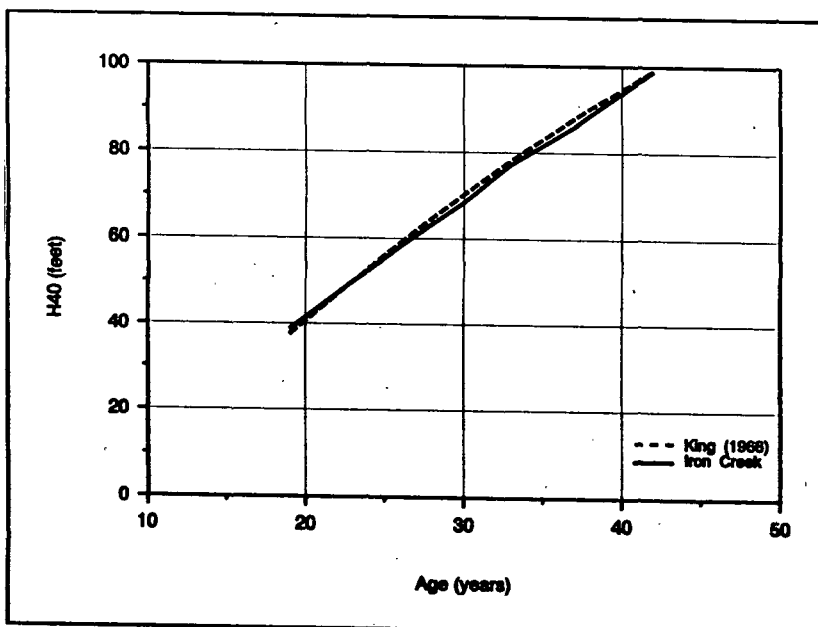


Figure 4—Observed H40 trend compared to King (1966) predicted heights.

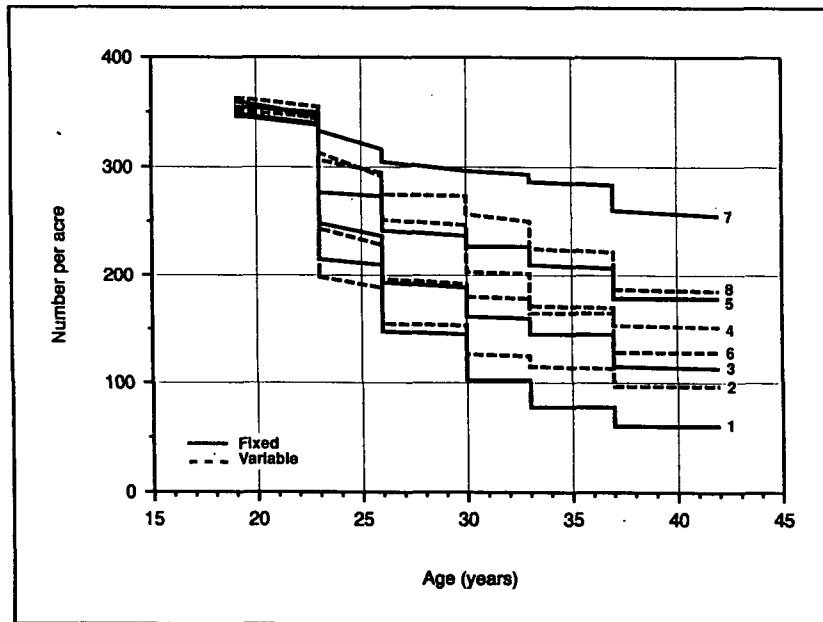


Figure 5—Numbers of trees per acre by treatment and age.

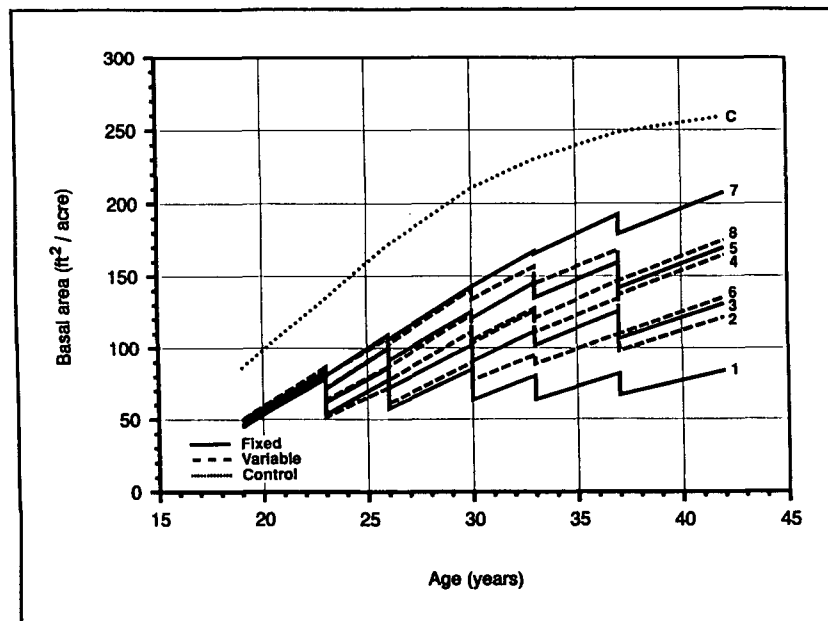


Figure 6—Trends of live basal area by treatment and age.

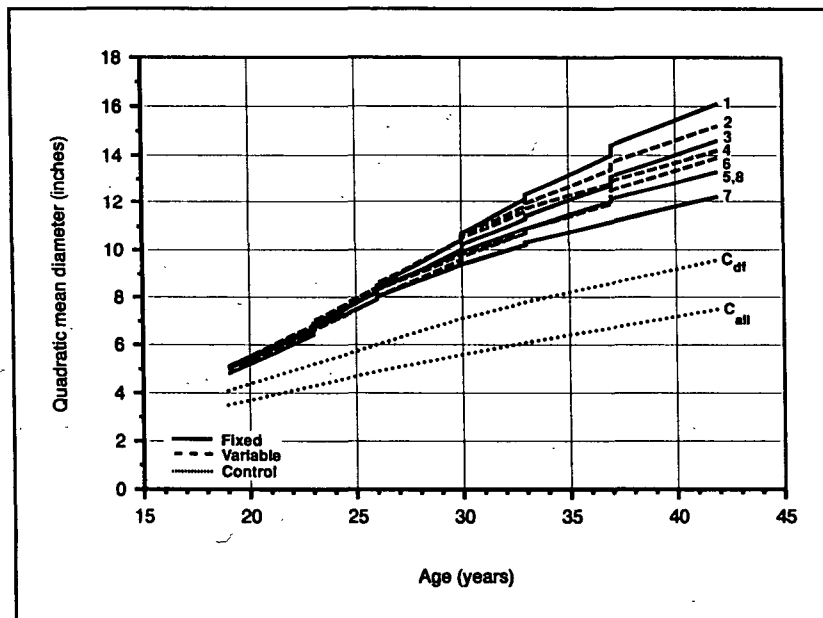


Figure 7—Attained quadratic mean diameters (QMD) by treatment and age.

Quadratic mean diameter (QMD)—Trends in quadratic mean diameter are shown in figure 7 and table 6. As discussed later, QMD values for the control are strongly influenced by presence of an understory of small stems of tolerant species. QMD of Douglas-fir only is a better measure of development relative to the thinned plots (which are almost pure Douglas-fir) than is QMD of all species.

Other diameter measures—Several other average diameters are sometimes used to express stand attributes. D40, average diameter of the 40 largest (by d.b.h.) trees per acre, corresponds to H40 and is useful in expressing effect of treatment on diameter growth of leading dominant trees. Unlike QMD, this is only slightly influenced by removal of trees through thinning or mortality, because few trees in this category are cut in the thinning regimes considered, and suppression mortality does not occur.

Trends in development of D40 over time are shown in figure 8 and table 7. Thinning has had much less effect on D40 than on QMD. Thinning, none the less, has had a consistent effect on diameter growth of these largest trees.

A second measure of diameter development is D80, quadratic mean diameter of the largest (by d.b.h.) 80 stems per acre. This is similar to D40, though somewhat smaller in value, and is sometimes used for similar purposes as a value roughly corresponding to the expected number of surviving trees at harvest age under some commonly used regimes.

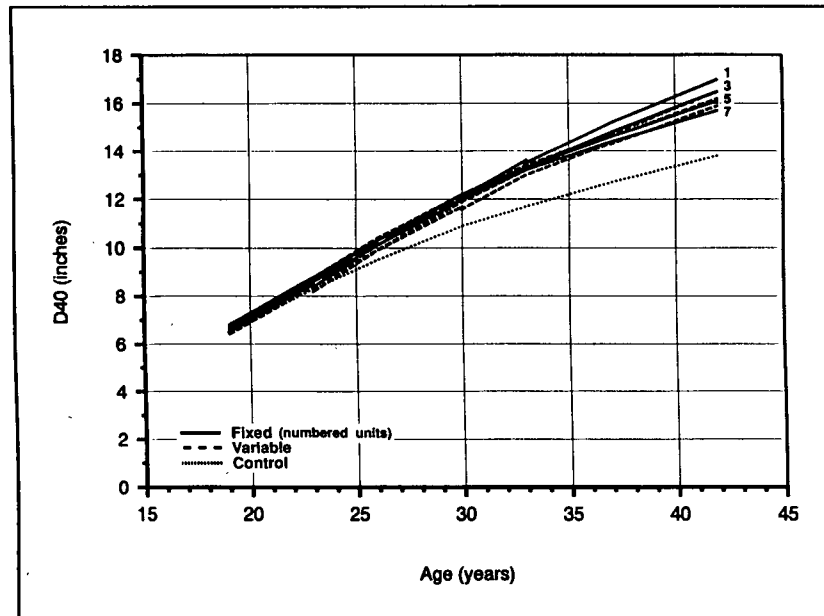


Figure 8—D40 (average diameter of largest 40 trees per acre) by treatment and age.

A third measure of diameter development is Dcrop, quadratic mean diameter of designated crop trees, shown in table 7. The study plan envisioned an initial selection of crop trees based on a combination of vigor and spacing, with these trees to be favored during thinning and retained to the end of the experiment. Although there were 80 such trees per acre, diameters were expected to be somewhat less than D80 because of the spacing constraint. Interpretation of this value is somewhat obscured by substitution of new crop trees for damaged and low-vigor trees, but values are given for comparability with other reports.

Both D80 and Dcrop values become equal to QMD once the number of stems (some treatments only) has been reduced to 80 per acre.

Total cubic volume (CVTS)—Trends in cubic volume of total stem are shown in figure 9, with numerical values given in tables 8 and 9.

Merchantable cubic volume (CV6)—Trends in merchantable cubic volume to a 6-inch top diameter inside bark (d.i.b.) are shown in figure 10; numerical values are in table 10.

Relative Density Measures

Relative density measures are useful in describing thinning regimes, as guides for density control, as values interpretable as measures of competition, and as predictors of growth. Here, treatments were compared by using two common relative density measures that are nearly equivalent, except for scale factors. These are Curtis' (1982) relative density (RD) and Reineke's (1933) stand density index (SDI). Relative density is defined by the equation,

$$RD = \frac{\text{basal area}}{\sqrt{QMD}},$$

and is merely a rearrangement of Reineke's equation (with a slight difference in exponent) into a form that some find easier to use.

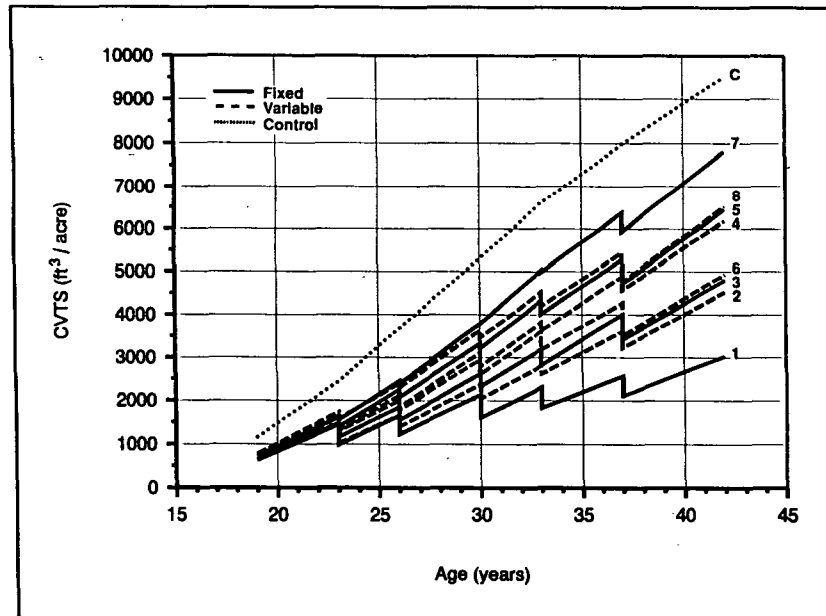


Figure 9—Total stem volume (CVTS) in live trees, by treatment and age.

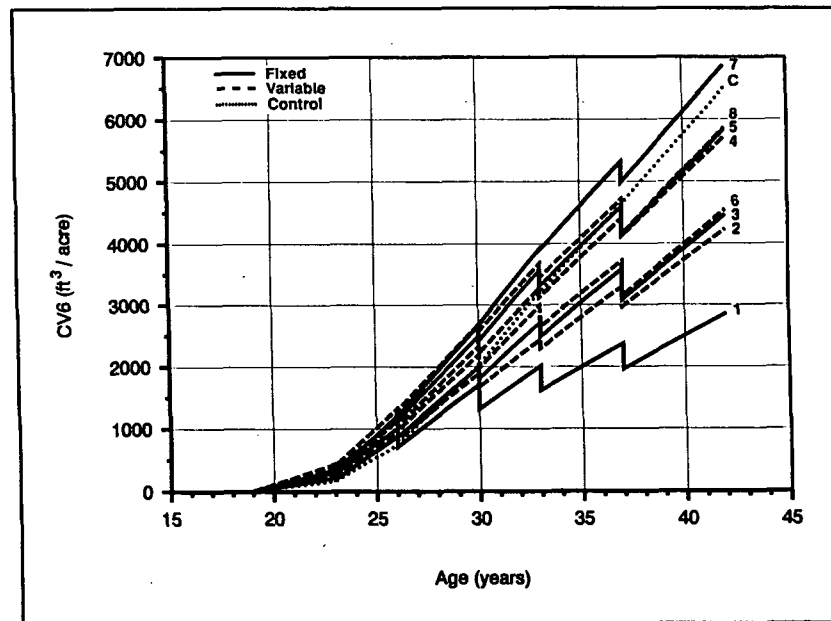


Figure 10—Merchantable volume (CV6) in live trees, by treatment and age.

Figures 11 and 12 display trends of RD over time for the various thinning regimes. The corresponding trends for the control are useful as reference points for thinning regimes (that is, their relation to “maximum”), and the asymptote represents an estimate of the maximum attainable density in an unthinned stand at this location. This differs among locations and is not closely related to site index (report no. 8—Curtis and Marshall 1986).

The diameter distribution (fig. 13) for the Iron Creek control plots illustrates a mensurational problem of common occurrence in western Washington. The main stand consists of Douglas-fir, with an understory of tolerant species—western hemlock and redcedar. The understory trees contribute little to volume and basal area (13 percent of basal area at age 42) and almost nothing to volume or basal area growth, and have negligible effect on growth of the stand; but they do represent a large fraction of the total number of stems present (47 percent at age 42). This has a considerable effect on computation of QMD and of density measures, such as RD and SDI, that involve QMD; and can lead to grossly inflated values that are probably meaningless as indicators of stand-level competition. Thinned plots had understory removed at establishment, and ingrowth has not been measured; therefore, they are unaffected.

For the stand structures on the Iron Creek unthinned plots, several methods of adjustment are possible that give values approximating those for a stand with a more or less symmetrical diameter distribution and equivalent level of competition. One procedure is to truncate the distribution at a point that excludes most of the understory. At Iron Creek, a diameter of D40/3 seems a reasonable truncation point for all measurements. An alternative procedure is to calculate RD by using basal area of all trees (which is little influenced by the understory) and QMD of the Douglas-fir. For these data, results of the two procedures are nearly identical. The resulting curves (dashed lines in figs. 11 and 12) suggest that maximum RD for this stand is in the range RD80-85. The value of RD95 indicated by the calculation using all trees is almost certainly a gross overestimate of competition level.

Reineke diagram—Figures 14 and 15 show the trends of number in relation to QMD of all trees on log-log scales (Reineke 1933), by treatments. Truncation of the diameter distribution has no effect on values for thinning treatments but shifts the curve for the control down and to the right.

Stand density index—Figures 16 and 17 show the trends of SDI over time for the various thinning treatments. The trend of SDI for the control plots appears to be approaching a maximum value in the vicinity of SDI 500. As with RD, inclusion of small understory stems of a younger age class probably leads to an overestimate.

Total cubic volume—Cumulative total cubic volume production under the various treatments is shown in figure 18 and table 9. Estimated volume of material cut at the calibration thinning has been added to provide a common origin with the curve for the control. In the thinned treatments, mortality has been relatively slight and due to root rot rather than suppression, and gross production values differ only slightly from the net values shown.

Although net CVTS production on the control has been higher than on any of the thinning treatments, with the onset of suppression-related mortality, it is declining relative to the thinning treatments, and it seems likely that the higher density thinning treatments soon will cross the control curve.

Text continued on page 16

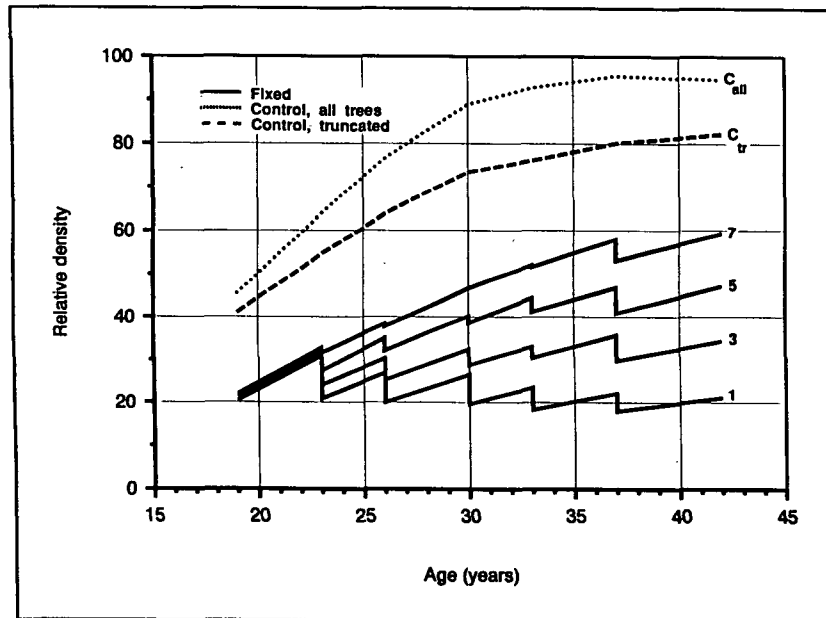


Figure 11—Trends in relative density (RD) in relation to age, for fixed treatments and control.

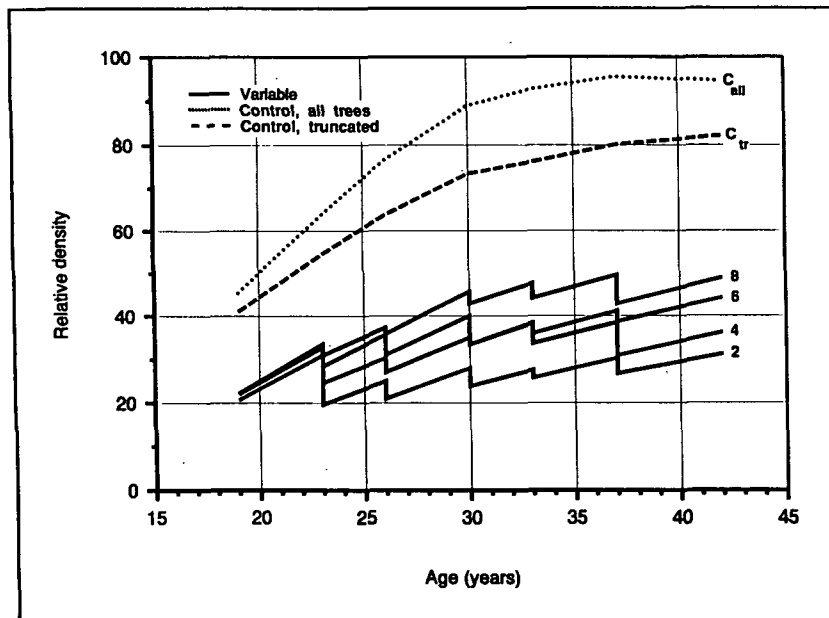


Figure 12—Trends in relative density (RD) in relation to age, for variable treatments and control.

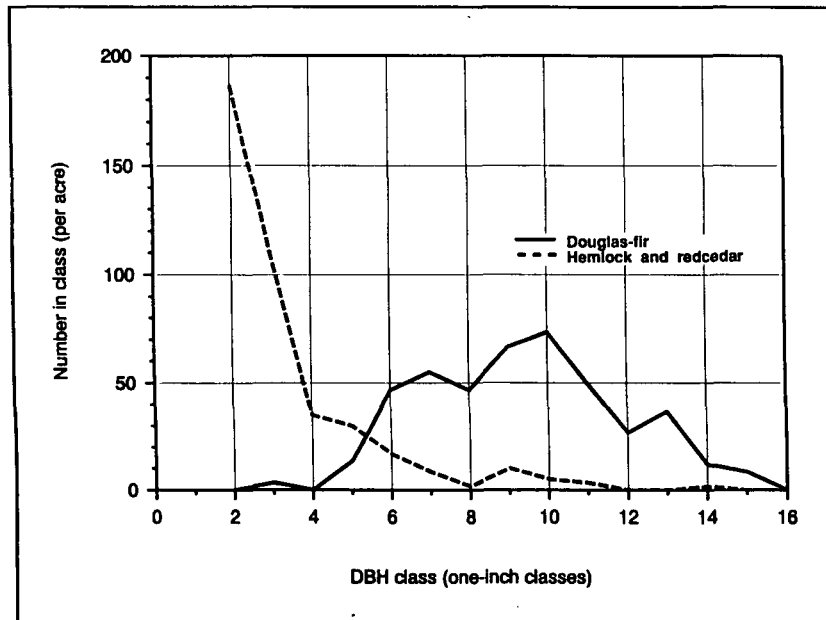


Figure 13—Numbers of trees on control in 1989, by diameter class and species group.

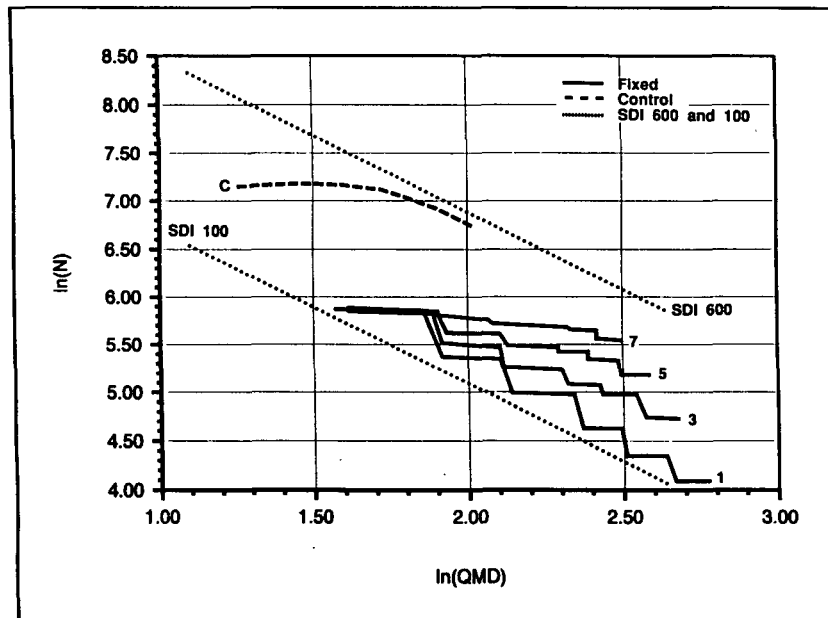


Figure 14—Reineke plot of $\ln$ (number of trees) over $\ln$ (QMD), for fixed treatments and control.

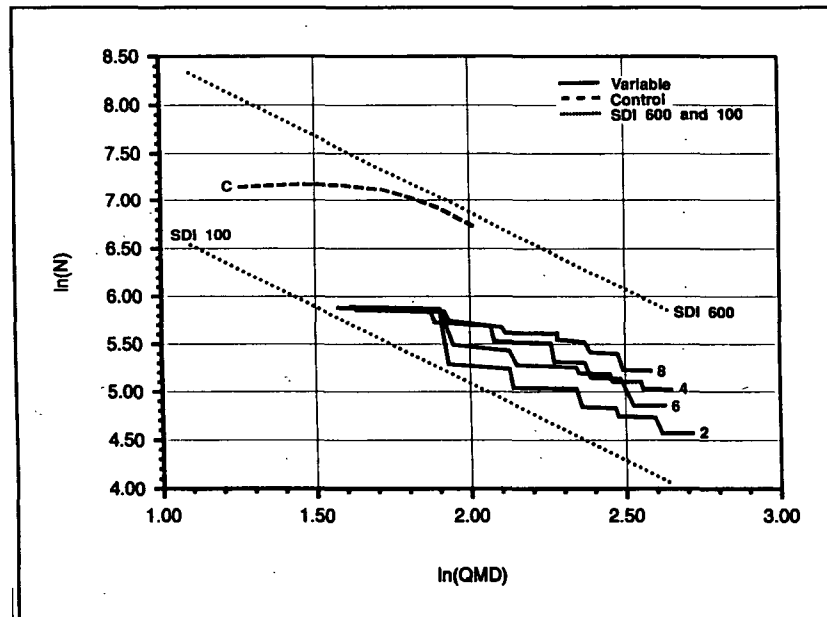


Figure 15—Reineke plot of ln(number of trees) over ln(QMD), for variable treatments and control.

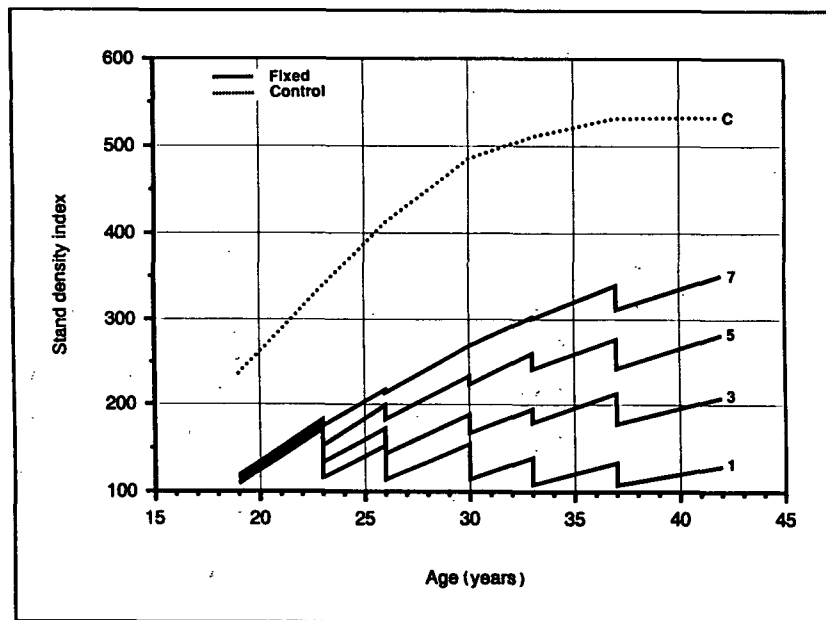


Figure 16—Stand density index (SDI) in relation to age, fixed treatments and control.

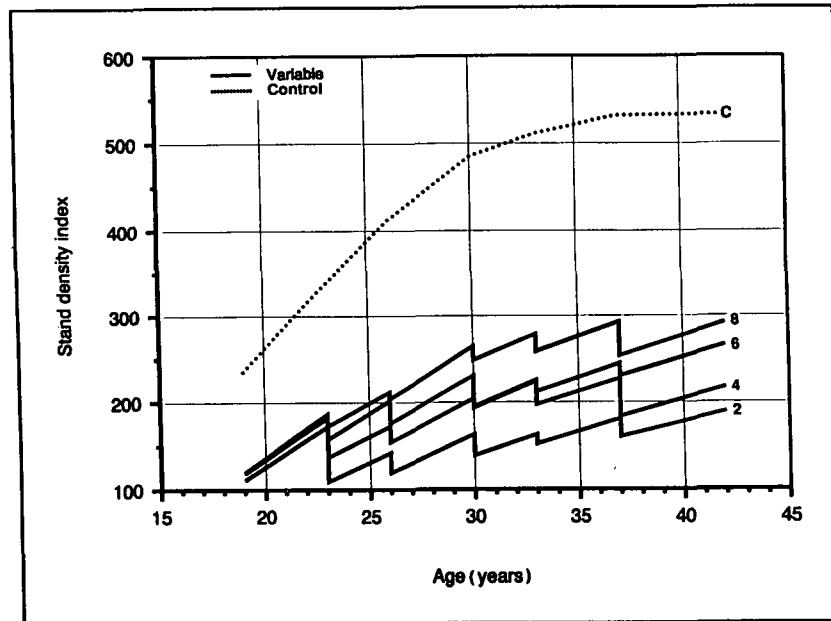


Figure 17—Stand density index (SDI) in relation to age, variable treatments and control.

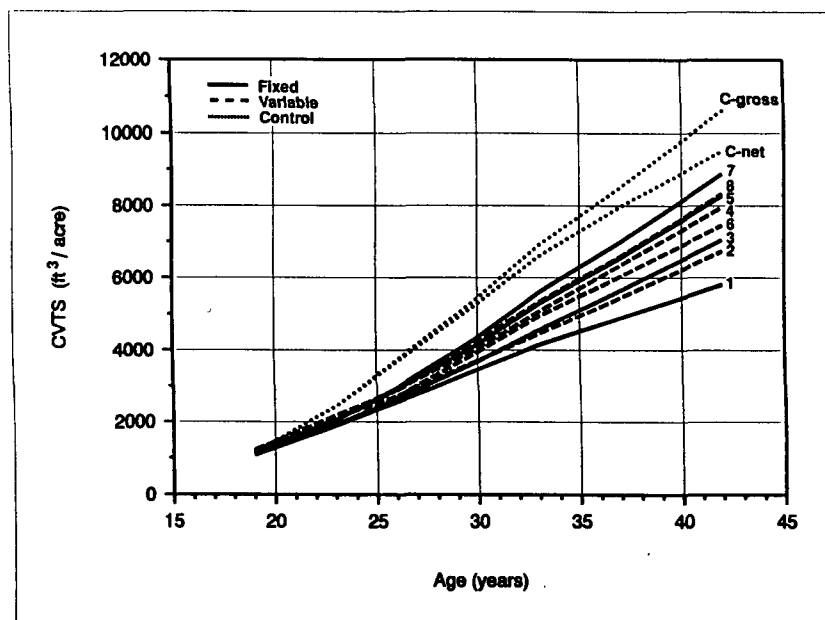


Figure 18—Cumulative net total volume (CVTS) production in relation to age, and treatment.

Merchantable cubic volume—Cumulative merchantable volume production for the various treatments is shown in figure 19 and table 9. All values are net. Treatments 5, 7, and 8 have exceeded the control volume, and treatment 4 has produced virtually the same volume as the control; all thinning treatments have produced considerably larger diameter trees. As yet suppression-related mortality has had little effect on the control because mortality has been principally in trees too small to contribute to CV6 totals.

Volume Distribution by Tree Size Classes

Distribution of CVTS by tree size classes is shown in three graphs. Figure 20 shows volumes in live trees 15.6+, 13.6+, 11.6+, 9.6+, 7.6+, and 1.6+ inches d.b.h. at the end of the fifth treatment period (1989). Figure 21 shows corresponding cumulative totals—live stand in 1989 plus volumes of trees removed in thinnings. Figure 22 shows distribution at end of fifth treatment period (1989) as percentages of total live standing volume. Although thinned plots have produced less total volume than the control, and lower density thinned plots have produced less total volume than higher density plots, thinned plots have their volume concentrated on fewer but considerably larger trees.

Periodic Annual Increment

Periodic annual increment (PAI) values presented are net. Mortality has been negligible on most thinned plots. There has been substantial suppression mortality on the controls, which is not presented here.

PAI in basal area—Time trends of net periodic annual increment in basal area are shown in figures 23 and 24 and in table 11, by treatments. Initially, the control is much above the others, but falls rapidly through the combination of reduced growth due to competition and increasing suppression mortality.

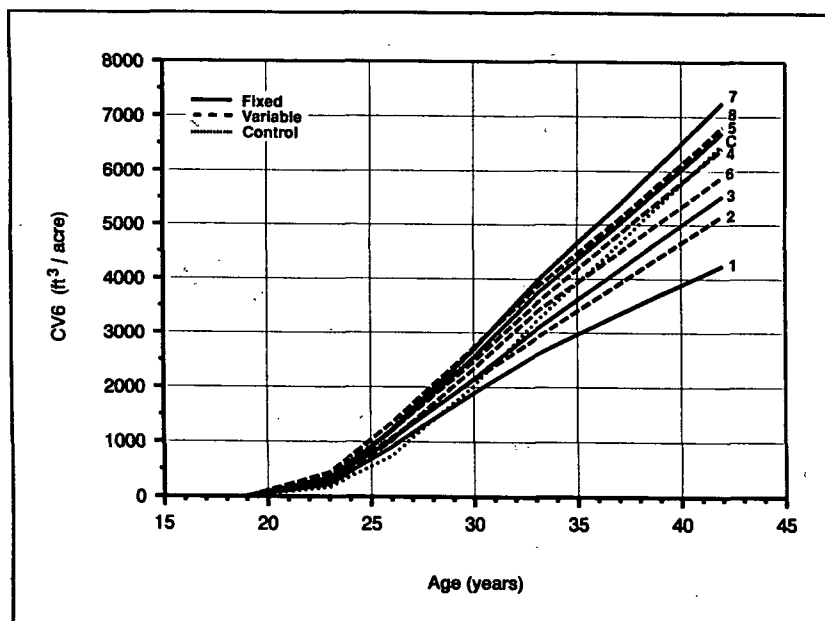


Figure 19—Cumulative net merchantable volume (CV6) production in relation to age and treatment.

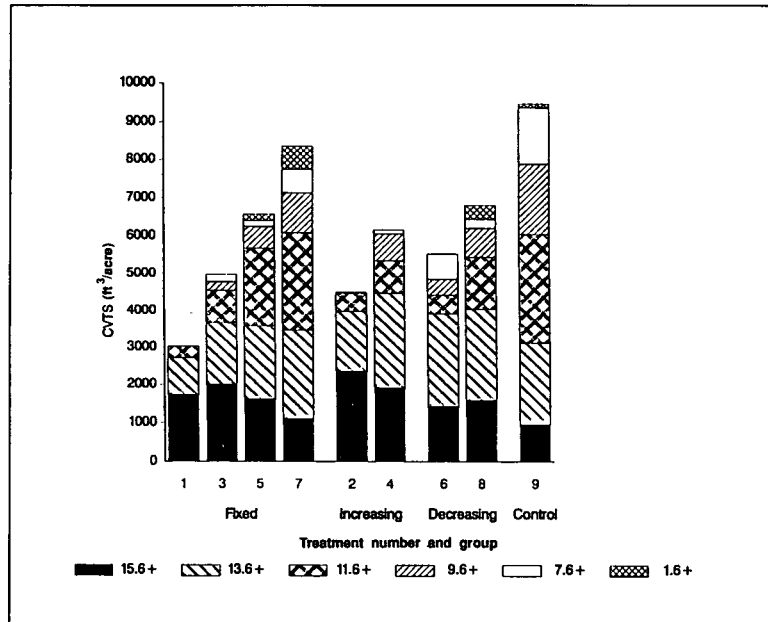


Figure 20—Distribution of total volume (CVTS) in live trees by size class and treatment, 1989.

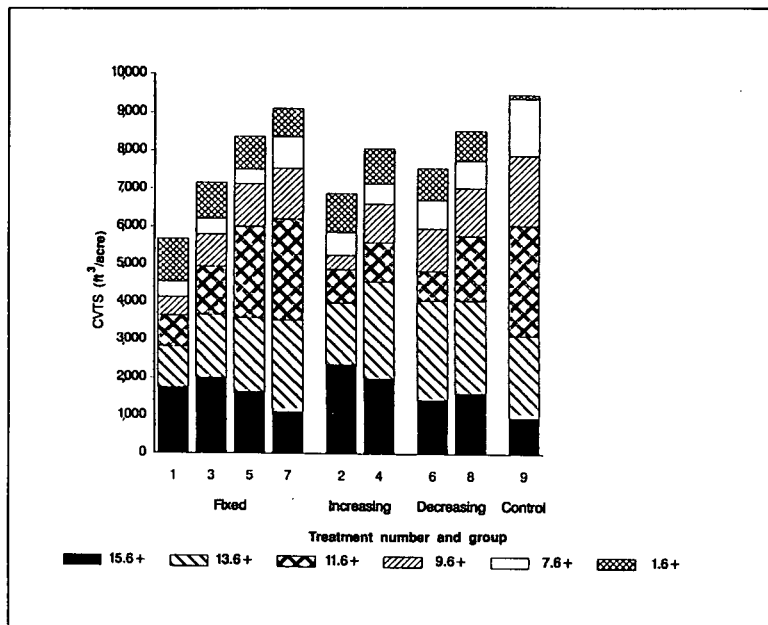


Figure 21—Cumulative production in total volume (CVTS) by tree size class and treatment, 1966-89.

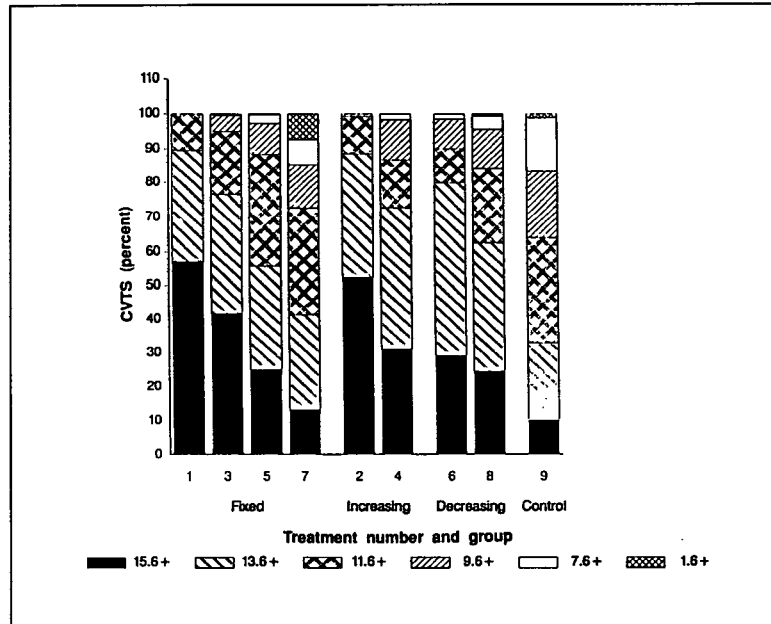


Figure 22—Percentage distribution of total volume (CVTS) by tree size and treatment, 1989.

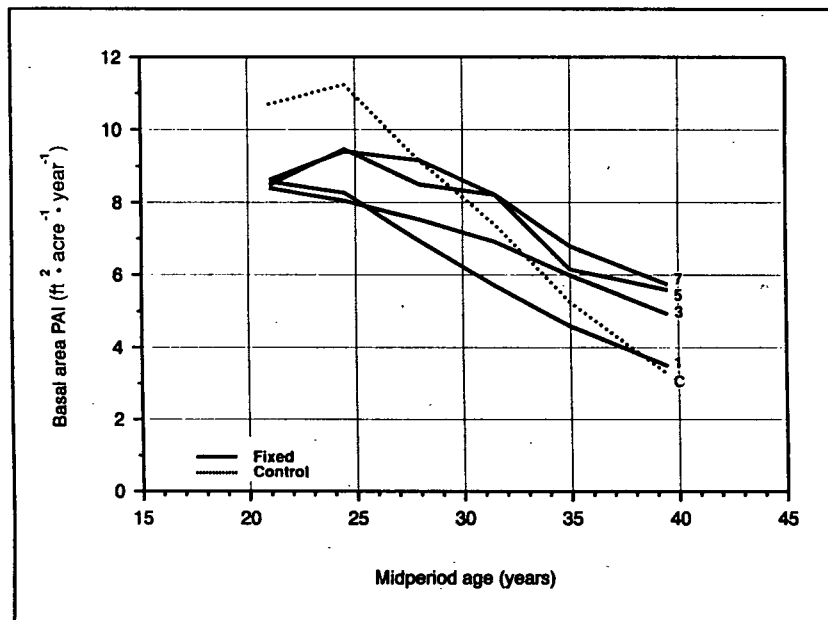


Figure 23—Net periodic annual increment in basal area in relation to age, fixed treatments and control.

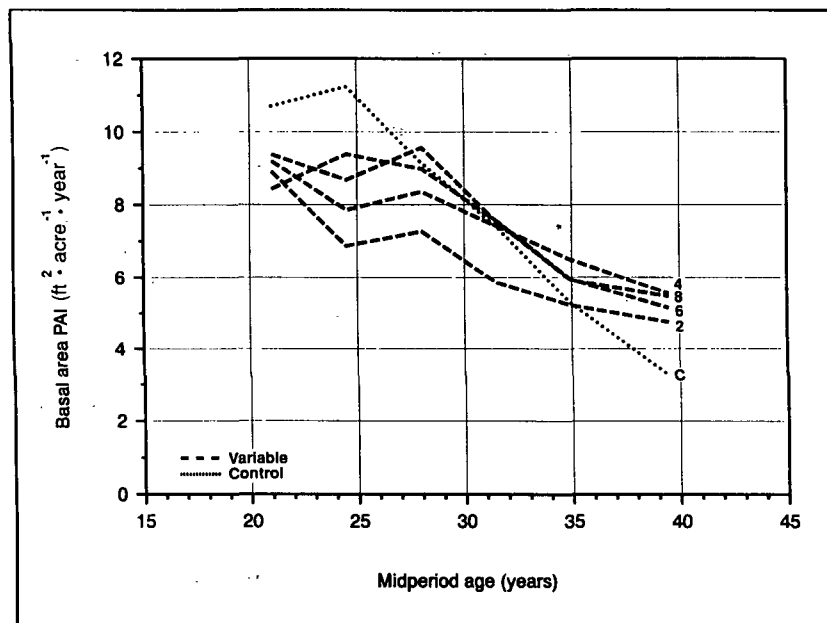


Figure 24—Net periodic annual increment in basal area in relation to age, variable treatments and control.

PAI in quadratic mean diameter—Time trends of periodic annual increment in QMD are shown in figures 25 and 26 and in table 12. For thinned plots, values of net change and of survivor growth are virtually identical, because there has been little mortality and no ingrowth. These values differ considerably for the control, however. Survivor growth is the more meaningful expression of actual biological growth (Curtis and Marshall 1989).

PAI in total cubic volume—Time trends of periodic annual increment in CVTS are shown in figures 27 and 28 and in table 13. Note the sharp depression in growth during the fourth treatment period. This reflects a corresponding depression in height growth in this period, as well as apparent slight reductions in basal area and diameter growth. This period represents the second through the fifth growing seasons following the Mount St. Helens ashfall and could possibly represent an aftereffect of the eruption.

PAI in merchantable cubic volume—Trends of CV6 PAI over time are shown in figures 29 and 30 and in table 13. The 6-inch merchantability limit markedly changes the shape of the curves, compared to that for CVTS.

Periodic annual mortality—Periodic annual mortality in number of trees, basal area, and CVTS is shown in tables 14 and 15. Values are low to negligible in all thinning treatments but became substantial on the unthinned plots in recent periods.

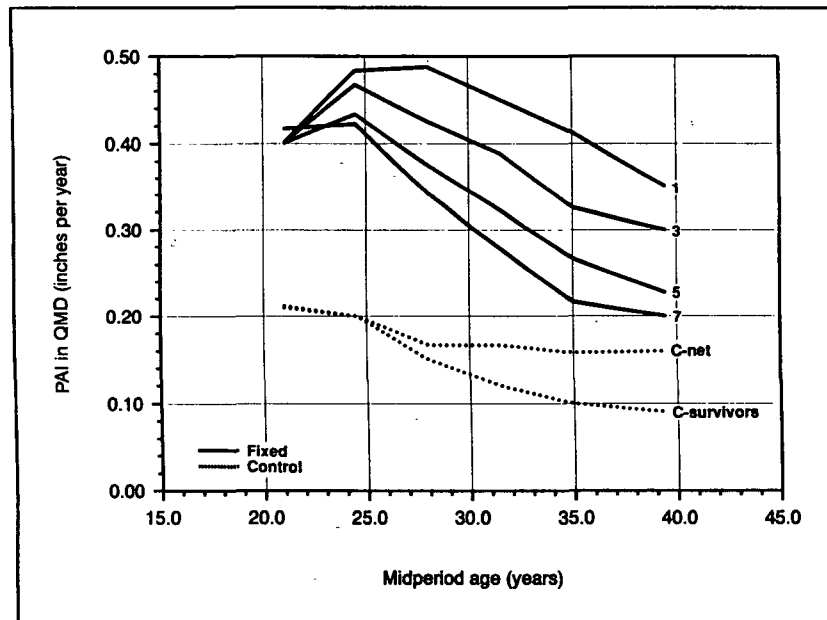


Figure 25—Periodic annual increment in quadratic mean diameter (QMD) in relation to age, fixed treatments and control.

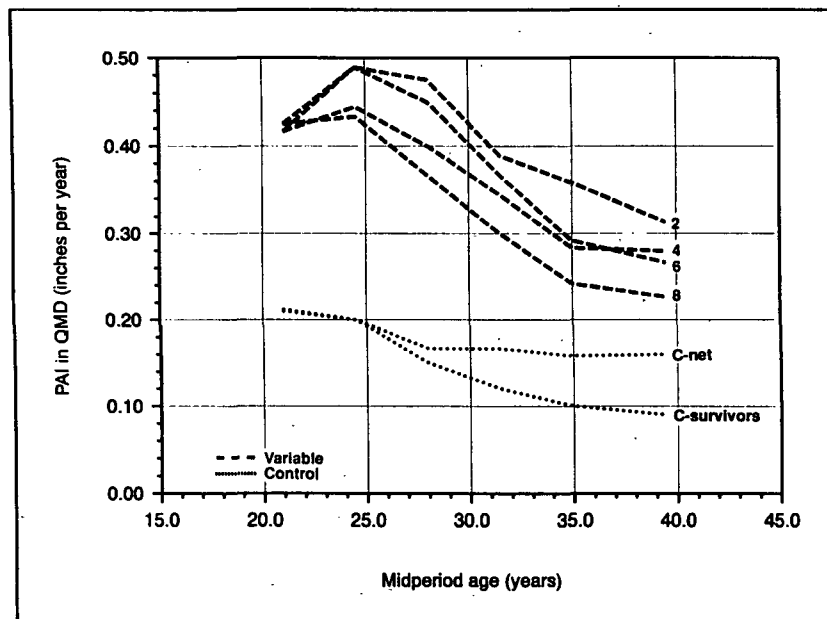


Figure 26—Periodic annual increment in quadratic mean diameter (QMD) in relation to age, variable treatments and control.

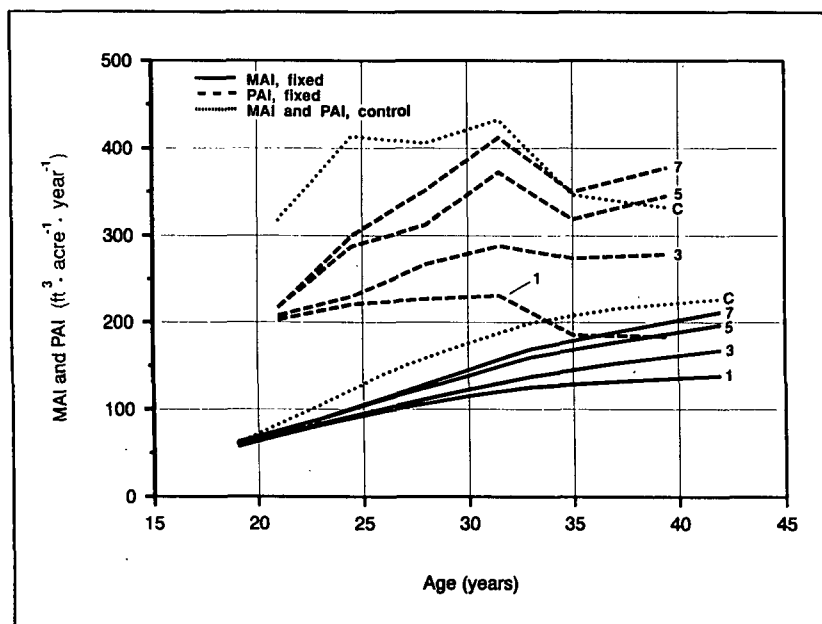


Figure 27—Mean annual increment and periodic annual increment in net volume (CVTS) in relation to age, fixed treatments and control.

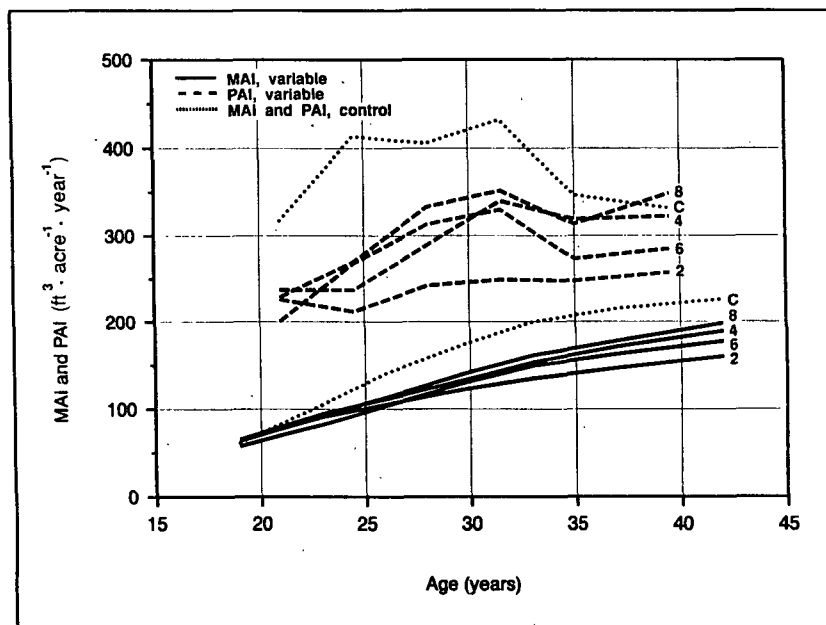


Figure 28—Mean annual increment and periodic annual increment in net volume (CVTS) in relation to age, variable treatments and control.

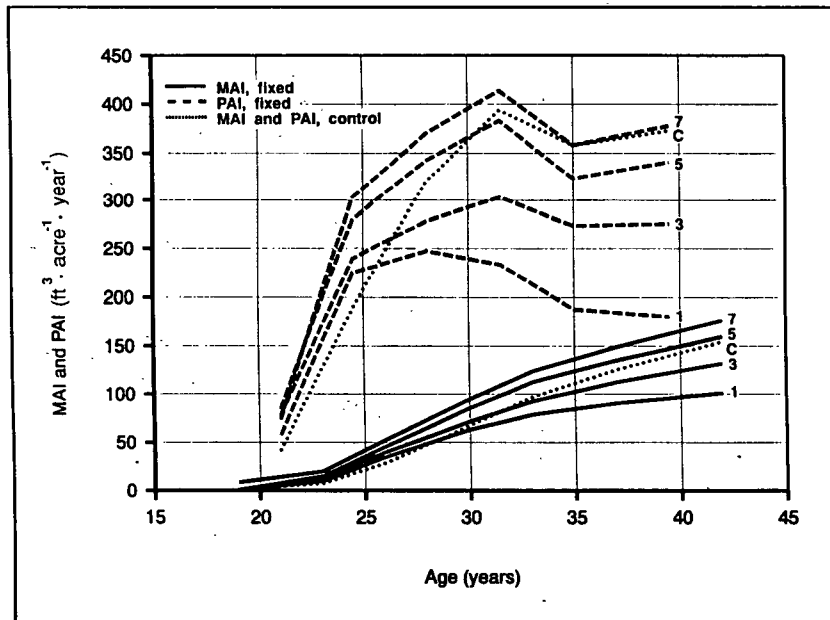


Figure 29—Mean annual increment and periodic annual increment in net merchantable volume (CV6) in relation to age, fixed treatments and control.

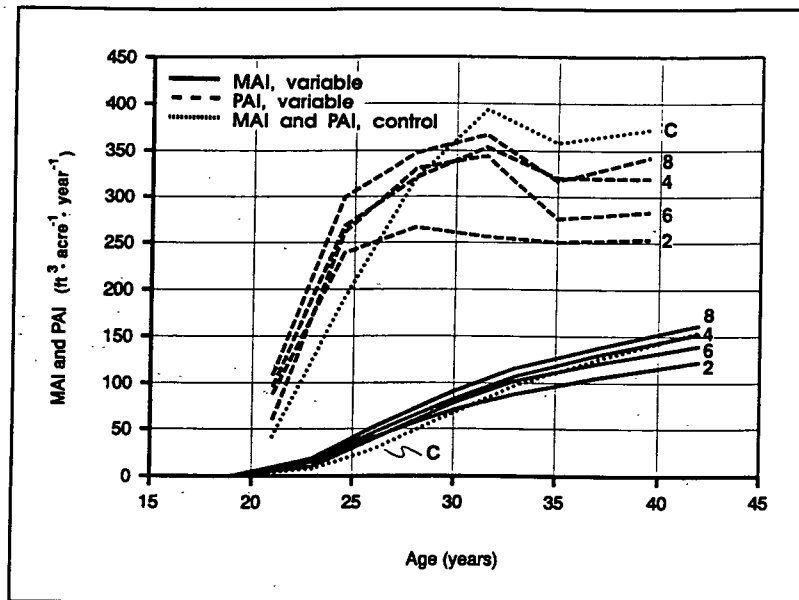


Figure 30—Mean annual increment and periodic annual increment in net merchantable volume (CV6) in relation to age, variable treatments and control.

Growth Percents

Growth percentage is one method of expressing growth rates. The argument that one should seek maximum return on growing stock, one expression of which is growth percent, had an important place in the thinking that led to the LOGS study. Growth percents used here are calculated as,

$$\text{growth percent} = 100 \left[\frac{PAI}{(X_1 + X_2)/2} \right]$$

where X_1 and X_2 are growing stock at beginning and end of the growth period.

Trends over time of growth percents for basal area of all trees, for CVTS, and for CV6 are shown in figures 31, 32, and 33 and in table 16.

Basal area growth percent—A consistent pattern has occurred, as expected, of growth percent declining over time. The higher density treatments have lower growth percents at a given age, because higher density means a larger divisor. The control falls much below the thinned treatments, both because of its larger divisor and because it has substantial suppression mortality.

CVTS growth percent—Patterns are similar but the spread between treatments is less, compared to basal area growth percent. Suppression mortality on the control represents proportionally much less volume than does basal area because of the small size of trees involved. In thinned treatments, although lower stocking reduces the divisor and is expected to result in higher growth percent, this is partially offset by the reduction in PAI associated with low stocking (further discussion below).

CV6 growth percent—The plots are in a stage of development where ratios of merchantable to total cubic volume are changing rapidly, and this has a considerable effect on the trends shown. Initial growth percents are very high because of the small values of CV6 used as the divisor. Ratios of merchantable volume to total volume increase faster on the lower stocked plots because of the larger trees; this tends to offset the relative increase in growth percent expected from lower total volume of growing stock. The net effect over the age range represented here is to reduce the differences in growth percent among treatments.

Comparisons at age 42—Growth percents in basal area, CVTS, and CV4 in relation to basal area stocking at age 42 (the most recent growth period available) are compared in figure 34. Volume growth percents are considerably higher than basal area growth percents, which in part represents the effect of rapid height growth. Growth percents in CV6 are somewhat higher than in CVTS and, at this stage in stand development, do not differ much among treatments. Because value increases with tree size, presumably value growth percents are higher than shown and might have somewhat different relations to level of growing stock and age.

Crown Development

For the 1989 data (age 42), height to live crown (HLC) measurements were plotted over d.b.h., by treatment. With the possible exception of a few of the smallest trees, the relation was in all cases well represented by a horizontal line. Similar plots of live crown ratio (LCR) generally showed a positive slope, as would be expected, because total height increases with diameter. Therefore, although HLC treatment values can be expressed as simple means, LCR cannot. It seems reasonable to characterize treatment values of LCR by the LCR corresponding to average dimensions of the 40 largest (by d.b.h.) trees per acre. This is readily obtained as $(H40\text{-mean HLC})/H40$.

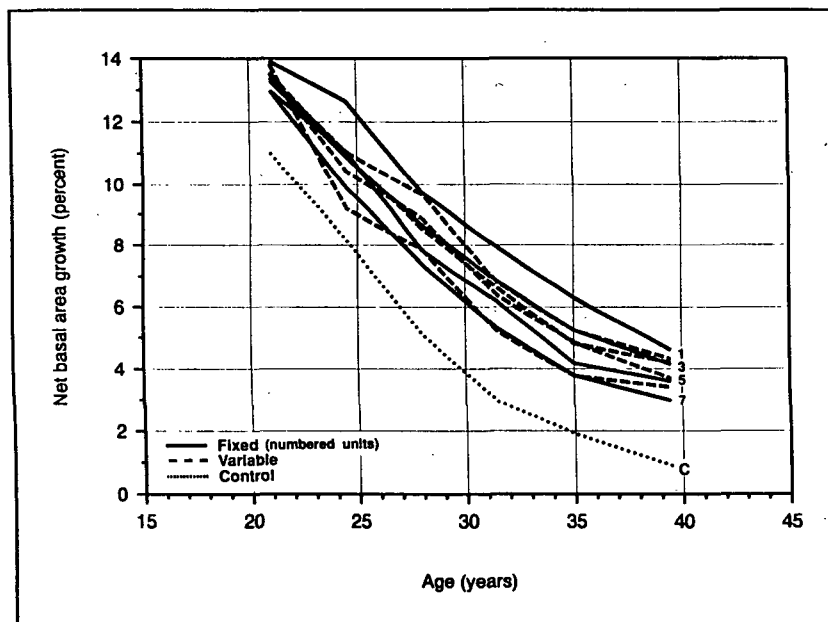


Figure 31—Net basal area growth percent in relation to age and treatment.

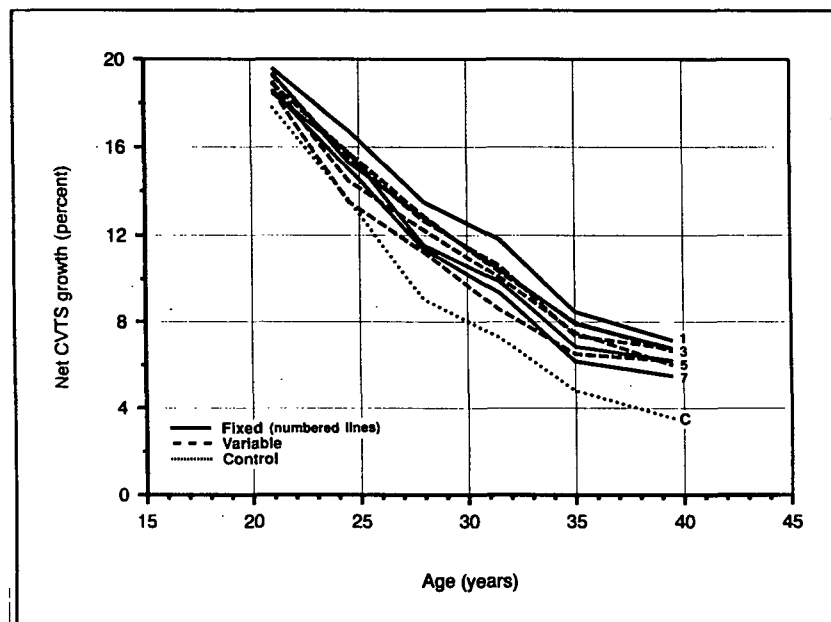


Figure 32—Net volume (CVTS) growth percent in relation to age and treatment.

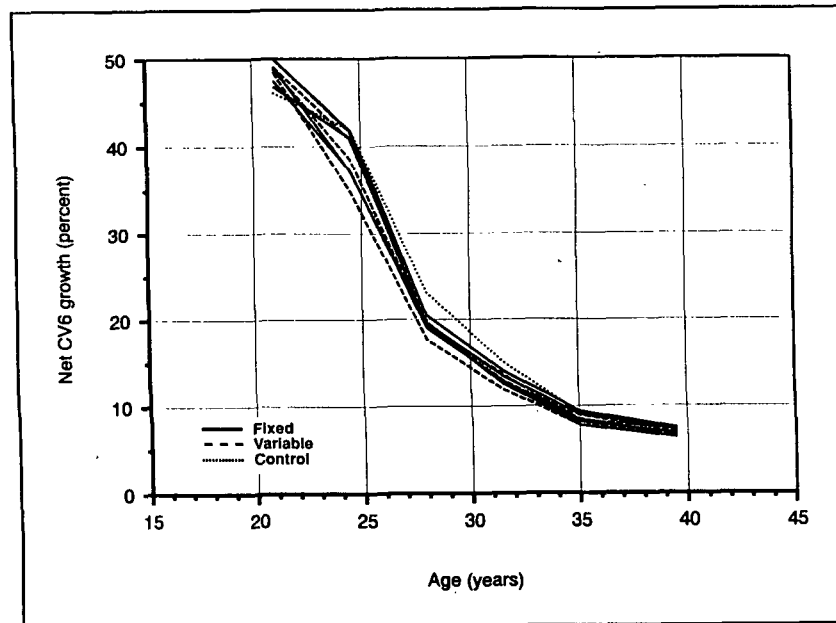


Figure 33—Net merchantable volume (CV6) growth percent in relation to age and treatment.

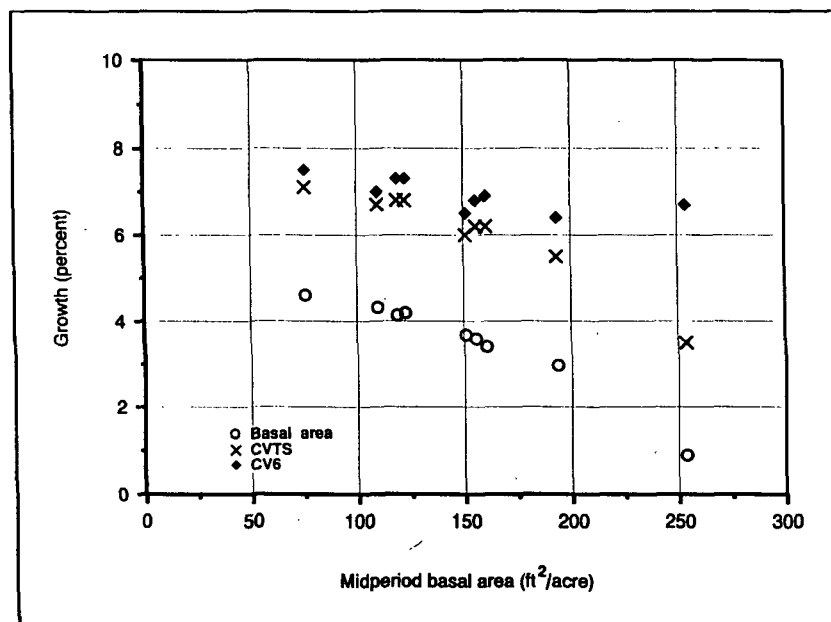


Figure 34—Comparison of growth percents in basal area, total volume, and merchantable volume in most recent growth period, 1984-89.

The resulting values at age 42 are shown in figure 35. Note that HLC values are almost identical for treatments 2, 3, and 6 and for treatments 7, 4, and 8. This corresponds to the expected equality of basal area at the end of the experiment, as shown in figure 3.

LCR40 values are strongly related to basal area (and, similarly, to RD), as shown in figure 36. A question not addressed in this report, but worthy of examination, is that of consistency of these relations over time and among installations.

Because total height within a treatment decreases with decreasing diameter, while HLC remains constant, the differences in live crown ratio associated with different stocking levels will be greater for smaller trees.

Discussion

Results from the Iron Creek LOGS installation are qualitatively similar to those from other site II installations, as reported by Curtis and Marshall (report no. 8—1986) and Marshall and others (report no. 10—1992). Although there are some quantitative differences related to site and stand peculiarities, results generally are consistent with and reinforce conclusions previously drawn from other installations.

Two basic ideas played a major role in conception and design of the LOGS study. The first of these was a concept sometimes termed the “Langsaeter hypothesis” (Langsaeter 1941, as quoted by Braathe 1957; Staebler 1960), widely believed to have been demonstrated by European experience (Mar:Moller 1954) and stated in standard silviculture textbooks (for example, Smith 1962: 43). According to this hypothesis, the main effect of thinning, over a wide range of residual densities, is to redistribute a near-constant gross increment across various numbers of trees. If true, this would greatly simplify construction of yield tables and prediction of thinning effects. This hypothesis had never been tested, however, for young Douglas-fir and was still controversial in Europe in the late 1950s (Holmsgaard 1958).

A second related idea (Staebler 1959) was that, for financial efficiency, one should retain the minimum amount of growing stock feasible without major loss in growth. If the “Langsaeter hypothesis” is assumed to hold, then growth percent should be in direct inverse relation to growing stock over a considerable range in growing stock.

The LOGS study was designed to test these two concepts. It also includes a specific additional comparison among fixed, increasing, and decreasing trends in growing stock, and it was recognized that it would provide much concomitant information.

Analysis of Variance

Results from the ANOVA were much the same as those previously reported for other LOGS installations and were consistent with the graphic comparisons of means that form most of this report.

Growth-Growing Stock Relations

Except where specifically indicated, the discussion refers to net growth rather than gross growth. (For the various thinning treatments gross and net growth are almost identical; however, they differ considerably for the control, where suppression mortality has become important in the last two growth periods.)

Regressions for gross basal area growth in relation to midperiod basal area (fig. 37) show PAI increasing with stocking, although the curves become flatter with advancing age. The curves form a consistent series, with elevation decreasing uniformly with advancing age. Those for net basal area (fig. 38) show, from the third period on, an apparent maximum near the highest stocking in the thinned treatments. This maximum is due almost entirely to the effect of mortality on the control and would not appear were the control omitted.

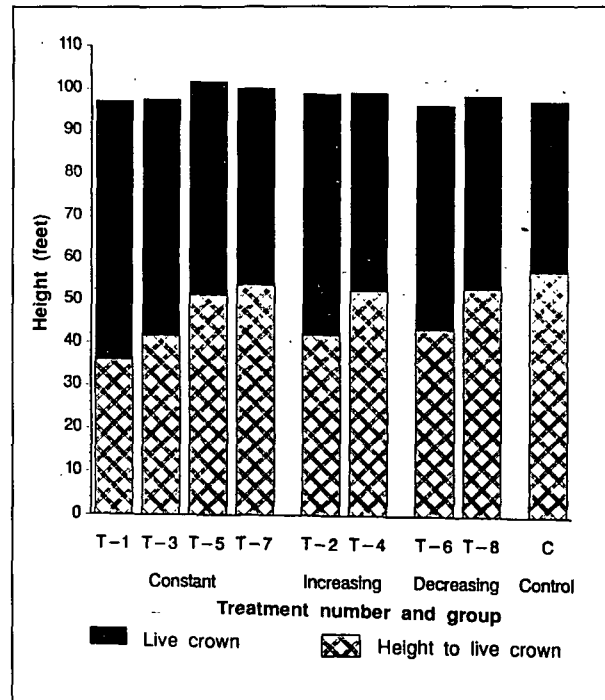


Figure 35—1989 heights and heights to live crown of 40 largest trees per acre, by treatment.

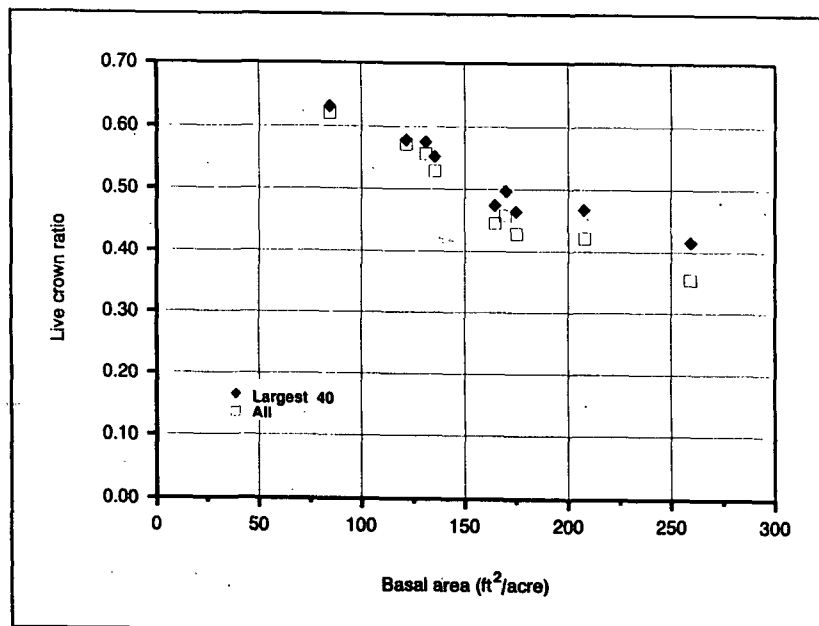


Figure 36—1989 (age 42) live crown ratios of largest 40 stems per acre and of all stems in relation to basal area.

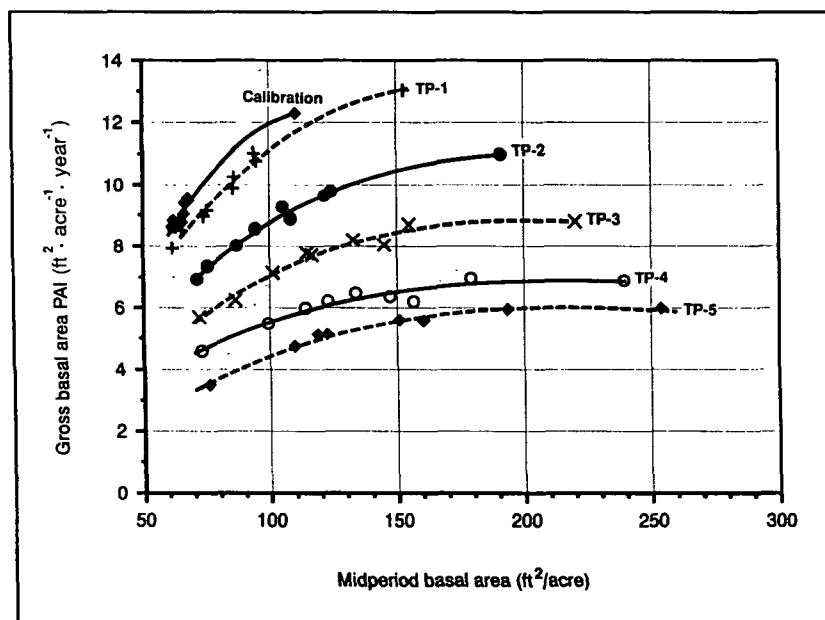


Figure 37—Gross basal area periodic annual increment in relation to midperiod basal area, by periods.

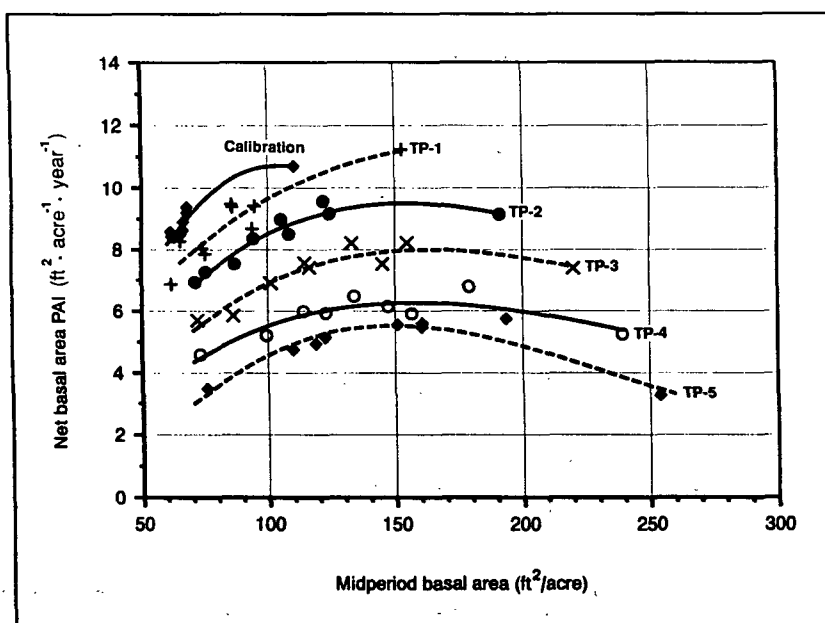


Figure 38—Net basal area periodic annual increment in relation to midperiod basal area, by periods.

Compared to the basal area increment regressions, similar regressions for gross and net CVTS PAI (figs. 39 and 40) have considerably steeper slopes, still present in the most recent period. This reflects rapid and continued height growth (report no. 8—Curtis and Marshall 1986: 80). No maximum is present for gross increment; for net, an apparent maximum occurs in the last two growth periods, arising entirely from mortality in the control.

Elevations decrease with advancing age, but the trend is somewhat irregular. This corresponds to irregularities in estimated height increments, which may or may not be real.

The corresponding net increment regressions for CV6 (fig. 41) strongly resemble the gross increment curves for CVTS. No maximum is present; mortality on the control is, so far, in small trees having little or no effect on the CV6 curve.

The above comparisons demonstrate that both net and gross volume increment are in fact **strongly related to growing stock**. The relation is considerably weaker for basal area increment; the difference is due to the height growth component of volume increment. Like other LOGS installations, Iron Creek clearly demonstrates that the “Langsaeter hypothesis” does not hold for young Douglas-fir stands making rapid height growth. The increased individual tree sizes and values associated with lower growing stock levels are bought at the cost of decreased total cubic volume production.

Growth Percents

As expected, growth percents decline over time and with increasing stocking. Trends differ with the variable involved. Greatest differences between treatments occur with basal area growth percent (fig. 31). Differences are less for CVTS (fig. 32) and least for CV6 (fig. 33). Differences between basal area and CVTS growth percents arise because CVTS growth is more strongly related to stocking than is basal area growth; hence, a decrease in the denominator (midperiod CVTS) is associated with a decrease in the numerator (PAI) and reduces differences in growth percent. This is also true for CV6, but an additional factor involved is the small volume in CV6 present in small-diameter stands (higher density treatments).

A clear relation exists between growth percent in basal area and basal area, and between growth percent in CVTS and basal area stocking, but only a very weak one exists between growth percent in CV6 and basal area stocking (fig. 34). The latter relation is expected to become stronger as trees in all thinning treatments pass into diameter classes having most of their volume in CV6.

At age 42, growth percents in both CVTS and CV6 do not differ greatly among thinning treatments and are much higher than those in basal area (fig. 34). This again reflects the effect of rapid height increment and emphasizes the fact that basal area growth is not a surrogate for volume growth.

Although the general direction of the trends of growth percent in relation to growing stock is as expected, the magnitude of differences in volume growth percents among treatments is considerably less than anticipated when the study was established. Again, this is a consequence of failure of the “Langsaeter hypothesis.”

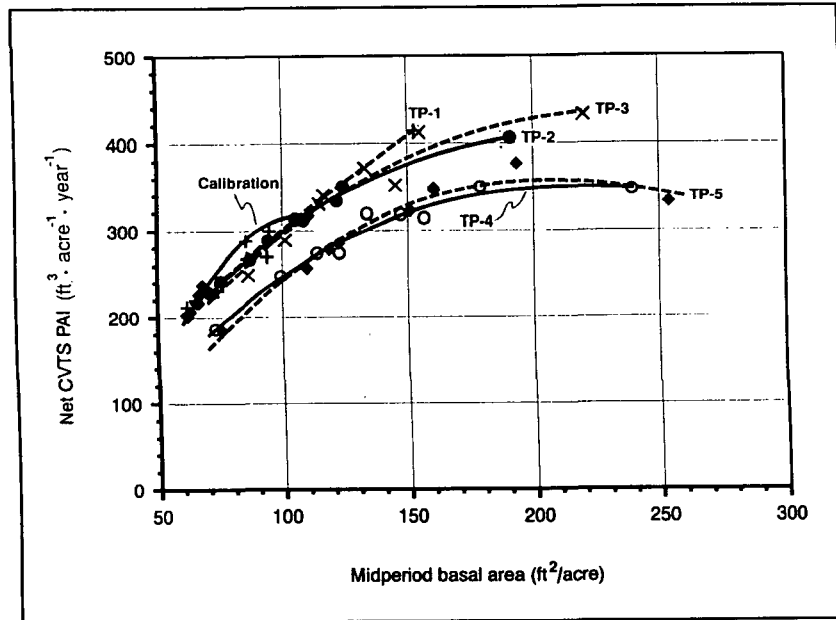


Figure 39—Periodic annual increment in net volume (CVTS) in relation to midperiod basal area, by periods.

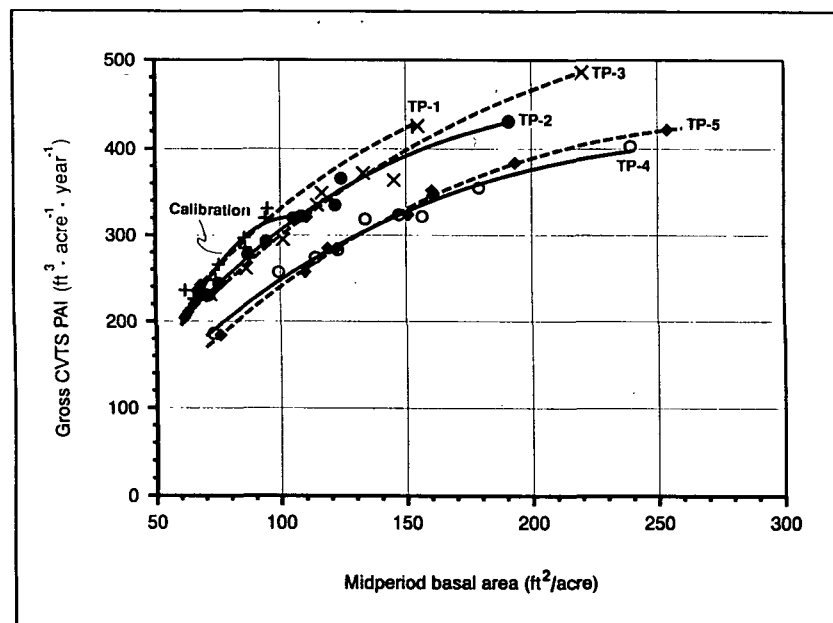


Figure 40—Periodic annual increment in gross volume (CVTS) in relation to midperiod basal area, by periods.

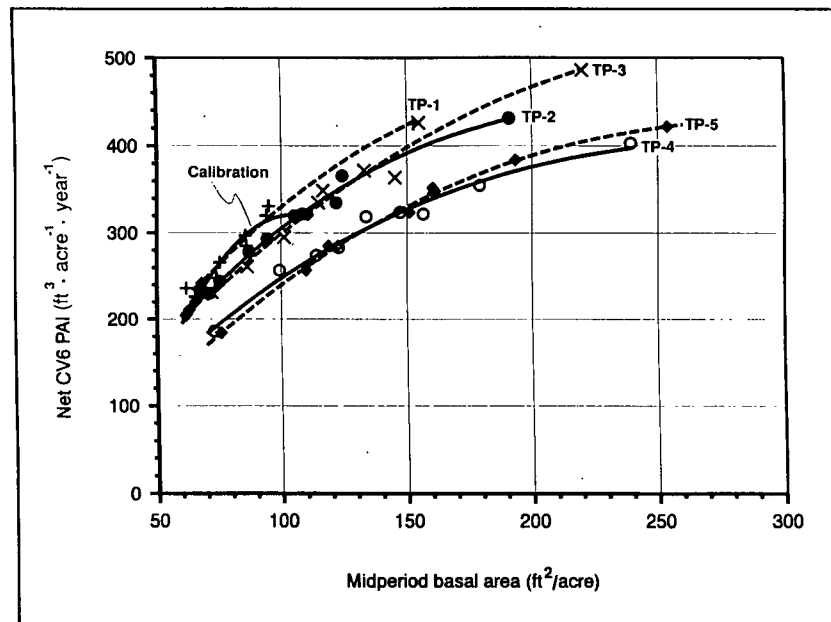


Figure 41—Periodic annual increment in net merchantable volume (CV6) in relation to midperiod basal area, by periods.

Increasing vs. Fixed vs. Decreasing Treatments

The original plan called for comparison of increasing vs. fixed vs. decreasing treatments at each of two final basal area levels (see inside front cover). Namely, T-4 (increasing) vs. T-5 vs. T-8 (decreasing), and T-2 (increasing) vs. T-3 vs. T-6 (decreasing). In each group, the order of cumulative volume production (table 9) is decreasing > fixed > increasing, while that of attained QMD at the final measurement is the reverse.

The goal of equal final basal areas within each treatment group was not completely attained. Differences were not large—165 vs. 170 vs. 174 square feet per acre for the higher level, and 122 vs. 131 vs. 135 square feet per acre for the lower level group. But these differences were sufficient to cast some doubt on the reality of observed differences in volumes and diameters. The graphs of volume distribution by size classes (figs. 21, 22, and 23) do, however, strongly suggest that the increasing treatments have more volume and a larger fraction of their volume in the largest tree size class than do the fixed and decreasing treatments.

Mean Annual Increment and Periodic Annual Increment

Mean annual increment (MAI) and PAI values in CVTS have been superimposed in figures 27 and 28, and those of MAI and PAI in CV6 in figures 29 and 30.

The jog in the PAI values for the period 1980-84 represents the second through the fifth growing seasons after the Mount St. Helens ashfall. It is tempting to consider this as a delayed effect (primarily on height increment) of the eruption; however, this is speculative and there could be quite a different cause.

The MAI and PAI curves shown bring out an important point, which is consistent with results to date from other LOGS installations and pertinent to current forest management controversies: at age 42, PAI is roughly twice MAI in total cubic volume (CVTS) and three times greater than MAI in merchantable volume (CV6) (tables 13, 17). All treatments are still far from culmination. It is clear that harvest at this age—not uncommon in the region today—would involve large losses in productivity relative to the potential.

Stand Damage

Bear damage was striking when the Iron Creek installation was first established, but further damage was eliminated by fencing and little evidence of damage is visible today. Effect on the experiment has been negligible.

Root disease has had a considerable and increasing effect on stand development. In 1989, existing root rot pockets were mapped. One plot (plot 51 in treatment 1) had been virtually destroyed and was eliminated from analyses. Three plots (52, 91, 101) contained holes comprising less than 25 percent of the plot area. Two others (53 and 63) contained holes or scattered root rot trees not considered to have had much effect as yet. But because declining trees were removed in the frequent light thinnings, mortality and loss from this cause, as shown in the record, is considerably less than would have occurred under operational thinning on a longer cycle.

Except for loss of plot 51, the main effect of root rot on the experiment to date has been disruption of the initial choice of crop trees. Excluding plot 51, on which the loss was almost total, 13 percent of the initial crop trees had been replaced by substitutes by 1989. In most cases suitable substitutes were available, and the effect on stand growth has probably been minor.

A secondary effect of root disease is accelerated development of an understory of tolerant species—redcedar and hemlock. Plot 51 is a particularly striking example and now is occupied by dense and vigorous redcedar. Development here (and also at the Rocky Brook LOGS installation) suggests that root disease is often a major factor in natural conversion of initially homogeneous and nearly pure Douglas-fir stands to considerably less uniform stands with a substantial redcedar component.

The Mount St. Helens ashfall, though spectacular at the time, has had only a transitory effect.

Volume Production

Cumulative totals—Cumulative net CVTS production to age 42 is still higher on the control than on any of the thinning treatments (fig. 18); although, with the onset of suppression mortality, the curves for the control and for treatment 7 appear to be converging. (When the LOGS study was planned, treatment 7 was designed as a treatment expected to do little more than forestall suppression-related mortality). In contrast, four treatments (5, 7, 6, and 8) exceed the control in cumulative net CV6 production (fig. 19). Treatment 1 ranks lowest in both CVTS and CV6.

Volume distribution by tree size—Figures 20 and 21 show distribution of total volume (CVTS) by tree size classes at age 42 and for cumulative production to age 42. From these it is clear that all thinning treatments except treatment 1 have produced substantially larger volumes than the control in the largest size classes, and that the proportions of volume in the larger size classes are much higher. This implies a considerably higher future value per cubic foot because of both lower logging cost and the much higher value of large trees, which are now moving into sizes where log grades will be changing rapidly.

At age 42, thinning treatments 5, 7, 6, and 8—the higher density treatments—appear to have produced the most favorable results in terms of the combination of relatively high CV6 and concentration of this volume on relatively large trees. Treatment 1 clearly has too few trees for a timber production objective and was in fact intended as an extreme treatment “designed to fail.”

The LOGS study was not intended as a comparison of operationally feasible thinning regimes. It was designed as (1) a test of hypotheses on relations between growth and growing stock, and growth percent and growing stock, and (2) a means of developing information on the nature and quantitative values of growth-growing stock relations that would aid in predicting the results of possible thinning regimes. These aims have been met.

The very short thinning cycle used (10 feet of height growth = 3-5 years) is clearly impractical operationally. However, several studies have indicated that—within limits—thinning cycle has only a minor influence on production. Essentially the same results probably could have been achieved by initial precommercial thinning to the numbers left in the first treatment thinning, followed by one or two entries (rather than the five actually made) designed to give a similar trend in average growing stock over time.

Future Uses of LOGS Study

This report summarizes the principal stand statistics for the Iron Creek installation to age 42 and represents completion of the study as originally planned. It also presents the principal analyses called for in the original study plan. This follows the pattern established by reports on other installations. There are a number of aspects not addressed, however, that should receive attention in the future.

Continuation of installations—Future development of these stands should be followed. Interpretation of the results and desirability of the stocking levels compared will be heavily influenced by the way they develop over the next few years. Early stocking levels that appeared relatively undesirable may change ranking with advancing age as densities, log grades, and values change. Further treatment is not feasible because of the relatively small plot sizes; there simply are too few trees left to allow reasonable thinning.

The members of the LOGS cooperative have agreed to continue remeasurement of these installations for at least 10 years after completion of the planned experiment.

Value development—To date, almost all analyses of LOGS installations (and all those presented for Iron Creek) have been in terms of volume and basal area rather than value production. This could be quite misleading, because value is strongly related to tree size. Interpretations could be very different and probably would be strongly influenced by choice of alternative harvest ages.

Iron Creek, and other LOGS installations, are now in a stage where values are changing rapidly. Further measurements soon will be available, and it should be possible, by using available simulators, to project present stand characteristics and size distributions for some distance into the future with a high degree of confidence.

Calculation and analyses of value development should provide much information on the value consequences of alternative growing stock levels and alternative harvest ages. These questions are highly pertinent to current controversies over forest management practices.

Understory development—To date, no quantitative descriptions or measurements have been made of the herbaceous vegetation, shrubs, and developing understory of hemlock and redcedar. Yet it is evident from casual inspection that strong relations exist among treatment, composition, and vigor of this secondary vegetation. At Iron Creek, the more heavily thinned treatments are developing a pronounced understory of hemlock and cedar that eventually will lead to a two-storied stand with distinctly different height and diameter distributions for Douglas-fir vs. the tolerant hemlock and cedar. Observation of other LOGS installations indicates that these relations differ markedly among sites. There is a need for examination and comparison of these relations across the various LOGS installations, for which long-term and very detailed records of development and treatment of the overstory are available. Again, these relations and differences are pertinent to current concerns about effects of thinning and stocking levels on development of wildlife habitat and biodiversity in young stands.

Crown development—Present crown dimensions and live crown ratios at Iron Creek (figs. 35, 36) are closely related to current basal area stocking (and to relative density). Crown measurements also exist for most of the past measurement dates at Iron Creek and for some of the other LOGS installations. An analysis of trends over time of crown dimensions in relation to tree dimensions, position, and stand density, and of the consistency of such relations across installations, would be highly desirable. Such information is an important component of a number of widely used stand development models, and good data are scarce.

Metric Equivalents

- 1 inch = 2.54 centimeters
- 1 foot = 0.3048 meter
- 1 square foot = 0.09290 square meter
- 1 cubic foot = 0.028 cubic meter
- 1 acre = 0.4047 hectare
- 1 square foot per acre = 0.2296 square meter per hectare
- 1 cubic foot per acre = 0.06997 cubic meter per hectare
- 1 mile = 1.609 kilometers

Literature Cited

- Braathe, Peder. 1957.** Thinnings in even-aged stands: a summary of European literature. New Brunswick, NS: University of New Brunswick, Faculty of Forestry. 92 p.
- Brackett, Michael. 1973.** Notes on tariff tree volume computation. Resour. Mgmt. Rep. 24. Olympia, WA: Washington Department of Natural Resources. 26 p.
- Bruce, David; DeMars, Donald J. 1974.** Volume equations for second-growth Douglas-fir. Res. Note PNW-239. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.
- Curtis, Robert O. 1982.** A simple index of stand density for Douglas-fir. Forest Science. 28(1): 92-94.
- Curtis, Robert O.; Marshall, David D. 1989.** On the definition of stand diameter growth for remeasured plots. Western Journal of Applied Forestry. 4(3): 102-103.

- Holmsgaard, Erik. 1958.** Comments on some German and Swedish thinning experiments in Norway spruce. *Forest Science*. 4(1): 54-60.
- Hyink, D.M.; Scott, W.; Leon, R.M. 1988.** Some important aspects in the development of a managed stand growth model for western hemlock. In: Ek, A.L.; Shifley, S.R.; Burk, T.E., eds. *Forest growth modelling and prediction: Proceedings of IUFRO conference; 1987 August 23-27; Minneapolis, MN*. Gen. Tech. Rep. NC-120. Minneapolis, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 9-21.
- King, James E. 1966.** Site index curves for Douglas-fir in the Pacific Northwest. For. Pap. 8. Centralia, WA: Weyerhaeuser Forestry Research Center. 49 p.
- Langsaeter, A. 1941.** Om tynning i enaldret gran-og furskog = Thinning of even-aged spruce and pine forests. Referat: Produktionsuntersuchungen von Fichtenwald. *Meddelelser fra det Norske Skogforsoksesvesen*. 8: 131-216.
- Mar:Moller, Carl. 1954.** The influence of thinning on volume increment. In: *Thinning problems and practices in Denmark*. Tech. Publ. 76. Syracuse, NY: State University of New York, College of Forestry at Syracuse: 5-44.
- Reineke, L.H. 1933.** Perfecting a stand-density index for even-aged forests. *Journal of Agricultural Research*. 46: 627-638.
- SAS Institute. 1988.** SAS/STAT user's guide, Release 6.03 edition. Cary, NC: SAS Institute, Inc. 1028 p.
- Smith, David M. 1962.** The practice of silviculture. 7th ed. New York: John Wiley and Sons. 578 p.
- Snedecor, George W.; Cochran, William G. 1980.** Statistical methods. 7th ed. Ames, IA: Iowa State University Press. 507 p.
- Staebler, George R. 1959.** Optimum levels of growing stock for managed stands. *Proceedings, Society of American Foresters*: 110-113.
- Staebler, George R. 1960.** Theoretical derivation of numerical thinning schedules for Douglas-fir. *Forest Science*. 6(2): 98-109.
- Topik, Christopher; Halverson, Nancy M.; Brockway, Dale G. 1986.** Plant association and management guide for the western hemlock zone. R6-ECOL-230A-1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 132 p.

Appendix 1: Description of Experiment

The following information is excerpted (and paraphrased) from Williamson and Staebler (report no. 1—1971).

The experiment is designed to test a number of thinning regimes beginning in young stands made alike at the start through a calibration thinning. Thereafter, through the time required for 60 feet of height growth, growing stock is controlled by allowing a specified addition to the growing stock between successive thinnings. Any extra growth is cut and is one of the measured effects of the thinning regime.

Experimental Design

A single experiment consists of eight thinning regimes plus unthinned plots whose growth is the basis for treatment in these regimes. There are three plots per treatment arranged in a completely randomized design for a total of 27 plots of one-fifth acre each.

Crop Tree Selection

Well-formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees before initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees or no more than five—another criterion for stand uniformity.

Initial or “Calibration” Thinning

All 24 treated plots are thinned initially to the same density to minimize the effect of variations in original density on stand growth. Density of residual trees is controlled by quadratic mean diameter (diameter of tree of average basal area) of the residual stand according to the formula,

$$\text{Average spacing in feet} = (0.6167 \times \text{QMD}) + 8 .$$

If one concentrates on leaving a certain amount of basal area corresponding to an estimated overall quadratic mean d.b.h. ...[QMD], then the residual number of trees may vary freely and the actual...[QMDs] may differ among plots...plus or minus 10 percent. Alternatively, if emphasis is on leaving a certain number of trees to correspond to an estimated overall...[QMD], then the basal areas differ among plots and the actual...[QMDs] may vary...plus or minus 15 percent between plots.

Treatments

The eight tested thinning regimes differ in the amount of basal area allowed to accumulate in the growing stock. The amount of growth retained in any thinning is a predetermined percentage of the gross increase found in the unthinned plots since the last thinning...(table inside front cover). The average residual basal area for all thinned plots after the calibration thinning is the foundation upon which all future growing stock accumulation is based. As used in the study, control plots may be thought of as providing a “local gross yield table” for the study area.

Control of Thinning Interval

Thinnings will be made (after the calibration thinning) whenever average height growth of crop trees...comes closest to each multiple of 10 feet [above the initial height].

Control of Type of Thinning

As far as possible, type of thinning is eliminated as a variable in the treatment thinnings through several specifications.

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).
2. The quadratic mean diameter of cut trees should approximate that of trees available for cutting.
3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

Appendix 2: Tables

Table 1—Analysis of variance

Source of variation	Degrees of freedom (5 treatment periods)
Treatments:	(7)
A. Fixed vs. variable percentage treatments	1
B. Among levels of fixed percentage treatments—	
Linear effects	1
Quadratic effects	1
Cubic effects	1
C. Increasing percentage treatments	1
D. Between levels of increasing percentage treatments	1
E. Between levels of decreasing percentage treatments	1
Error a for testing treatments	15
P periods	4
Treatments x period interactions:	
P x A	4
P x B linear effects	4
P x B quadratic effects	4
P x B cubic effects	4
P x C	4
P x D	4
P x E	4
Error b for testing interactions	60
Total	<u>115</u>

Table 2—Analysis of variance results for periodic annual gross growth and gross growth percent in volume (CVTS) and basal area, and net periodic annual growth in quadratic mean diameter

Source of variation	P-values ^a and mean square errors				
	Volume		Basal area		Diameter
	PAI	Growth %	PAI	Growth %	PAI
Treatments:	0.00**	0.00**	0.00**	0.00**	0.00**
A. Fixed vs. variable	.66	.38	.29	.96	.83
B. Fixed (linear)	.00**	.00**	.00**	.00**	.00**
B. Fixed (quadratic)	.14	.33	.17	.13	.37
B. Fixed (cubic)	.85	.20	.71	.41	.60
C. Increasing vs. decreasing	.00**	.00**	.00**	.00**	.00**
D. Between increasing	.00**	.00**	.00**	.00**	.07
E. Between decreasing	.00**	.00**	.16	.00**	.05
Error a mean square	841.39	.290	.423	.190	.00244
P periods:	.00**	.00**	.00**	.00**	.00**
P x A	.66	.74	.41	.07	.37
P x B (linear)	.00**	.10	.08	.00**	.00**
P x B (quadratic)	.05*	.52	.00**	.04*	.50
P x B (cubic)	.77	.76	.22	.70	.52
P x C	.02*	.26	.00**	.00**	.04*
P x D	.06	.41	.26	.99	.06
P x E	.13	.17	.12	.00**	.15
Error b mean square	290.72	.310	.0668	.0376	.000301

^a P is the probability of a larger F, given that the null hypothesis of no difference among means is true.

Significance levels: * = 0.01 < p < 0.05; ** = 0.00 < p < 0.01.

Table 3a—Treatment mean heights (H40) of 40 largest diameter trees per acre and of crop trees (Hcrop) by treatment, period, and year

Treatment	After cut	Before cut					
	1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
<i>Feet</i>							
Fixed:							
1 ^b H40	39.9	50.1	59.0	68.9	78.7	85.3	97.3
Hcrop	35.2	46.0	53.3	64.0	72.9	81.0	94.4
3 H40	37.3	49.1	56.4	67.6	75.5	84.4	97.8
Hcrop	35.2	46.8	54.4	65.0	73.2	82.1	94.8
5 H40	38.4	50.3	59.4	69.7	78.3	87.8	102.0
Hcrop	37.0	48.7	57.6	67.8	76.9	85.5	98.5
7 H40	38.5	49.3	58.6	69.9	78.5	87.8	100.6
Hcrop	36.3	47.1	55.8	66.8	75.9	84.4	96.4
Increasing:							
2 H40	40.1	50.7	57.8	67.3	75.7	85.5	99.4
Hcrop	38.2	48.9	57.3	66.4	74.6	83.7	95.3
4 H40	40.8	52.8	59.6	68.6	77.5	87.4	99.7
Hcrop	39.4	50.4	57.8	67.3	76.3	85.6	96.9
Decreasing:							
6 H40	36.9	47.6	55.7	67.2	75.3	83.7	96.9
Hcrop	35.6	46.1	53.8	64.6	73.2	82.2	94.3
8 H40	40.4	51.0	60.0	69.0	79.2	85.8	99.2
Hcrop	38.4	48.8	57.4	66.4	79.2	83.4	96.6
Unthinned:							
C H40	36.6	48.5	57.1	67.7	76.5	85.9	98.1
Hcrop	35.4	46.9	55.6	65.4	74.7	83.5	95.3

^a Stand age in parentheses.

^b Plot 51 omitted from mean of treatment 1 because of root rot.

Table 3b—Treatment mean heights (H40) of 100 largest diameter trees per hectare and of crop trees, by treatment, period, and year

Treatment	After cut	Before cut					
	1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
<i>Meters</i>							
Fixed:							
1 ^b H40	12.2	15.3	18.0	21.0	24.0	26.0	29.6
Hcrop	10.7	14.0	16.2	19.5	22.2	24.7	28.8
3 H40	11.4	15.0	17.2	20.6	23.0	25.7	29.8
Hcrop	10.7	14.3	16.6	19.8	22.3	25.0	28.9
5 H40	11.7	15.3	18.1	21.2	23.9	26.8	31.1
Hcrop	11.3	14.8	17.6	20.7	23.4	26.1	30.0
7 H40	11.7	15.0	17.9	21.3	23.9	26.8	30.7
Hcrop	11.1	14.4	17.0	20.4	23.1	25.7	29.4
Increasing:							
2 H40	12.2	15.5	17.6	20.5	23.1	26.1	30.3
Hcrop	11.6	14.9	17.5	20.2	22.7	25.5	29.0
4 H40	12.4	16.1	18.2	20.9	23.6	26.6	30.4
Hcrop	12.0	15.4	17.6	20.5	23.3	26.1	29.5
Decreasing:							
6 H40	11.2	14.5	17.0	20.5	22.9	25.5	29.5
Hcrop	10.8	14.0	16.4	19.7	22.3	25.1	28.8
8 H40	12.3	15.6	18.3	21.0	24.1	26.2	30.2
Hcrop	11.7	14.9	17.5	20.2	24.1	25.4	29.4
Unthinned:							
C H40	11.1	14.8	17.4	20.6	23.3	26.2	29.9
Hcrop	10.8	14.3	17.0	19.9	22.8	25.5	29.0

^a Stand age in parentheses.

^b Plot 51 omitted from mean of treatment 1 because of root rot.

Table 4a—Number of trees per acre by treatment, plot, period, year and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- <i>Number of Trees</i> -----													
Fixed:													
1 ^b	21	350	345	205	205	140	140	95	95	75	75	55	55
	33	360	355	225	215	155	150	110	110	80	80	65	65
	51	355	330	240	210	160	145	95	85	75	75	65	65
3	31	355	350	275	270	225	220	185	185	160	160	135	135
	42	335	335	215	210	165	165	145	145	125	125	100	100
	52	355	335	255	230	190	180	155	150	150	150	110	105
5	12	345	335	275	275	230	230	215	215	195	195	165	165
	41	335	330	255	255	220	220	205	205	185	185	160	160
	72	360	350	300	290	275	260	260	260	250	240	210	210
7	11	345	340	305	305	280	280	280	280	265	265	235	230
	23	355	345	340	335	325	310	310	310	305	300	270	270
	63	380	355	355	310	310	300	300	290	290	285	275	265
Increasing:													
2	82	360	355	200	195	150	150	125	125	110	110	95	95
	91	370	350	215	190	175	175	135	130	130	130	110	110
	101	350	335	180	180	140	135	120	120	105	100	85	85
4	13	335	330	200	190	155	155	150	145	140	140	130	130
	62	400	390	285	265	235	230	215	215	190	190	180	175
	111	355	345	245	230	200	190	175	175	165	165	150	150
Decreasing:													
6	15	350	335	290	285	240	235	205	200	170	165	130	130
	43	370	350	315	290	255	250	195	195	170	170	130	130
	81	360	345	315	310	260	255	210	210	175	175	125	125
8	14	340	330	290	290	245	245	225	220	195	190	150	150
	53	360	350	345	315	310	305	285	275	270	265	230	225
	73	355	355	305	270	270	270	260	255	210	210	180	180
Unthinned:													
C	22	1345	1390	1390	1325	1325	1260	1260	1180	1180	1105	1105	920
	25	1385	1400	1400	1395	1395	1320	1320	1180	1180	1035	1035	830
	71	1085	1140	1140	1160	1160	1110	1110	1025	1025	890	890	785

^a Stand age in parentheses.

^b Plot 51 abandoned 1989 because of severe root rot.

Table 4b—Number of trees per hectare by treatment, plot, period, year and age

Treatment	Plot	Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
		After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- <i>Number of Trees</i> -----													
Fixed:													
1 ^b	21	865	853	507	507	346	346	235	235	185	185	136	136
	33	890	877	556	531	383	371	272	272	198	198	161	161
	51	877	815	593	519	395	358	235	210	185	185	161	161
3	31	877	865	680	667	556	544	457	457	395	395	334	334
	42	828	828	531	519	408	408	358	358	309	309	247	247
	52	877	828	630	568	469	445	383	371	371	371	272	259
5	12	853	828	680	680	568	568	531	531	482	482	408	408
	41	828	815	630	630	544	544	507	507	457	457	395	395
	72	890	865	741	717	680	642	642	642	618	593	519	519
7	11	853	840	754	754	692	692	692	692	655	655	581	568
	23	877	853	840	828	803	766	766	766	754	741	667	667
	63	939	877	877	766	766	741	741	717	717	704	680	655
Increasing:													
2	82	890	877	494	482	371	371	309	309	272	272	235	235
	91	914	865	531	469	432	432	334	321	321	321	272	272
	101	865	828	445	445	346	334	297	297	259	247	210	210
4	13	828	815	494	469	383	383	371	358	346	346	321	321
	62	988	964	704	655	581	568	531	531	469	469	445	432
	111	877	853	605	568	494	469	432	432	408	408	371	371
Decreasing:													
6	15	865	828	717	704	593	581	507	494	420	408	321	321
	43	914	865	778	717	630	618	482	482	420	420	321	321
	81	890	853	778	766	642	630	519	519	432	432	309	309
8	14	840	815	717	717	605	605	556	544	482	469	371	371
	53	890	865	853	778	766	754	704	680	667	655	568	556
	73	877	877	754	667	667	667	642	630	519	519	445	445
Unthinned:													
C	22	3324	3435	3435	3274	3274	3114	3114	2916	2916	2731	2731	2273
	25	3422	3459	3459	3447	3447	3262	3262	2916	2916	2558	2558	2051
	71	2681	2817	2817	2866	2866	2743	2743	2533	2533	2199	2199	1940

^a Stand age in parentheses.^b Plot 51 abandoned 1989 because of severe root rot.

Table 5a—Basal area per acre by treatment, plot, period, year and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- <i>Square feet</i> -----													
Fixed:													
1 ^b	21	45.0	78.1	52.9	77.7	57.8	85.4	62.5	79.2	64.6	83.3	65.9	82.2
	33	44.0	79.5	53.1	77.9	57.1	84.9	64.5	82.0	63.0	81.0	68.0	86.6
	51	41.3	70.5	52.8	69.8	56.5	77.9	55.8	63.0	59.1	74.5	67.7	85.6
3	31	43.9	75.0	61.9	87.1	73.9	105.8	92.6	115.2	100.4	125.3	110.5	136.4
	42	51.0	88.7	62.2	86.8	69.3	100.6	92.9	114.5	100.6	122.0	104.6	129.5
	52	43.9	75.9	61.6	84.2	72.8	100.0	86.7	104.7	104.7	130.2	104.4	127.6
5	12	48.2	82.5	71.4	101.6	92.3	129.1	122.1	147.5	134.2	160.0	141.1	169.2
	41	51.1	85.8	71.3	102.3	91.0	128.7	121.9	148.3	135.1	161.5	142.2	171.1
	72	46.5	79.4	71.3	95.3	90.6	118.1	118.1	140.2	135.4	157.0	141.8	168.6
7	11	52.2	88.5	81.3	114.6	107.6	147.3	147.3	173.1	169.4	198.9	179.5	209.1
	23	46.8	81.3	79.5	109.6	107.5	144.0	144.0	170.5	169.1	195.1	179.5	208.6
	63	48.7	81.4	81.4	102.7	102.7	136.4	136.4	158.1	158.1	183.8	178.6	206.0
Increasing:													
2	82	49.3	88.1	52.5	74.5	60.0	89.1	77.9	97.2	88.3	109.7	99.2	123.3
	91	45.0	77.2	51.2	67.1	61.7	92.8	74.5	89.2	89.2	112.4	98.7	123.5
	101	52.1	88.0	51.1	75.0	60.7	87.7	80.2	98.9	89.2	107.1	95.8	118.1
4	13	51.7	90.6	61.8	85.4	74.6	108.4	106.0	125.5	123.0	147.3	135.9	163.6
	62	47.2	83.5	64.8	90.0	82.1	115.9	107.2	130.6	118.6	144.6	138.4	166.7
	111	50.1	85.3	64.0	85.9	76.3	109.0	102.9	126.7	120.7	148.1	137.0	164.2
Decreasing:													
6	15	46.3	80.6	72.0	102.3	86.8	121.7	105.6	126.1	110.8	131.7	110.3	135.5
	43	45.9	79.1	71.5	96.1	87.9	125.4	99.6	122.9	109.5	134.6	109.5	136.0
	81	43.9	77.5	72.1	101.7	86.8	122.2	104.7	128.9	112.5	137.6	109.4	134.8
8	14	51.7	89.7	80.8	115.7	104.0	144.5	135.9	159.6	144.9	171.0	146.9	176.9
	53	46.4	82.9	81.6	102.9	101.7	137.2	127.8	148.4	144.8	167.5	146.5	171.9
	73	49.5	87.6	80.4	102.3	102.3	141.1	137.9	161.4	144.5	166.6	146.8	173.4
Unthinned:													
C	22	97.8	147.8	147.8	183.1	183.1	224.1	224.1	245.6	245.6	267.9	267.9	272.9
	25	90.9	141.2	141.2	181.6	181.6	225.9	225.9	242.6	242.6	261.0	261.0	272.9
	71	70.2	114.3	114.3	149.9	149.9	181.9	181.9	201.5	201.9	216.4	216.4	232.2

^a Stand age in parentheses.

^b Plot 51 abandoned 1989 because of severe root rot.

Table 5b—Basal area per hectare by treatment, plot, period, year, and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- <i>Square meters</i> -----													
Fixed:													
1 ^b	21	10.3	17.9	12.1	17.8	13.3	19.6	14.3	18.2	14.8	19.1	15.1	18.9
	33	10.1	18.3	12.2	17.9	13.1	19.5	14.8	18.8	14.5	18.6	15.6	19.9
	51	9.5	16.2	12.1	16.0	13.0	17.9	12.8	14.5	13.6	17.1	15.5	19.7
3	31	10.1	17.2	14.2	20.0	17.0	24.3	21.3	26.4	23.1	28.8	25.4	31.3
	42	11.7	20.4	14.3	19.9	15.9	23.1	21.3	26.3	23.1	28.0	24.0	29.7
	52	10.1	17.4	14.2	19.3	16.7	22.9	19.9	24.0	24.0	29.9	24.0	29.3
5	12	11.1	18.9	16.4	23.3	21.2	29.6	28.0	33.9	30.8	36.7	32.4	38.8
	41	11.7	19.7	16.4	23.5	20.9	29.6	28.0	34.0	31.0	37.1	32.6	39.3
	72	10.7	18.2	16.4	21.9	20.8	27.1	27.1	32.2	31.1	36.0	32.6	38.7
7	11	12.0	20.3	18.7	26.3	24.7	33.8	33.8	39.7	38.9	45.7	41.2	48.0
	23	10.7	18.7	18.3	25.2	24.7	33.1	33.1	39.2	38.8	44.8	41.2	47.9
	63	11.2	18.7	18.7	23.6	23.6	31.3	31.3	36.3	36.3	42.2	41.0	47.3
Increasing:													
2	82	11.3	20.2	12.1	17.1	13.8	20.5	17.9	22.3	20.3	25.2	22.8	28.3
	91	10.3	17.7	11.8	15.4	14.2	21.3	17.1	20.5	20.5	25.8	22.7	28.3
	101	12.0	20.2	11.7	17.2	13.9	20.1	18.4	22.7	20.5	24.6	22.0	27.1
4	13	11.9	20.8	14.2	19.6	17.1	24.9	24.3	28.8	28.2	33.8	31.2	37.6
	62	10.8	19.2	14.9	20.7	18.8	26.6	24.6	30.0	27.2	33.2	31.8	38.3
	111	11.5	19.6	14.7	19.7	17.5	25.0	23.6	29.1	27.7	34.0	31.5	37.7
Decreasing:													
6	15	10.6	18.5	16.5	23.5	19.9	27.9	24.2	28.9	25.4	30.2	25.3	31.1
	43	10.5	18.2	16.4	22.1	20.2	28.8	22.9	28.2	25.1	30.9	25.1	31.2
	81	10.1	17.8	16.5	23.4	19.9	28.1	24.0	29.6	25.8	31.6	25.1	30.9
8	14	11.9	20.6	18.5	26.6	23.9	33.2	31.2	36.6	33.3	39.3	33.7	40.6
	53	10.6	19.0	18.7	23.6	23.3	31.5	29.3	34.1	33.2	38.4	33.6	39.5
	73	11.4	20.1	18.5	23.5	23.5	32.4	31.7	37.0	33.2	38.2	33.7	39.8
Unthinned:													
C	22	22.5	33.9	33.9	42.0	42.0	51.4	51.4	56.4	56.4	61.5	61.5	62.6
	25	20.9	32.4	32.4	41.7	41.7	51.9	51.9	55.7	55.7	59.9	59.9	62.6
	71	16.1	26.2	26.2	34.4	34.4	41.8	41.8	46.3	46.3	49.7	49.7	53.3

^a Stand age in parentheses.^b Plot 51 abandoned 1989 because of severe root rot.

Table 6a—Quadratic mean diameter of all live trees by treatment, plot, period, year and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- Inches -----													
Fixed:													
1 ^b	21	4.9	6.4	6.9	8.3	8.7	10.6	11.0	12.4	12.6	14.3	14.8	16.6
	33	4.7	6.4	6.6	8.1	8.2	10.2	10.4	11.7	12.0	13.6	13.9	15.6
	51	4.6	6.3	6.3	7.8	8.0	9.9	10.4	11.7	12.0	13.5	13.8	15.5
3	31	4.8	6.3	6.4	7.7	7.8	9.4	9.6	10.7	10.7	12.0	12.3	13.6
	42	5.3	7.0	7.3	8.7	8.8	10.6	10.8	12.0	12.1	13.4	13.9	15.4
	52	4.8	6.4	6.7	8.2	8.4	10.1	10.1	11.3	11.3	12.6	13.2	14.9
5	12	5.1	6.7	6.9	8.2	8.6	10.1	10.2	11.2	11.2	12.3	12.5	13.7
	41	5.3	6.9	7.2	8.6	8.7	10.4	10.4	11.5	11.6	12.7	12.8	14.0
	72	4.9	6.5	6.6	7.8	7.8	9.1	9.1	9.9	10.0	11.0	11.1	12.1
7	11	5.3	6.9	7.0	8.3	8.4	9.8	9.8	10.6	10.8	11.7	11.8	12.9
	23	4.9	6.6	6.5	7.7	7.8	9.2	9.2	10.0	10.1	10.9	11.0	11.9
	63	4.8	6.5	6.5	7.8	7.8	9.1	9.1	10.0	10.0	10.9	10.9	11.9
Increasing:													
2	82	5.0	6.7	6.9	8.4	8.6	10.4	10.7	11.9	12.1	13.5	13.8	15.4
	91	4.7	6.4	6.6	8.0	8.0	9.9	10.1	11.2	11.2	12.6	12.8	14.3
	101	5.2	6.9	7.2	8.7	8.9	10.9	11.1	12.3	12.5	14.0	14.4	16.0
4	13	5.3	7.1	7.5	9.1	9.4	11.3	11.4	12.6	12.7	13.9	13.8	15.2
	62	4.7	6.3	6.5	7.9	8.0	9.6	9.6	10.6	10.7	11.8	11.9	13.2
	111	5.1	6.7	6.9	8.3	8.4	10.3	10.4	11.5	11.6	12.8	12.9	14.2
Decreasing:													
6	15	4.9	6.6	6.7	8.1	8.1	9.7	9.7	10.8	10.9	12.1	12.5	13.8
	43	4.8	6.4	6.5	7.8	8.0	9.6	9.7	10.7	10.9	12.0	12.4	13.9
	81	4.7	6.4	6.5	7.8	7.8	9.4	9.6	10.6	10.9	12.0	12.7	14.1
8	14	5.3	7.1	7.1	8.6	8.8	10.4	10.5	11.5	11.7	12.8	13.4	14.7
	53	4.9	6.6	6.6	7.7	7.8	9.1	9.1	9.9	9.9	10.8	10.8	11.8
	73	5.1	6.7	7.0	8.3	8.3	9.8	9.9	10.8	11.2	12.1	12.2	13.3
Unthinned:													
C	22	3.7	4.4	4.4	5.0	5.0	5.7	5.7	6.2	6.2	6.7	6.7	7.4
	25	3.5	4.3	4.3	4.9	4.9	5.6	5.6	6.1	6.1	6.8	6.8	7.8
	71	3.4	4.3	4.3	4.9	4.9	5.5	5.5	6.0	6.0	6.7	6.7	7.4

^a Stand age in parentheses.

^b Plot 51 abandoned 1989 because of severe root rot.

Table 6b—Quadratic mean diameter of all live trees by treatment, plot, period, year and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- Centimeters -----													
Fixed:													
1 ^b	21	12.4	16.3	17.5	21.1	22.1	26.9	27.9	31.5	32.0	36.3	37.6	42.2
	33	11.9	16.3	16.8	20.6	20.8	25.9	26.4	29.7	30.5	34.5	35.3	39.6
	51	11.7	16.0	16.0	19.8	20.3	25.1	26.4	29.7	30.5	34.3	35.1	39.4
3	31	12.2	16.0	16.3	19.6	19.8	23.9	24.4	27.2	27.2	30.5	31.2	34.5
	42	13.5	17.8	18.5	22.1	22.4	26.9	27.4	30.5	30.7	34.0	35.3	39.1
	52	12.2	16.3	17.0	20.8	21.3	25.7	25.7	28.7	28.7	32.0	33.5	37.8
5	12	13.0	17.0	17.5	20.8	21.8	25.7	25.9	28.4	28.4	31.2	31.8	34.8
	41	13.5	17.5	18.3	21.8	22.1	26.4	26.4	29.2	29.5	32.3	32.5	35.6
	72	12.4	16.5	16.8	19.8	19.8	23.1	23.1	25.1	25.4	27.9	28.2	30.7
7	11	13.5	17.5	17.8	21.1	21.3	24.9	24.9	26.9	27.4	29.7	30.0	32.8
	23	12.4	16.8	16.5	19.6	19.8	23.4	23.4	25.4	25.7	27.7	27.9	30.2
	63	12.2	16.5	16.5	19.8	19.8	23.1	23.1	25.4	25.4	27.7	27.7	30.2
Increasing:													
2	82	12.7	17.0	17.5	21.3	21.8	26.4	27.2	30.2	30.7	34.3	35.1	39.1
	91	11.9	16.3	16.8	20.3	20.3	25.1	25.7	28.4	28.4	32.0	32.5	36.3
	101	13.2	17.5	18.3	22.1	22.6	27.7	28.2	31.2	31.8	35.6	36.6	40.6
4	13	13.5	18.0	19.1	23.1	23.9	28.7	29.0	32.0	32.3	35.3	35.1	38.6
	62	11.9	16.0	16.5	20.1	20.3	24.4	24.4	26.9	27.2	30.0	30.2	33.5
	111	13.0	17.0	17.5	21.1	21.3	26.2	26.4	29.2	29.5	32.5	32.8	36.1
Decreasing:													
6	15	12.4	16.8	17.0	20.6	20.6	24.6	24.6	27.4	27.7	30.7	31.8	35.1
	43	12.2	16.3	16.5	19.8	20.3	24.4	24.6	27.2	27.7	30.5	31.5	35.3
	81	11.9	16.3	16.5	19.8	19.8	23.9	24.4	26.9	27.7	30.5	32.3	35.8
8	14	13.5	18.0	18.0	21.8	22.4	26.4	26.7	29.2	29.7	32.5	34.0	37.3
	53	12.4	16.8	16.8	19.6	19.8	23.1	23.1	25.1	25.1	27.4	27.4	30.0
	73	13.0	17.0	17.8	21.1	21.1	24.9	25.1	27.4	28.4	30.7	31.0	33.8
Unthinned:													
C	22	9.4	11.2	11.2	12.7	12.7	14.5	14.5	15.7	15.7	17.0	17.0	18.8
	25	8.9	10.9	10.9	12.4	12.4	14.2	14.2	15.5	15.5	17.3	17.3	19.8
	71	8.6	10.9	10.9	12.4	12.4	14.0	14.0	15.2	15.2	17.0	17.0	18.8

^a Stand age in parentheses.^b Plot 51 abandoned 1989 because of severe root rot.

Table 7a—Quadratic mean diameters of largest 40 trees per acre, crop trees, and largest 80 trees per acre by treatment, period, and year

Treatment	QMD	Before cut						
		After cut						
		1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
----- Inches -----								
Fixed:								
1 ^b	largest 40	6.5	8.6	10.2	12.2	13.6	15.2	17.0
	crop trees	5.6	7.4	9.0	11.1	12.5	14.2	16.1
	largest 80	6.1	8.0	9.5	11.5	12.6	13.9	— ^c
3	largest 40	6.6	8.6	10.1	12.0	13.3	14.8	16.5
	crop trees	5.9	7.8	9.2	11.0	12.3	13.6	15.1
	largest 80	6.3	8.2	9.6	11.4	12.6	13.9	15.5
5	largest 40	6.8	8.8	10.3	12.2	13.3	14.6	16.1
	crop trees	6.1	8.0	9.5	11.2	12.3	13.5	14.8
	largest 80	6.4	8.3	9.8	11.5	12.6	13.8	15.1
7	largest 40	6.7	8.7	10.3	12.0	13.2	14.4	15.7
	crop trees	5.7	7.5	9.0	10.5	11.5	12.6	13.7
	largest 80	6.3	8.2	9.7	11.4	12.4	13.6	14.8
Increasing:								
2	largest 40	6.6	8.5	9.9	11.9	13.2	14.7	16.5
	crop trees	5.8	7.7	9.3	11.1	12.2	13.7	15.3
	largest 80	6.2	8.1	9.5	11.3	12.6	14.0	15.6
4	largest 40	6.5	8.5	10.1	12.1	13.3	14.7	16.2
	crop trees	5.9	7.8	9.3	11.2	12.4	13.7	15.0
	largest 80	6.3	8.2	9.7	11.6	12.8	14.1	15.5
Decreasing:								
6	largest 40	6.4	8.4	9.9	11.7	13.0	14.3	15.9
	crop trees	5.7	7.6	9.0	10.8	12.0	13.3	15.0
	largest 80	6.1	8.0	9.5	11.3	12.4	13.8	15.2
8	largest 40	6.7	8.8	10.4	12.2	13.4	14.7	16.1
	crop trees	5.9	8.0	9.6	11.1	12.1	13.2	14.6
	largest 80	6.4	8.4	10.0	11.7	12.8	13.7	15.3
Unthinned:								
C	largest 40	6.5	8.3	9.5	10.9	11.7	12.7	13.8
	crop trees	5.8	7.4	8.6	9.7	10.5	11.2	12.2
	largest 80	6.1	7.8	9.0	10.4	11.2	12.1	13.2

^a Stand age in parentheses.

^b Treatment 1 mean omits plot 51, because of severe root rot.

^c Number per acre <80.

Table 7b—Quadratic mean diameters of largest 100 trees per hectare, crop trees, and largest 200 trees per hectare by treatment, period, and year

Treatment	QMD	Before cut						
		After cut						
		1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
----- Centimeters -----								
Fixed:								
1 ^b	largest 100	16.5	21.7	25.8	31.0	34.4	38.5	43.1
	crop trees	14.2	18.8	22.9	28.2	31.8	36.1	40.9
	largest 200	15.5	20.4	24.2	29.1	32.1	35.2	— ^c
3	largest 100	16.8	21.8	25.7	30.5	33.7	37.6	41.8
	crop trees	15.0	19.8	23.4	27.9	31.2	34.5	38.4
	largest 200	16.0	20.8	24.5	29.0	32.0	35.4	39.4
5	largest 100	17.2	22.3	26.2	30.9	33.8	37.0	40.9
	crop trees	15.5	20.3	24.1	28.4	31.2	34.3	37.6
	largest 200	16.3	21.1	25.0	29.1	31.9	35.0	38.4
7	largest 100	17.1	22.1	26.1	30.6	33.4	36.5	39.8
	crop trees	14.5	19.1	22.9	26.7	29.2	32.0	34.8
	largest 200	16.1	20.8	24.6	28.9	31.6	34.5	37.6
Increasing:								
2	largest 100	16.7	21.6	25.1	30.2	33.5	37.4	41.9
	crop trees	14.7	19.6	23.6	28.2	31.0	34.8	38.9
	largest 200	15.8	20.7	24.0	28.7	32.0	35.6	39.7
4	largest 100	16.6	21.5	25.7	30.6	33.8	37.3	41.1
	crop trees	15.0	19.8	23.6	28.4	31.5	34.8	38.1
	largest 200	15.9	20.8	24.6	29.5	32.5	35.8	39.3
Decreasing:								
6	largest 100	16.3	21.3	25.1	29.7	32.9	36.4	40.5
	crop trees	14.5	19.3	22.9	27.4	30.5	33.8	38.1
	largest 200	15.4	20.3	24.2	28.7	31.6	35.0	38.7
8	largest 100	17.1	22.3	26.3	31.1	34.0	37.3	41.0
	crop trees	15.0	20.3	24.4	28.2	30.7	33.5	37.1
	largest 200	16.2	21.3	25.3	29.8	32.5	34.7	38.8
Unthinned:								
C	largest 100	16.5	21.1	24.1	26.9	29.7	32.3	35.0
	crop trees	14.7	18.8	21.8	24.6	26.7	28.4	31.0
	largest 200	15.5	19.8	22.9	26.4	28.4	30.7	33.5

^a Stand age in parentheses.

^b Treatment 1 mean omits plot 51 because of severe root rot.

^c Number per hectare <200.

Table 8a—Total cubic volume (CVTS) per acre by treatment, plot, period, year and age

Treatment	Plot	Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
		After cut	Before cut	After cut	Before cut	After cut	Before cut	After cut	Before cut	After cut	Before cut	After cut	1989 (42)
		1966 (19) ^a	1970 (23)	1970 (23)	1973 (26)	1973 (26)	1977 (30)	1977 (30)	1980 (33)	1980 (33)	1984 (37)	1984 (37)	
----- Cubic feet -----													
Fixed:													
1 ^b	21	614	1390	959	1590	1201	2124	1564	2228	1822	2612	2087	2969
	33	644	1491	1006	1698	1252	2143	1646	2366	1828	2524	2134	3090
	51	551	1281	960	1435	1170	1862	1359	1685	1600	2204	2010	2870
3	31	609	1321	1100	1849	1574	2686	2355	3295	2879	4004	3546	4993
	42	739	1730	1225	1923	1535	2637	2436	3344	2928	3967	3406	4860
	52	607	1392	1145	1767	1536	2522	2178	2927	2927	4052	3267	4540
5	12	740	1618	1407	2320	2130	3503	3316	4485	4079	5324	4714	6452
	41	768	1679	1411	2344	2094	3378	3204	4380	3989	5295	4672	6476
	72	697	1492	1347	2093	1991	3079	3079	4084	3947	5215	4728	6369
7	11	788	1690	1554	2590	2438	3948	3948	5320	5211	6647	6011	7884
	23	667	1519	1485	2380	2336	3777	3777	5035	4992	6302	5801	7751
	63	744	1590	1590	2362	2362	3623	3623	4704	4704	6153	5984	7822
Increasing:													
2	82	773	1743	1049	1766	1438	2430	2131	2878	2625	3653	3327	4693
	91	648	1489	998	1511	1389	2359	1864	2581	2581	3642	3196	4477
	101	821	1724	1013	1691	1371	2315	2131	2910	2630	3517	3151	4365
4	13	822	1774	1235	1979	1733	2814	2748	3680	3618	4785	4417	5978
	62	687	1603	1260	1928	1765	2969	2734	3754	3419	4655	4449	6101
	111	826	1806	1365	2088	1859	3045	2874	3981	3798	5226	4838	6460
Decreasing:													
6	15	686	1487	1333	2171	1844	3066	2653	3561	3121	4160	3496	4891
	43	605	1397	1266	1930	1778	3108	2471	3433	3068	4187	3454	4915
	81	628	1443	1347	2258	1931	3134	2698	3798	3329	4454	3564	4984
8	14	824	1716	1552	2604	2353	3665	3461	4560	4153	5543	4795	6645
	53	673	1579	1554	2192	2166	3389	3155	4121	4020	5202	4559	6191
	73	819	1751	1627	2367	2367	3829	3746	4847	4373	5564	4919	6667
Unthinned:													
C	22	1324	2697	2697	3998	3998	5730	5730	7291	7291	8651	8651	10000
	25	1206	2496	2496	3806	3806	5625	5625	6853	6853	8289	8289	9983
	71	942	2086	2086	3196	3196	4512	4512	5616	5616	6980	6980	8527

^a Stand are in parentheses.

^b Plot 51 abandoned 1989 because of severe root rot.

Table 8b—Total cubic volume (CVTS) per hectare by treatment, plot, period, year and age

Treatment	Plot	Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
		After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- Cubic meters -----													
Fixed:													
1 ^b	21	43	97	67	111	84	149	109	156	127	183	146	208
	33	45	104	70	119	88	150	115	166	128	177	149	216
	51	39	90	67	100	82	130	95	118	112	154	141	201
3	31	43	92	77	129	110	188	165	231	201	280	248	349
	42	52	121	86	135	107	184	170	234	205	278	238	340
	52	42	97	80	124	107	176	152	205	205	283	229	318
5	12	52	113	98	162	149	245	232	314	285	372	330	451
	41	54	117	99	164	146	236	224	306	279	371	327	453
	72	49	104	94	146	139	215	215	286	276	365	331	446
7	11	55	118	109	181	171	276	276	372	365	465	421	552
	23	47	106	104	167	163	264	264	352	349	441	406	542
	63	52	111	111	165	165	254	254	329	329	431	419	547
Increasing:													
2	82	54	122	73	124	101	170	149	201	184	256	233	328
	91	45	104	70	106	97	165	130	181	181	255	224	313
	101	57	121	71	118	96	162	149	204	184	246	220	305
4	13	57	124	86	138	121	197	192	257	253	335	309	418
	62	48	112	88	135	123	208	191	263	239	326	311	427
	111	58	126	95	146	130	213	201	279	266	366	339	452
Decreasing:													
6	15	48	104	93	152	129	215	186	249	218	291	245	342
	43	42	98	89	135	124	217	173	240	215	293	242	344
	81	44	101	94	158	135	219	189	266	233	312	249	349
8	14	58	120	109	182	165	256	242	319	291	388	335	465
	53	47	110	109	153	152	237	221	288	281	364	319	433
	73	57	122	114	166	166	268	262	339	306	389	344	466
Unthinned:													
C	22	93	189	189	280	280	401	401	510	510	605	605	700
	25	84	175	175	266	266	394	394	480	480	580	580	699
	71	66	146	146	224	224	316	316	393	393	488	488	597

^a Stand age in parentheses.^b Plot 51 abandoned 1989 because of severe root rot.

Table 9a—Average per acre stand statistics, by treatment, year, and age

Treatment	Year	Age	Period	H40	After thinning					Removed in thinning						Mortality				Cum Yield		
					Trees left	QMD all	QMD crop	Basal area	CVTS	Trees cut	QMD	Basal area	CVTS	CV6	d/D	Trees dead	QMD	Basal area	CVTS	Net CVTS	Gross CVTS	Net CV6
					<i>Ft</i>	<i>-- Inches --</i>		<i>Ft²</i>	<i>Ft³</i>						<i>In</i>	<i>Ft²</i>	<i>Ft³</i>	<i>--- Cubic feet ---</i>				
Fixed: 1	1966	19	0	40	355	4.8	5.6	44.5	629											1079	1079	0
	1970	23	1	50	215	6.8	7.4	53.0	982	135	5.9	25.8	458	29	0.92	5.0	3.8	0.4	4	1890	1894	230
	1973	26	2	59	148	8.5	9.1	57.4	1226	65	7.6	20.4	418	163	.92	2.5	7.7	.8	16	2551	2571	905
	1977	30	3	69	102	10.7	11.1	63.5	1605	43	9.7	21.7	528	391	.94	2.5	6.1	.5	11	3458	3489	1893
	1980	33	4	79	78	12.3	12.5	63.8	1824	25	11.2	16.8	472	391	.93	0	0	0	0	4150	4181	2594
	1984	37	5	85	60	14.4	14.3	67.0	2110	18	12.6	15.2	458	411	.90	0	0	0	0	4893	4924	3345
	1989	42	6	97	60	16.1	16.1	84.4	3029	0	0	0	0	0	0	0	0	0	0	5812	5843	4246
	1966	19	0	37	348	5.0	5.9	46.3	652				450							1102	1102	4
	1970	23	1	49	248	6.8	7.8	61.9	1156	92	5.9	18.0	325	22	.92	11.7	3.8	.9	13	1931	1944	313
	1973	26	2	56	193	8.3	9.2	72.0	1548	43	7.7	14.1	298	138	.94	11.7	6.6	2.8	55	2621	2689	1032
3	1977	30	3	68	162	10.2	11.0	90.7	2323	27	8.9	11.4	292	185	.86	5.0	8.3	1.9	47	3687	3802	2148
	1980	33	4	76	145	11.4	12.3	101.9	2911	15	10.9	9.6	277	230	.88	1.7	8.7	.7	18	4553	4686	3058
	1984	37	5	84	115	13.1	13.6	106.5	3406	30	10.9	19.3	601	497	.85	0	0	0	0	5649	5782	4155
	1989	42	6	98	113	14.6	15.1	131.1	4798	0	0	0	0	0	0	1.7	10.4	1.0	33	7040	7207	5537
	1966	19	0	38	347	5.1	6.1	48.6	735				450							1185	1185	10
	1970	23	1	50	277	6.9	8.0	71.3	1388	62	5.8	11.2	208	6	.88	8.3	4.9	1.1	18	2046	2064	347
	1973	26	2	59	242	8.4	9.5	91.3	2072	32	7.1	8.4	181	60	.90	3.3	8.2	1.2	27	2910	2955	1188
	1977	30	3	70	227	9.9	11.2	120.7	3200	10	9.2	4.6	120	78	.85	5.0	7.4	1.5	38	4158	4241	2557
	1980	33	4	78	210	10.9	12.3	134.9	4005	17	10.5	10.5	311	258	.96	0	0	0	0	5274	5357	3706
	1984	37	5	88	178	12.1	13.5	141.7	4705	28	10.8	17.8	573	466	.86	3.3	6.7	.8	23	6547	6653	5001
5	1989	42	6	102	178	13.3	14.8	169.6	6432	0	0	0	0	0	0	0	0	0	0	8275	8381	6705
	1966	19	0	38	360	5.0	5.7	49.2	733				450							1183	1183	13
	1970	23	1	49	333	6.7	7.5	80.7	1543	13	4.0	3.0	57	6	.99	13.3	4.7	1.6	29	2050	2078	306
	1973	26	2	59	305	8.0	8.9	105.9	2378	12	4.6	3.0	65	24	.88	16.7	6.7	4.1	92	2950	3071	1215
	1977	30	3	70	297	9.4	10.5	142.6	3782	0	0	0	0	0	0	8.3	7.4	2.5	62	4354	4536	2694
	1980	33	4	78	287	10.3	11.5	165.6	4969	7	4.3	1.8	51	19	.78	3.3	8.8	1.4	41	5592	5815	3955
	1984	37	5	88	260	11.2	12.6	179.2	5932	23	12.1	13.4	435	338	.90	3.3	6.2	.7	19	6990	7233	5367
	1989	42	6	101	255	12.2	13.7	207.9	7819	0	0	0	0	0	0	5.0	6.4	1.1	34	8877	9153	7255
	1966	19	0	40	360	5.0	5.8	48.8	747											1197	1197	0
	1970	23	1	51	198	6.9	7.7	51.6	1020	148	6.3	32.8	632	122	.95	3.75	5.0	.5	36	2102	2138	350
Increasing: 2	1973	26	2	58	155	8.5	9.3	60.8	1399	33	8.0	11.5	257	118	.95	3.33	7.8	1.1	73	2738	2847	1066
	1977	30	3	67	127	.6	11.1	77.5	2042	27	9.3	12.3	326	224	.89	.42	5.7	.1	7	3707	3823	2131
	1980	33	4	76	115	1.9	12.2	88.9	2612	10	10.7	6.2	178	141	.88	.56	11.3	.4	34	4454	4604	2900
	1984	37	5	86	97	3.7	13.7	97.9	3224	17	11.4	11.8	379	327	.86	.42	11.2	.3	35	5446	5631	3902
	1989	42	6	99	97	5.2	15.3	121.6	4511	0	0	0	0	0	0	0	0	0	0	6733	6918	5170

Table 9a—Average per acre stand statistics, by treatment, year, and age (continued)

Treatment	Year	Age	Period	H40	After thinning					Removed in thinning					d/D	Mortality				Cum Yield		
					Trees left	QMD all	QMD crop	Basal area	CVTS	Trees cut	QMD	Basal area	CVTS	CV6		Trees dead	QMD	Basal area	CVTS	Net CVTS	Gross CVTS	Net CV6
					<i>Ft</i>	-- Inches --	<i>Ft</i> ²	<i>Ft</i> ³		<i>In</i>	<i>Ft</i> ²	- Cubic feet -				<i>In</i>	<i>Ft</i> ²	<i>Ft</i> ³	--- Cubic feet ---			
4	1966	19	0	41	363	5.0	5.9	49.7	778											1228	1228	4
	1970	23	1	53	243	7.0	7.8	63.5	1286	112	6.1	22.9	441	51	.91	2.08	4.7	.3	18	2178	2196	387
	1973	26	2	60	197	8.6	9.4	77.7	1786	32	7.4	9.4	213	98	.88	5.00	7.0	1.3	87	2889	2994	1190
	1977	30	3	69	180	.5	11.2	105.4	2785	12	9.4	5.7	157	115	.91	1.25	5.6	.2	17	4046	4168	2473
	1980	33	4	78	165	1.7	12.4	120.8	3612	13	9.8	6.8	194	146	.85	.56	10.0	.3	26	5066	5230	3534
	1984	37	5	87	153	2.9	13.7	137.1	4568	12	12.3	9.6	321	285	.95	0	0	0	0	6343	6507	4815
Decreasing: 6	1989	42	6	100	152	14.2	15.0	164.8	6180	0	0	0	0	0	0	.33	5.7	.1	8	7955	8127	6414
	1966	19	0	37	360	4.8	5.7	45.4	639											1089	1089	0
	1970	23	1	48	307	6.6	7.6	71.9	1315	37	6.0	7.0	127	13	.93	4.17	4.2	.4	25	1892	1917	238
	1973	26	2	56	252	8.0	9.0	87.2	1851	43	7.3	10.1	269	86	.93	3.89	6.3	.9	50	2696	2771	1021
	1977	30	3	67	203	9.7	10.8	103.3	2607	43	9.2	12.3	496	333	.96	1.25	6.4	.3	26	3948	4049	2344
	1980	33	4	75	172	10.9	12.0	111.0	3172	30	9.6	16.1	425	309	.89	.56	8.4	.2	17	4938	5055	3376
8	1984	37	5	84	128	12.5	13.3	109.7	3504	42	10.5	23.1	762	614	.87	.42	11.3	.3	37	6032	6187	4479
	1989	42	6	97	128	13.9	15.0	135.4	4930	0	0	0	0	0	0	0	0	0	0	7457	7612	5895
	1966	19	0	40	352	5.1	5.9	49.2	772											1222	1222	6
	1970	23	1	51	313	6.9	8.0	80.9	1578	32	6.1	5.8	104	21	.90	1.67	4.4	.2	12	2132	2144	439
	1973	26	2	60	275	8.3	9.6	102.6	2295	17	6.9	4.3	92	34	.85	7.22	7.7	2.3	151	2941	3104	1337
	1977	30	3	69	257	9.8	11.1	133.9	3454	17	8.6	7.0	174	198	.88	.42	5.7	.1	7	4274	4444	2727
Control: C	1980	33	4	79	225	10.9	12.1	144.8	4182	25	10.0	11.7	327	222	.94	2.22	6.5	.5	36	5329	5534	3827
	1984	37	5	86	187	12.1	13.2	146.7	4757	35	10.7	21.6	679	556	.90	.83	8.0	.3	33	6583	6822	5096
	1989	42	6	99	185	13.3	14.6	174.1	6501	0	0	0	0	0	0	.33	7.7	.1	16	8326	8581	6808
	1966	19	0	37	1272	3.5	5.8	86.3	1157	0	0	0	0	0	0					1157	1157	5
	1970	23	1	49	1310	4.3	7.4	134.4	2426	0	0	0	0	0	0	26.7	2.7	.9	14	2426	2439	173
	1973	26	2	57	1293	4.9	8.6	171.5	3667	0	0	0	0	0	0	43.3	2.8	2.0	35	3667	3715	741
	1977	30	3	68	1230	5.6	9.7	210.6	5289	0	0	0	0	0	0	93.3	3.0	4.9	100	5289	5438	2022
	1980	33	4	77	1128	6.1	10.5	229.9	6586	0	0	0	0	0	0	113.3	3.4	7.1	160	6586	6895	3203
	1984	37	5	86	1010	6.7	11.2	248.4	7973	0	0	0	0	0	0	123.3	3.7	9.0	1087	7972	8505	4634
	1989	42	6	98	845	7.5	12.2	259.3	9503	0	0	0	0	0	0	163.3	4.7	19.0	581	9503	10616	6496

^a Plot in treatment 1 omitted because of root rot.^b Estimated 450 cubic feet per acre removed in calibration is included in total yield.

Table 9b—Average per hectare stand statistics, by treatment, year, and age

Treatment	Year	Age	Period	H40	After thinning					Removed in thinning					d/D	Mortality				Cum Yield			
					Trees left	QMD all	QMD crop	Basal area	CVTS	Trees cut	QMD	Basal area	CVTS	CV6		Trees dead	QMD	Basal area	CVTS	Net CVTS	Gross CVTS	Net CV6	
					<i>m</i>	<i>Centimeters</i>	<i>m²</i>	<i>m³</i>			<i>Cm</i>	<i>m²</i>	<i>Cubic meters</i>				<i>Cm</i>	<i>m²</i>	<i>m³</i>	<i>-- Cubic meters --</i>			
Fixed:																							
1^a																							
3	1966	19	0	12.2	877	12.2	14.2	10.2	44				31.5 ^b							75	75	0	
	1970	23	1	15.3	531	17.3	18.8	12.2	69	333	15.0	5.9	32.0	2.0	0.92	12	9.6	0.1	0.3	132	132	16	
	1973	26	2	18.0	366	21.6	23.1	13.2	86	161	19.3	4.7	29.2	11.4	.92	6	19.6	.2	1.1	178	180	63	
	1977	30	3	21.0	252	27.2	28.2	14.6	112	106	24.6	5.0	36.9	27.4	.94	6	15.5	.1	.8	242	244	132	
	1980	33	4	24.0	193	31.2	31.8	14.6	128	62	28.4	3.9	33.0	27.4	.93	0	0	0	0	290	293	182	
	1984	37	5	26.0	148	36.6	36.3	15.4	148	44	32.0	3.5	32.0	28.8	.90	0	0	0	0	342	344	234	
	1989	42	6	29.6	148	40.9	40.9	19.4	212	0	0	0	0	0	0	0	0	0	0	407	409	297	
	1966	19	0	11.4	860	12.7	15.0	10.6	46				31.5							77	77	0	
	1970	23	1	15.0	613	17.3	19.8	14.2	81	227	15.0	4.1	22.7	1.5	.92	29	9.6	.2	.9	135	136	22	
	1973	26	2	17.2	477	21.1	23.4	16.5	108	106	19.6	3.2	20.8	9.7	.94	29	16.8	.6	3.8	183	188	72	
5	1977	30	3	20.6	400	25.9	27.9	20.8	162	67	22.6	2.6	20.4	12.9	.86	12	21.1	.4	3.3	258	266	150	
	1980	33	4	23.0	358	29.0	31.2	23.4	204	37	27.7	2.2	19.4	16.1	.88	4	22.1	.2	1.3	319	328	214	
	1984	37	5	25.7	284	33.3	34.5	24.4	238	74	27.7	4.4	42.0	34.8	.85	0	.0	.0	.0	395	405	291	
	1989	42	6	29.8	279	37.1	38.4	30.1	336	0	0	0	0	0	0	4	26.4	.2	2.3	493	504	387	
	1966	19	0	11.7	857	13.0	15.5	11.2	51				31.5							83	83	1	
	1970	23	1	15.3	684	17.5	20.3	16.4	97	153	14.7	2.6	14.6	.4	.88	20	12.4	.2	1.3	143	144	24	
	1973	26	2	18.1	598	21.3	24.1	21.0	145	79	18.0	1.9	12.7	4.2	.90	8	20.8	.3	1.9	204	207	83	
	1977	30	3	21.2	561	25.1	28.4	27.7	224	25	23.4	1.1	8.4	5.5	.85	12	18.8	.3	2.7	291	297	179	
	1980	33	4	23.9	519	27.7	31.2	31.0	280	42	26.7	2.4	21.8	18.0	.96	0	0	0	0	369	375	259	
	1984	37	5	26.8	440	30.7	34.3	32.5	329	69	27.4	4.1	40.1	32.6	.86	8	17.0	.2	1.6	458	466	350	
7	1989	42	6	31.1	440	33.8	37.6	38.9	450	0	0	0	0	0	0	0	0	0	0	579	586	469	
	1966	19	0	11.7	889	12.7	14.5	11.3	51				31.5							83	83	1	
	1970	23	1	15.0	822	17.0	19.0	18.5	108	32	10.2	.7	4.0	.4	.99	33	11.9	.4	2.0	143	145	21	
	1973	26	2	17.9	753	20.3	22.6	24.3	166	30	11.7	.7	4.5	1.7	.88	41	17.0	.9	6.4	206	215	185	
	1977	30	3	21.3	734	23.9	26.7	32.7	265	0	0	0	0	0	0	20	18.8	.6	4.3	305	317	188	
	1980	33	4	23.9	709	26.2	29.2	38.0	348	17	10.9	.4	3.6	1.3	.78	8	22.4	.3	2.9	391	407	277	
	1984	37	5	26.8	642	28.4	32.0	41.1	415	57	30.7	3.1	30.4	23.6	.90	8	15.7	.2	1.3	489	506	376	
	1989	42	6	30.7	630	31.0	34.8	47.7	547	0	0	0	0	0	0	12	16.3	.2	2.4	621	640	508	
	Increasing:																						
	2																						
1966	19	0	12.2	889	12.7	14.7	11.2	52												84	84	0	
1970	23	1	15.5	489	17.5	19.6	11.8	71	366	16.0	7.5	44.2	8.5	0.95	9.3	12.7	0.1	2.5	147	150	24		
1973	26	2	17.6	383	21.6	23.6	14.0	98	82	20.3	2.6	18.0	8.2	.95	8.2	19.8	.2	5.1	192	199	75		
1977	30	3	20.5	314	26.9	28.2	17.8	143	67	23.6	2.8	22.8	15.7	.89	1.0	14.5	0	.1	259	268	149		
1980	33	4	23.1	284	30.2	31.0	20.4	183	25	27.2	1.4	12.4	9.9	.88	1.4	28.7	.1	2.4	312	322	203		
1984	37	5	26.1	240	34.8	34.8	22.5	226	42	29.0	2.7	26.5	22.9	.86	1.0	28.4	.1	2.4	381	394	273		
1989	42	6	30.3	240	38.6	38.9	27.9	316	0	0	0	0	0	.00	0	0	0	0	471	484	362		

Table 9b—Average per hectare stand statistics, by treatment, year, and age (continued)

Treatment	Year	Age	Period	H40	After thinning					Removed in thinning					d/D	Mortality				Cum Yield		
					Trees left	QMD all	QMD crop	Basal area	CVTS	Trees cut	QMD	Basal area	CVTS	CV6		Trees dead	QMD	Basal area	CVTS	Net CVTS	Gross CVTS	Net CV6
					<i>m</i>	<i>Centimeters</i>	<i>m²</i>	<i>m³</i>		<i>Cm</i>	<i>m²</i>	<i>Cubic meters</i>		<i>Cm</i>		<i>m²</i>	<i>m³</i>	<i>-- Cubic meters --</i>				
Fixed:																						
4	1966	19	0	12.4	897	12.7	15.0	11.4	54											86	86	0
	1970	23	1	16.1	600	17.8	19.8	14.6	90	277	15.5	5.3	30.9	3.6	0.91	5.1	11.9	0.1	1.3	152	154	27
	1973	26	2	18.2	487	21.8	23.9	17.8	125	79	18.8	2.2	14.9	6.9	.88	12.4	17.8	.3	6.1	202	209	83
	1977	30	3	20.9	445	26.7	28.4	24.2	195	30	23.9	1.3	11.0	8.0	.91	3.1	14.2	.1	1.2	283	292	173
	1980	33	4	23.6	408	29.7	31.5	27.7	253	32	24.9	1.6	13.6	10.2	.85	1.4	25.4	.1	1.8	354	366	247
	1984	37	5	26.6	378	32.8	34.8	31.5	320	30	31.2	2.2	22.5	19.9	.95	0	0	0	0	444	455	337
	1989	42	6	30.4	375	36.1	38.1	37.8	432	0	0	0	0	0	0	.8	14.5	0	.6	557	569	449
Decreasing:																						
6	1966	19	0	11.2	889	12.2	14.5	10.4	45											76	76	0
	1970	23	1	14.5	758	16.8	19.3	16.5	92	91	15.2	1.6	8.9	.2	.93	4.2	10.7	.1	1.7	132	134	17
	1973	26	2	17.0	622	20.3	22.9	20.0	130	106	18.5	2.3	18.8	6.0	.93	9.6	16.0	.2	3.5	189	194	71
	1977	30	3	20.5	501	24.6	27.4	23.7	182	106	23.4	2.8	34.7	23.3	.96	3.1	16.3	.1	1.8	276	283	164
	1980	33	4	22.9	425	27.7	30.5	25.5	222	74	24.4	3.7	29.7	21.6	.89	1.4	21.3	.1	1.2	346	354	236
	1984	37	5	25.5	316	31.8	33.8	25.2	245	104	26.7	5.3	53.3	43.0	.87	1.0	28.7	.1	2.6	422	433	313
	1989	42	6	29.5	316	35.3	38.1	31.1	345	0	0	0	0	0	0	0	0	0	0	522	533	412
8	1966	19	0	12.3	869	13.0	15.0	11.3	54											86	86	0
	1970	23	1	15.6	773	17.5	20.3	18.6	110	79	15.5	1.3	7.3	1.5	.90	4.1	11.2	0	.8	149	150	31
	1973	26	2	18.3	679	21.1	24.4	23.6	161	42	17.5	1.0	6.4	2.4	.85	17.8	19.6	.5	10.6	206	217	94
	1977	30	3	21.0	635	24.9	28.2	30.7	242	42	21.8	1.6	12.2	13.8	.88	1.0	14.5	0	.5	299	311	191
	1980	33	4	24.1	556	27.7	30.7	33.1	292	62	25.4	2.7	22.9	15.5	.94	5.5	16.5	.1	2.5	373	387	268
	1984	37	5	26.2	462	30.7	33.5	33.7	333	86	27.2	5.0	47.5	38.9	.90	2.0	20.3	.1	2.3	461	477	357
	1989	42	6	30.2	457	33.8	37.1	40.0	455	0	0	0	0	0	0	.8	19.6	0	1.1	583	600	476
Control:																						
C	1966	19	0	11.2	3142	8.9	14.7	19.8	81	0	0	0	0	0	0					81	81	0
	1970	23	1	14.8	4298	10.9	18.8	30.8	170	0	0	0	0	0	0	65.9	6.8	.2	1.0	170	171	12
	1973	26	2	17.4	4242	12.4	21.8	39.4	257	0	0	0	0	0	0	107.0	7.1	.5	2.4	257	260	52
	1977	30	3	20.6	4035	14.2	24.6	48.3	370	0	0	0	0	0	0	230.4	7.6	1.1	7.0	370	381	141
	1980	33	4	23.3	3701	15.5	26.7	52.8	461	0	0	0	0	0	0	279.8	8.6	1.6	11.2	461	482	224
	1984	37	5	26.2	3314	17.0	28.4	57.0	558	0	0	0	0	0	0	304.6	9.4	2.1	76.1	558	595	324
	1989	42	6	29.9	2772	19.0	31.0	59.5	665	0	0	0	0	0	0	403.4	11.9	4.4	40.6	665	743	454

^a Plot 51 in treatment 1 omitted because of root rot.

^b Estimated 31.5 cubic meters per hectare (CVTS) removed in calibration is included in total yield.

Table 10a—Merchantable cubic volume (CV6) per acre by treatment, plot, period, year and age

Treatment	Plot	Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
		After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- Cubic feet -----													
Fixed: 1 ^b	21	0	248	229	898	751	1725	1314	1986	1634	2424	1953	2813
3	33	0	211	172	854	676	1679	1308	2036	1607	2320	1968	2910
	51	0	206	180	718	670	1429	1104	1462	1411	2021	1851	2698
	31	0	204	204	908	796	1908	1715	2706	2369	3491	3133	4584
	42	12	420	374	1197	970	2115	2005	2944	2590	3624	3148	4574
5	52	0	316	297	925	851	1945	1694	2493	2493	3629	2973	4243
	12	18	352	352	1282	1232	2701	2586	3798	3453	4718	4211	5915
	41	12	456	440	1334	1230	2685	2564	3776	3446	4757	4209	5981
7	72	0	233	233	932	905	2088	2088	3111	3012	4320	3976	5614
	11	26	445	445	1520	1448	2985	2985	4331	4273	5734	5221	7093
	23	13	302	284	1091	1091	2604	2604	3806	3806	5157	4783	6690
	63	0	171	171	1016	1016	2403	2403	3577	3577	5062	4934	6821
Increasing: 2	82	0	369	217	1027	883	1967	1762	2524	2333	3360	3081	4422
4	91	0	163	119	770	702	1772	1443	2191	2191	3270	2889	4163
	101	0	518	349	1036	893	1935	1797	2593	2359	3259	2938	4127
	13	0	668	552	1316	1209	2392	2344	3307	3260	4419	4075	5606
	62	0	122	122	920	852	2168	1979	3064	2822	4071	3900	5562
	111	13	372	335	1183	1062	2412	2304	3439	3291	4726	4387	5989
Decreasing: 6	15	0	290	273	1196	1044	2291	1973	2914	2588	3619	3086	4480
8	43	0	239	217	829	829	2275	1829	2827	2559	3698	3091	4539
	81	0	186	186	999	893	2168	1933	3091	2760	3899	3197	4600
	14	0	615	551	1565	1463	2898	2769	3897	3582	4976	4370	6172
	53	0	319	319	1033	1033	2248	2075	3126	3039	4257	3738	5374
	73	18	382	382	1350	1350	2870	2845	3967	3703	4895	4351	6050
Unthinned: C	22	0	153	153	734	734	2241	2241	3564	3564	4955	4955	6839
	25	0	246	246	807	807	2038	2038	3132	3132	4655	4655	6657
	71	16	120	120	683	683	1787	1787	2913	2913	4293	4293	5992

^a Stand age in parentheses.

^b Plot 51 abandoned 1989 because of severe root rot.

Table 10b—Merchantable cubic volume (CV6) per hectare by treatment, plot, period, year and age

		Calibration		Period 1		Period 2		Period 3		Period 4		Period 5	
Treatment	Plot	After cut 1966 (19) ^a	Before cut 1970 (23)	After cut 1970 (23)	Before cut 1973 (26)	After cut 1973 (26)	Before cut 1977 (30)	After cut 1977 (30)	Before cut 1980 (33)	After cut 1980 (33)	Before cut 1984 (37)	After cut 1984 (37)	1989 (42)
----- Cubic feet -----													
Fixed: 1 ^b	21	0	17	16	63	53	121	92	139	114	170	137	197
	33	0	15	12	60	47	117	91	142	112	162	138	204
	51	0	14	13	50	47	100	77	102	99	141	130	189
3	31	0	14	14	64	56	134	120	189	166	244	219	321
	42	1	29	26	84	68	148	140	206	181	254	220	320
	52	0	22	21	65	60	136	119	174	174	254	208	297
5	12	1	25	25	90	86	189	181	266	242	330	295	414
	41	1	32	31	93	86	188	179	264	241	333	295	419
	72	0	16	16	65	63	146	146	218	211	302	278	393
7	11	2	31	31	106	101	209	209	303	299	401	365	496
	23	1	21	20	76	76	182	182	266	266	361	335	468
	63	0	12	12	71	71	168	168	250	250	354	345	477
Increasing: 2	82	0	26	15	72	62	138	123	177	163	235	216	309
	91	0	11	8	54	49	124	101	153	153	229	202	291
	101	0	36	24	73	63	135	126	181	165	228	206	289
4	13	0	47	39	92	85	167	164	231	228	309	285	392
	62	0	9	9	64	60	152	138	214	197	285	273	389
	111	1	26	23	83	74	169	161	241	230	331	307	419
Decreasing: 6	15	0	20	19	84	73	160	138	204	181	253	216	313
	43	0	17	15	58	58	159	128	198	179	259	216	318
	81	0	13	13	70	62	152	135	216	193	273	224	322
8	14	0	43	39	109	102	203	194	273	251	348	306	432
	53	0	22	22	72	72	157	145	219	213	298	262	376
	73	1	27	27	94	94	201	199	278	259	343	304	423
Unthinned: C	22	0	11	11	51	51	157	157	249	249	347	347	479
	25	0	17	17	56	56	143	143	219	219	326	326	466
	71	1	8	8	48	48	125	125	204	204	300	300	419

^a Stand age in parentheses.^b Plot 51 abandoned 1989 because of severe root rot.

Table 11a—Periodic annual increment in net basal area per acre, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Square feet</i>						
Fixed:						
1 ^a	8.6	8.3	6.9	5.7	4.6	3.5
3	8.4	8.0	7.5	6.9	6.0	4.9
5	8.5	9.5	8.5	8.2	6.2	5.6
7	8.6	9.4	9.2	8.2	6.8	5.7
Increasing:						
2	8.9	6.9	7.3	5.9	5.2	4.7
4	9.2	7.9	8.4	7.4	6.5	5.5
Decreasing:						
6	8.4	9.4	9.0	7.6	5.9	5.1
8	9.4	8.7	9.6	7.5	5.9	5.5
Unthinned:						
C	10.7	11.2	9.2	7.4	5.2	3.3

^a Plot 51 omitted from treatment 1 means because of root rot.

Table 11b—Periodic annual increment in net basal area per hectare, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Square meters</i>						
Fixed:						
1 ^a	1.97	1.90	1.59	1.31	1.05	0.80
3	1.93	1.85	1.73	1.59	1.37	1.13
5	1.95	2.17	1.95	1.89	1.41	1.28
7	1.98	2.16	2.10	1.89	1.56	1.32
Increasing:						
2	2.05	1.58	1.67	1.34	1.20	1.09
4	2.11	1.80	1.92	1.70	1.49	1.27
Decreasing:						
6	1.93	2.16	2.06	1.73	1.36	1.18
8	2.15	1.99	2.20	1.73	1.36	1.26
Unthinned:						
C	2.46	2.58	2.10	1.70	1.20	0.75

^a Plot 51 omitted from treatment 1 means because of root rot.

Table 12a—Periodic annual net increment in quadratic mean diameter of all trees and of survivors (control only, in parentheses), by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Inches</i>						
Fixed:						
1 ^a	0.41	0.49	0.48	0.45	0.42	0.36
3	.41	.47	.43	.39	.32	.31
5	.40	.43	.38	.32	.26	.23
7	.41	.43	.35	.28	.22	.20
Increasing:						
2	.42	.49	.47	.41	.36	.31
4	.42	.48	.45	.37	.30	.26
Decreasing:						
6	.42	.44	.40	.35	.29	.28
8	.43	.44	.36	.31	.24	.23
Unthinned:						
C	.21 (.21) ^b	.20 (.20)	.17 (.15)	.17 (.12)	.15 (.10)	.16 (.09)

^a Plot 51 omitted from treatment 1 means because of root rot.

^b Survivor growth.

Table 12b—Periodic annual net increment in quadratic mean diameter of all trees and of survivors (control only, in parentheses), by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Centimeters</i>						
Fixed:						
1 ^a	1.04	1.24	1.22	1.14	1.07	0.91
3	1.04	1.19	1.09	.99	.82	.79
5	1.02	1.09	.96	.81	.66	.58
7	1.04	1.09	.89	.71	.56	.51
Increasing:						
2	1.07	1.24	1.19	1.04	.91	.79
4	1.07	1.22	1.14	.94	.76	.66
Decreasing:						
6	1.07	1.12	1.02	.89	.74	.71
8	1.09	1.12	.91	.79	.61	.58
Unthinned:						
C	.53 (.53) ^b	.51 (.51)	.43 (.38)	.43 (.30)	.38 (.25)	.41 (.23)

^a Plot 51 omitted from treatment 1 means because of root rot.

^b Survivor growth.

Table 13a—Periodic annual increment in net total cubic volume (CVTS) and merchantable volume (CV6) per acre, by treatment and period

Treatment		Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Cubic feet</i>							
Fixed:							
1 ^a	CVTS	203	220	227	231	186	184
	CV6	57	225	247	234	188	180
3	CVTS	207	230	267	289	274	278
	CV6	77	239	279	303	274	276
5	CVTS	217	288	312	372	318	346
	CV6	84	280	342	383	324	341
7	CVTS	217	300	351	412	350	377
	CV6	73	303	370	414	358	378
Increasing:							
2	CVTS	226	212	242	249	248	257
	CV6	88	239	266	256	251	254
4	CVTS	237	237	289	340	319	322
	CV6	96	268	321	354	320	320
Decreasing:							
6	CVTS	201	268	313	330	274	285
	CV6	60	261	331	344	276	283
8	CVTS	229	270	333	352	314	349
	CV6	108	300	347	367	317	342
Unthinned:							
C	CVTS	317	414	406	432	347	332
	CV6	42	419	320	394	358	372

^a Plot 51 omitted from treatment 1 means because of root rot.

Table 13b—Periodic annual increment in net total cubic volume (CVTS) and merchantable volume (CV6) per hectare, by treatment and period

Treatment		Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Cubic meters</i>							
Fixed:							
1 ^a	CVTS	14.2	15.4	15.9	16.2	13.0	12.9
	CV6	4.0	15.7	17.3	16.4	13.2	12.6
3	CVTS	14.5	16.1	18.7	20.2	19.2	19.4
	CV6	5.4	16.7	19.5	21.2	19.2	19.3
5	CVTS	15.2	20.2	21.8	26.0	22.2	24.2
	CV6	5.9	19.6	23.9	26.8	22.7	23.9
	CVTS	15.2	21.0	24.6	28.8	24.5	26.4
	CV6	5.1	21.2	25.9	29.0	25.0	26.4
Increasing:							
2	CVTS	15.8	14.8	16.9	17.4	17.4	18.0
	CV6	6.2	16.7	18.6	17.9	17.6	17.8
4	CVTS	16.6	16.6	20.2	23.8	22.3	22.5
	CV6	6.7	18.8	22.5	24.8	22.4	22.4
Decreasing:							
6	CVTS	14.1	18.8	21.9	23.1	19.2	19.9
	CV6	4.2	18.3	23.2	24.1	19.3	19.8
8	CVTS	16.0	18.9	23.3	24.6	22.0	24.4
	CV6	7.6	21.0	24.3	25.7	22.2	23.9
Unthinned:							
C	CVTS	22.2	29.0	28.4	30.2	24.3	23.2
	CV6	2.9	29.3	22.4	27.6	25.0	26.0

^a Plot 51 omitted from treatment 1 means because of root rot.

Table 14a—Periodic annual mortality in number of trees and in basal area, per acre, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Number per acre</i>						
Fixed:						
1 ^a	1.25	0.84	0.63	0	0	0*
3	2.08	3.89	1.25	.56	0	.33
5	2.08	.11	1.25	0	.83	0
7	3.33	5.56	2.08	1.11	.83	1.00
Increasing:						
2	3.75	3.33	.42	.56	.42	0
4	2.08	5.00	1.25	.56	0	.33
Decreasing:						
6	4.17	3.89	1.25	.56	.42	0
8	1.67	7.22	.42	2.22	.83	.33
Control:						
C	6.67	14.44	23.33	37.78	24.17	32.67
<i>Basal area, square feet per acre</i>						
Fixed:						
1 ^a	.09	.25	.13	0	0	0
3	.22	.92	.47	.23	0	.20
5	.27	.41	.38	0	.21	0
7	.18	.30	.54	.11	.10	.09
Increasing:						
2	.51	1.07	.07	.39	.28	0
4	.27	1.30	.20	.30	0	.06
Decreasing:						
6	.41	.87	.29	.21	.29	0
8	.18	2.34	.07	.51	.29	.11
Control:						
C	.23	.67	1.22	2.38	1.75	3.81

^a Plot 51 in treatment 1 excluded because of root rot.

Table 14b—Periodic annual mortality in number of trees and in basal area, per hectare, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Number per hectare</i>						
Fixed:						
1 ^a	3.10	2.10	1.60	0	0	0
3	5.10	9.60	3.10	1.40	.00	.80
5	5.10	.30	3.10	0	2.00	0
7	8.20	13.70	5.10	2.70	2.00	2.50
Increasing						
2	9.30	8.20	1.00	1.40	1.00	0
4	5.10	12.40	3.10	1.40	0	.80
Decreasing						
6	10.30	9.60	3.10	1.40	1.00	0
8	4.10	17.80	1.00	5.50	2.00	.80
Control						
C	16.50	35.70	57.60	93.30	59.70	80.70
<i>Basal area, square meters</i>						
Fixed:						
1 ^a	.02	.06	.03	0	0	0
3	.05	.21	.11	.05	0	.05
5	.06	.09	.09	.00	.05	0
7	.04	.07	.12	.02	.02	.02
Increasing						
2	.12	.25	.02	.09	.06	0
4	.06	.30	.06	.07	0	.01
Decreasing						
6	.09	.20	.07	.05	.07	0
8	.04	.54	.02	.12	.07	.02
Control						
C	.05	.15	.28	.55	.40	.87

^a Plot 51 in treatment 1 excluded because of root rot.

Table 15a—Periodic annual mortality in total cubic volume (CVTS) per acre, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Cubic feet per acre</i>						
Fixed:						
1 ^a	1.1	5.4	2.8	0	0	0
3	3.3	18.3	11.7	6.1	.0	6.7
5	4.5	9.0	9.5	0	5.8	0
7	7.2	30.6	15.4	13.8	4.8	6.7
Increasing						
2	9.1	24.3	1.7	11.3	8.8	0
4	4.5	29.0	4.2	8.5	0	1.6
Decreasing						
6	6.3	16.6	6.5	5.6	9.3	0
8	3.0	50.4	1.6	12.0	8.2	3.2
Control						
C	3.4	11.6	25.0	53.2	56.0	116.1

^a Plot 51 in treatment 1 excluded because of root rot. CV6 mortality has been negligible.

Table 15b—Periodic annual mortality in total cubic volume (CVTS) per hectare, by treatment and period

Treatment	Calibration; midperiod age 21.0	Period 1; midperiod age 24.5	Period 2; midperiod age 28.0	Period 3; midperiod age 31.5	Period 4; midperiod age 35.0	Period 5; midperiod age 39.5
<i>Cubic meters</i>						
Fixed:						
1 ^a	0.07	0.38	0.20	0	0	0
3	.23	1.28	.82	.42	0	.47
5	.31	.63	.66	0	.40	0
7	.50	2.14	1.08	.96	.34	.47
Increasing:						
2	.64	1.70	.12	.79	.62	0
4	.31	2.03	.29	.59	0	.11
Decreasing:						
6	.44	1.16	.45	.39	.65	0
8	.21	3.53	.11	.84	.57	.22
Control:						
C	.24	.81	1.75	3.72	3.92	8.12

^a Plot 51 in treatment 1 excluded because of root rot. CV6 mortality has been negligible.

Table 16—Net basal area (BA) growth percent, net cubic volume (CVTS) growth percent, and net merchantable volume (CV6) growth percent (based on midperiod values), by treatment and period

		Period					
Treatment	Unit	Calibration 1966-70 age 21.0	TP-1 1970-73 age 24.5	TP-2 1973-77 age 28.0	TP-3 1977-80 age 31.5	TP-4 1980-84 age 35.0	TP-5 1984-89 age 39.5
----- Percent -----							
Fixed:							
1 ^a	BA	13.9	12.6	9.7	7.9	6.3	4.6
	CVTS	19.6	16.8	13.5	11.8	8.5	7.1
	CV6	50.0	41.9	20.5	14.1	9.4	7.3
3	BA	13.3	10.9	8.7	6.8	5.2	4.1
	CVTS	19.4	15.3	12.8	10.4	7.9	6.8
	CV6	49.1	37.1	19.6	13.4	9.1	7.3
5	BA	13.0	11.1	7.8	6.2	4.2	3.6
	CVTS	18.5	15.8	11.5	9.9	6.9	6.2
	CV6	47.6	37.2	19.0	12.8	8.2	6.8
7	BA	13.0	9.9	7.4	5.3	3.8	3.0
	CVTS	18.6	15.0	11.4	9.3	6.2	5.5
	CV6	46.8	41.0	19.4	12.6	7.8	6.4
Increasing:							
2	BA	13.4	11.0	9.7	6.8	5.2	4.3
	CVTS	18.9	15.8	12.9	10.3	8.0	6.7
	CV6	50.0	41.8	19.7	12.6	9.0	7.0
4	BA	13.5	10.4	8.9	6.4	4.8	3.7
	CVTS	19.0	14.5	12.2	10.1	7.5	6.0
	CV6	48.9	38.5	19.2	13.0	8.5	6.5
Decreasing:							
6	BA	13.5	10.9	8.5	6.6	4.8	4.2
	CVTS	19.3	15.5	12.6	10.6	7.4	6.8
	CV6	49.1	40.9	19.4	13.6	8.4	7.3
8	BA	13.8	9.2	7.9	5.2	3.8	3.4
	CVTS	18.6	13.5	11.2	8.6	6.5	6.2
	CV6	48.5	34.8	17.7	11.9	7.8	6.9
Unthinned:							
C	BA	11.0	8.1	5.1	2.9	1.9	.9
	CVTS	17.8	13.6	9.0	7.3	4.8	3.5
	CV6	46.1	42.0	23.1	15.1	9.2	6.7

^a Treatment 1 mean omits plot 51, because of root rot.

Table 17a—Net mean annual increment in total cubic feet (CVTS) and merchantable cubic feet (CV6) per acre, by treatment, year, and age

Treatment	Unit	1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
----- Cubic feet per acre per year ^b -----								
Fixed:								
1 ^c	CVTS	57	82	98	115	126	132	138
	CV6	0	10	35	63	79	90	101
3	CVTS	58	84	101	123	138	153	168
	CV6	0	14	40	72	93	112	132
5	CVTS	62	89	112	139	160	177	197
	CV6	0	15	46	85	112	135	160
7	CVTS	62	89	114	145	169	189	211
	CV6	9	20	52	95	124	149	176
Increasing:								
2	CVTS	63	91	105	124	135	147	160
	CV6	0	15	41	71	88	106	123
4	CVTS	65	95	111	135	154	171	189
	CV6	0	17	46	82	107	130	153
Decreasing:								
6	CVTS	57	82	104	132	150	163	178
	CV6	0	10	39	78	102	121	140
8	CVTS	64	93	113	142	161	178	198
	CV6	0	19	51	91	116	138	162
Control:								
C	CVTS	61	105	141	176	200	215	226
	CV6	0	8	28	67	97	125	155

^a Stand age in parentheses.

^b Estimated cut of 450 cubic feet per acre has been included in totals for CVTS.

^c Plot 51 in treatment 1 excluded because of root rot.

Table 17b—Net mean annual increment in total cubic volume (CVTS) and merchantable cubic volume (CV6) per hectare, by treatment, year, and age

Treatment	Unit	1966 (19) ^a	1970 (23)	1973 (26)	1977 (30)	1980 (33)	1984 (37)	1989 (42)
----- Cubic meters ^b -----								
Fixed:								
1 ^c	CVTS	4.0	5.7	6.9	8.0	8.8	9.2	9.7
	CV6	0	.7	2.4	4.4	5.5	6.3	7.1
3	CVTS	4.1	5.9	7.1	8.6	9.7	10.7	11.8
	CV6	0	1.0	2.8	5.0	6.5	7.8	9.2
5	CVTS	4.3	6.2	7.8	9.7	11.2	12.4	13.8
	CV6	0	1.0	3.2	5.9	7.8	9.4	11.2
7	CVTS	4.3	6.2	8.0	10.1	11.8	13.2	14.8
	CV6	.6	1.4	3.6	6.6	8.7	10.4	12.3
Increasing:								
2	CVTS	4.4	6.4	7.3	8.7	9.4	10.3	11.2
	CV6	0	1.0	2.9	5.0	6.2	7.4	8.6
4	CVTS	4.5	6.6	7.8	9.4	10.8	12.0	13.2
	CV6	0	1.2	3.2	5.7	7.5	9.1	10.7
Decreasing:								
6	CVTS	4.0	5.7	7.3	9.2	10.5	11.4	12.5
	CV6	0	.7	2.7	5.5	7.1	8.5	9.8
8	CVTS	4.5	6.5	7.9	9.9	11.3	12.5	13.8
	CV6	0	1.3	3.6	6.4	8.1	9.7	11.3
Control:								
C	CVTS	4.3	7.3	9.9	12.3	14.0	15.0	15.8
	CV6	0	8.0	2.0	4.7	6.8	8.7	10.8

^a Stand age in parentheses

^b Estimated calibration cut of 31.5 cubic meters per hectare has been included in totals for CVTS.

^c Plot 51 in treatment 1 excluded because of root rot.

Appendix 3: The Nine Study Areas

Study Area	Cooperator
Skykomish Clemons	Western Forestry Research Department Weyerhaeuser Company Tacoma, WA
Hoskins	College of Forestry Oregon State University Corvallis, OR
Rocky Brook Stampede Creek Iron Creek	USDA Forest Service Pacific Northwest Research Station and Pacific Northwest Region Portland, OR
Francis	State of Washington Department of Natural Resources Olympia, WA
Sayward Forest Shawnigan Lake	Canadian Forest Service Pacific and Yukon Region Pacific Forest Research Centre Victoria, BC

Curtis, Robert O.; Clendenen, Gary W. 1994. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 12—the Iron Creek study: 1966-89. Res. Pap. PNW-RP-475. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 67 p.

Results of the Iron Creek installation of the levels-of-growing-stock study in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) are summarized. To age 42 (planned completion of the experiment) volume growth in this site II Douglas-fir plantation has been strongly related to level of growing stock, partially offsetting the decrease in volume growth percent expected with increasing growing stock. Basal area growth-growing stock relations were much weaker than those for volume. Marked differences in tree size distributions have resulted from thinning. Periodic annual volume increments are two to three times greater than mean annual increments at age 42; this stand is far from culmination. Results in general are similar to those reported for other installations in the series on medium to good sites.

Keywords: Thinning, growing stock, growth and yield, stand density, Douglas-fir, *Pseudotsuga menziesii*, series—Douglas-fir LOGS.

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