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David D. Marshall for the degree of Doctor of Philosophy

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Title: The Effects of Thinning on Stand and Tree Growth in a Young, High Site Douglas-fir Stand in Western Oregon

Abstract approved: ______________________________

Susan G. Stafford

The Levels-of-Growing-Stock Studies in Douglas-fir is a regional cooperative to investigate the effects of levels of growing stock on young stand growth. The Hoskins installation, in western Oregon, was established in a dense, high site natural stand at total age 20 years. The initial thinning resulted in an immediate 131 percent increase in diameter growth. Subsequent crown type thinning treatments retained eight different, predetermined percentages of the gross basal area growth on the control plots.

At age 45, diameter growth remains strong on the heavily thinned treatments, but decreases with increased growing stock. Gross volume growth increased with growing stock, while gross basal area growth was much less influenced by growing stock. Volume growth was strongly related to density because of the rapid height growth of this young

stand. Heavy thinnings reduced volume production because of the depletion of growing stock. Total volume production was only slightly reduced on the light thinnings, whereas merchantable volume was greater than the unthinned control. Mortality was heavy on the control, but negligible on the treated plots. Heavy mortality in the last period, reduced net volume growth on the control to less than the treatments. Periodic annual increment (PAI) for cubic foot volume appear to have culminated for the treatments, although they are nearly twice the mean annual increments on the thinned plots. Board foot volume PAI does not appear to have culminated for any of the treatments. The diameter growth of individual trees was particularly influenced by the amount of density in trees larger than any given tree. Density had only a minor effect on height growth. Trees in lower densities had longer crowns and greater taper.

Results from simulations of alternative thinning regimes show the desirability of early thinnings. Compared to thinning from below, crown thinning appeared to give the greatest release to the residual stand and produce high volume growth. Management must consider the trade-offs between greater diameter growth at low densities and greater volume growth at high densities.

The Effects of Thinning on Stand and Tree Growth in a Young, High Site Douglas-fir Stand in Western Oregon

by

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Table of Contents

List of Figures

List of Tables

Table | Page

List of Appendix Tables

Table		Page

The Effects of Thinning on Stand and Tree Growth in a Young, High Site Douglas-fir Stand in Western Oregon

Chapter 1

Introduction

Projected decreases in harvest levels of "old-growth" Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) over the next decade in most areas of western Oregon, will have significant impacts on many local economies (Sessions et al. 1990). In the future, harvests will come from younger stands and smaller trees. The continual demand for wood products and the decreased supply of raw materials will require intensive management of these young-growth stands.

Density control through thinning has long been recognized as an important intensive management tool. The first thinning experiments in the Pacific Northwest were established in the early 1930's by the U.S. Forest Service's Pacific Northwest Forest and Range Experiment Station. Operational thinning practices began in the 1940's (King 1986). Thinning has traditionally been used for two primary purposes. First, it benefits residual trees through the redistribution of a stand's total growth capacity on fewer, larger, and better quality trees. Secondly, harvesting potential mortality ensures more complete utilization of the material produced (Worthington and Staebler 1961).

Many of the initial commercial thinning trials were established in older stands (King 1986). The Levels-of-Growing-Stock (LOGS) Cooperative Studies in Douglas-fir were begun in 1963 to gather data on the response of young, even-aged Douglas-fir to intensive, frequent thinnings. The five cooperators were: Forestry Canada, Oregon State University, USDA Forest Service, Washington State Department of Natural Resources, and the Weyerhaeuser Company. By 1972, nine studies had been established throughout Oregon, Washington, and Vancouver Island, British Columbia (Figure 1-1). Descriptions of the LOGS Cooperative and the individual studies have been presented by Williamson and Staebler (1971) [Curtis and Marshall (1986) provided a 20-year summary report].

The Hoskins LOGS study was established in 1963 by Oregon State University in western Oregon on lands owned by Starker Forests of Corvallis, Oregon. Intermediate results for this installation have been reported by Bell and Berg (1972) for the calibration (1963-66) and first treatment (1966-70) periods; Berg and Bell (1979) for the

Figure 1-1: Location of the nine Levels-of-Growing-Stock Studies in Douglas-fir. Solid triangle identifies the study area of this report.

second (1970-73) and third (1973-75) treatment periods, and Tappeiner et al. (1982) for the fourth treatment period (1975-79). At the end of the 1983 growing season the study completed the fifth and final treatment period of the experiment as originally designed. Marshall et al. (in press) reported results through this fifth treatment period.

1.1 Objectives

The purpose of this study is to perform a more indepth and comprehensive analysis of stand and tree growth on the Hoskins plots than has been done in previous summary reports. The specific objectives are to (1) update the summary of stand growth and development through an additional measurement period (1983-88), with particular interest in differences in stand characteristics and resulting volume growth, (2) investigate the effects of different stand densities created by the thinning regimes on tree form, and (3) to summarize the effects of stand density on individual tree height and diameter growth. The LOGS studies were designed to consider only differences in growing stock. The final objective (4) is to use simulation methods to investigate how different thinning regimes would affect stand growth.

1.2 Methods

1.2.1 Description of Study Area

The Hoskins study was established in a uniform, even-aged 20-year-old Douglas-fir stand, naturally regenerated after wildfire in the Oregon Coast Range near Hoskins, Oregon about 22 miles west of Corvallis (Figure 1-2) in Benton County (Section 27, Township 10 South, Range 7 West, Willamette Meridian). The breast height age was 13 years, calculated from boring 54 trees (two per plot) during plot establishment in 1963. Initially, on the unthinned control plots, the number of trees ranged from 1610 to 1885 per acre, basal area from 120 to 160 square feet per acre, and average quadratic mean diameter at breast height (DBH) from 3.6 to 4.2 inches. Height-to-live-crown (HLC) was uniform and near eight feet at the time of plot establishment in 1963; crown ratios were approximately 80 percent.

Annual precipitation (primarily as rain) is about 65 to 75 inches. The temperature averages 50^{o}F with 160 to 190 frost free days per year (Knezevich 1975).

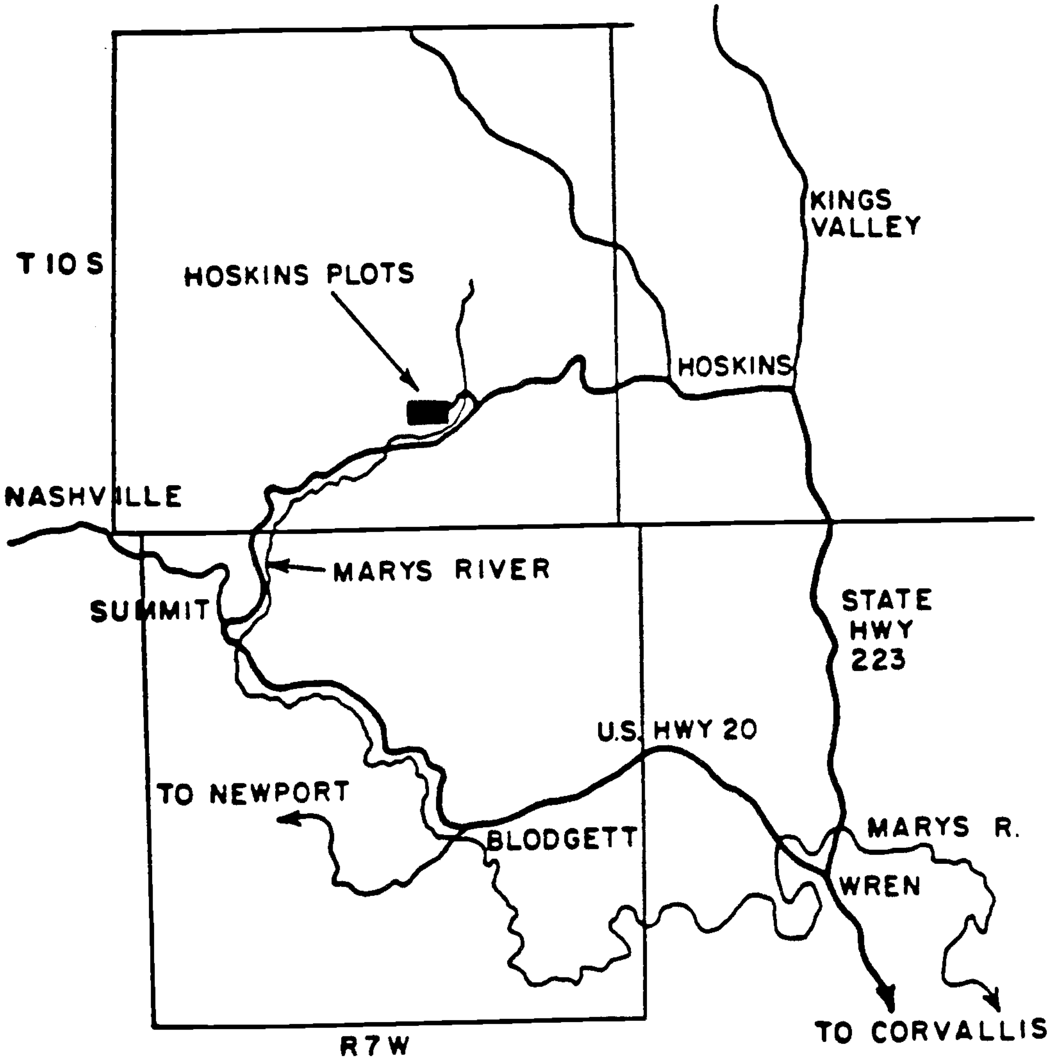


Figure 1-2: Location of the Hoskins Levels-of-Growing-Stock Study.

The soils are described by Knezevich (1975) as deep well-drained silty clay loams of the Apt series formed in colluvium from mixed sedimentary and igneous rocks. The surface layer is a very dark brown and very dark grayish-brown silty clay loam about ten inches thick. The subsoil is dark-brown, dark yellowish-brown, or strong-brown silty clay and clay about 60 inches deep. The water holding capacity ranges from seven to ten inches. Slopes range from 10 to 40 percent on a southerly aspect at an elevation of about 1000 feet on the upper 1/3 of the slope.

The main stand is 100% Douglas-fir. Initially there was no understory vegetation in the area because of the dense overstory. This condition remains on the control plots. Some of the understory species that have developed on the thinned plots include: sword fern (Polystichum munitum) and salal (Gaultheria shallon) on the lighter thinnings, ocean spray (Holodiscus discolor) in the intermediate densities, and hazel (Corylus cornuta californica) on the most heavily thinned plots. The climax plant association is Tsuga/Gaultheria/Polystichum (Franklin 1979).

Because of the heavy thinning on many of the plots, the control plots offered the best estimate of site index. Using height-diameter curves, the 50-year site index in 1988 (38 years breast height age) was 127 to 140 feet (133 feet average) using the 40-largest diameter trees per plot and King's (1966) site curves and 127 to 140 (135 feet average) using the largest diameter tree per plot and the Means and Sabin (1989) site curves. The approximate 100-year site index was 157 to 175 feet (average 167 feet) (McArdle et al. 1961).

1.2.2 Experimental Design

This experiment was designed to test eight thinning regimes. The treatments associated with these regimes were prescribed to achieve a wide range in growing stock conditions. Each of the eight thinning treatments and an unthinned control were replicated three times on 27 square sample plots 0.2 acre in size in a completely randomized design. The experiment consists of five periodic thinnings in each treatment. For the purposes of the analysis, periods between treatment thinnings were considered to be "subplots" and analyzed as a split plot in time or a repeated measures design (Marshall et al. in press). The experiment was designed to last for five treatment periods after an initial calibration period.

The final treatment period was completed at Hoskins after the 1983 growing season. An additional measurement was made in 1988.

The criteria for initial stand selection were:

1. A high degree of uniformity in stocking and site quality over an area sufficient to accommodate approximately a nine-acre installation.
2. Stand height between 20-40 feet and an average stand diameter less than 6 inches.
3. A vigorously growing stand with no apparent disease or damage and of such density that individual tree development had not been strongly influenced by competition, e.g. evidence of live crown extending over most of the bole.
4. At least 80 percent of the basal area in Douglas-fir.

The Hoskins installation met all of these criteria. However, not all of the plots were contiguous. Because of space limitations, five plots had to be located on closely adjacent, but similar areas (Figure 1-3).

A thinned buffer strip was maintained around the installation, but buffers were not established between plots.

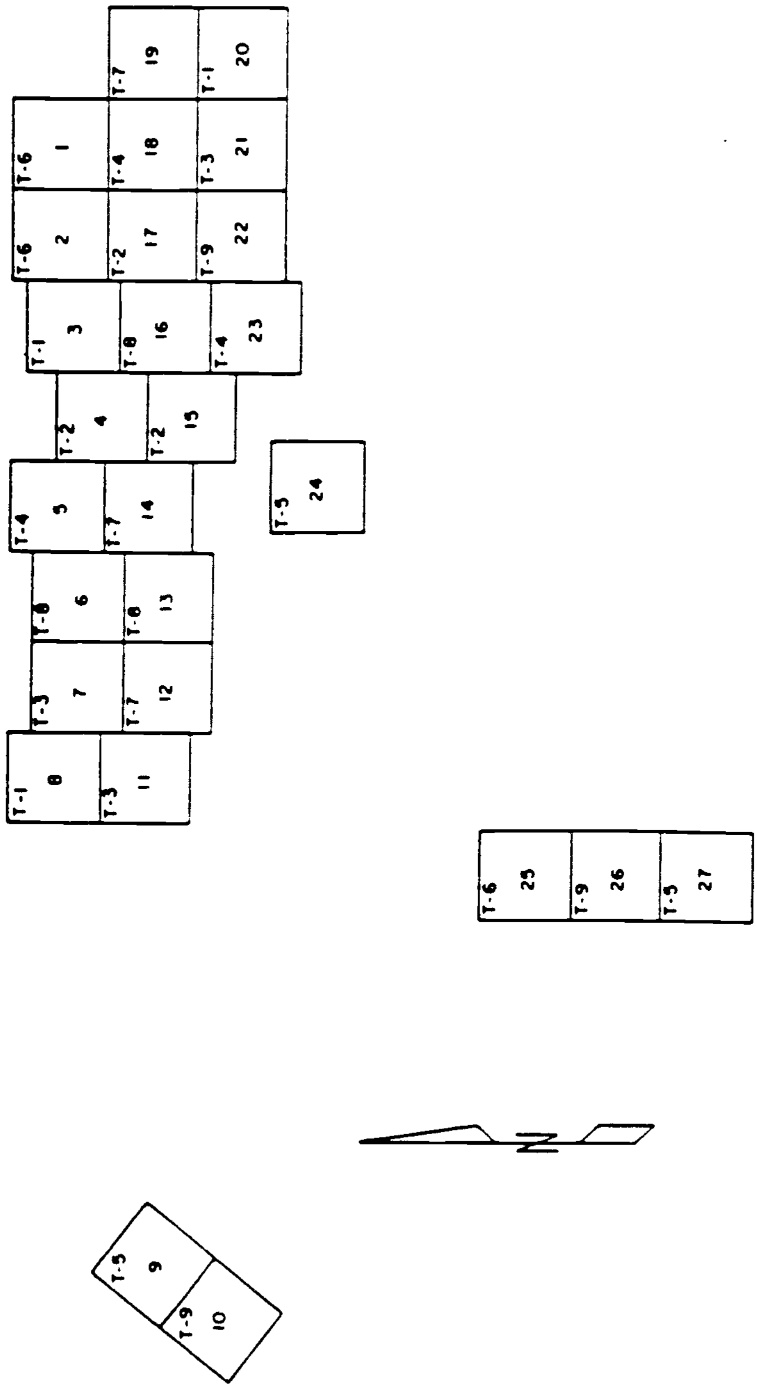


Figure 1-3: Plot layout for the Hoskins Levels-of-Growing-Stock Study with plot numbers and treatments (T-1). Plots are one-fifth acre in size.

1.2.3 Stand Treatments

The prescribed treatments were controlled by a common design to provide for compatibility among installations on different sites among the cooperators. Yearly meetings of the cooperators have provided oversight and have been used to interpret design implementation questions.

Selection of crop trees. Crop trees were selected before the initial calibration thinning at the rate of 16 per plot or 80 per acre. These trees were well-formed, vigorous dominants, with at least 13.5 feet between adjacent crop trees. Ideally, there would be four crop trees on each plot quarter. At Hoskins, crop trees were numbered 1 through 16 and marked with white paint to distinguish them from other trees on a plot which were painted with different treatment-specific colors.

Of the total 384 crop trees on the treated plots, 23 (6%) were replaced early during the study, primarily for slow growth; (one was cut after it developed a dead top). These replacements were distributed throughout the treatments. Of the replaced crop trees, two survived through the fifth treatment period, one later died (treatment 7) and the rest were cut in the period after being replaced. Where replacements were made, tree statistics were calculated using the new trees rather than the originals. During the last two treatment periods, after all noncrop trees had been cut, 17 and 3 crop trees were cut in treatments 1 and 2 respectively in order to meet the basal area requirement for the treatment thinning. (This decision generated much debate within the cooperators). In addition, a crop tree was cut from both treatments 3 and 5 for unknown reasons. In the control plots, two crop trees died during the study and one was later replaced.

<u>Calibration thinning</u>. All of the 24 plots assigned to receive thinning treatments also received a calibration or preparatory thinning. This initial thinning was intended to reduce the variation in the original growing stock, resulting in uniform growth potential for all the treated plots.

The study plan (Staebler and Williamson 1962) called for the stand to be thinned to an initial spacing based on the equation (Smith 1962 (p.104)):

$$S = 0.6167*D + 8$$

where:

S = average spacing in feet.

D = quadratic mean DBH of the trees left.

This equation assumes an initial spacing of 8 feet for a stand 4.5 feet tall and 100 trees per acre when the average stand DBH is 20.9 inches. A linear relationship between spacing and DBH is assumed (Williamson and Staebler 1965).

The calibration thinning was controlled by specifying that the average DBH of the leave-trees had to be within ±10% of the installation mean and that leave-tree basal area would be within ±3% of the amount specified by the above equation. The study plan recommended control by basal area for stands with an estimated average DBH, after thinning, greater than 4.5 inches, Smaller stands were controlled by the number of trees and required the DBH to be within ±15% and have the exact numbers of trees required.

Thinning treatments. Plots were thinned each time the crop trees grew 10 feet in height so that thinnings would be frequent when height growth and crown development were most rapid (Staebler 1960). This resulted in treatment thinnings in 1966, 1970, 1973, 1975, and 1979 at total ages of 23, 27, 30, 32 and 36 years. The 1975 treatment appears to have been premature, possibly due to height measurement errors, and produced inconsistent growth trends in the short (2 year) period. The last remeasurement, at the end of the final treatment period, was in 1983 at stand age 40 years.

Thinning intensity was related to gross basal area growth on the controls and to predetermined thinning regimes (Table 1) designed to give a wide range in densities. Basal area after thinning was calculated with the following formula:

$$BA_n = BA_{n-1} + GBAG(P)$$

where:

BA_n = basal area (ft^2/acre) retained after thinning at the beginning of a treatment period.

BA_{n-1} = basal area (ft^2/acre) at the beginning of the preceding treatment period.

GBAG = average gross basal area growth on the control plots (i.e., the increase in basal area of the live trees plus the mortality during the preceding period).

P = predetermined percentage of gross basal area growth of the control plots to be retained (Table 1-1).

A percentage of the gross growth on the control plots was used because it was assumed to approximate the full production of a given site at full stocking. The expected trends in residual basal area created by the 8

Table 1-1: Levels-of-Growing-Stock Study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock.

	Treatment							
Thinning	1	2	3	4	5	6	7	8
	percentage							
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

treatments are shown in Figure 1-4 and the actual in Figure 1-5.

The 8 treatments all accumulated growing stock throughout the experiment (i.e., all treatments increase in basal area), but at fixed, increasing, or decreasing rates. The four fixed percentage treatment regimes (1, 3, 5, and 7) always retained growing stock at four constant percentages of the control plots' gross basal area growth. The levels are 10, 30, 50, and 70 percent, which represent heavier to lighter thinnings. The variable percentage treatments represent two increasing and two decreasing percentage treatment regimes. The increasing treatments accumulated growing stock slowly at first by heavier cuts and then more rapidly with lighter, subsequent thinnings. The percentages of growing stock retained progress from 10 to 50 and 30 to 70 for treatments 2 and 4, respectively. The decreasing treatments (6 and 8) were opposite to treatments 2 and 4 in that they quickly accumulated growing stock by initially thinning lightly and then had progressively heavier cuts giving percentages of 50 to 10 and 70 to 30, respectively.

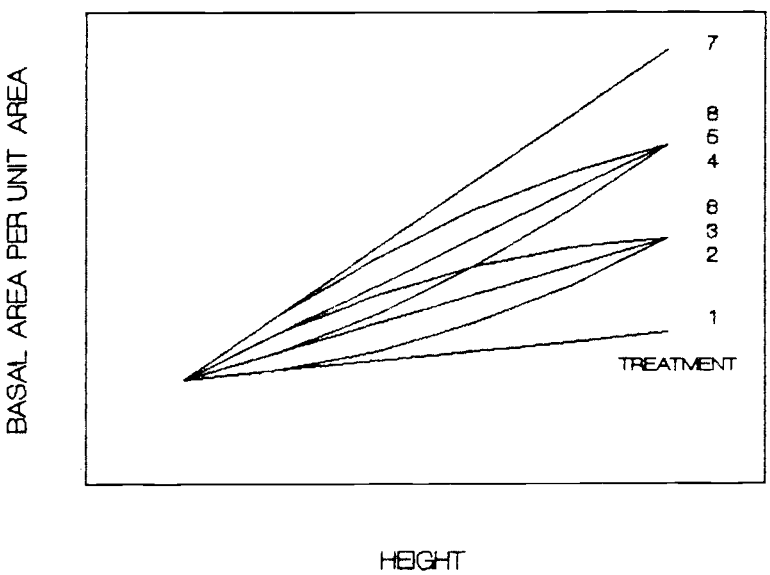


Figure 1-4: Levels-of-Growing-Stock Study in Douglas-fir idealized trends in residual basal area for eight treatment regimes.

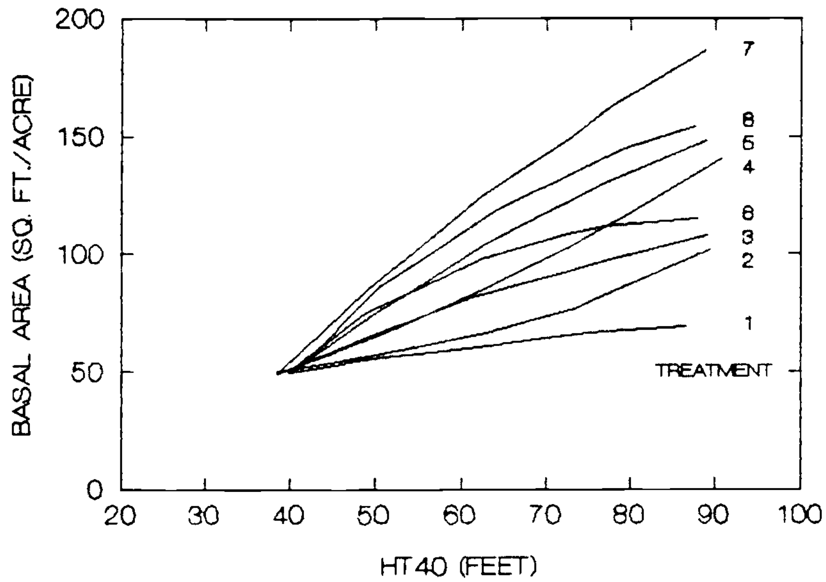


Figure 1-5: Actual residual basal area growing stock trends for eight treatment regimes through 1983 by height of the 40-largest diameter trees (HT40).

Tree removal guidelines. The thinning guidelines for tree removal were:

1. No crop trees were to be cut until all non-crop trees had been cut.
2. The average diameter of the trees removed at each thinning (d) was to be equal to the average diameter of the non-crop trees before thinning (D) (i.e., d/D=1.0 for the non-crop trees only). For all trees this resulted in a d/D ratio of less than 1, approximating a crown type thinning.
3. Trees removed in a thinning were to be distributed across the entire diameter range of the trees available for cutting without regard to merchantability.

After all non-crop trees had been removed, some additional crop trees were removed attempting to achieve a d/D of 1.0 and meet treatment basal area requirements.

Treatment history. The calibration thinning was a precommercial thinning and was performed as a training exercise by a State of Oregon Forestry Department emergency fire crew. The trees were felled and the crowns chopped and left in place. The crew also broke off all dead branches on live trees with axe handles to facilitate marking. The marking for the calibration and five treatment thinnings and supervision of data collection and logging was done by Professors John F. Bell (mensuration) and the late Alan B. Berg (silviculture) of the College of Forestry at Oregon State University. During the five treatment thinnings, trees were bucked and unmerchantable material and tops were left on the plots. Merchantable logs were removed by horse and tractor (winched to skid trails) for the land owner. Logging damage was very minimal.

1.2.4 Data Collection

All trees with a diameter at breast height of 1.6 inches or greater were painted with numbers at the time of the initial calibration thinning. The DBH point was also permanently marked with a painted ring. A different color was used for each treatment. At each measurement, the DBH of all live trees was measured to the nearest 0.1 inch. In addition, 12 to 15 trees on each plot were measured for total height to develop local volume equations. These trees were distributed through out the range of diameters, with two-thirds of the sample trees larger than the stand quadratic mean DBH. Height sample trees that died or were cut, were replaced with trees of similar size. The initial measurements were made following the end of the 1963 growing season. Heights-to live-crown were measured on the height sample trees in

1983 and 1988. All subsequent remeasurements and thinnings were made during the dormant period after the growing season.

Chapter 2

Twenty-Five Year Stand Development and Growth After Repeated Thinning

The Levels-of-Growing-Stock studies were designed to examine (1) cumulative wood production, (2) tree size development, and (3) growth-growing stock ratios (Williamson and Staebler 1965). Staebler (1959) discussed the concept of growth as a return on the capital investment in growing stock. Under a timber production objective, existing stands should be utilized to maximize returns and it would be undesirable to maintain excessive inventories of growing stock that produce little or no increase in growth. Environmental concerns for the site and operational aspects also are important considerations.

The report by Marshall et al. (in press) gives results for the Hoskins LOGS installation through the end of the originally designed experiment at age 40 (1983). This chapter updates that report to include results for an additional 5-year growth period and considers the resulting stand growth and development 25 years after the initial thinning at age 20.

2.1 Methods

2.1.1 Data Summarization

Measurements of height-to-live crown (HLC) were taken during the 1983 and 1988 remeasurements on the same trees that were measured for total height (HT). To estimate initial crowns height, measurements of height to remaining branch stubs (dead branches were removed in 1963) were taken on 136 trees in treatments 1, 3, 5 and 7 and control. Crown data were available from felled trees in 1966, including 32 trees felled in the first treatment thinning after the calibration period when all of the treated plots had the same density, and 27 trees felled in an adjacent, unthinned area. Felled tree data with crown measurements were also available from the 1970 treatment thinning. Data were pooled for treatments with the same growing stock at that time (i.e. 1-2, 3-4, 5-6, and 7-8) to give approximately 30 trees for each treatment pair. For measurements with crown data, treatment specific crown ratios [CR = 1.0 - (HLC/HT)] were estimated from diameter at breast height (DBH) as:

$$CR = a_1 * EXP[a_2/DBH] \qquad [2\text{-}1]$$

where a_1 and a_2 are the parameters estimated and EXP is the exponential function. For measurements without crown data, parameters were interpolated as linear functions of age.

Stand height is presented as the average height of the 40 largest DBH trees per acre (HT40) on a plot. This was calculated using the quadratic mean DBH of the eight largest diameter trees per plot (largest 40 per acre) and the corresponding average tree volume from the plot's local volume equation. The HT40 was found by substituting the mean volume and DBH of the largest eight trees per plot into the Bruce and DeMars (1974) volume equation and solving for tree height. This procedure was used to provide consistency with previous LOGS reports (See Curtis and Marshall (1986) for further details). The HT40 calculated from volume local volume equations was an average of 0.89 feet (1.3 percent) taller than using HT-DBH curves of the form (Curtis 1967):

$$HT = b_1 * EXP[b_2/DBH] \qquad [2\text{-}2]$$

with fitted parameters b_1 and b_2.

Total volume (cubic feet, inside bark) was calculated for each sample tree with measured heights using the Bruce and DeMars (1974) equation for cubic foot volume (CVTS). Volumes for all trees on each plot were calculated using local volume equations of the form:

$$\ln(CVTS) = c1 + c2 * \ln(DBH) \qquad [2\text{-}3]$$

where ln is the natural logarithm and c_1 and c_2 are regression coefficients fitted using the sample trees from each plot. Individual tree Scribner board foot volume to a 6-inch top in 16-foot logs (SV616) was calculated from measured DBH and calculated CVTS using the tarif system (Chambers and Foltz 1979). Plot volumes were calculated by summing the individual tree volumes. The tree heights measured on plot 10 in 1975 were found to be consistently low from apparent measurement errors. Individual trees were adjusted using the previous and later measurements to fit the equation

$$HT = d_0 + d_1{*}age + d_2{*}age^2 \qquad [2\text{-}4]$$

where age is the stand age at each measurement and d_0, d_1, and d_2 are estimated coefficients.

2.1.2 Analysis

Net periodic growth was calculated as the difference between the live stand at the start and end of the growth period. The gross periodic growth in basal area and volume is the growth on all live trees at the beginning of a growth period, even if they die (i.e., net growth plus the mortality occurring during that period). Net growth represents "usable" wood production while the gross growth, in a fully stocked stand, is assumed to approximate the productive capacity of the site. Net diameter growth is strongly influenced by mortality of small trees and may not be clearly interpretable as a response to thinning. For this reason survivor growth, which represents the growth of only the trees alive at the end of the period, was used (Curtis and Marshall 1989).

Volume growth percent for any given period (growth as a percent of the mean period growing stock, X) was calculated as:

$$\frac{100(\text{period increment of X})}{(X_1 + X_2)/2}$$

where X_1 and X_2 were the live cubic foot volume per acre growing stock at the start (X_1) and end (X_2) of the growth period.

Growth-growing stock relationships were investigated with regressions of growth versus growing stock for all plots. The gross basal area, gross volume growth and survivor diameter growth were used. Each plot's mid-period basal area in square feet per acre (G) and relative density (RD) (Curtis 1982) were used as measures of growing stock. Relative density (RD = Basal Area/(QMD)$^{1/2}$, where QMD is the quadratic mean DBH) presents the data relative to a maximum attainable density (or biological limit) rather than on an absolute scale of basal area (Curtis and Marshall 1986), thus making it easier to interpret.

Relative Density is comparable to percent of maximum stand density index (SDI) (Reineke 1933) for the Hoskins plots (r^2 = 0.99, Marshall et al. in press).

The model form of Curtis and Marshall (1986):

$$\ln(Y) = e_0 + e_1*\ln(X) + e_2(X) \qquad [2\text{-}5]$$

was used for gross basal area and volume growth (Y), with growing stock (X). The ln is the natural logarithm and e_0, e_1 and e_2 are fitted parameters. For diameter growth, the equations used were:

$$Y = f_0 + f_1*G + f_2*G^2 \qquad [2\text{-}6a]$$

and

$$\ln(Y) = g_0 + g_1*\ln(RD) \qquad [2\text{-}6b]$$

The growth of survivor trees was used to remove mortality effects on diameter change (Curtis and Marshall (1989) and to give a more accurate measure of thinning response.

2.2 Results

The following results are plotted to present the development of the treatments from establishment (1963) until the last remeasurement (1988). Whenever possible, HT40 was used on the horizontal axis to facilitate comparisons with results reported for other LOGS Study installations (Curtis and Marshall 1986). This removes site effects, although age is implicit for a single installation where site is relatively constant. Tables in this chapter present summary data for the last period (1983 to 1988). A complete summary of the stand statistics, growth, mortality and thinnings can be found in the Appendix.

2.2.1 Height and Crown Development

Height of the 40 largest (HT40). Thinnings had only a minor effect on HT40. The average difference between the HT40 calculated before and after thinnings was 0.2 feet (excluding the calibration cut). The average H40 of the treated plots was always shorter than for the controls. This difference, however, decreased with time and was only significant at the first measurement ($p<0.05$) when the heights averaged 39.6 and 42.6 feet on the treated and control plots, respectively. This was partially due to the removal of some larger trees in the calibration thinning from differences in initial stand tables. The local volume equations for individual plots also may have caused differences in initial HT40. By pooling data on all plots for a common HT/DBH curve for the first measurement, the control was still larger, but not significantly. At age 45, the HT40 averaged 112.0 feet for all plots (Table 2-1). The total change in HT40 was not different between the control and the treatments.

Site Index. The site index estimates have been quite variable between plots (Tappeiner et al. 1982), although the control plots have been consistent. The 50-year site index was estimated by King (1966) using the HT40 and for Means and Sabin (1989) using the largest tree per plot and HT-DBH curves. Initial estimates using the treated plots were low because of the removal of some larger site trees, although these differences are no longer significant (Table 2-2). The installation site index at 45 years stand age the is 135 (King 1966) and 133 (Means and Sabin 1989).

Table 2-1: Hoskins per acre stand summary statistics by treatment after the 1988 growing season (45 years stand age).

	TREATMENTS								
	1	2	3	4	5	6	7	8	C
HT40 (feet)	108.2	111.6	111.2	112.3	115.5	110.6	113.7	112.7	112.6
CR40 (%)	58.5	52.2	50.8	45.1	44.9	49.8	41.1	45.4	29.2
No. Trees	51.7	80.0	101.7	133.3	161.7	110.0	214.3	180.0	488.3
QMD (inches)	20.1	19.1	17.2	16.6	15.3	17.1	14.9	15.1	10.6
Basal Area (sq.ft.)	114.0	156.9	163.0	197.1	207.4	175.4	256.0	222.5	296.3
Relative Density	25.4	35.9	39.3	48.4	53.0	42.4	66.3	57.3	91.0
Stand Density Index	158.0	225.3	242.2	299.9	319.3	259.5	405.6	348.0	536.0
Volume									
Total stem (cu.ft.)	4441	6264	6649	8112	8625	7081	10773	9269	12115
Scribner[1]	23742	33262	34469	41603	43320	36587	53274	46003	47299

[1] Scribner board foot volumes are to a 6-inch top and in 16-foot logs.

<u>Height-to-live-crown (HLC)</u>. Initial CR was estimated to be nearly 80 percent. As expected, the live crown lengths have developed in relation to the level of growing stock. The control had the greatest amount of crown recession with an average of 2.8 feet per year (4.1 feet per year during the calibration period). The fixed treatments (1, 3, 5, and 7) experienced average rates of recession of 1.5, 2.0, 2.2, and 2.4 feet per year, respectively (Figure 2-1). All the treated plots averaged only 1.6 feet per year of crown recession during the calibration period. At the 1988 remeasurement the crown ratio for the 40 largest DBH trees averaged was only 29 percent on the control. Crown ratios on the fixed treatments decreased with increasing growing stock and averaged 58.5, 50.8, 44.9 and 41.1 percent for treatments 1,3,5 and 7 respectively. Treatments 2 and 6 are between treatments 1 and 3 (52 and 50 percent respectively), while treatments 4 and 8 where similar to treatment 5 (both at 45 percent) (Table 2-1).

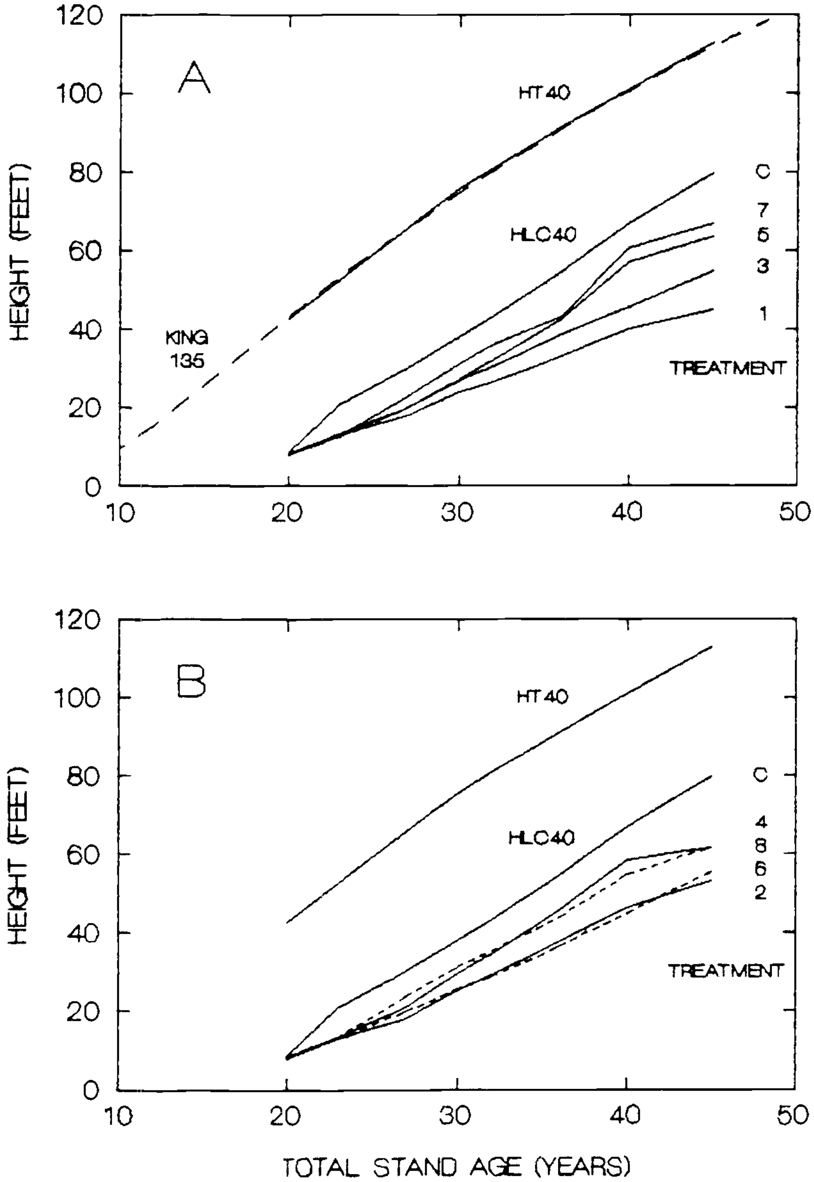


Figure 2-1: Development of 40-largest diameter trees in average total height (HT40) and height-to-live-crown (HLC40) for (A) the fixed treatments 1, 3, 5, 7, and the control and (B) the variable treatments 2, 4, 6, 8 and the control.

Table 2-2: Calculated 50-year site index from King (1966), using height of the 40-largest diameter trees, and Means and Sabin (1989), using the largest tree per plot.

Measurement Year	BH-age	King controls	King all	Means and Sabin control	Means and Sabin all
	years	feet	feet	feet	feet
1963	13	133.1	124.3	132.1	128.1
1966	16	133.4	126.7	132.6	129.7
1970	20	135.2	130.0	133.5	131.0
1973	23	136.7	132.5	135.6	133.6
1975	25	135.8	131.2	136.4	132.7
1979	29	135.6	132.2	140.4	132.6
1983	33	135.3	135.2	132.6	134.2
1988	38	135.8	135.2	132.9	133.4

2.2.2 Growing Stock Trends and Mortality

No data was available on the plots before the calibration thinning. However, based on the control plots, the stand initially had 1727 trees per acre, 138.1 square feet of basal area, and a RD of 70.8 (SDI=372). In the control plots mortality reduced the trees per acre by 72 percent to 488 by stand age 45 (Figure 2-2), and basal area increased to 296.3 square feet (Figure 2-3). The diameter of the trees dying increased from 2.1 to 6.2 inches, but the mortality was in relatively small trees (55 to 68 percent of the stand average DBH). The RD decreased to 91.0 (SDI=536) at age 45 from a high of 99.8 (SDI=559) at age 30 on the control (Figure 2-4).

The purpose of the calibration thinning was to produce uniform conditions on all the treated plots. The calibration cut reduced the trees per acre to an average of 342 (290-395 range), basal area to a uniform average of 49.8 square feet (48.2-51.2 range), and an average relative density of 21.9 (21.1-22.9 range). The quadratic mean DBH increased from 3.9 inches to 5.2 inches by the removal of mostly smaller trees (Table 2-3).

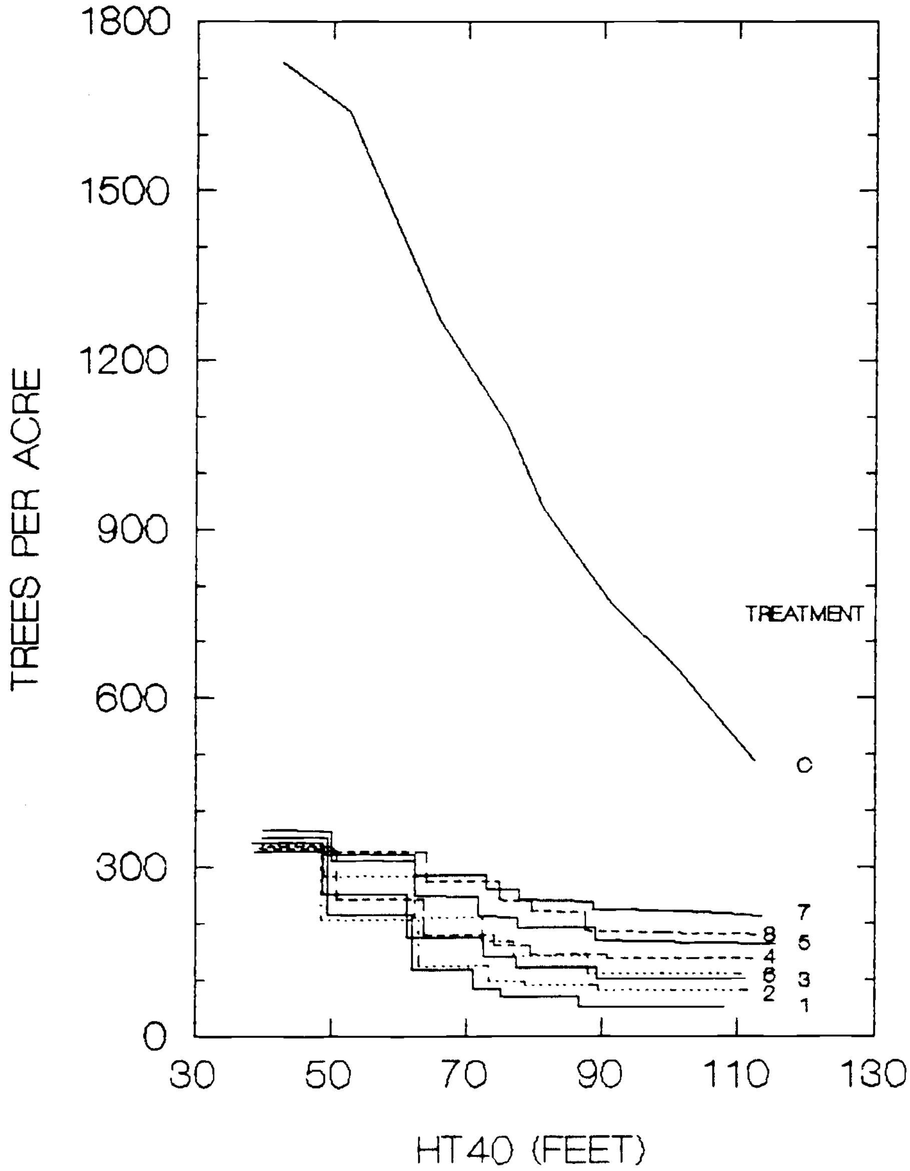


Figure 2-2: Numbers of trees per acre in relation to height of the 40-largest diameter trees (HT40) by treatment.

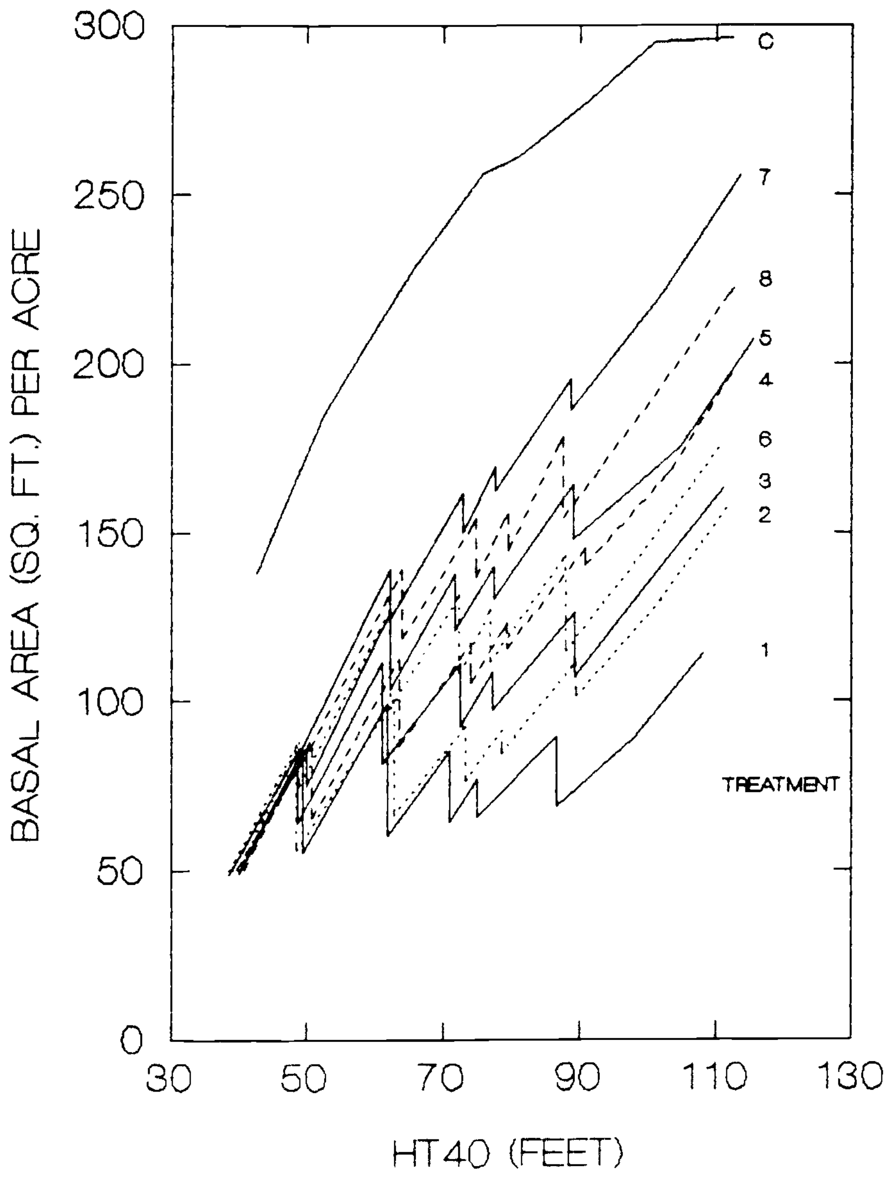


Figure 2-3: Basal area per acre in relation to height of the 40-largest diameter trees (HT40) by treatment.

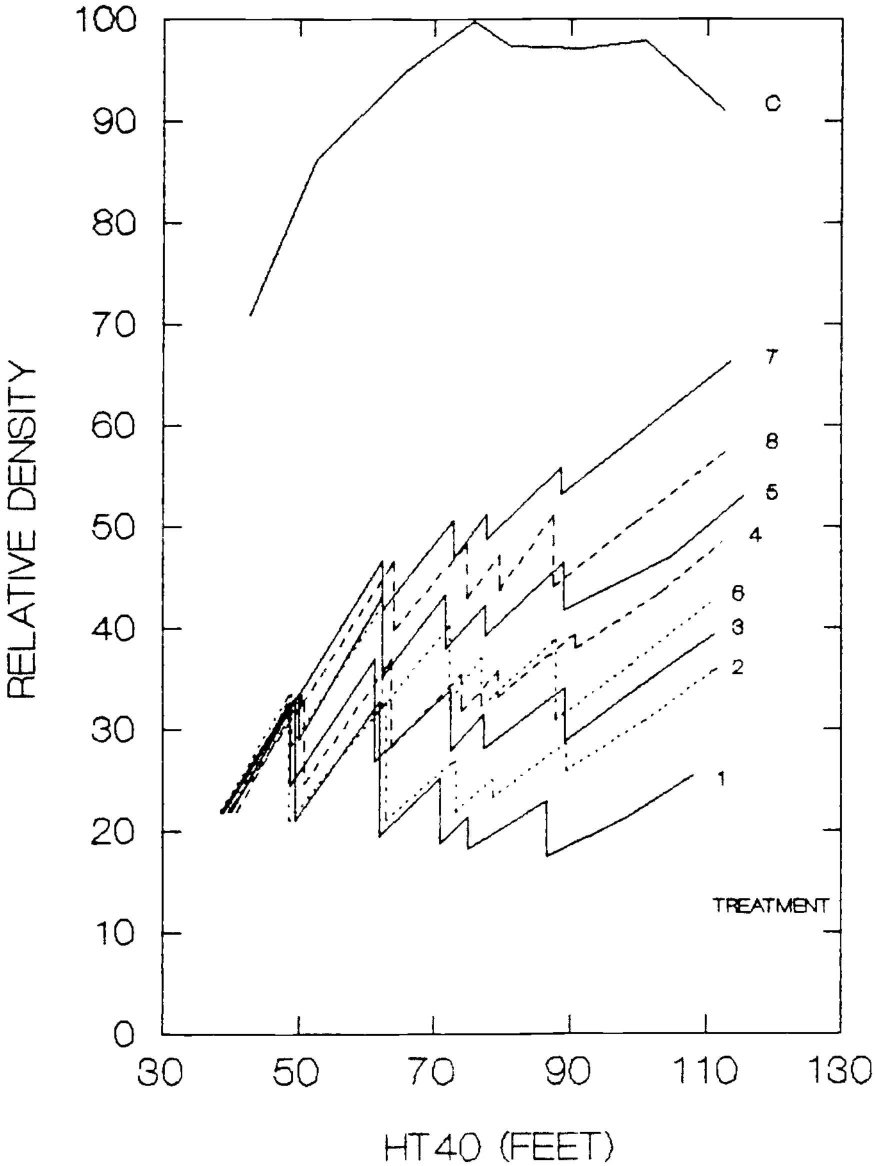


Figure 2-4: Relative density (Curtis 1982) in relation to height of the 40-largest diameter trees (HT40) by treatment.

Table 2-3: Stand statistics for the 3 control and 24 treatment plots after the calibration thinning. Standard deviations are in parentheses.

	Number of trees	Quadratic mean DBH	Basal area	Total volume	Height of 40-largest
	per acre	inches	ft^2/acre	ft^3/acre	feet
Control Plots	1726.7 (142.2)	3.8 (0.3)	138.1 (18.5)	1982.3 (313.9)	42.7 (1.9)
Treated Plots	342.7 (28.4)	5.2 (0.2)	49.8 (0.9)	743.8 (31.4)	39.5 (1.6)

For the heaviest and lightest thinning regimes, treatments 1 and 7 respectively, the five thinnings following the calibration removed from 97 to 300 trees per acre and 44.5 to 121.5 square feet per acre, although basal area increased in all treatments. In 1988, treatments 1 and 7 represented the range in densities on the treated plots (Table 2-1). The trees per acre ranged from 52 to 214 (Figure 2-2), basal area ranged from 114.0 to 256.0 square feet per acre (Figure 2-3), and the relative densities range from 25.4 to 66.3 (Figure 2-4) for treatments 1 and 7 respectively.

Mortality was negligible on the treated plots. The number of dead trees per acre ranged from 0 to 5.6 percent (average 2.2 percent) of the after calibration trees per acre, tending to decrease with thinning intensity (Table 2-4). The greatest yearly average mortality for the study occurred in the lightest thinning treatment during the latest period. This may be expected as this plot has reached a RD of over 60 where competition related mortality (self-thinning) is expected (Long 1985).

Table 2-4: Hoskins per acre yield summary statistics by treatment after the 1988 growing season (45 years stand age).

	TREATMENTS								
	1	2	3	4	5	6	7	8	C
TOTAL THINNING REMOVALS (excluding calibration) - 1966, 1970, 1973, 1975, 1979									
No. Trees	300.0	260.0	240.0	191.7	190.0	228.3	96.7	145.0	0.0
QMD (inches)	8.6	8.3	8.7	8.2	8.6	9.4	9.2	9.7	0.0
Basal Area (sq.ft.)	121.5	98.3	99.5	70.6	76.7	109.3	44.5	75.1	0.0
Volume									
Total stem (cu.ft.)	2971	2308	2530	1667	1990	2897	1205	2125	0
Scribner[1]	8602	6279	7398	4214	5548	9296	3575	7019	0
NET YIELD - 1988 (45 years)									
Volume									
Total stem (cu.ft.)	7412	8572	9179	9779	10615	9978	11978	11394	12115
MAI - cubic feet	165	190	203	217	236	222	266	253	269
Scribner[1]	32344	39541	41867	45817	48868	45883	56849	53022	47299
MAI - Scribner[1]	719	879	930	1018	1086	1020	1263	1178	1051
TOTAL MORTALITY 1963-1988 (20-45 years)									
No. Trees	1.7	3.3	1.7	8.3	13.3	0.0	18.3	11.7	1238.3
QMD (inches)	3.5	4.2	4.1	6.8	8.0	0.0	7.5	5.9	3.9
Basal Area (sq.ft.)	0.1	0.3	0.2	2.1	4.6	0.0	5.2	2.2	103.0
Volume									
Total stem (cu.ft.)	2	5	3	75	147	0	187	73	3038
Scribner[1] (board ft.)	0	0	0	152	394	0	338	61	1271
GROSS YIELD - 1988 (45 years)									
Volume									
Total stem (cu.ft.)	7414	8578	9182	9854	10762	9978	12165	11467	15153
MAI - cubic feet	165	191	204	219	239	222	270	255	337
Scribner[1] (bd.ft.)	32344	39541	41867	45969	49262	45883	57187	53083	48570
MAI - Scribner	719	879	930	1022	1095	1020	1271	1180	1079

[1] Scribner board foot volumes are to a 6-inch top and in 16-foot logs.

2.2.3 Growth-Growing Stock Relationships

Gross basal area and volume growth represent the productive capacity or biological potential of a "fully" stocked site. Gross and net basal area and volume growth for the last measurement period (1983-88) are summarized in Table 2-5 and for all periods in the Appendix (Tables A-9 and A-10). Diameter growth of the survivor trees is used to eliminate the effects of mortality in small trees on diameter growth and is also summarized in Table 2-5 for the last measurement period and for all periods in the Appendix (Table A-12).

Basal area growth. The gross basal area growth increased with growing stock, but has shown an increased flattening trend with age. The maximum growth has also decreased with age and the maximum appeared to have occurred at higher densities (Figure 2-5).

Volume growth and growth percent. Volume growth is determined by the growth in stand basal area, height and the change in tree form (Evert 1964, Curtis and Marshall 1986). Although the growth rate has decreased with age, growth has increased and is highly related to the level of growing stock (Figure 2-6). It has only been in the last two periods, since it has reached RD greater than

Table 2-5: Hoskins diameter, basal area and volume growth summary for the 1983-1988 growth period (40-45 years stand age).

	TREATMENTS								
	1	2	3	4	5	6	7	8	C
Quadratic Mean DBH (inches/year)									
Net	0.47	0.38	0.33	0.31	0.27	0.33	0.28	0.28	0.29
Survivor	0.47	0.38	0.33	0.27	0.25	0.33	0.23	0.26	0.13
Basal Area (sq. ft./acre/year)									
Net	5.0	5.9	6.0	5.7	6.4	6.5	7.0	7.2	0.2
Gross	5.0	5.9	6.0	6.1	6.5	6.5	7.5	7.4	7.0
Total Cubic Volume (cubic ft./acre/year)									
Net	244.9	316.4	348.2	363.9	391.3	375.4	471.5	460.5	249.1
Gross	244.9	316.4	348.2	377.9	394.9	375.4	492.1	467.3	498.3
Scribner Volume[1] (Board ft./acre/year)									
Net	1495	1945	2130	2242	2388	2287	2933	2799	2434
Gross	1495	1945	2130	2272	2389	2287	2958	2811	2632

[1] Scribner board foot volumes are to a 6-inch top and in 16-foot logs.

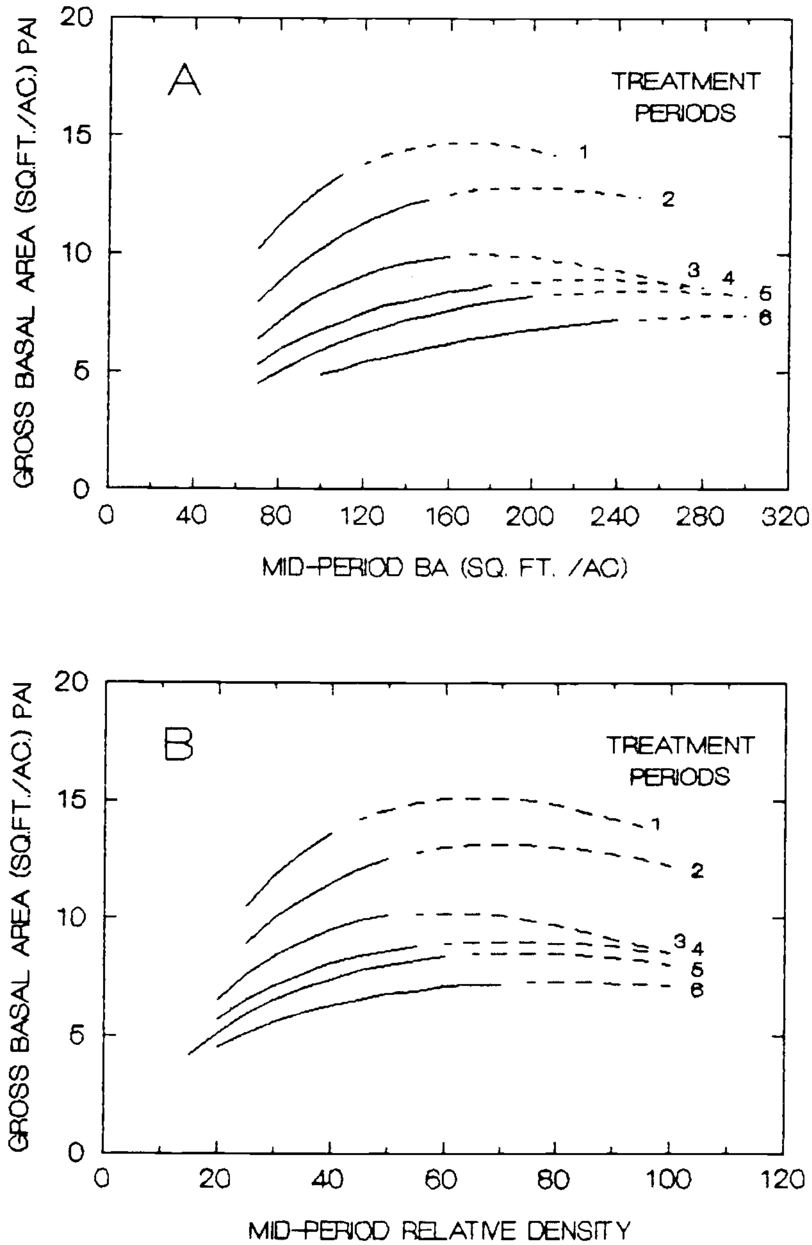


Figure 2-5: Relation of periodic annual gross basal area increment to mid-period growing stock: (A) basal area per acre and (B) relative density (Curtis 1982). Solid lines represent the range of the thinned plot data and the dashed lines extend to the upper range of the control plots.

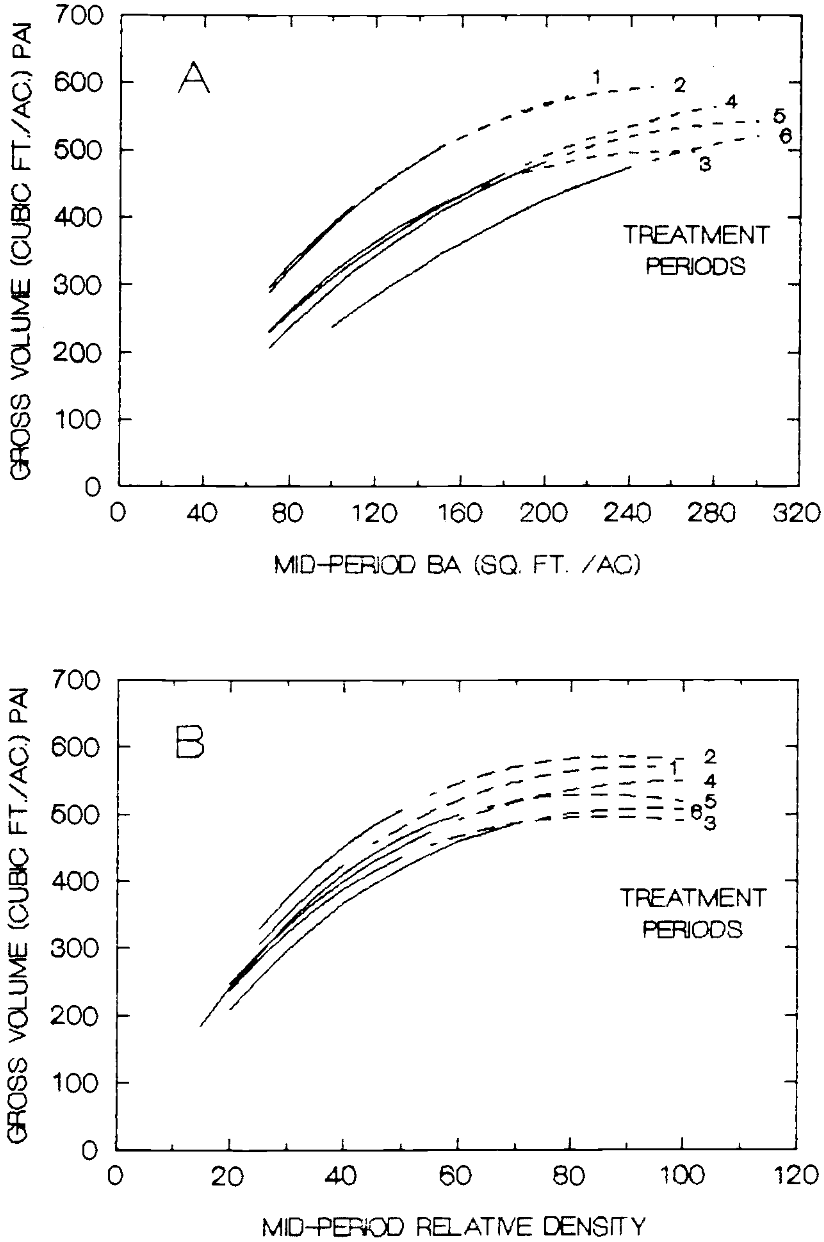


Figure 2-6: Relation of periodic annual gross volume increment to mid-period growing stock: (A) basal area per acre and (B) relative density (Curtis 1982). Solid lines represent the range of the thinned plot data and the dashed lines extend to the upper range of the control plots.

60, that the lightest treatment (7) has achieved growth rates comparable to the control. Volume growth percent (VGP) has decreased with growing stock and age. The relationship of VGP to growing stock has also become flatter with age (Figure 2-7). Figure 2-7 only shows the fixed percentage treatments for clarity. Treatment 2 was between 1 and 3, while treatments 4 and 6 was between 3 and 5 (treatment 6 closer to 3). Treatment 8 was just below treatment 7.

Diameter growth. The diameter growth of the surviving trees, like volume, was highly related to growing stock. Diameter growth, however, decreased with increasing growing stock. Diameter growth rates have also decreased with age (Figure 2-8).

Net growth. The difference in net and gross growth is mortality. To date, there has been little mortality on the treated plots (Table 2-4). Therefore, over the range of the treatments, these results would not change appreciably by using net growth. The control, however, has suffered substantial mortality after the first period. Eliminating this mortality from the growth estimates has the effect of the reducing basal area and volume growth on the control. The result was a peak in

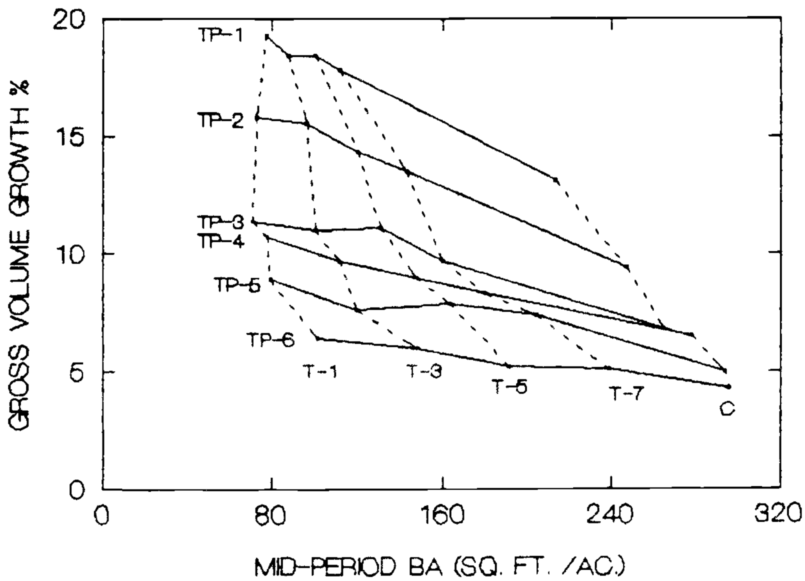


Figure 2-7: Volume growth percent in relation to mid-period basal area per acre growing stock. Dashed lines connect values for the same treatments (T) and the solid lines connect values for different treatments in the same growth period (TP). Values are shown for the fixed treatments 1, 3, 5, 7, and the control.

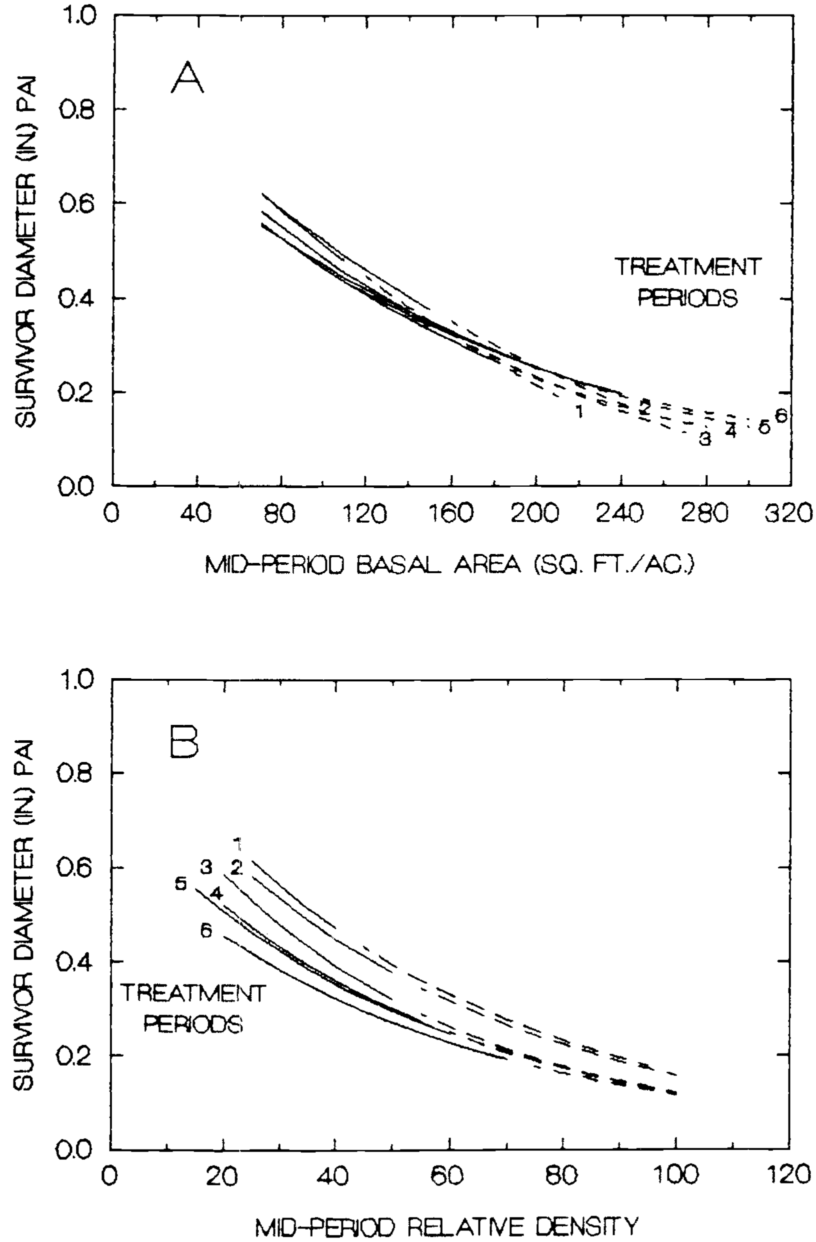


Figure 2-8: Relation of periodic annual survivor diameter increment to mid-period growing stock: (A) basal area per acre and (B) relative density (Curtis 1982). Solid lines represent the range of the thinned plot data and the dashed lines extend to the upper range of the control plots.

net growth at the growing stock levels of the lightest thinning treatments. Mortality occurred in smaller trees and increased the average stand diameter, similar to the effect of a low thinning. Net diameter growth still decreased with level of growing stock for the treatments, but leveled off in the high densities of the control to growth rates similar to the lightest thinning treatment.

2.2.4 Attained Stand Diameter and Volume Yield

Attained stand diameter. The initial stand DBH on the controls was 3.8 inches. The calibration thinning primarily removed trees from the lower diameter classes and increased the initial DBH on the treated plots to 5.2 inches (Table 2-1). By age 45, the diameter on the control plots averaged 10.6 inches (43 percent of the growth from to mortality in smaller trees). The lightest thinning (treatment 7) increased to 15 inches. The heaviest thinning (treatment 1) increased to nearly twice the control (20.1 inches) (Table 2-1 and Figure 2-9). The average d/D ratio was 0.90 for the five treatment thinnings (the range was 0.67 to 1.18, both occurred in the last thinning when tree choice for removal was limited).

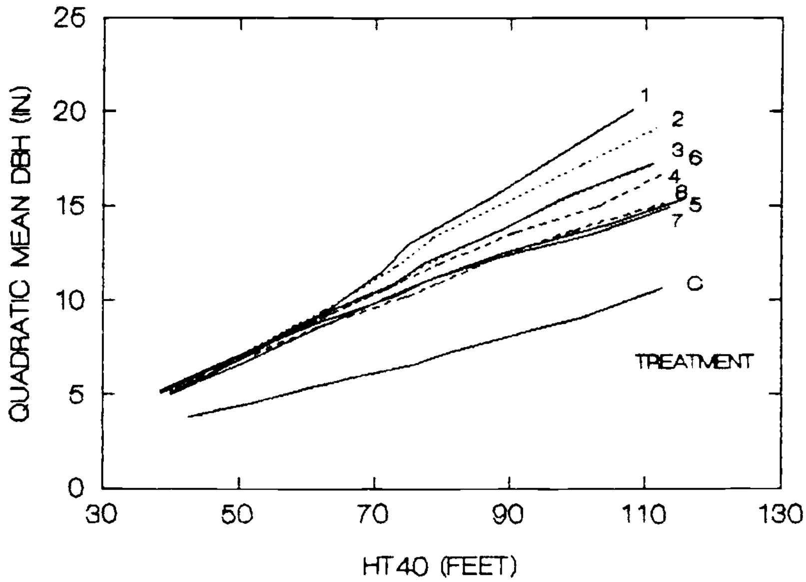


Figure 2-9: Quadratic mean diameter (after thinning) in relation to height of the 40-largest diameter trees (HT40) by treatment.

Volume yield. At age 45, the control had the greatest standing cubic foot volume (12115 cubic feet). Standing volume in the heaviest thinning was to 4441 and 10773 in the lightest thinning (Table 2-1, Figure 2-10). Scribner board foot volume was least on treatment 1, but was greater on the lightest thinning, treatment 7, (53274) than on the control (47299) (Table 2-1). In all treatments, the volume was in larger diameters (Figure 2-11). In total volume production (the standing volume plus the volume removed in thinnings) all the thinnings except the heaviest compared favorably with the control's yield (Table 2-4). Nearly all the volume on the treatments was in the 12-inch class or greater (Figure 2-12). Mortality was less than 1 percent on all but treatments 5 and 7, where it was less than 1.5 percent of the gross yield at age 45. The control plot lost 20 percent of its gross yield (but only 3 percent of Scribner).

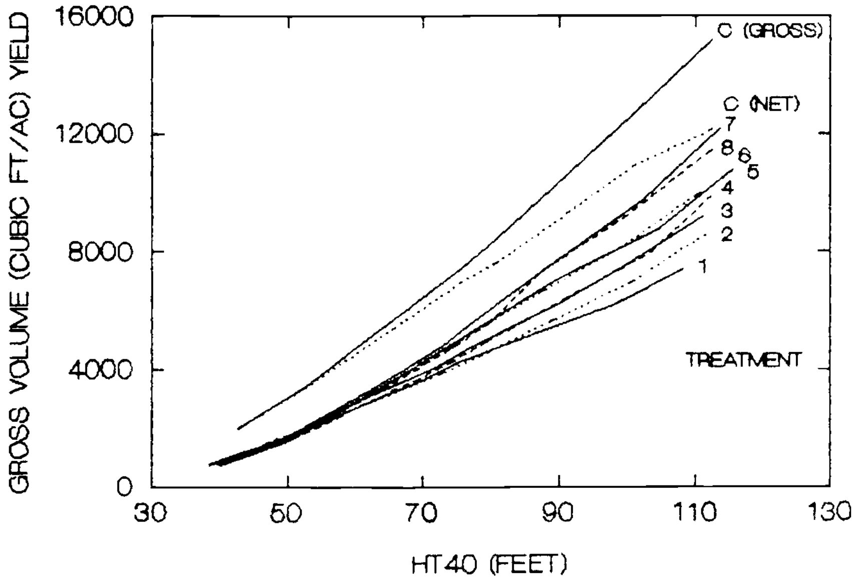


Figure 2-10: Cumulative gross cubic volume yield in trees 1.6 inches DBH and larger (excluding volume removed in calibration cut) in relation to height of the 40-largest diameter trees (HT40) by treatment.

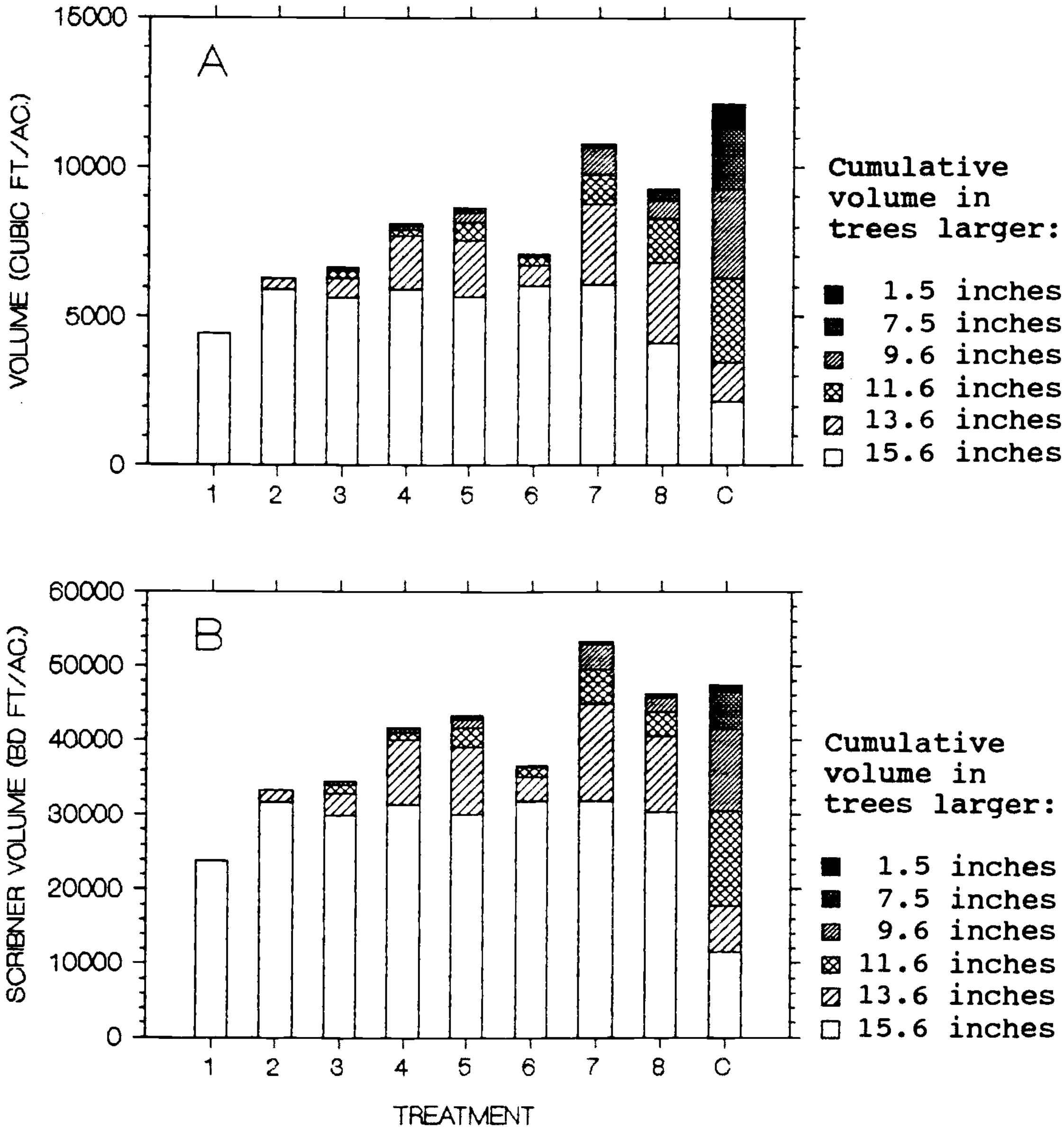


Figure 2-11: Standing volume in (A) cubic foot per acre and (B) Scribner board feet in 1988 (45 years stand age) by tree DBH size classes.

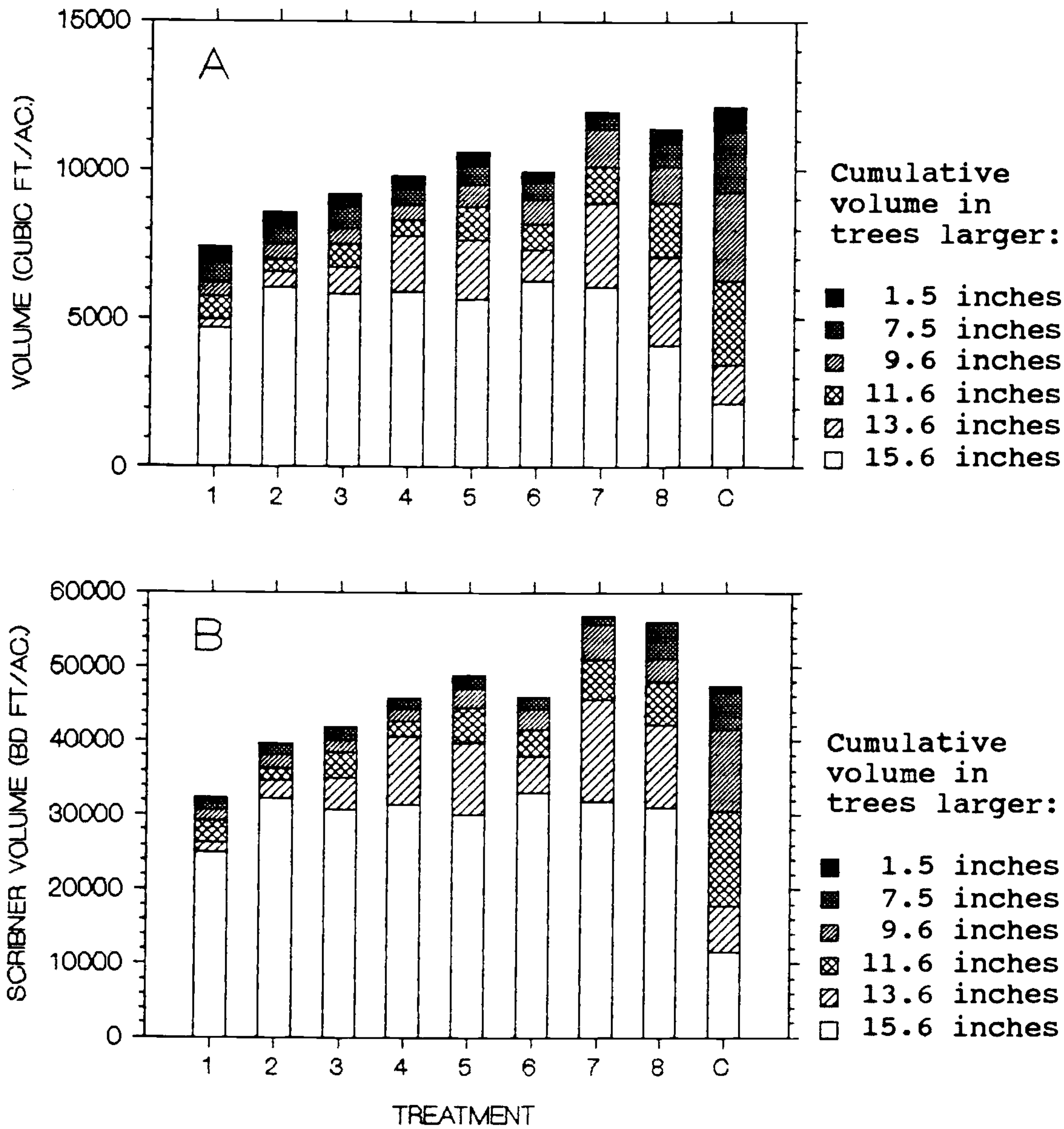


Figure 2-12: Cumulative volume production (standing plus thinnings) in (A) cubic foot per acre and (B) Scribner board feet in 1988 (45 years stand age) by tree DBH size classes.

2.2.5 Periodic and Mean Annual Increments

Although the periodic annual increment (PAI) is variable by period, it does appear to have culminated in all treatments. The mean annual increment (MAI) continues to increase on all treatments (including the control) and ranges from 67 to 55 percent of the periodic annual increment at age 45 (Figure 2-13). Net MAI and PAI is nearly the same as for the gross in the treatments, however, net MAI has culminated on the control plot in the last period. Scribner board foot PAI is also quite variable, but unlike cubic volume, does not appear to have culminated for any of the treatments or the control (Figure 2-14). The control does not have the largest MAI or PAI, as with cubic volume, but is increasing stongly due to trees continuing to grow into the merchantable size class.

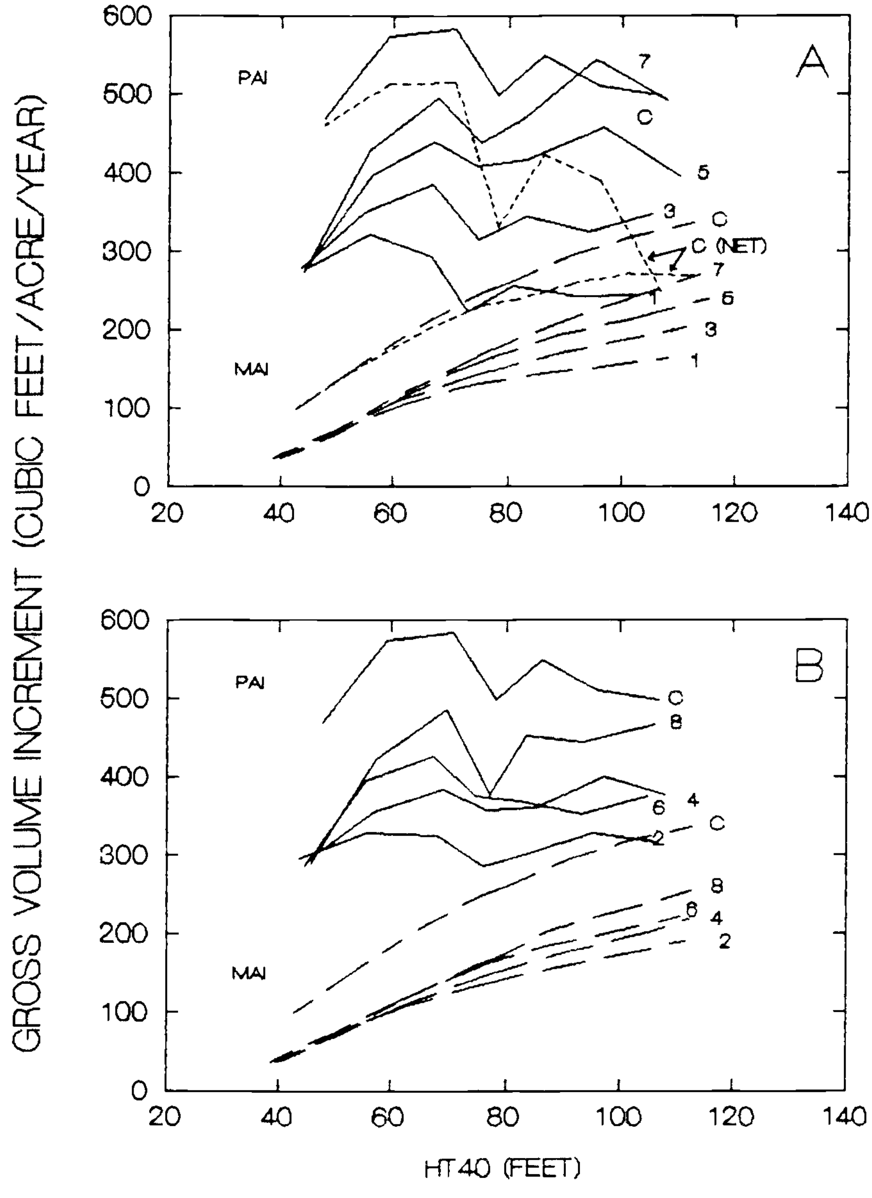


Figure 2-13: Trends in mean annual increment (MAI) and periodic annual increment (PAI) for gross cubic foot volume in relation to height of the 40-largest diameter trees (HT40): (A) fixed treatments 1, 3, 5, 7, and control (including net increment) and (B) variable treatments 2, 4, 6, 8, and control.

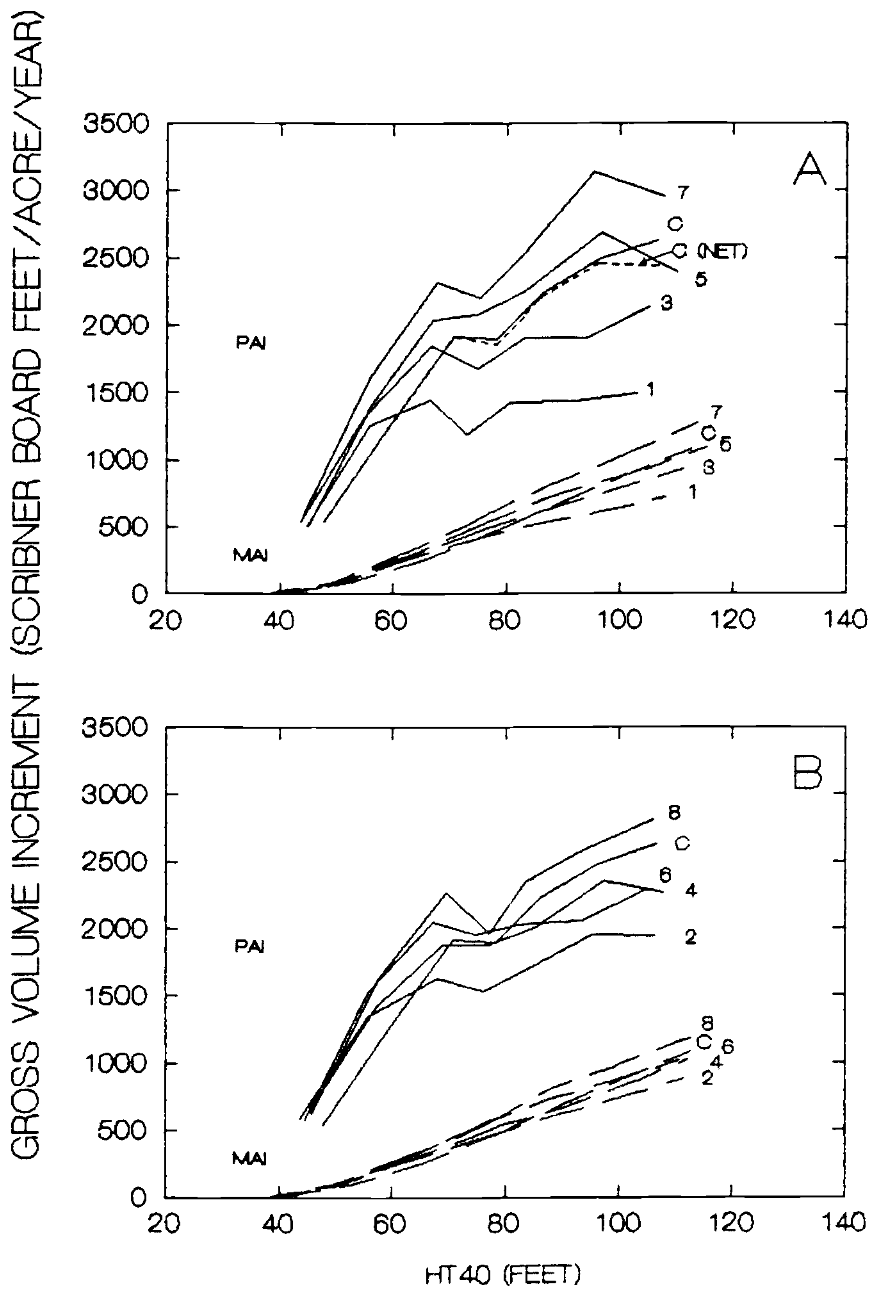


Figure 2-14: Trends in mean annual increment (MAI) and periodic annual increment (PAI) for gross Scribner Board foot volume in relation to height of the 40-largest diameter trees (HT40): (A) fixed treatments 1, 3, 5, 7, and control (including net increment) and (B) variable treatments 2, 4, 6, 8, and control.

2.3 Discussion

The calibration thinning represented a precommercial thinning late in the life of the stand (Reukema 1975). The results of this study indicate that precommercial thinning of dense, older (20 years) stands will give good results. Later thinnings could be expected to reduce the response from suppression and produce smaller trees with less merchantable volume later in the rotation (Omule 1984). Even with the initial high stockings and lateness of the treatment, there was an immediate release response with more than a 131 percent increase in net diameter growth over the controls.

The Langsaeter (1941) hypothesis (as discussed by Braathe 1957) describes the relationship of stand growth to the level of growing stock. At low levels of growing stock, trees are free to grow and growth increases proportionally to stocking (zone I). As competition begins, the growth rate decreases with an increase in growing stock (zone II). In zone III, growth is nearly constant over a wide range of stand density. At high levels of competition, growth may even decrease (zone IV) as the trees are less able to resist disease, insects, damage, and stagnation (Figure 2-15A). At these higher

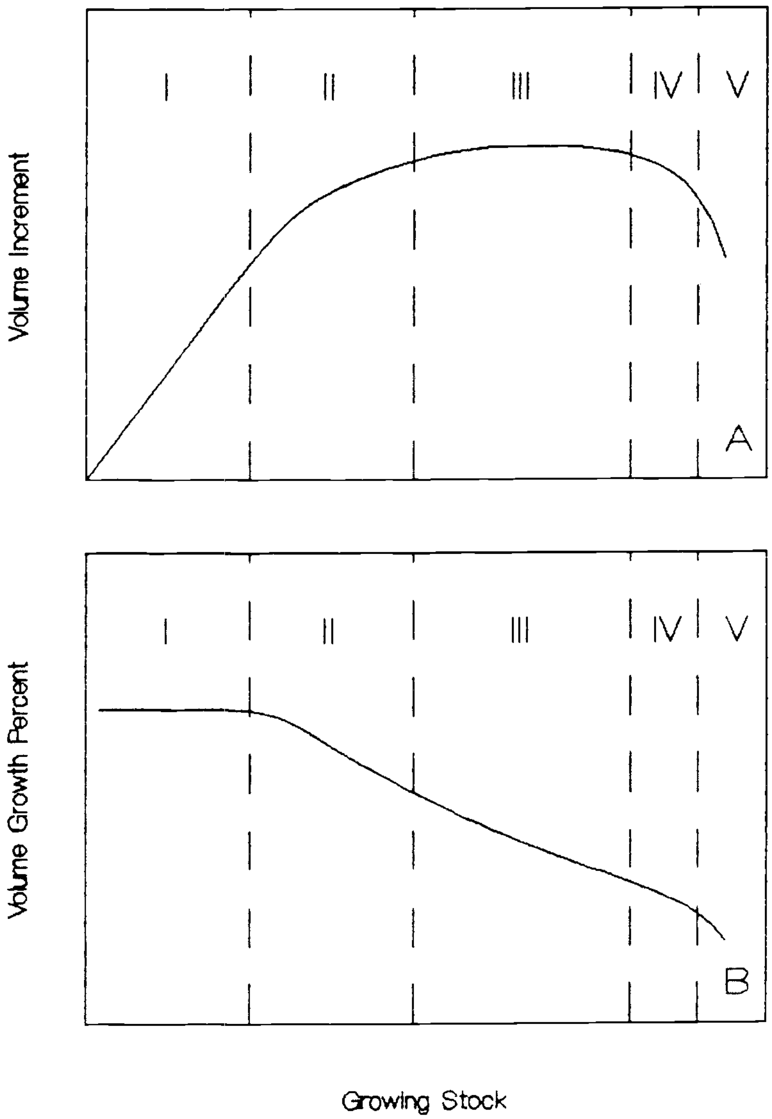
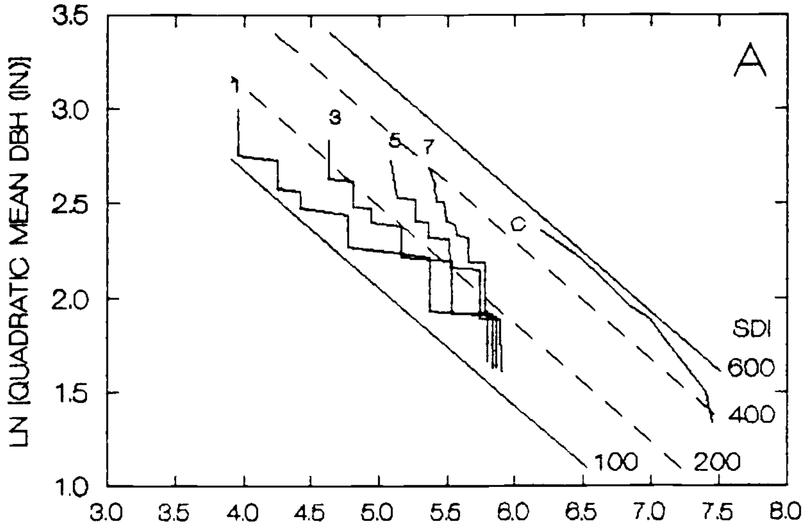


Figure 2-15: Langsaeter's (1941) growth-growing stock diagram.

density levels, the growth relative to the amount of growing stock decreases (Figure 2-15B).

The periodic gross volume growth curves at Hoskins have not shown a clear plateau as hypothesized by Langsaeter (1941). In the early periods, all of the treatments appeared to be in zones I and II. Using the method of stand volume growth analysis of Wiedemann (1951), Buckman (1962) and Evert (1964) have shown that volume growth is not necessarily proportional to basal area growth. Following release, thinned stands may have similar basal area growth as a denser unthinned stand. However, in stands with rapid height growth, the height is added on to a greater amount of growing stock (or more stems) in the dense stand. In the last two periods, however, the lightest thinning has developed growth rates near or above the controls, but with 25 percent less growing stock at the start of the period. This may indicate the development of a plateau as the stand ages and growing stock accumulates. This relationship is species- and age-dependent and may be very sensitive to stand structure or the type of growing stock retained (Oliver and Murray 1983, O'Hara 1988).

The development of the Hoskins plots is shown in Figure 2-16 on a Reineke-type density management diagram proposed by Long et. al. (1988). Long (1985) suggested that the lower limit of self-thinning occurs at about 60 percent of maximum stand density index (SDI) (approximately RD=60) and that the lower limit of "full site occupancy" is at about 35 percent (approximately RD=35). The maximum SDI for coastal Douglas-fir is near 600 (Reineke 1933), which is approximately equal to a RD of 100, and is similar to estimates given by Drew and Flewelling (1979). The control had an initial SDI of 367 (61 percent of maximum) with very little apparent past mortality. During the next period,87 trees per acre died suggesting that the stand was initially (in 1963) very near the start of self-thinning. In the later periods, the control approached and tracked just below the maximum density line. The calibration thinning reduced the treated plots to a SDI of near 120 (20 percent of maximum). Mortality had been negligible through the fifth treatment period with the lightest thinning, treatment 7, reaching a SDI of 357 (60 percent of maximum) at the last remeasurement. Mortality would be expected to begin in this treatment during the next period. It appears that Long's (1985) lower limit of full site occupancy and maximum stand growth (35 percent) may be low. Management in the range of 40 to 60 percent



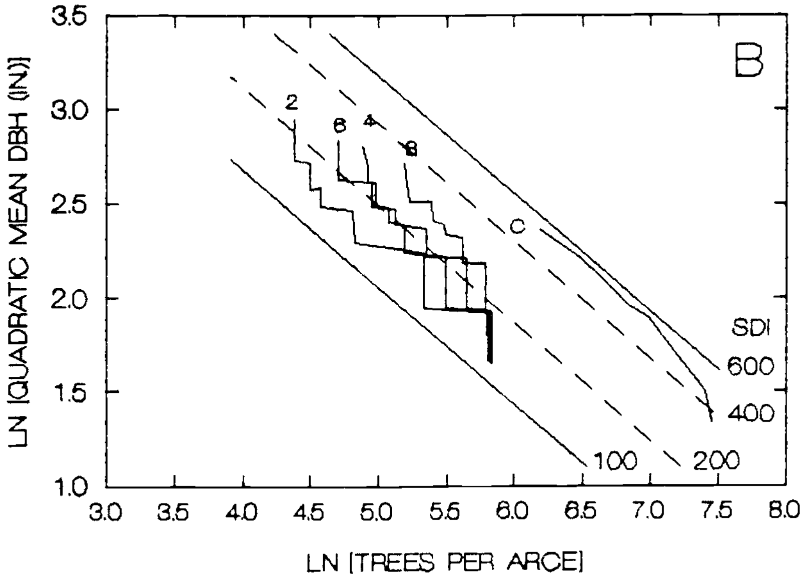


Figure 2-16: Reineke (1933) based stand density management diagram (Long et. al. 1988): (A) fixed treatments 1, 3, 5, 7, and control and (B) variable treatments 2, 4, 6, 8, and control.

of maximum SDI (RD=40 to RD=60) should achieve maximum stand volume growth whereas diameter growth will be highest below these levels.

The trade-offs between stand volume production and tree sizes are large. Although the control has yielded more cubic foot volume, the lightest thinnings have produced similar total volumes and only the heaviest thinnings have less merchantable cubic foot and board foot volumes than the control. In both cases, most of the volume for the treatments is in larger trees and net growth is greatly decreased at the high densities of the control due to mortality. These results are consistent with the other LOGS installations reported by Curtis and Marshall (1985).

It appears that the periodic annual increment for the control has probably culminated although the treatments are fairly flat. The mean annual increment for all treatments continues to increase. This suggests the possibility of longer biological (maximum MAI) rotations resulting from the thinning treatments. The PAI for Scribner board foot volume is still increasing and it appears that the MAI will culminate later than for cubic foot volume.

Chapter 3

Component Analysis of Volume Growth

Stand basal area is commonplace for foresters to measure. To calculate stand volume, however, average stand height and form must also be known, since stand volume (V) is calculated by the product of basal area (G), mean stand height (H) and average form factor (F):

$$V = G*H*F. \qquad [3\text{-}1]$$

Basal area growth is also relatively easy to measure, but as originally shown by Wiedemann (1932) (presented by Braathe (1957)), it is only one component of volume growth. Wiedemann derived periodic volume growth as the difference of initial stand volume (a function of stand basal area (G), mean height (H), and form factor (F) at the start of the period) and the change in basal area (G+ΔG), height (H+ΔH) and form factor (F+ΔF) during the period:

$$\begin{aligned}\Delta V &= (G + \Delta G)*(H + \Delta H)*(F + \Delta F) - (G*H*F) \\ &= F*(G*\Delta H + H*\Delta G + \Delta G*\Delta H) \\ &\quad + \Delta F*(G*H + G*\Delta H + H*\Delta G + \Delta G*\Delta H) \qquad [3\text{-}2]\end{aligned}$$

This relationship has been simplified by assuming that all factors with more than one growth component make only minor contributions to stand growth (0 to 3% according to Wiedemann 1932), except in young stands, or by assuming that ΔF is negligible (Buckman 1962, Hegyi 1969). Evert (1964) also presents Wiedemann's derivation of the components of volume growth and suggests that all components are important in analyzing and explaining the outcome of thinning experiments.

Hegyi (1969) used calculus and differentiated equation (3-1) with respect to time (t) (or age) and expressed the annual volume increment as:

$$dV/dt = F*G*(dH/dt) + F*H*(dG/dt) + G*H*(dF/dt) \qquad [3-3]$$

where values of dG/dt, dH/dt, and dF/dt are rates of change for basal area, height, and form factor (approximated by periodic annual increments). The values for G, H, and F were defined as the period mean stand basal area, mean height and mean form factor, respectively by Curtis and Marshall (1986). The G*H*(dF/dt) term generally made only a minor contribution to total volume growth.

These approaches have been used to explain how stands with different amounts of growing stock can produce similar volume growth but different basal area growth, or how thinned and unthinned stands with similar basal area growth can produce quite different volume growth. Although height growth would be expected to be similar between treatments, in stands with rapid height growth, height is being added upon the greater basal area of denser stands and produces more volume growth. This demonstrates the importance of growing stock and height growth, as well as basal area growth, in determining stand volume growth.

Few studies have used these approaches to consider the results of thinning experiments (Curtis and Marshall 1986) or have considered the change in contribution of the components of volume growth over time. The objective of this study is to look at differences in the components of volume growth and their change with time in the repeatedly thinned Hoskins plots.

3.1 Methods

For equation (3-2) the mean stand height was defined as the Lorey's height (height of the tree of mean basal area, H_L) and was calculated at the start and end of the treatment period using quadratic mean diameter and treatment specific height-diameter curves. Average form factor was calculated indirectly using equation (3-1) as:

$$F = V/(G*H_L). \qquad [3\text{-}4]$$

For equation (3-3) the height of the 40-largest diameter trees (HT40) was used for the average stand height and F was calculated using equation (3-4) and HT40 instead of H_L. Mid-period values of G, HT40, and F were calculated as the average of the start and end of the growth period values.

Net growth in basal area and volume was the difference in the trees alive at the start and end of the period. Gross growth included the mortality occurring during the period. Changes in height and form factor were calculated as the difference between the values at the end (gross included trees dying during the period) and start of the period. Periodic changes were used in equations (3-2) and (3-3) used periodic annual increments.

To make comparisons of the periodic values of equation (3-2), each component was divided by the period length to give periodic annual values. Relative contributions of the components of stand volume growth, the seven components of equation (3-2) and the three components of equation (3-3) were compared by expressing each period's components as a percent of the period volume growth. The annual and percent contribution for each component were plotted against mid-period age. Thinning treatments 1 (heavy), 3 (moderately heavy), 5 (moderately light), and 7 (light) and the unthinned control were used to give the greatest range in growing stock. The third treatment was not used in this analysis because of its abnormal growth. Results for net and gross growth is presented only for the control. The small amount of mortality on the treatments make the differences in net and gross growth negligible.

3.2 Results and Discussion

At the start of the calibration period the thinning treatments basal area growing stock was 27 percent of the highly stocked control. Net basal area growth was greatest for the control, which was 22 percent greater than the treatments (Table 3-1). Only a very minor amount of mortality occurred on the treatments during this period, but mortality on the control gave a gross basal area growth of 0.7 ft^2/acre/year greater than net growth (Table 3-1).

Table 3-1: Initial basal area growing stock, net and gross periodic annual basal area increment (PAI), and the growth as a percent of the growing stock for the calibration period (1963-66) and sixth period (1983-88).

Treatment	Basal Area	Net PAI Growth	Net PAI %	Gross PAI Growth	Gross PAI %
	ft^2/acre	ft^2/acre/year		ft^2/acre/year	
		1963 - 1966			
1	49.4	12.1	24.49	12.1	24.49
3	49.1	12.0	24.41	12.0	24.41
5	49.2	12.3	24.91	12.3	25.09
7	50.1	11.9	23.75	11.9	23.57
Control	184.7	15.5	8.39	16.2	8.77
		1983 - 1988			
1	89.1	5.0	5.61	5.0	5.61
3	132.9	6.0	4.52	6.0	4.52
5	175.4	6.4	3.65	6.5	3.71
7	221.1	7.0	3.17	7.5	3.39
Control	295.1	0.2	0.07	7.0	2.37

By the final remeasurement period, basal area per acre had increased on all plots. The heavy and light thinnings had basal area growing stock of 30 and 75 percent of the control, respectively. Basal area growth has decreased in the older, denser stands. Net growth was greatest for the lightest treatment, but only 2 ft^2/acre/year greater than the heaviest thinning which had nearly 2.5 times less basal area at the start of the period. Heavy mortality on the control nearly equalled its growth. Slight mortality occurred on the thinnings where gross growth was similar to the control (Table 3-1).

Cubic foot volume growth showed similar rankings to basal area growth (Table 3-2). In the calibration period, however, the volume growth on the control was 1.7 times greater than the treatments compared to 1.3 for basal area. As with basal area, mortality has decreased net volume growth in the last period. However, where net basal area growth was almost zero, volume growth was nearly equal to the growth for the heavy thinning, which was nearly half the light thinning treatment's growth. Gross volume growth was the same for the heavy thinning and the control.

Table 3-2: Initial basal area growing stock, net and gross periodic annual total cubic foot increment (PAI), and the growth as a percent of the growing stock for the calibration period (1963-66) and sixth period (1983-88).

Treatment	Basal Area	Net PAI Growth	Net PAI %	Gross PAI Growth	Gross PAI %
	ft^2/acre	ft^3/acre/year		ft^3/acre/year	
		1963 - 1966			
1	49.4	278.4	563.6	279.0	564.8
3	49.1	277.5	565.2	278.4	567.0
5	49.2	281.9	573.0	283.3	575.9
7	50.1	274.7	548.3	274.7	548.3
Control	184.7	459.8	248.9	468.7	253.8
		1983 - 1988			
1	89.1	244.9	274.9	244.9	274.9
3	132.9	348.2	262.0	348.2	262.0
5	175.4	391.3	223.1	394.9	225.2
7	221.1	471.5	213.3	492.1	222.6
Control	295.1	249.1	84.4	498.3	168.9

The first three components associated with F in equation (3-2) are the major contributors to volume growth with the remaining four ΔF components contributing only an average of -5.5 percent (although the controls reached values nearly four times this in later periods from the ΔFGH component) (Table 3-3). The percent contribution of the seven components of cubic foot volume growth given by Wiedemann and Evert in equation (3-2) above, are plotted in Figures 3-1 through 3-7 by mid-period age. The percent contribution of the three components given by Hegyi in equation (3-3) above are also plotted by mid-period in Figures 3-8 through 3-10. As with the Wiedemann model, the change in form (dF/dt) component contributed the least (always less than 10 percent and averaged 2 percent) to net cubic foot volume growth (Table 3-3).

Initially during the calibration period, contribution of the two primary components for both models were similar on the control (around 50 percent) reflecting the high density, the resulting high basal area growth rate, and an accumulation of height growth on this larger amount of growing stock. The treatments, however, had a much greater proportion of their contribution in the components associated with basal area growth ($FH\Delta G$ and

Table 3-3: Mean, minimum, and maximum percent contribution of components to net cubic foot volume growth according to Wiedemann (1951) and Hegyi (1969).

	Component	Mean	Minimum	Maximum
	Wiedemann (1951)			
	$\Delta V = FG\Delta H + FH\Delta G + F\Delta G\Delta H + \Delta FGH + \Delta FG\Delta H + \Delta FH\Delta G + \Delta F\Delta G\Delta H$			
1	$FG\Delta H$	35.4	22.2	110.0
2	$FH\Delta G$	58.7	3.6	73.3
3	$F\Delta G\Delta H$	11.4	0.5	19.8
4	ΔFGH	-3.5	1.9	-17.6
5	$\Delta FG\Delta H$	-0.7	0.3	-3.4
6	$\Delta FH\Delta G$	-1.1	0.6	-3.2
7	$\Delta F\Delta G\Delta H$	-0.3	0.1	-1.0
	Hegyi (1969)			
	$dV/dt = FG(dH/dt) + FH(dG/dt) + GH(dF/dt)$			
1	$FG(dH/dt)$	38.2	30.0	101.8
2	$FH(dG/dt)$	63.8	3.8	76.2
3	$GH(dF/dt)$	-2.0	-8.1	9.3

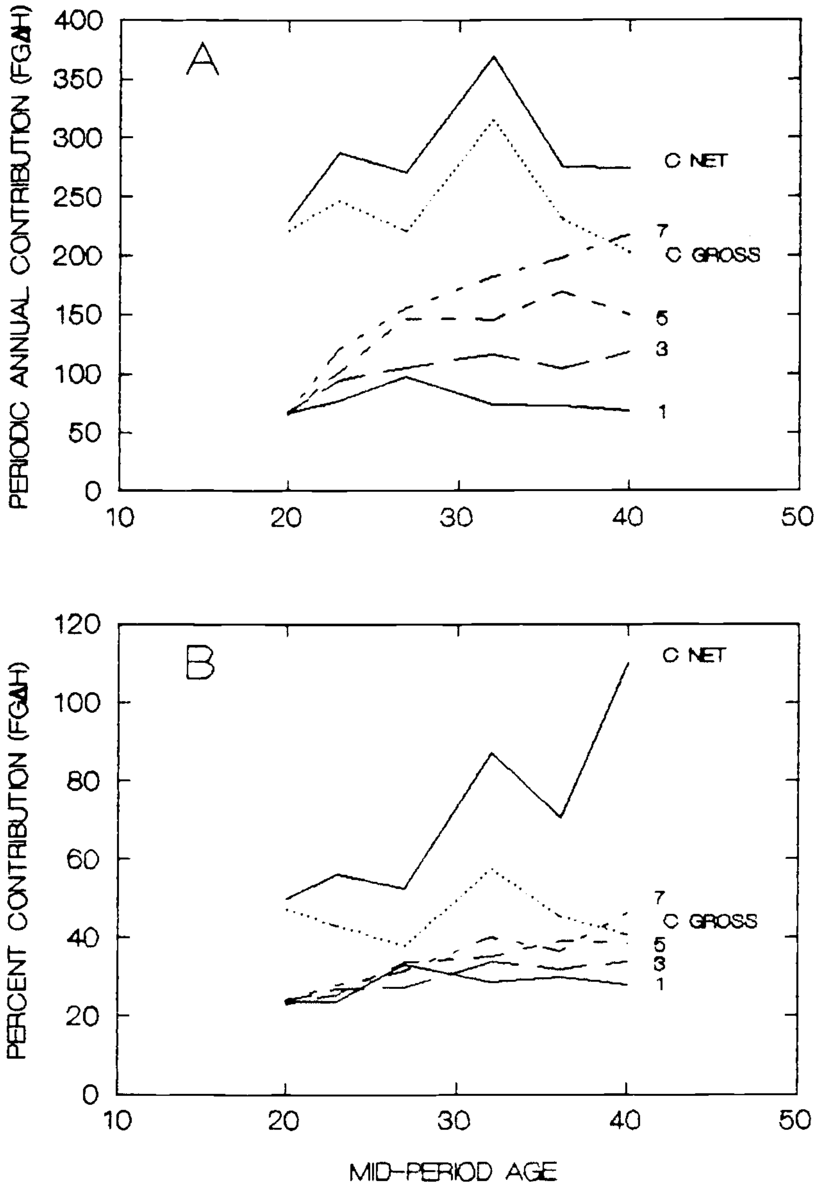


Figure 3-1: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the FGΔH component (Evert 1964).

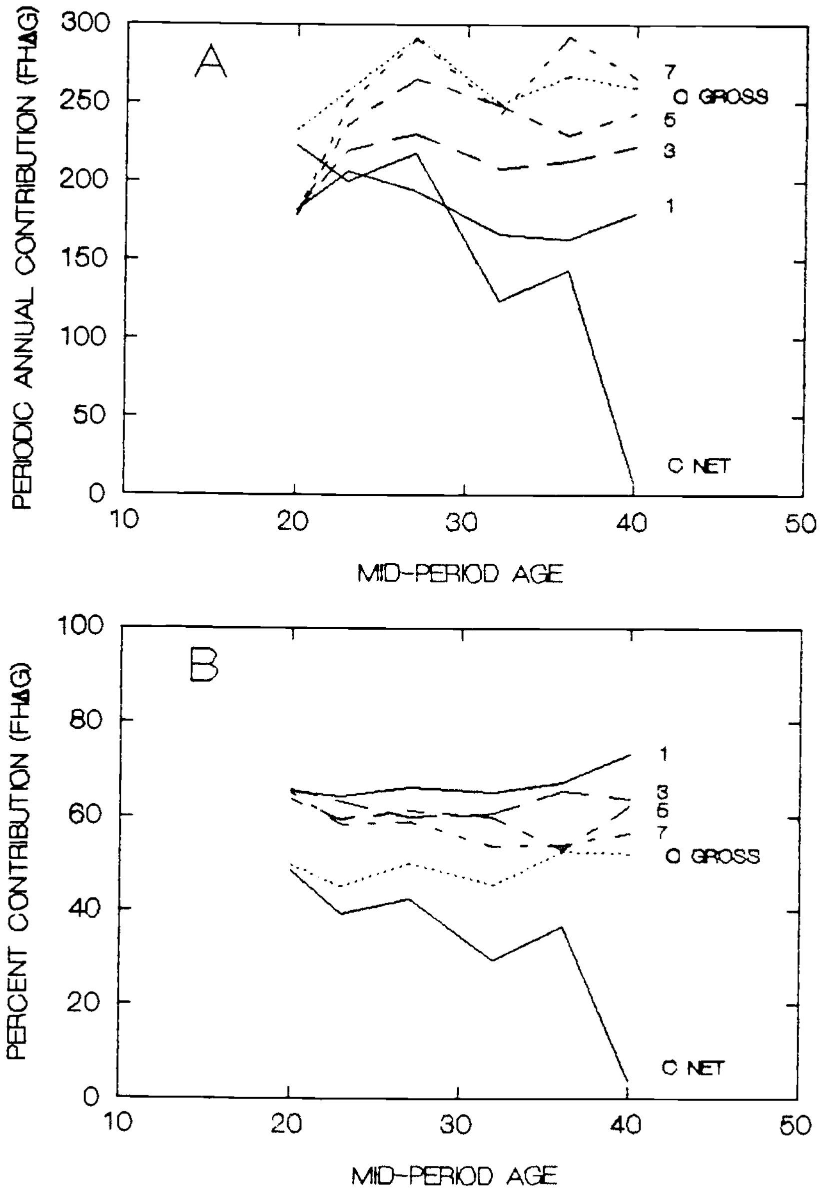


Figure 3-2: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the FHΔG component (Evert 1964).

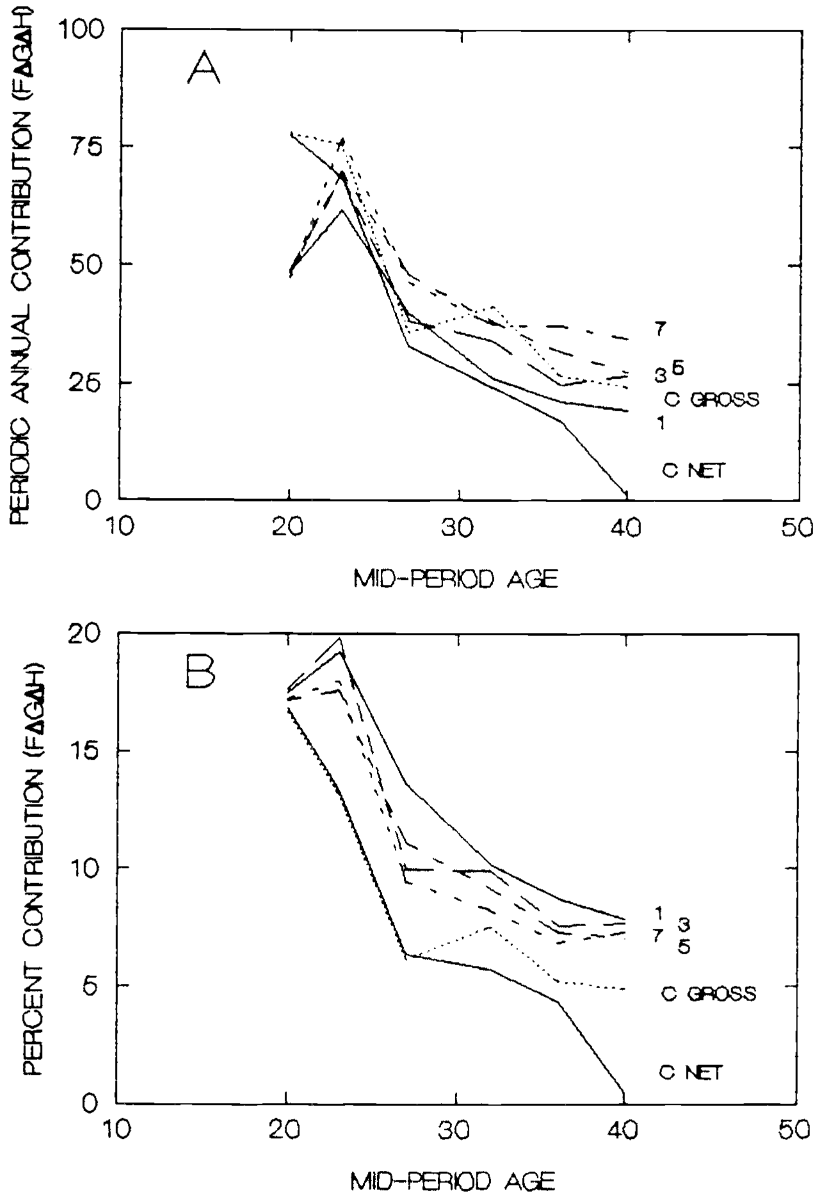


Figure 3-3: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the FΔGΔH component (Evert 1964).

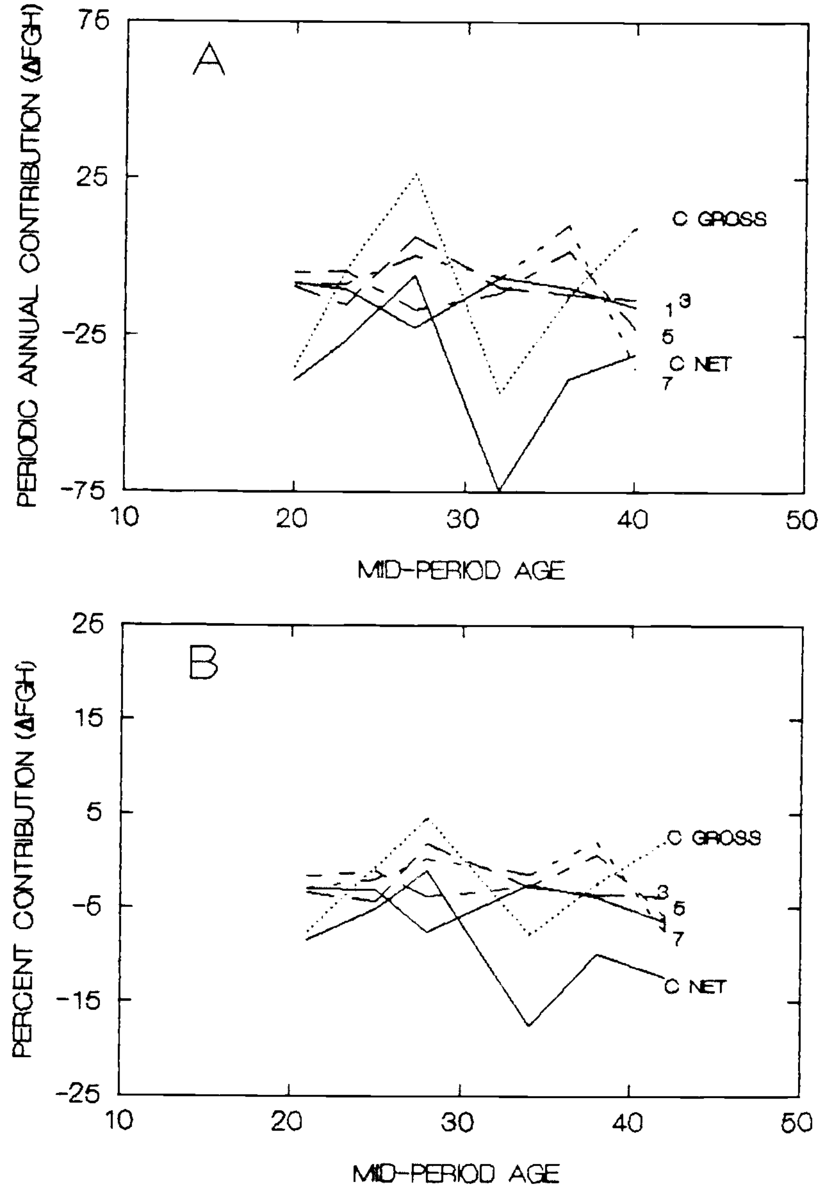


Figure 3-4: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the ΔFGH component (Evert 1964).

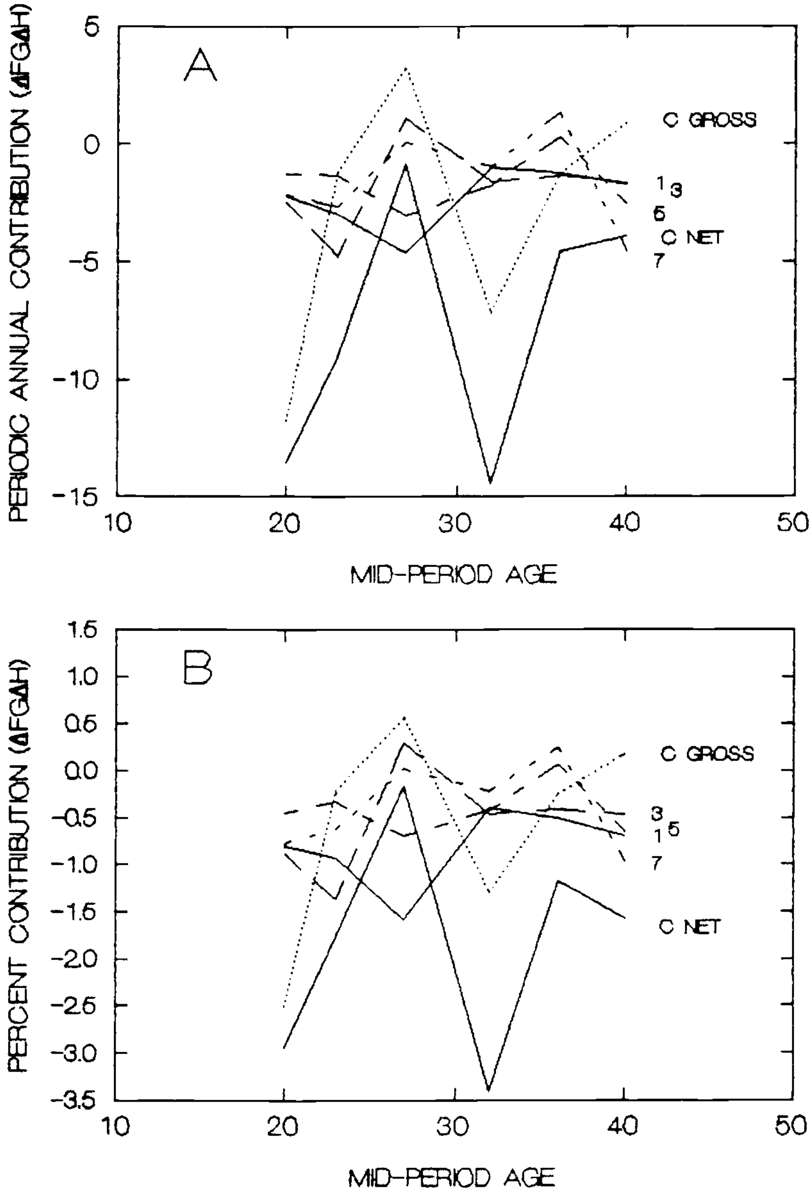


Figure 3-5: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the ΔFGΔH component (Evert 1964).

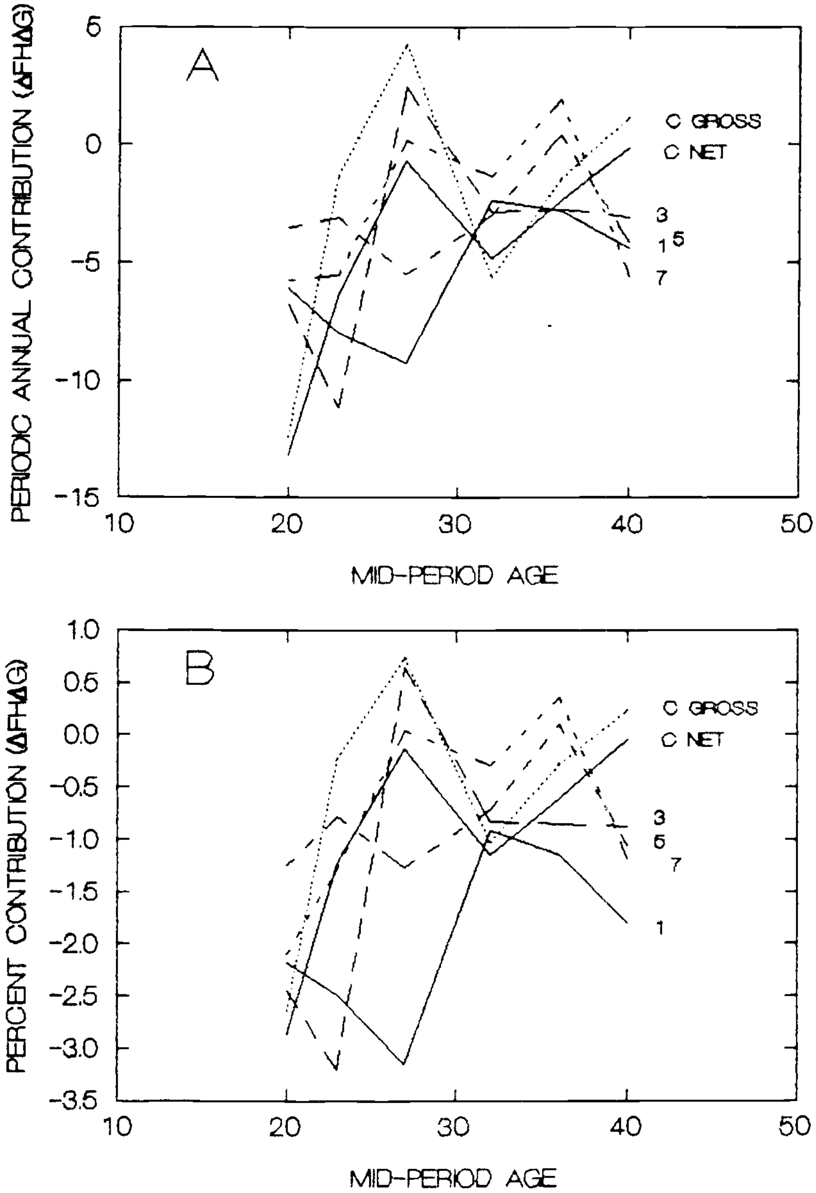


Figure 3-6: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the ΔFHΔG component (Evert 1964).

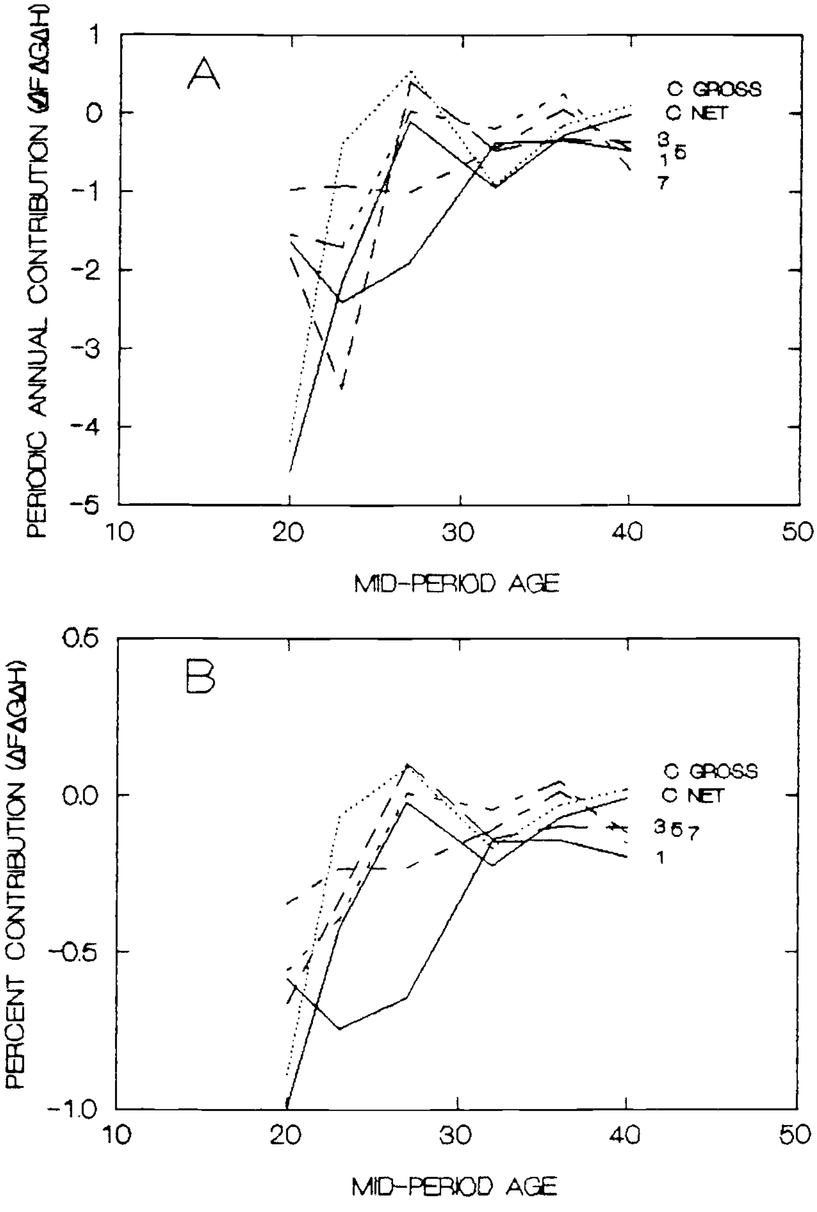


Figure 3-7: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the ΔFΔGΔH component (Evert 1964).

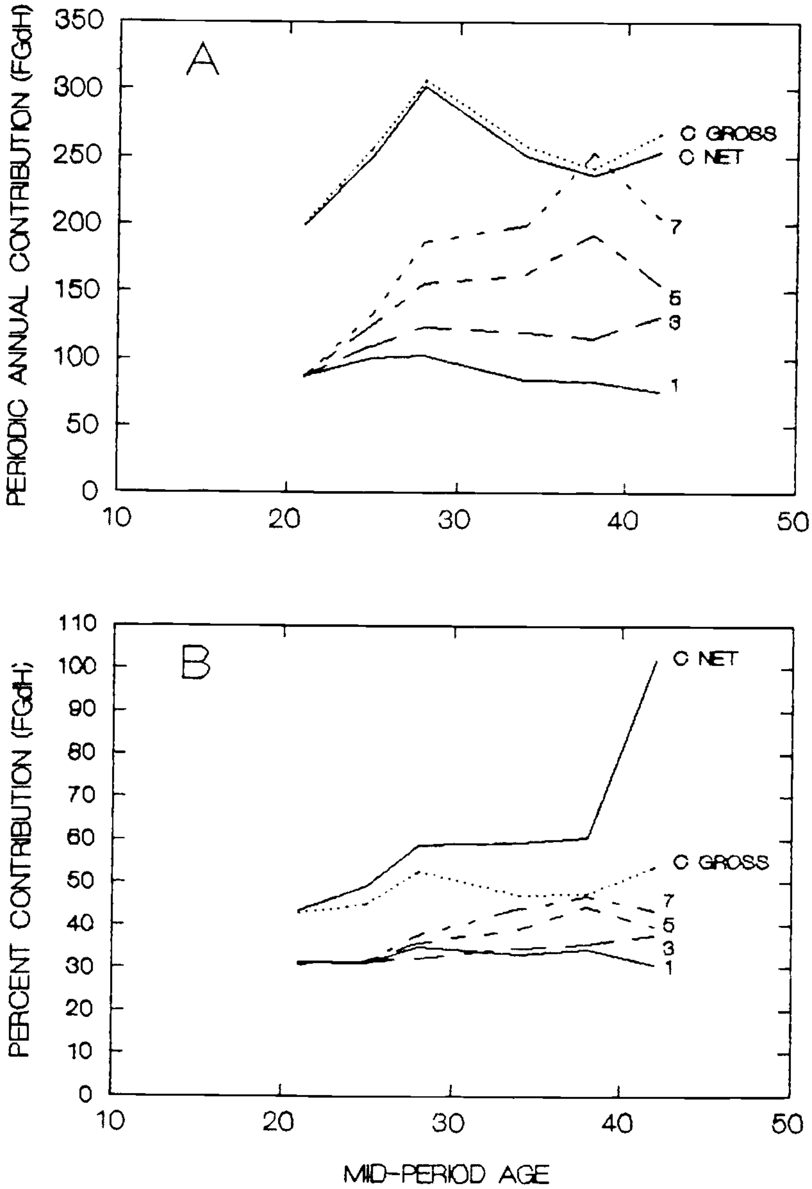


Figure 3-8: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the FG(dH/dt) component (Hegyi 1969).

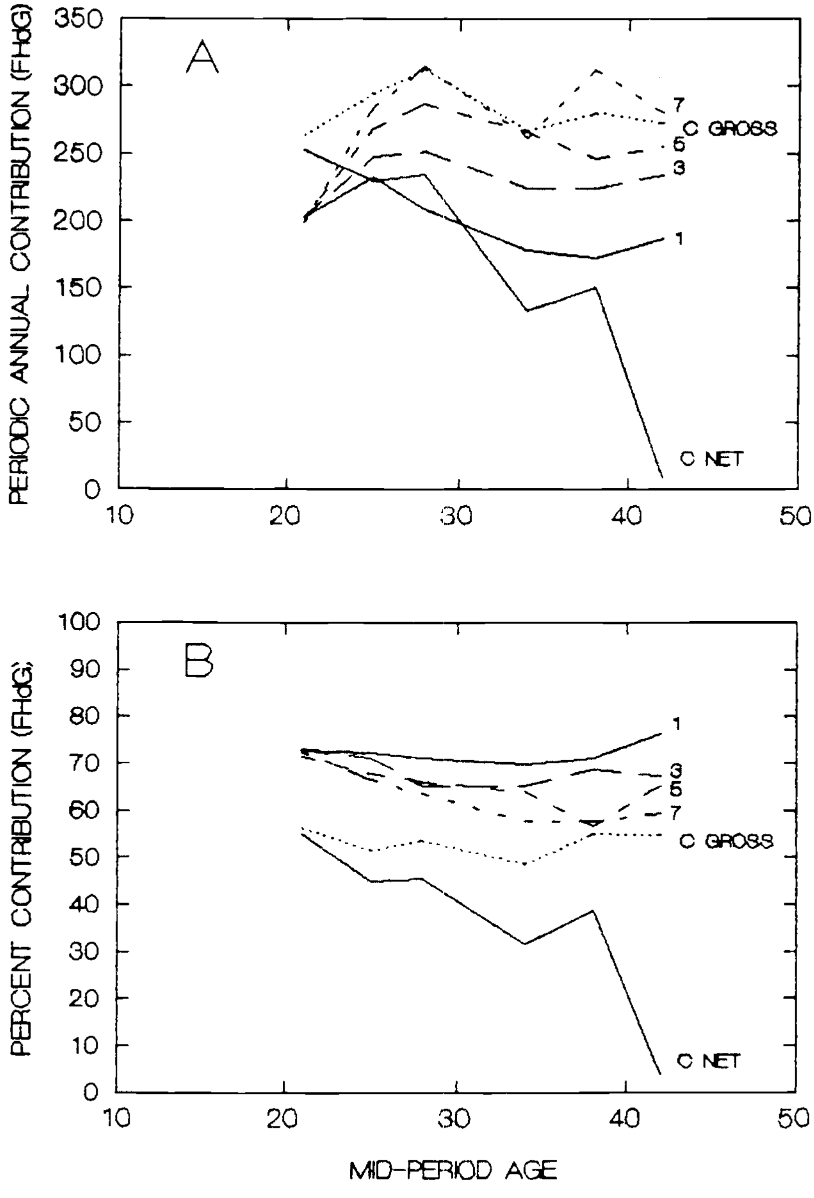


Figure 3-9: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the FH(dG/dt) component (Hegyi 1969).

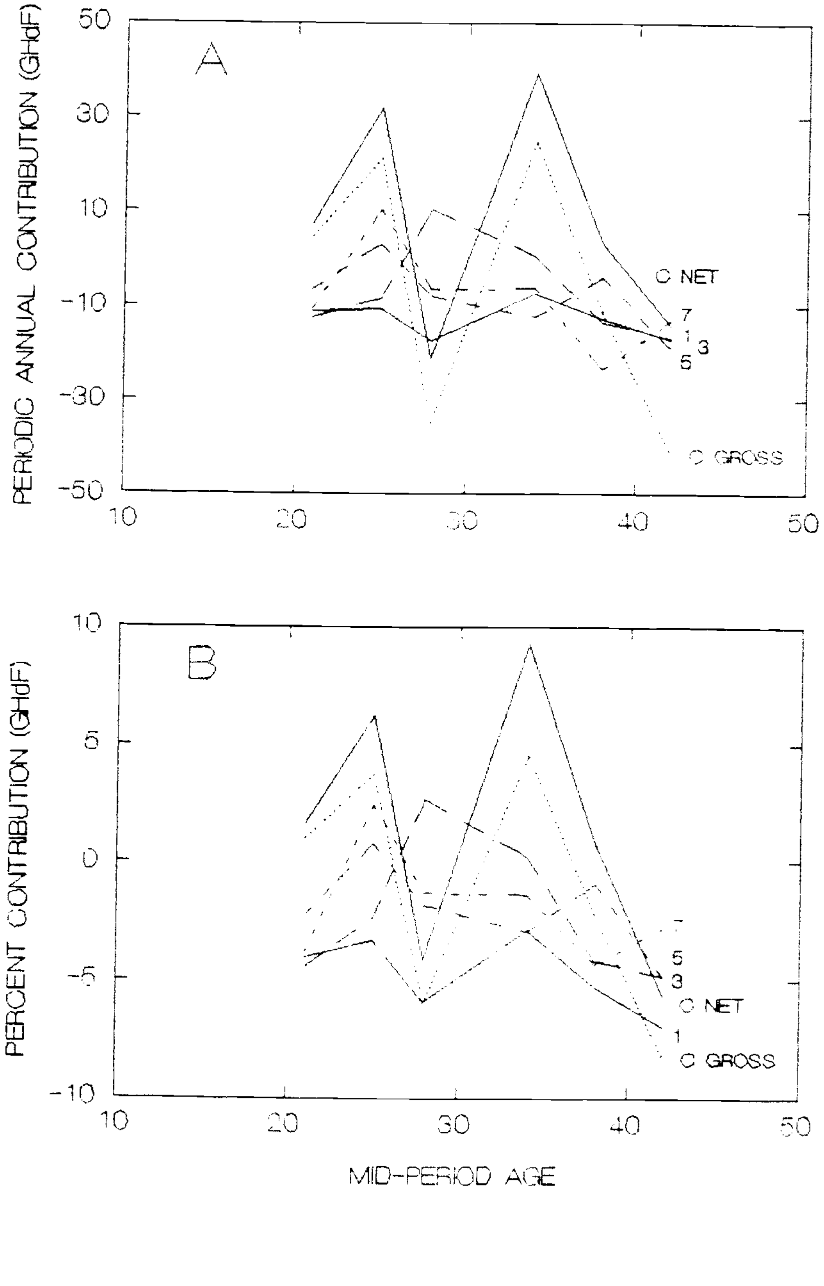


Figure 3-10: Periodic annual (A) and percent (B) contribution to per acre cubic foot volume growth by the GH(dF/dt) component (Hegyi 1969).

FHdG) because of the release effect in basal area growth by the calibration thinning.

As the stands have developed, the relative contributions of the primary components have changed. Decreases in basal area growth on the control from mortality caused decreases in net growth which has become dominated by the FGΔH and FGdH components in equations (3-2) and (3-3), respectively. For the treatments, the FHΔG and FHdG components continue to be the greatest contributors to cubic volume growth with the continued thinning release effects. The proportion of contribution by the FG_H and FGdH components increased as the treatments increased growing stock. Gross growth contribution continues to be similar on the control for the two primary components since the basal area in morality is included in the change in basal area. Because mortality is negligible on the treatments, there is little difference for net growth.

The measures of stand height used were the height of the tree of mean basal area (Lorey height) for equation (3-2) and the height of the 40-largest diameter trees for equation (3-3). While both measures of height are affected by differences in height-diameter curves between treatments, the Lorey height is more influenced by mortality and thinnings. Beginning of the period Lorey height (for the control and average of the treatments) and the HT40 are compared to site tree heights for a King's (1966) site 134 in Figure 3-11a. As is shown in Figure 3-11b, the average annual change for all measures of height growth have reached a maximum and is decreasing, causing a decrease the contribution of components that include height growth.

Change in average stand form factor was highly variable because it was indirectly calculated. Initial form factors based on Lorey height were 0.432 for the treatments and 0.485 for the control ($p<0.001$). Based on HT40 the average form factor was not different between the treatments and the control ($p>0.5$) and averaged 0.712. The periodic annual change in form factor was primarily negative, with average stand form becoming more conic, and decreased with age. Due to the variability, however, there were no consistent differences between treatments or the control by period in form factor change (Figure 3-12).

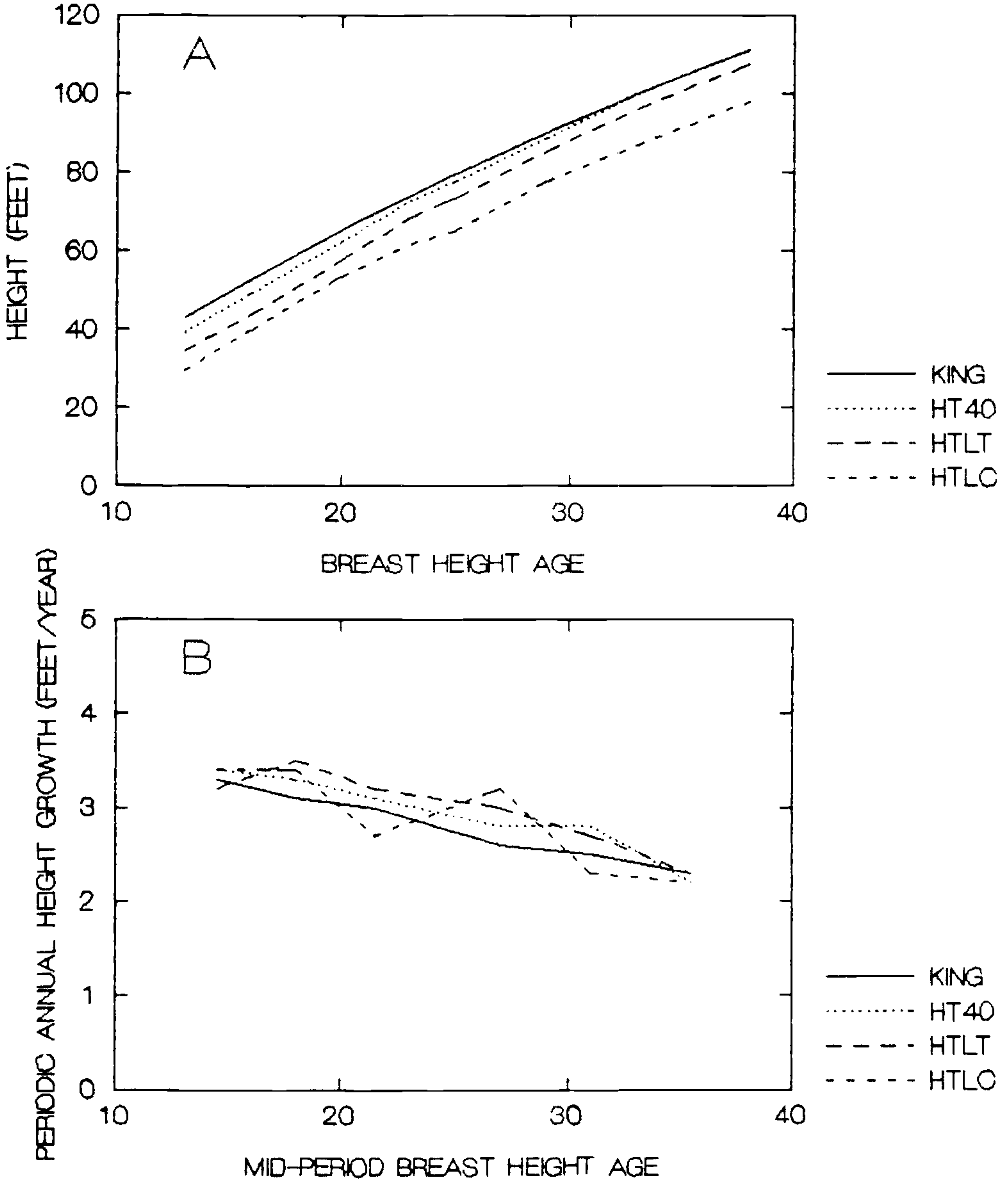


Figure 3-11: Height growth (A) and height growth rates (B) for King (1966) site 134, height of the 40-largest diameter trees (HT40) and the average Lorey height for the treatments (HTLT) and the control (HTLC).

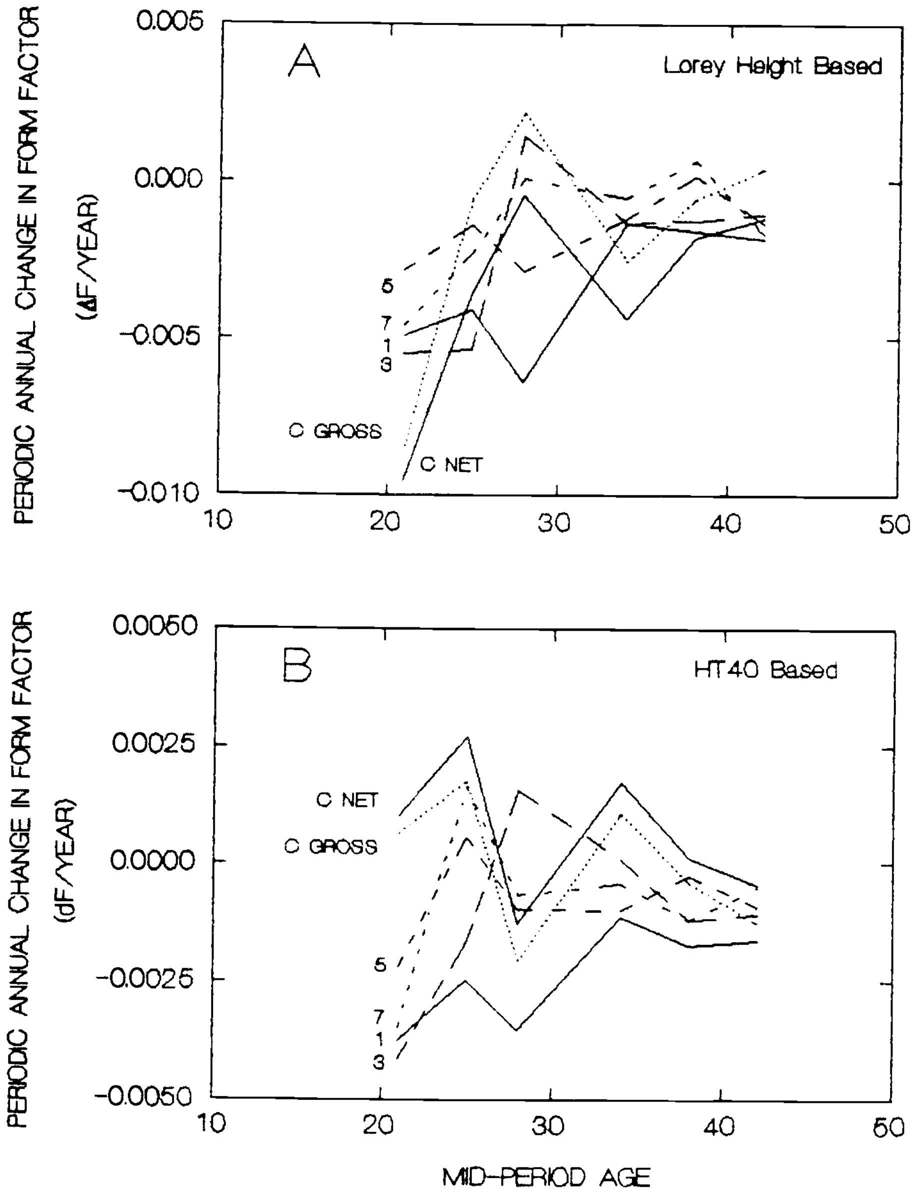


Figure 3-12: Periodic annual change in stand form factor indirectly calculated from stand cubic foot volume, basal area and height by age. The average stand height used was (A) Lorey height and (B) the height of the 40 largest diameter trees.

3.3 Conclusions

This analysis used two models to look at the components of stand volume growth and their change over time in four thinning treatments and unthinned control on a high site. Height growth, basal area and basal area growth, and to a much lesser extent change in form factor, all contribute to volume growth. Considering only one of these factors will not necessarily give an accurate assessment of volume growth.

In this young, high site stand, the amount of growing stock, the response in basal area growth to thinning and the height growth all changed with time and were reflected in volume growth and its components. While basal area growth has not developed a strong relationship with growing stock, volume growth has. The relationship of increasing gross volume growth with increasing growing stock is due to the large amount of height growth being added to greater basal area in the denser treatments and control.

As this stand ages, height growth is expected to continue to decrease. The change in stand form factor, while only a small contributor to volume growth, may also decrease. This will cause components with basal area growth to become more important in determining volume growth and the potential to develop a Langsaeter (1941) plateau should increase. Mortality will decrease the importance of basal area growth on the control and lighter thinning treatments as basal area growing stock accumulates. Net growth will be driven more by basal area and height growth. This should cause more of a peak in the volume growth to growing stock relationship as long as height growth is strong.

To get a more complete understanding of the dynamics of stand volume growth, this analysis should be done for thinning trials on different sites, in older stands, and for different thinning regimes.

Chapter 4

Effects of Thinning on Stem Form

In the previous chapters, the thinning response of Douglas-fir in basal area and volume growth was discussed. Diameter growth at breast height (DBH) consistently showed large responses (the 25-year survivor diameter growth on the heaviest thinning has been over 3.5 times greater than the control) whereas total tree height (HT) has been little affected by thinning. This implies that trees in thinned stands will have greater taper (i.e. greater DBH/HT ratio).

Most thinning studies are ultimately interested in volume. One important aspect of volume and volume growth is tree shape, which is often overlooked. Sole consideration of only diameter at breast height and height could give misleading results if tree form is influenced by treatments. Reukema (1971) suggested that small form changes can have substantial effects on estimated volume. Stem form is also important in determining tree quality and resistance of stems to wind and snow breakage. Tall and slender trees will generally contain a greater percentage of recoverable, higher quality wood but will be more susceptible to breakage (Smith and Reukema 1986).

Data on tree volume and taper from thinning studies, like the Hoskins Levels-of-Growing-Stock Study, usually represent the types of trees removed from treated plots. This causes several limitations including: (1) most data is from lower crown classes or poorer formed trees, (2) too few trees are cut at from each treatment for comparisons, and (3) the range of densities is limited with little data from high densities and no data from unthinned controls. The objective of this study is to consider the effects of levels of growing stock on tree taper in a young Douglas-fir stand after repeated thinnings over a 20 year period beginning at stand age 20. Taper and volume differences for the range of densities will be described and quantified for a hypothesized decrease in taper with increasing density.

4.1 Methods

4.1.1 Data Collection

Chapter 1 described the Hoskins LOGS study design and treatments. The fixed percentage treatments 1, 3, 5, and 7 and the controls were used in this study. The initial (1963) and the last (1983) remeasurement stand summaries are given in Table 4-1. The calibration cut in 1962 reduced the numbers of trees on the treatments by nearly 80 percent of the control. By 1983, the five treatment thinnings had further reduced the numbers of trees on the treatments by 15 to 70 percent of the after calibration numbers of trees and the diameter of the heaviest thinning (treatment 1) was nearly twice the control. The average live crown ratio was nearly 50 percent for the trees on the treated plots compared to 30 percent for the control trees.

Because the study is on-going and trees could not be destructively sampled, an optical dendrometer was used. In the winter of 1985, upper stem diameters of 78 trees in the 42 year-old stand were measured with a Barr and Stroud optical dendrometer Type FP 12 (Groman 1970). A minimum of 5 trees (15 per treatment) were measured on each plot. Trees selected for measurement represented

Table 4-1: Per acre treatment summary statistics after the 1963 calibration thinning (stand age 20) and after the 1983 remeasurement (stand age 40).

	1963			1983		
Trt	No. trees	Basal area	Quadratic mean DBH	No. trees	Basal area	Quadratic mean DBH
	no.	sq.ft.	in.	no.	sq.ft.	in.
1	353	49.4	5.1	52	89.1	17.8
3	343	49.0	5.1	102	132.9	15.5
5	365	49.2	5.0	165	175.4	14.0
7	328	50.1	5.3	223	221.1	13.5
C	1727	138.1	3.8	653	295.1	9.1

the smallest and largest diameter tree on a plot. Three additional trees covering this range also were measured. Selected trees were to be of good form and have no noticeable breaks or forks, thus often eliminating the smallest and largest trees. Because there were no buffer strips, trees near plot edges between very different density treatments were not used. In some treatments, understory vegetation or dense overstory crowns made stem visibility along the lower bole or within the crown a factor in tree selection. The diameter, height and crown characteristics of the sampled trees are summarized in Table 4-2.

For each selected tree, diameters at and below the 4.5 feet mark were measured to the nearest 0.1 inch with a diameter tape at 1.0-foot intervals. A 30-foot collapsible leveling rod was used to take sightings at the 16.5 foot reference height following the methods of Groman (1970). The pole also aided in locating the 10.5, 24.5 and 32.5 foot points for lower stem measurements. Additional sightings were taken along the bole at roughly 8-foot intervals up to the crown base. A sighting was taken at crown base (judged by the point at which there was live crown in three quarters of the stem) and whenever possible, within the crown. Total height was

Table 4-2: Summary of Hoskins 1985 dendrometer data.

Trt	obs	Diameter at breast height mean	min	max	Total height mean	min	max
		---- inches ----			------ feet ------		
1	15	19.2	15.5	23.4	102.3	89.8	119.4
3	15	16.2	9.9	21.2	100.4	82.6	109.2
5	16	14.0	6.8	20.3	95.9	70.0	114.9
7	16	13.3	7.4	19.4	99.2	70.7	110.5
C	16	10.6	6.0	16.7	93.1	75.7	112.8

Trt	obs	Height to live crown mean	min	max	Live crown ratio mean	min	max
		----- feet -----			------ pct -----		
1	15	40.8	30.4	49.8	60.2	52.8	68.2
3	15	46.2	39.7	56.7	53.8	44.3	60.9
5	16	55.9	42.1	69.2	40.5	12.3	58.6
7	16	60.7	53.2	68.8	38.2	19.5	48.0
C	16	65.5	60.8	74.8	29.9	17.6	44.2

measured with a clinometer attached to the dendrometer (Groman 1970).

The manufacturer's instructions (Barr and Stroud, undated) claimed an "uncertainty of observation" for "a good observer under average practical conditions" of 0.1 inch for diameters between 1.5 and 10.0 inches and 1 percent between 10 and 200 inches. Accuracy of height measurements was 1.5 percent at vertical angles greater than 10 degrees. A study by Bell and Groman (1971) compared actual diameters and heights with those measured by the dendrometer under normal sighting conditions in a typical Douglas-fir stand. The data confirmed that most diameter and height values fall within the allowances claimed by the manufacturer.

4.1.2 Analysis

Initially, three measures of stem form were considered:

1. DBH/HT ratio
2. Form quotient (FQ = $dob_{16.5}$/DBH)
3. Cylindrical form factor (CFF = V/(BA*HT)).

To avoid bark thickness problems, diameter outside bark at 16.5 feet ($dob_{16.5}$) was used to calculate FQ. The CFF is the ratio of the outside bark total stem cubic foot volume (V) to the volume of a cylinder with the same height (HT) and basal area (BA) in square feet ($0.005454154*DBH^2$) at DBH (Hush et al. 1982 (p.108)). Total stem volume was calculated by summing the volume of each measured section in a tree. Section volume was calculated using diameters outside bark (at both ends), section length and assuming geometric solids (Bell and Dilworth 1988). Bole sections, less than 20 percent of total height, were assumed to be frustrums of a neiloid and the subneiloid formula was used. The equation for a cone and cylinder were used for the top section and stump, respectively. All other sections were assumed to be frustrums of a parabaloid and the smalian formula was used.

An analysis of variance was used to look at differences in dob relative to DBH at heights (h) measured in common on all trees (fixed heights) and for 10 percent relative height (h/HT) classes for each treatment. Two contrasts tested differences between the treatments and the control and for hypothesized linear trends among the four treatments. A linear relationship was tested because treatments 1, 3, 5, and 7 increased growing stock at 10, 30 , 50, and 70 percent.

Actual taper and volume differences were quantified by using an independent and published taper equation. Differences between the predictions of diameter inside bark (dib) from the published equation and the diameter outside bark (dob) measured on the dendrometer trees was modelled. The taper model (Czaplewski et al. 1989) included Douglas-fir data from Oregon and Washington. The model was a segmented polynomial (Max and Burkhart 1976) that used quadratic submodels to describe the lower and upper bole and a linear submodel for the middle section of the tree, each grafted at join points.

$$dib = DBH*(-2.8758*(Z-1) + 1.3458*(Z^2-1) - 1.6264*(k_1-Z)^2*I_1 + 20.1315*(k_2-Z)^2*I_2)^{1/2} \quad [4\text{-}1]$$

where

dib = the predicted diameter inside bark (inches) at height h,

h = height at the point of upper stem diameter prediction (feet),

Z = h/HT,

I_1 = 1, if $Z < k_1$; 0, otherwise,

I_2 = 1, if $Z < k_2$; 0, otherwise,

and k_1 and k_2 are the join points, 0.72 and 0.12 respectively. The model is conditioned to give dib=0 at the tree top, continuous at the join points, and to have continuous first partial derivatives with respect to Z at the join points.

Using the approach of Czaplewski et al. (1989), the calibration modelled [(dob - dib)/dib] as a function of measured tree variables. To estimate volume inside bark, dib was estimated using the model of Cao and Pepper (1986) which was fit to 3175 observations on 232 trees felled as part of the five treatment thinnings:

$$dib/dob = 0.89056 + 0.21098*Z - 0.26949*Z^2 + 0.00030*HT \quad [4-2]$$

$$(R^2 = 0.601,\ S^2 = 0.000238)$$

The DBH range was from 2.4 to 18.9 inches and measurements for double bark thickness and outside bark diameter were taken at 4-foot intervals starting at a 0.5-foot stump.

The fit of the overall taper model was evaluated using the mean difference (MD) as a measure of bias and the mean square error (MSE) as a measure of prediction:

$$MD = \Sigma(dob - dob)/n \quad [4-3]$$

and

$$MSE = [\Sigma(dob - dob)^2/n]^{1/2}. \quad [4-4]$$

4.2 Results

The DBH/HT ratios of the treatments were different from the control ($p=0.032$). Multiple comparisons using Fisher's LSD method (Milliken and Johnson 1984) suggested that treatments 5 and 7 did not differ. The ratio also increases with tree size (DBH) and for trees with longer crown (Table 4-3). There was no significant difference in outside bark 16.5-foot form quotient by treatment or by crown ratio class. Trees in the class less than 10 inches, however, had a signifiacntly greater form quotient than the larger diameter classes which showed no consistant differences (Table 4-3). The cylindrical form factor of the control was significantly greater than the treatments ($p=0.002$), although the treatments were not different (Table 4-3). On the average, the treated trees have greater taper than the controls whereas trees of the same DBH and HT on control plots have greater volume and a more cylindrical form. Cylindrical form factor for the smallest diameter class was greater, while the classes above 10 inches were not different. By crown ratio, however, CCF decreased with longer crowns (Table 4-3).

Table 4-3: Summary of DBH/HT ratio, form quotient ($FQ = dob_{16.5}$ / DBH) and outside bark cylindrical form factor (CFF) for the dendrometer sample trees by treatment, diameter classes, and crown classes. Values followed by the same letter were not different using Fisher's LSD (95 percent).

Trt	Number obs.	DBH/HT	FQ	CFF
1	15	0.188a	0.904	0.472a
3	15	0.161b	0.903	0.467a
5	16	0.143c	0.898	0.479a
7	16	0.132c	0.903	0.479a
C	16	0.112d	0.900	0.505b

Diameter Class	Number Obs. Trt.	Cont.	DBH/HT	FQ	CFF
inches					
6.0- 9.9	9	9	0.098a	0.922a	0.521a
10.0-13.9	3	9	0.126b	0.878b	0.472b
14.0-17.9	4	25	0.156c	0.901c	0.472b
18.0+	0	19	0.191d	0.898c	0.458b

Crown Class	Number Obs. Trt.	Cont.	DBH/HT	FQ	CFF
%					
10-29	7	4	0.096a	0.912	0.513a
30-49	9	30	0.136b	0.899	0.482b
50-69	0	28	0.179c	0.901	0.464c

The treatments and control are not well represented in all of the diameter and crown ratio classes. The smallest diameter and crown ratio classes contain mostly trees from the control and lightest thinning while the heaviest thinnings fill the largest classes. However, comparint the treatments and control, only the 10 to 30 percent crown ratio class had any significant differences, where DBH/HT ($p=0.2$, treatment=0.109 and control=0.088) and CCF ($p=0.05$, treatment=0.486 and control=0.529) where significantly different (Table 4-3).

Relative diameter was only significant ($p<0.05$) for relative height classes between 55 and 75 percent (Table 4-4). Contrasts for testing the treatments versus the control were significant for these classes; however, the four treatments were not significantly different, assuming a linear contrast (Table 4-4). No differences were significant in the lower portion of the stem ($P>0.7$ below 35 percent of total height).

Table 4-4: Analysis of variance summary of dendrometer data for dob/DBH.

	Number of observations					ANOVA			Treatment Means					Contrasts (P-values)	
	1	3	5	7	C	DF	MSE	P	1	3	5	7	C	TrxC	Tr(Lin)
Fixed heights															
0.5 ft	6	10	13	13	14	51	0.00956	0.277	1.355	1.308	1.371	1.400	1.351	0.807	0.196
1.5 ft	15	15	16	16	16	73	0.00347	0.397	1.175	1.142	1.151	1.167	1.141	0.281	0.831
2.5 ft	15	15	16	16	16	73	0.00060	0.554	1.073	1.062	1.064	1.073	1.065	0.631	0.915
3.5 ft	15	15	16	16	16	73	0.00023	0.310	1.030	1.023	1.024	1.027	1.033	0.096	0.591
4.5 ft									1.000	1.000	1.000	1.000	1.000		
9-12 ft	15	15	15	16	16	72	0.00088	0.922	0.929	0.938	0.934	0.936	0.936	0.819	0.584
16.5 ft	15	15	16	16	16	73	0.00104	0.988	0.904	0.903	0.898	0.903	0.900	0.877	0.860
Relative heights															
5%	78	79	84	84	84	404	0.01875	0.775	1.095	1.094	1.105	1.118	1.109	0.710	0.234
15%	23	25	24	26	25	118	0.00129	0.965	0.909	0.915	0.913	0.917	0.915	0.837	0.522
25%	21	17	19	19	18	89	0.00155	0.947	0.853	0.852	0.857	0.847	0.855	0.789	0.704
35%	19	17	20	19	19	89	0.00195	0.374	0.783	0.794	0.790	0.784	0.809	0.063	0.972
45%	17	20	16	18	15	81	0.00187	0.551	0.723	0.718	0.721	0.715	0.739	0.109	0.622
55%	12	12	17	14	17	67	0.00261	0.048	0.628	0.622	0.634	0.627	0.672	0.003	0.866
65%	14	11	15	13	20	68	0.00328	0.003	0.523	0.489	0.517	0.559	0.566	0.004	0.061
75%	16	10	10	15	13	59	0.00368	0.004	0.393	0.364	0.381	0.428	0.454	0.002	0.093
85%	6	6	10	8	10	35	0.00472	0.266	0.254	0.301	0.268	0.298	0.325	0.088	0.409
95%	1	6	3	1	3										

(1) Contrasts: TrxC = Treatments versus Control
Tr(lin) = Linear among treatments

(2) P is the probability of a larger F statistic, given the null hypothesis of no difference among means is true.

The calibration model for the regional taper equation (4-1) is:

$$\begin{aligned}(dob - dib)/dib = {} & 0.23101 - 0.00747*h \\ & + 0.000259*h^2 \\ & + 0.000058*h^2*I \\ & - 0.000002125*h^3 \\ & + 0.00000043*h^3*I \qquad [4\text{-}5]\end{aligned}$$

where I=1 if plot is treatment and 0 if it is a control. The $R^2 = 0.292$ and $s^2 = 0.0085$ with all parameters significant at the $p<0.02$. The MD and MSE trends over relative height are shown in Figure 4-1.

Figure 4-2 showed the predicted dib stem profiles for 10 and 15-inch trees representing the range of the data set (20 inch and larger trees were only sampled on the heaviest thinning). Given the same DBH and HT, the outside bark total stem volumes are 6.9 and 7.9 percent greater for the 10 and 15-inch trees respectively if they were on the control plots. The trees in control plots also had longer merchantable stem lengths (to a 6-inch dob) (Table 4-5).

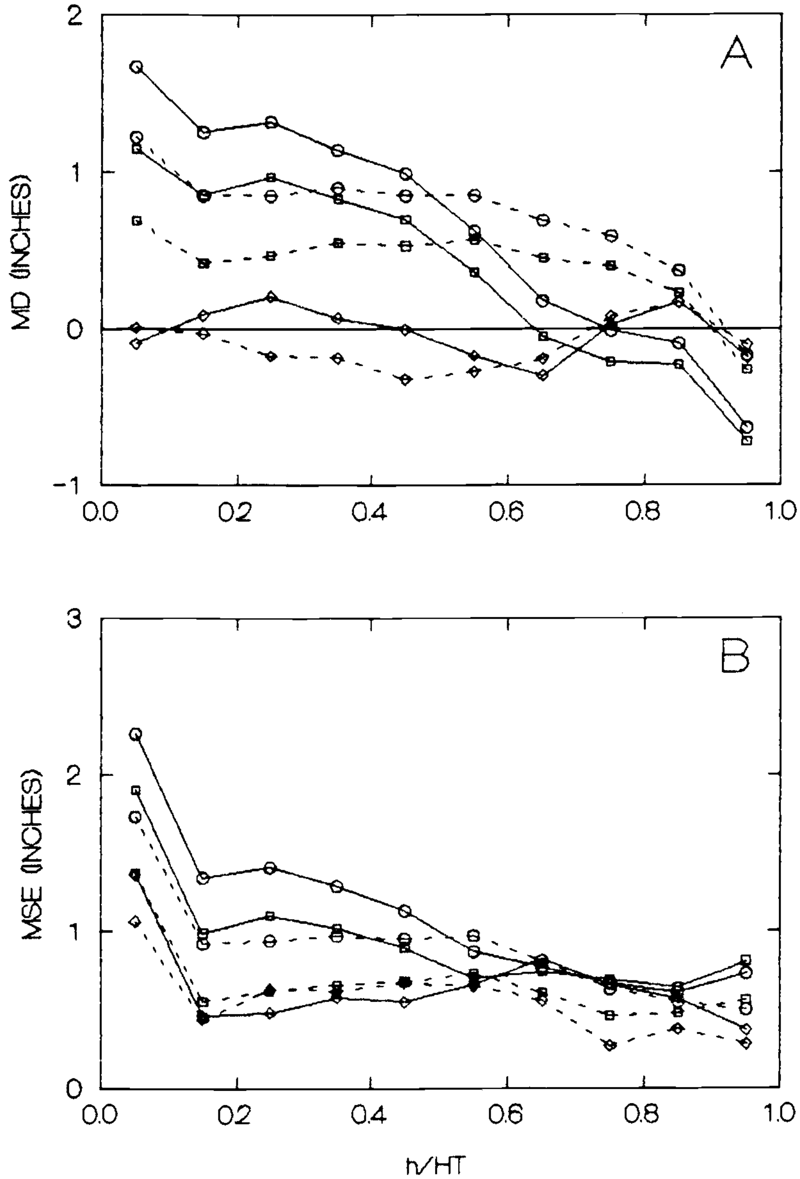


Figure 4-1: Bias (MD) (A) and error (MSE) (B) of diameter inside bark predictions (inches) in controls (- - -) and treatments (——) for regional taper equation with (o) and without (□) published bias correction and with "local" correction (◊).

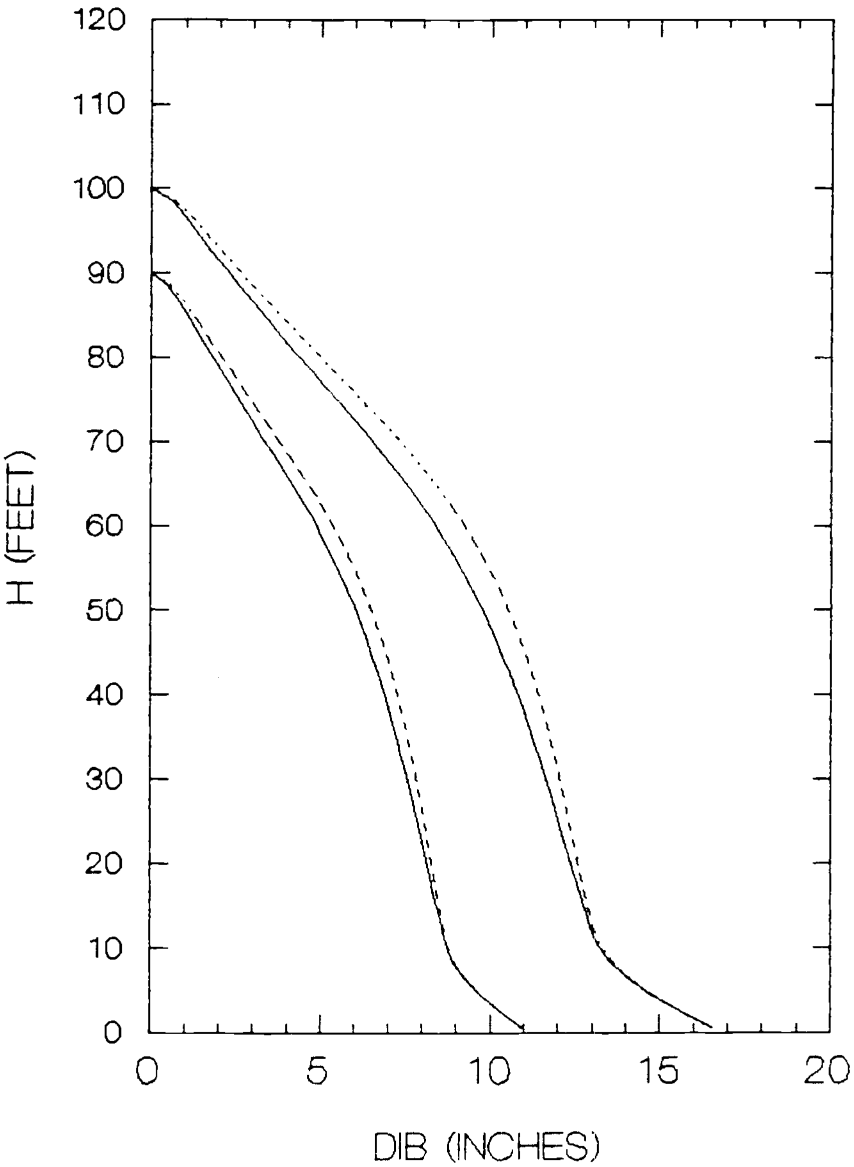


Figure 4-2: Predicted taper of representative 10 and 15 inch trees in the controls (- - -) and treatments (———).

Table 4-5: Comparisons of estimated volume and taper differences for representative 10 and 15 inch sample trees.

DBH (inches)	10.0	15.0
HT (feet)	90.0	100.0
Total stem (outside bark) volume (cubic feet)		
Control	24.78	62.09
Treatment	23.08	57.21
% of Control	-6.9	-7.9
Height to a 6-inch dob (feet)		
Control	57.7	77.7
Treatments	53.2	74.4
% of Control	-7.8	-4.2
Total stem (inside bark) volume (cubic foot)		
Bruce/DeMars	20.60	48.01
Control	22.53	53.62
Treatment	20.53	51.21
Local[1/]	21.76	52.05
Local[2/]	22.12	50.71

1/ Total stem cubic foot volume from 78 dendrometer trees:
$$\ln(VOL) = -5.89925 + 1.88283*\ln(DBH) + 1.03203*\ln(HT)$$
$$R^2 = 0.994 \quad s^2 = 0.0039.$$

2/ Total stem cubic foot volume from 232 felled trees:
$$\ln(VOL) = -6.23592 + 1.73762*\ln(DBH) + 1.18484*\ln(HT)$$
$$R^2 = 0.996 \quad s^2 = 0.0032.$$

The inside bark volumes calculated from the taper model are larger than the widely used Bruce and DeMars (1972) volume equation for second growth Douglas-fir (Table 4-5). As a check, volume equations were fitted to the 78 dendrometer trees adjusted to inside bark and also to the 232 felled trees. Predicted volumes for both equations were close to those for the taper model and also greater than the Bruce-DeMars equation. All volumes were larger than the Bruce and DeMars equation which is used to analyze the LOGS studies (Curtis and Marshall 1986).

4.3 Discussion

Yerkes (1960) reported that in a 41-year-old Douglas-fir stand, 9 years after release, no difference could be found in form class in felled dominant and codominant trees, although unreleased trees were more cylindrical in form and the released trees grew faster along the lower stem and slower in the upper stem. Using a dendrometer, Groman and Berg (1971) found differences in growth patterns in a thinned and unthinned 55-year-old Douglas-fir stand. For trees of the same DBH, HT and crown class, they found that trees in thinned stands had more consistent diameter increment along the bole while trees in unthinned stands and trees in the lower crown classes had the greatest growth on their upper stem.

Studies of thinning in older stands have shown less growth response. By entering a stand that is younger, growth responses to density control are greater. By thinning earlier and carrying lower densities for the length of a rotation, greater differences also may be found in tree form. Using form quotients along the stem, Barclay and Brix (1985) found increased taper in trees 12 years after thinning in young Douglas-fir. Thomson and Barclay (1984), looking at the same study, found differences in the distribution of growth along the bole at an earlier age. They observed that the average stem growth was near the base of the live crown with lower than average growth above this point and greater than average growth below (ie. greatest taper within the crowns). They also found increased butt swell in smaller trees which decreased with time.

Many studies (Gray 1956, Larson 1963, and Assmann 1970) have discussed the mechanical and physiological theories of stem form and their relationship to crown structure and resulting distribution of growth along the stem. Because crown is affected by density, some researchers have attempted to incorporate crown information into volume (Farrar 1985, Walters et. al. 1985) and taper (Burkhart and Walton 1985, Walters and Hann 1986) equations. Taper equations for Douglas-fir in southwest Oregon using crown ratio (Walters and Hann 1986), predict 4.5 and 4.1 percent greater volume in the control for the 10 and 15 inch sample trees, respectively; (assuming an average of 30 and 50 percent crown ratios for the control and treated plots respectively) (Table 4-5).

The DBH/HT ratio decreased with increasing stand density, producing very tall, slender trees in the control. If thinned now, these trees would be unstable and less resistance to breakage than the thinned stands. It was somewhat surprising to find no significant differences in the ratio of DBH to stump diameter. More buttressing for greater tree stability was expected for the heavier thinnings. Form quotient detects only form changes in the lower bole, in this case between DBH and 16.5 feet where no differences among the treatments or the control were detected. Only the trees in the smallest diameter class showed a larger form quotient. The cylindrical form factor showed that the trees form the control and the smallest diameter class were more cylindrical in form. Cylindrical form factor increased as crown ratio decreased. A calibrated taper equation showed that for trees with the same DBH/HT ratio, trees in the control had less taper and more volume in the upper stem. No significant taper differences were found between the treatments. The analysis of variance suggested some possible differences in the upper stem, although none were significant (see Table 4-4). The small sample size resulted in a lower power in tests. The wide range in crown ratios also added variation as did the dendrometer estimation error and estimation of diameters inside bark. The fewer number of sightings in the upper stem due to limited visibility of the bole in the crown, where differences in taper occur, made small differences harder to find. One onther problem was that the "initial" form of the measured trees was an unknown (although the initial stand was selected for its high degree of uniformity) and observed differences are assumed to be caused by the treatments.

Taper trends by diameter and crown ratio classes were considered, although sample sizes where too small in most cases to reliably test. Plots of relative taper (dob/DBH versus h/HT) did produced consistant results. The trees with from smaller diameter and lower crown ratio classes showed less upper stem taper (as with the control) than larger or long crowned trees. This is not surprising sincethe majority of the small, short crown trees came from the control plots.

The results of this study are consistent with the findings of others. The larger differences found in volumes betwen trees on the thinned plots and the control are, at least in part, due to the calibrated model prematurely initiating differences in the lower stem (Figure 4-2). The ANOVA did not give significant differences in relative diameter until 55 percent of total height, although differences were suggested, but not significant, above 35 percent.

At the time this study was done, the stand was 42 years old and had been under management for 22 years. Maintaining lower stocking throughout a rotation will cause these taper differences to increase and could affect final volumes, grades and lumber yields. It is expected that as stocking increases on the lighter thinning treatments the differences between the treatments will become greater and significant. One way to obtain better information on the effects of treatments on taper would be to establish permanent dendrometer points as presented by Groman and Berg (1971) and discussed by Marshall (1988) to monitor future treatment effects over time.

Chapter 5

Effects of Thinning on Individual Tree Height and Diameter Growth

Photosynthate, originally produced in the tree crown, is required for the maintenance and construction of tissue throughout the tree. Within a tree, the demands for available carbon may not all be equal and the allocation to the various sinks may be done in priority to "increase the plant's or its progeny's chances of survival" (Waring and Schlesinger (1985, p.8). The rate of net photosynthesis depends on light, carbon dioxide, temperature, water and nutrients (Assmann 1970). Differences in competitive status, or the ability to "capture" and utilize limiting resources and space, is a major factor in causing differences in growth rates among trees in a single species stand, although genetic and environmental factors also are important (Ford 1976 and Cannell 1978). The effect of competition on response is difficult to quantify because of the interaction of so many other important factors. Stand density, site, tree size, age and position all influence a tree's competitive ability and its response to treatment.

Height growth is difficult to measure and is not well understood. Top height growth responses to thinning and effects of density are inconclusive or minimal for Douglas-fir. King (1966) could find no effect of stand density on site index or on the shape of the growth trends for site trees. Bruce (1981), while finding slightly taller top height in dense stands, could not find an effect on height growth. Hann and Ritchie (1988) showed only minor effects of stand density on dominant trees after live crown ratios were greater than 33 percent. However, as trees were overtopped and became part of the lower crown classes, height growth was greatly reduced. Average tree height may improve in a stand where poorer growers have been thinned or where understory trees have been released from competition from above. Mortality also will increase average stand height by the removing shorter, slower growing trees. Trees grown in plantations or in stands treated to create early, wide spacing may be an exception, however. Curtis and Reukema (1970) found on a low site that average tree height and the average height of the 100-largest diameter trees decreased at close initial plantation spacings and increased at wider spacings. The heights of all the crown classes, except suppressed trees, also showed this trend. Reukema (1979) and Harrington and Reukema (1983) also found that height growth of the average tree and the

100-largest diameter trees benefitted from wider spacings after thinning in two young stands on low sites.

Diameter growth, unlike height growth, has consistently shown large, rapid response after release from thinning. Work in southwest Oregon (Hann and Larsen in preparation) suggests that Douglas-fir diameter growth is affected more by a tree's position (relative to the density in trees larger than the subject tree) than by total stand density. Even at low densities, diameter increment is very sensitive to inter-tree competition.

To date, summaries of the Hoskins Levels-of-Growing-Stock Study have considered only stand level growth. This chapter describes the effects of thinning on individual tree height and diameter growth. Models are used to quantify competition effects by density and tree position on tree growth rates. One approach to modeling tree growth has been to modify a potential growth rate for competition. For diameter growth, the definitions of potential are arbitrary. Two definitions of potential diameter growth will be compared.

5.1 Methods

5.1.1 Data

Tree heights. At each remeasurement, total tree height (HT) was measured on a sample of trees on each plot. The original study plan called for the measurement of a minimum of eight crop trees and any additional non-crop tree to cover the diameter range. Two-thirds of the trees measured were to be from the upper one-half of the diameter range. The same trees were to be used for repeated measurements and were to be replaced with a tree of similar diameter if they died or were cut. Initially, 15 trees were measured on each plot at Hoskins. Replacements were not always assigned, however, and the number of measurements decreased to 10 on some plots by 1979. During the 1983 remeasurement, though, the sample of heights was increased back to the initial number of at least 15 when available. Height measurements were made with a Haga altimeter and clinometer.

Only trees with measurements at the start and end of a period were used for this analysis. Felled tree measurements were used, when available, for an end-of-period height. After eliminating trees with zero or negative height growth, a total of 2130 observations were available (12 percent was from the controls) with 22 percent having measured crown ratios. The height data is summarized in Table 5-1.

Tree diameters. Diameters at breast height (DBH) were measured on all trees at each remeasurement using diameter tapers to the nearest 0.1 inch. To avoid errors during remeasurements, the past DBH measurement records were consulted about any discrepancies in the field. Trees that died during a period were not used in the analysis. Trees that shrank during a period were also not used. This was usually no more than 0.1 inch and normally preceded mortality. This left a total of 11590 diameter growth measurements (41.8 percent from the controls) with 4.2 percent having actual crown measurements. The diameter growth data is summarized in Table 5-2.

5.1.2 Analysis

Models for individual tree height and diameter growth from the literature were used. Variables were used to describe tree vigor, tree position and stand density. To better describe the processes, the approach taken considered potential growth modified by competition to give annual tree growth (Hahn and Leary 1979). Actual

Table 5-1: Numbers of trees for Hoskins height growth data and summary for: periodic annual height growth (ΔHT), tree height (HT), diameter at breast height (DBH), crown ratio (CR), potential height growth (ΔHTp), and the ratio of tree height to site tree height (HT/HS).

	Control (n=265)			Treatments (n=1865)		
	Min.	Max.	Mean	Min.	Max.	Mean
ΔHT (feet/year)	0.5	5.0	2.4	0.2	6.0	2.9
HT (feet)	20.0	107.0	63.1	18.0	113.0	65.3
DBH (inches)	2.6	17.5	8.3	2.9	22.4	10.7
CR (%)	16.7	84.8	48.1	25.0	84.6	61.7
ΔHTp (feet/year)	2.4	3.3	3.0	2.4	3.3	3.0
HT/HS	0.46	1.12	0.88	0.42	1.15	0.90

Table 5-2: Numbers of trees for Hoskins diameter growth data and summary for: periodic annual diameter growth (ΔDBH), diameter at breast height (DBH), crown ratio (CR), basal area in larger (BAL) and stand basal area (SBA).

	Control (n=4850)			Treatments (n=6740)		
	Min.	Max.	Mean	Min.	Max.	Mean
ΔDBH (in./year)	0.00	0.67	0.12	0.00	1.00	0.44
DBH (inches)	1.3	18.6	5.5	2.4	22.4	8.9
CR (%)	12.3	84.8	43.8	21.3	84.6	62.8
BAL (ft^2/acre)	2.4	320.2	152.8	1.4	222.5	61.6
SBA (ft^2/acre)	121.9	320.2	216.8	48.2	222.5	97.5

crown ratios (CR) were used when available or were calculated from treatment-specific CR-DBH curves. Productivity, usually measured by site index, was assumed to be constant. The purpose was to build models that were biologically meaningful and statistically sound. Models were judged by residual mean square error, Furnival's (1961) index of fit, and the characteristics of residuals (plotted against predicted values and the dependent variables).

Tree height growth. Individual tree height growth was estimated by modifying a potential height growth estimate for competition. The potential height growth for a tree was defined using methods of Krumland (1982) and Ritchie and Hann (1986):

$$\Delta HTp = HT_2 - HT_1 \qquad [5\text{-}1]$$

where:

HT_1 = the tree height at the start of the growth period.

HT_2 = the predicted tree height at the end of the growth period using site index and growth effective age (GEA) at the end of the period (GEA+1 year).

An average site index (Means and Sabin 1989) was calculated to be 133 feet using the largest tree on each of the three control plots in 1988 (breast height age 38 years). The growth effective age (GEA) was determined by solving the Means and Sabin (1989) height growth equation for age at the start of the growth period.

To estimate competition, Ritchie (1985) found that CR gave the best measure of tree vigor. The ratio of the tree height to the site tree height (HT/HS) best characterized tree position. The model used was based on Ritchie and Hann (1986):

$$\Delta HT = \Delta HTp * b_1 * (1.0 - EXP[b_2 * CR]) * EXP[b_3 * ((HT/HS)^{b_4} - 1.0)]. \quad [5\text{-}2]$$

where b_1, b_2, b_3, and b_4 are estimated coefficients.

<u>Tree diameter growth</u>. Diameter growth has been predicted using both basal area growth and diameter growth equations. West (1980) concluded that there was no *a priori* justification for choosing one method over the other. This study is interested in diameter growth, so diameter growth was predicted directly.

After considering a number of diameter growth functions, the model of Hann and Larsen (in preparation) was chosen:

$$\begin{aligned}\Delta DBH = EXP[b_0 &+ b_1 * \ln(DBH + 1.0) + b_2 * DBH^2 \\ &+ b_3 * \ln((CR + 0.2)/1.2) \\ &+ b_4 * BAL^2/\ln(DBH + 1.0) \\ &+ b_5 * SBA^{1/2}] \quad [5\text{-}3]\end{aligned}$$

where SBA is the stand basal area (ft^2/acre) and BAL (ft^2/acre) is the basal area per acre in trees larger than the subject tree. The variable BAL has been used in diameter growth models to represent the average horizontal position of a tree (Wykoff et al. 1982, Hilt et al. 1987). Stand basal area represents competition ot trees smaller and larger than the subject tree. This equation can be decomposed into a relative maximum predicted growth rate and modifiers due to CR (vigor), BAL (position), and SBA (density). The relative maximum diameter growth for a tree is represented by a full crown (CR=1.0), the largest tree in the stand (BAL=0), and no compete due to density (SBA=0).

In an attempt to better define competition effects on tree diameter growth, a two-stage approach was also tried. In the first stage, "potential" diameter growth was estimated from the five most rapidly growing trees in each 1-inch diameter class. Potential growth can be defined as the growth of a tree in a forest stand free of competition from its neighbors or as the fastest growing dominants (Hahn and Leary 1979, Wensel et al. 1987). In the second stage, the estimated "potential" growth was adjusted by a multiplicative modifier using transformations of CR, SBA and BAL.

Initial screenings of the independent variables were done by linearizing the equation using logarithms. Final equations were estimated by nonlinear least squares using diameter growth as the dependent variable. Heterogeneity of the residuals is typical of basal area and diameter equations (West 1980). Ritchie and Hann (1986) found that residuals from their linearized models were not normally distributed, making standard log bias correction procedures (Flewelling and Pienaar 1981) inappropriate. They, therefore, use weighted nonlinear least squares. Hann and Larsen (in preparation) found that iteratively reweighting by the reciprocal of the predicted diameter growth was the best weight. SAS (SAS Institute, Inc. 1987) was used to complete this analysis.

5.2 Results

5.2.1 Height Growth

During the three-year period after the calibration cut which reduced the stocking from 1727 to 343 trees per acre, there was no significant difference in the change of height of the surviving 40-largest, 80-largest (by DBH), and all trees based on treatment specific HT-DBH curves (Table 5-3). The cumulative period height growth of surviving trees showed significantly less height

Table 5-3: Calibration period and cumulative total survivor height growth of the 40- and 80-largest diameter trees and all trees for HT-DBH curves (* denotes differences of $p < 0.001$ for test of treatments versus the controls using a contrast).

	Calibration Period (20-23 years)			Cumulative Total (20-45 years)		
Treatment	H40	H80	HT(all)	H40	H80	HT(all)
	feet	feet	feet	feet	feet	feet
1	10.16	9.82	9.01	71.07	71.29	70.39
2	10.21	10.12	9.09	73.36	72.69	70.26
3	10.14	9.97	9.12	72.80	72.67	70.94
4	9.97	9.92	9.18	73.16	72.89	69.38
5	10.11	9.91	9.01	75.12	74.11	69.22
6	10.23	10.10	9.30	71.44	71.24	69.45
7	10.05	9.81	9.10	73.80	73.48	69.68
8	10.28	10.09	9.24	72.32	72.31	69.59
Control	10.29	10.46	8.93	69.18*	68.06*	52.33*

growth in the controls for all three components after 25 years (Table 5-3). There were no differences among the controls for all trees. Differences among the treatments for the 40- and 80-largest trees were not related to density and may have been caused by differences in HT-DBH curves and the small sample sizes.

The height growth model (equation 5-2) was fit to data for the treatments, the controls, and for all data. The final parameter estimates are given in Table 5-4. Having both b_3 and b_4 was unnecessary due to the single site index and small range in HT/HS. Slightly better fits were obtained with b_4 alone. The CR and HT/HS modifiers for the three models and the Ritchie and Hann (1986) model are shown in Figure 5-1. Height growth decreases with shorter crowns (Figure 5-1A) and shorter trees (Figure 5-1B). Differences in the HT/HS modifier for trees large relative to the site trees is due to the differences in definition of site trees used. Ritchie and Hann (1986) used Bruce's (1981) top height curves for the 40-largest diameter trees. It would be expected that some trees would grow faster than the average of the 40-largest. In this analysis, however, the height growth curves of Means and Sabin (1989) were used which represent the largest tree on a 1 hectare plot.

Table 5-4: Parameter estimates for all trees, treatments and controls with the mean square error (s^2) for the height growth model.

$$\Delta HT = \Delta HTp*b_1*(1.0-EXP[b_2*CR])*EXP[(HT/HS)^{b_4}-1.0]$$

Parameter	All Data	Treatments	Controls
b_1	1.20626	1.14771	1.25449
b_2	-2.89130	-3.36926	-2.59124
b_4	0.22798	0.16931	0.56001
s^2	0.533	0.534	0.494
R^2	0.258	0.219	0.372

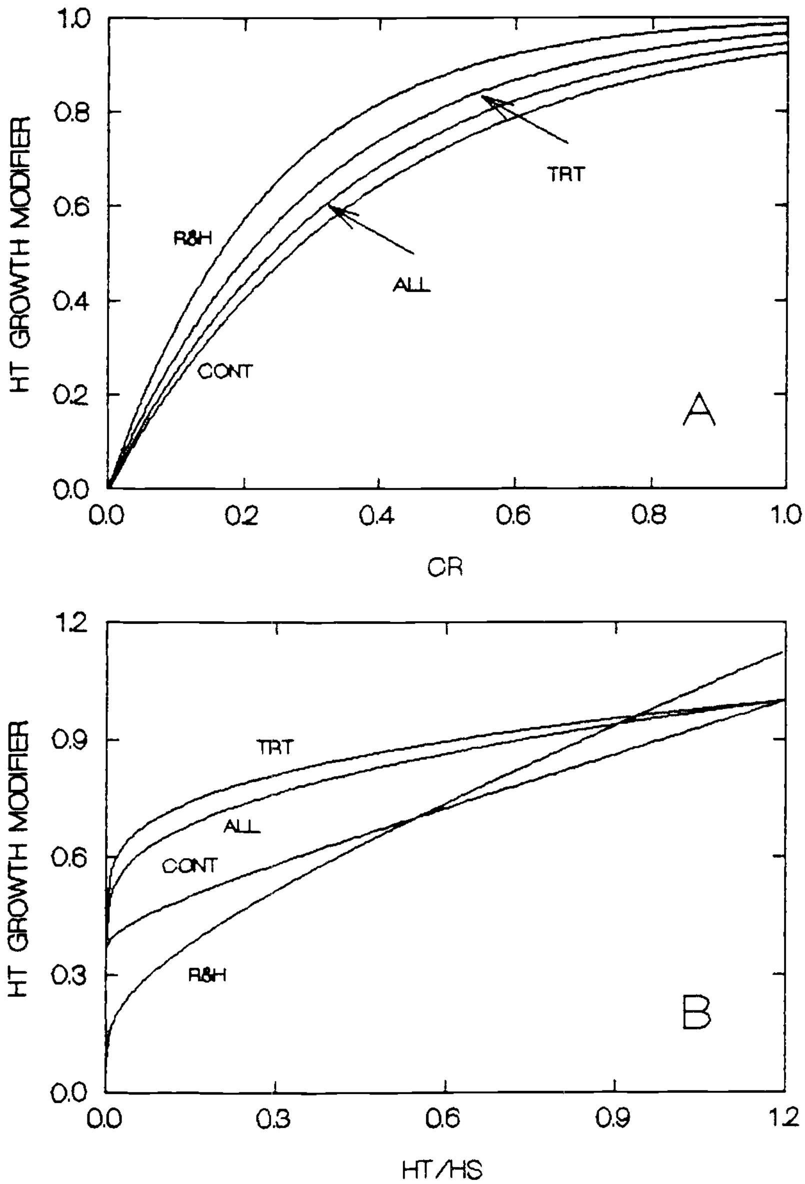


Figure 5-1: Potential height growth modifiers: (A) crown ratio and (B) tree position (tree height (HT) relative to height of site tree (HS)): Ritchie and Hann model (1986), all data (ALL), treatment data (TRT) and control data (CONT).

The differences in the HT/HS modifier for the treatments and the controls (Figure 5-1B) suggested that a density variable might explain additional variation. Stand basal area (s^2 = 0.528), BAL (s^2 = 0.521), and crown competition factor (CCF) (Krajicek et al. 1961) (s^2 = 0.529) all improved fits for all data when used as multipliers in the exponent on HT/HS. Basal area in larger gave the most improvement, but extrapolated very poorly). The CR modifier differed little among the treatments (Figure 5-1B). Low densities (CCF=50) had little effect (growth was greater than 90 percent for HT/HS greater than 0.3) on the HT/HS modifier. As density increased, however, the HT/HS modifier reduced height growth, even more for trees shorter than to the site tree (approximately 70 and 50 percent reductions in height growth for HT/HS of 0.9 and 0.3 respectively).

5.2.2 Diameter Growth

The diameter growth of the 40-, 80-, and 200-largest surviving trees and all surviving trees on the control plots averaged 1.44, 1.40, 1.26, and 0.55 inches, respectively, for the three-year calibration period. The treatments, however, showed immediate, large increases in diameter growth during the same period. The eight treatments showed three-year diameter growths of 1.78, 2.04, 1.81, and 1.63 inches for the same respective stand components (24 to 198 percent increases over the control). The largest tree on each plot showed a 32 percent increase in the treatments over the control. Over the 25 years of the study history history, cumulative diameter growth has consistently decreased with density for all treatments and stand components (Figure 5-2).

The potential diameter growth (ΔDBHp), based on the five fastest growing trees in each one inch diameter class, was described by the model:

$$\Delta DBHp = 0.3832*(DBH^{0.7586})*(0.9079^{DBH}) \qquad [5\text{-}3]$$

with s^2=0.00406 (R^2 = 0.770). The maximum predicted growth rate was 0.86 inches per year at a diameter of 7.9 inches. Trees up to the three-inch class primarily came from the controls in early periods. Larger DBH classes came mostly from treatments 1 and 2, which had the largest trees. Screenings for appropriate modifiers selected BAL as the strongest, followed by SBA and CR. No models were found, however, that predicted better than the Hann and Larsen (in preparation) model which was fit to the diameter growth data:

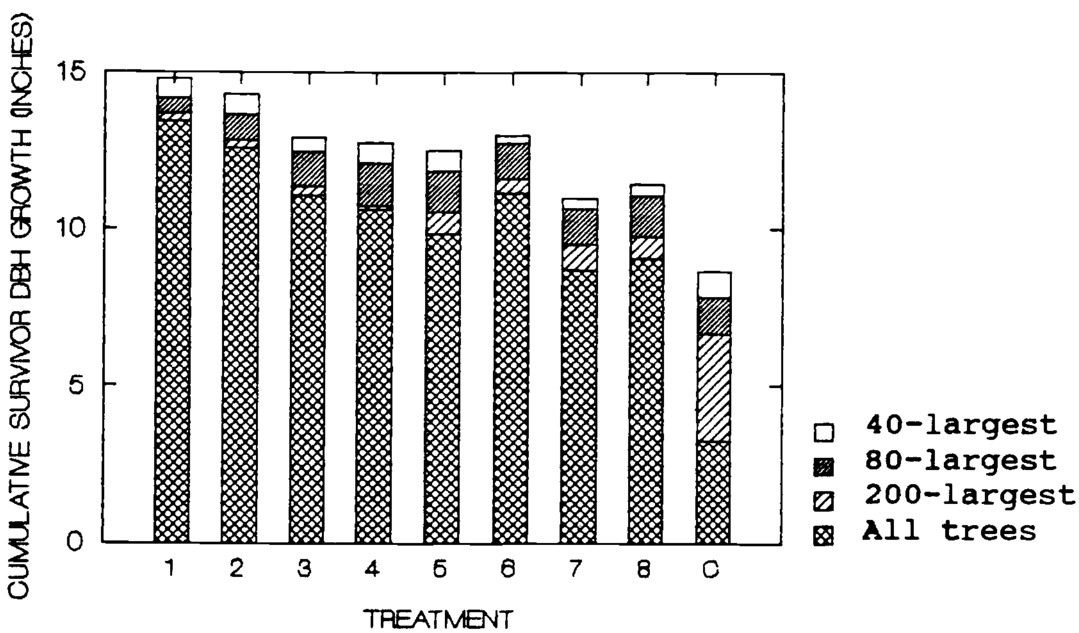


Figure 5-2: Cumulative (1963-1988) periodic survivor DBH growth for the 40-, 80-, and 200-largest diameter trees and all trees surviving during a growth period.

$$\begin{aligned}\Delta DBH = & \ EXP[-1.26569 + 0.80767*\ln(DBH+1.0) \\ & - 0.002442*DBH^2 \\ & + 0.78980*\ln((CR+0.2)/1.2) \\ & - 0.0000627105*BAL^2/LN(DBH+1.0) \\ & - 0.075215*SBA^{1/2}]\end{aligned} \qquad [5\text{-}4]$$

with the weighted s^2=0.0109 (R^2 = 0.904).

Figure 5-3 shows the "potential" diameter growth as defined by the fastest growing tree in each one-inch diameter class and the inferred potential of the final model above assuming full crowns and no BAL or SBA effects. Trees that are truly free to grow are difficult to find. This leads to several possible, but arbitrary definitions of potential (Hann and Larsen in preparation).

The variable BAL has the greatest effect on diameter growth. Diameter growth decreases with increasing levels of BAL (Figure 5-4). The effect of a given level of BAL is also greater on smaller trees. The SBA can be divided into BAL and the basal area in trees smaller than the subject tree. Stand density, in terms of SBA, shows strong effects on diameter growth even at low densities (Figure 5-5).

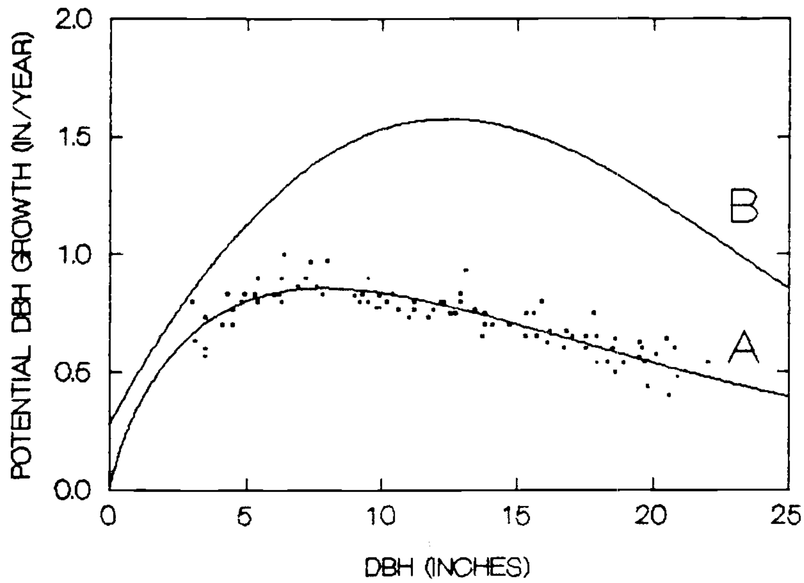


Figure 5-3: Potential diameter growth: (A) largest diameter growths by by one-inch DBH classes and (B) predicted relative potential DBH growth.

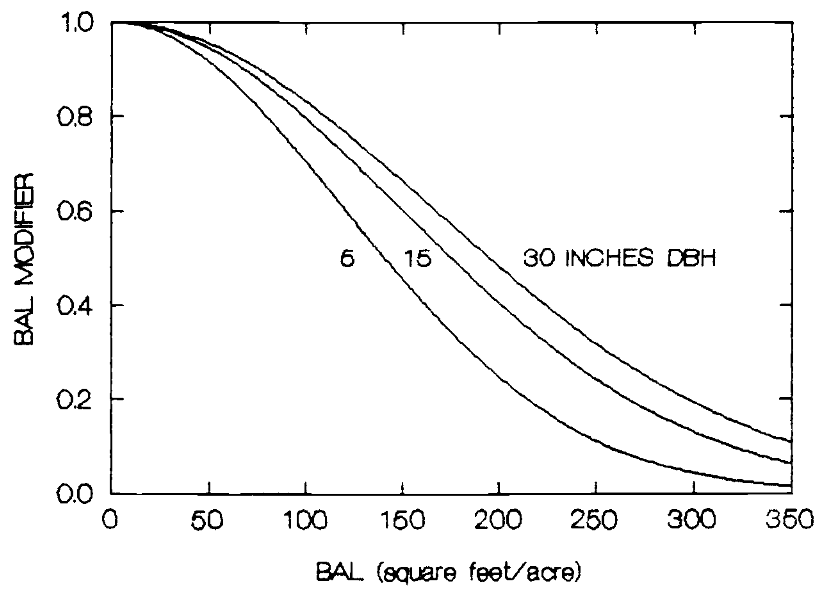


Figure 5-4: Diameter growth modifier for BAL (the basal area in trees larger than the subject tree, square feet per acre) for trees of DBH of 5, 15, and, 30 inches.

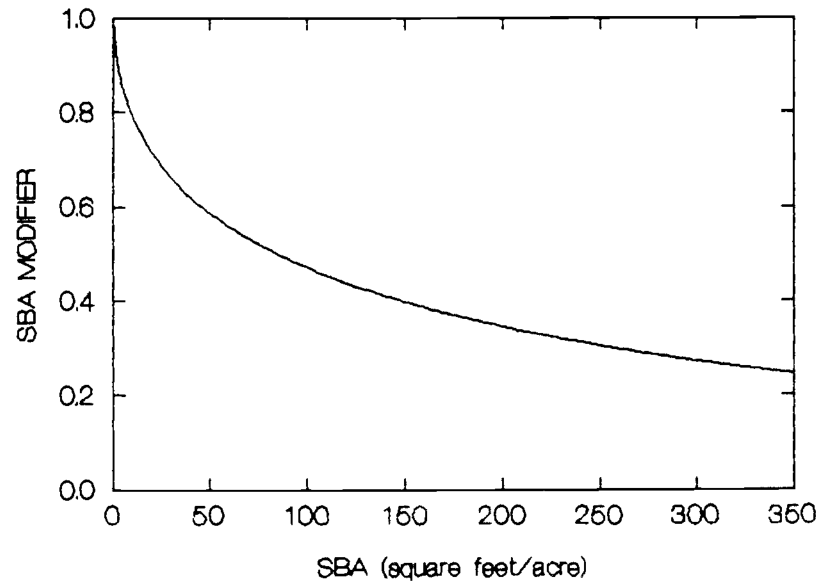


Figure 5-5: Diameter growth modifier for SBA (stand basal area, square feet per acre).

Data for missing crown ratios were estimated, therefore adding less new data on tree vigor than if measured. Also it is related to basal area because of its prediction from DBH. However, the modifier was still strongly significant and gave expected behavior of better growth on more vigorous, longer crowned trees (Figure 5-6). All three of these modifiers are consistent with the findings of Hann and Larsen (in preparation).

5.3 Discussion

The rate that a tree can occupy new growing space created by thinning or mortality of a neighbor depends on the growth of crowns (and roots). Crown length in Douglas-fir is only increased through height growth and the crowns of older trees expand more slower and occupy more space than younger trees (Staebler 1960). Tree vigor, in the form of healthy crowns (and probably root systems), is dependent upon stand treatment history. Density management helps to maintain longer crowns which enable trees to maintain strong growth rates, respond quickly, and utilize space more readily after thinning.

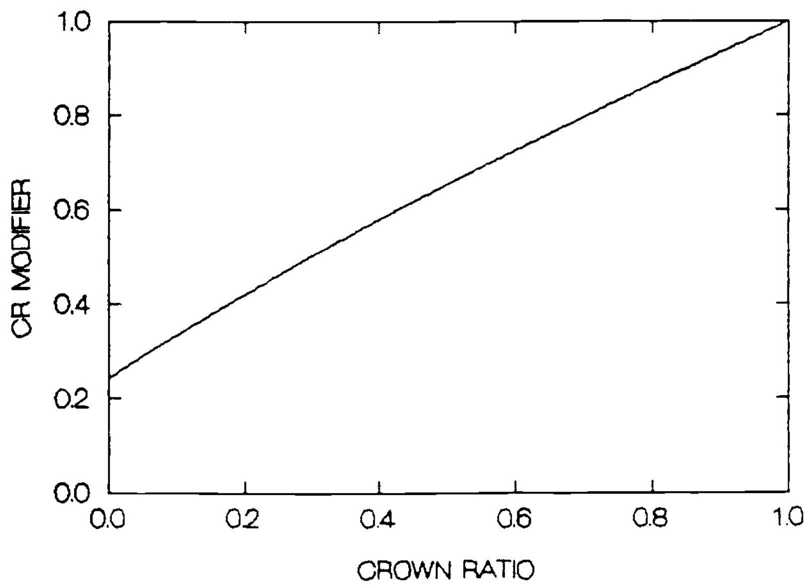


Figure 5-6: Diameter growth modifier for CR (crown ratio).

Processes such as photosynthesis and transpiration are functions of tree crown size (or area). Crowns are narrower and shorter in denser stands. Expansion of crown area after thinning comes primarily from height growth and a decreased rate of recession. Branch elongation is more affected by age (decreases with age) than density for codominants (Reukema 1964).

Lannar (1985) suggests that the differences in sensitivity of height and diameter growth to stand density can be heuristically described as competition between sinks. Height growth, which is much less sensitive to density, is a strong sink, with early demand and greater reliance on stored carbohydrates. Diameter growth, conversely, is a weaker sink whose demands are later and must rely on and compete for current photosynthate. In denser stands, survival strategy may be to put resources to developing root systems and crown, leaving less for diameter growth.

The Hoskins LOGS installation is on a high site with rapid height growth rates for the dominant trees. Height growth is also strong for trees in less favorable positions. Density appears to have negligible effect on dominant height growth. There was some indication, however, that density may affect trees in different competitive position differently. Tree position relative to density, as measured by BAL, improves the model even more suggesting that competition from above has a greater effect on height growth than stand density. Dominant and larger codominant trees and trees in plots with lower densities are less affected in height growth. This concurs with Hann and Ritchie (1988) in southwest Oregon who found that greater crown closure at the tip of a tree reduced height growth.

Diameter growth at Hoskins was much more affected by stand density, especially as competition from above. This suggests that thinning from below would have limited impact on release of the residual trees.

Competition is often described as one- or two-sided. Two-sided competition implies that all plants, regardless of size, are affected by a limited resource equally. With one-sided competition, larger plants affect the growth of smaller neighbors only (Cannell et al. 1984). One-sided competition is characteristic of systems where light is the main limiting resource (Ford and Diggle 1981). The importance of relative position variables (total tree height to average height of the site trees) and position variables (BAL) in describing height growth support a one-sided competition process. The positional variable BAL is the strongest in predicting diameter growth suggesting a strongly one-sided competition process, although stand basal area also contributes significantly. Volume may be a better measure of tree size and the increased taper (and less volume) associated with larger diameter and long crowned trees in a stand may increase the importance of competition from below (Brand and Magnussen 1988).

Chapter 6

Simulation Results

The LOGS studies were designed to consider how different levels of retained growing stock affected tree and stand growth. Chapter 2 showed the strong relationship of increasing volume and decreasing diameter growth with greater levels of growing stock. Mortality occurred at high densities only (greater than relative densities of 60). The heaviest thinnings produced the largest trees but resulted in decreases in volume. Net volume production in the lighter thinnings has reached the levels attained by the unthinned control.

For a given site, the response to thinning depends on (1) the amount of growing stock retained, (2) the interval between thinnings (thinning cycle), and (3) the type of thinning (Smith 1962 (p.90)). The LOGS studies chose to only vary the level of growing stock retained and to hold the other factors as constant as possible (Williamson and Staebler 1971) to keep the number of measurements manageable. For example, to test three different levels of the first three factors at a single site would require 27 different thinning regimes, or 81 plots if each was replicated three times. To study other factors would require a larger designed experiment and 20 or more years for results.

Reukema (1972) gave evidence that for thinning regimes retaining comparable growing stock or with comparable initial conditions and thinning intensities, thinning cycles of 3, 6, or 9 years differed little in their effect on stand growth. Therefore, similar results would be expected for regimes like those tested in the LOGS studies, but with longer thinning cycles, if similar periodic mean levels of growing stock where used (Curtis and Marshall 1986).

The type of thinning determines what types of trees are removed and the resulting arrangement of residual trees or stand structure (Smith 1962 (p.13)). Thinnings are often classified by the type of trees they remove. Low thinning removes small volume trees from the lower crown classes that have the greatest probability of mortality. Crown thinning (thinning from above) removes trees from the middle and upper crown classes to favor development of similar trees with increased growing space. Selection thinning removes dominant trees to favor trees in the lower crown classes. Oliver and Murray (1983) found that differences in volume growth for plots for the same site, initial basal area, and age was due to differences in stand structure. On a plot, the larger crown class trees grew more per tree and per basal area than the smaller trees. O'Hara (1988) also found that dominant and codominant trees had the greatest individual tree volume growth rates, but large crowned trees were less efficient in thinned stands. Thinning strategies that produce stand structures that favor the fastest growing and most efficient growing stock would be expected to produce the highest levels of recoverable volume. Since the fastest growers and most efficient are often not the same trees, some trade-offs may be required in designing thinning regimes.

Many "what if" questions have been asked about the development of the LOGS plots. Estimates of stand growth from regional growth models (Curtis et al. 1982, Arney 1985, and Hester et al. 1989) can be expected to vary greatly for specific sites (Curtis 1987). For this reason, results from previous chapters were used to develop a site specific simulation model to investigate the probable development of the stand at Hoskins under alternative thinning regimes. The model was tested against treatments 1, 3, 5, and 7 and the control. The thinning treatments 1 and 7 and the control were used for comparisons of alternative thinnings.

6.1 Methods

The general approach to the simulation model was to use an individual tree-distance independent model (Munro 1974). By using an individual tree model, the structural information will be better represented than if a whole stand model, like DFSIM (Curtis et al. 1982) was used. The model begins with a plot-specific tree list containing a diameter (DBH), height (HT), crown ratio (CR) and expansion factor (EXPAN) (the number of trees per acre each tree represents) for a given plot. Missing initial total heights and crown ratios are predicted by treatment specific HT-DBH and CR-DBH curves. The model updates individual tree records on a yearly basis by growing HT, DBH, and CR following the relationships developed in earlier chapters. Mortality is then removed if necessary. Stand values are obtained by summing the individual tree records weighted by their expansion factor (EXPAN). Thinning is done at the beginning of a growth period by removing trees (i.e. EXPAN set to zero if a tree is removed).

6.1.1 Height and Diameter Growth

Individual tree height and diameter growths are predicted with the equations developed in chapter 4. Height growth is predicted using:

$$HT = HTp*1.20626*(1.0-EXP[-2.89130*CR]) *EXP[(HT/HS)^{0.22798}-1.0] \qquad [6\text{-}1]$$

where HTp is the potential height growth (the growth of the tree if it was a site tree), and HS is the height of the site trees (Means and Sabin 1989). The diameter growth is predicted from:

$$\begin{aligned} DBH = EXP[&-1.26569 + 0.80767*\ln(DBH+1.0) \\ &- 0.002442*DBH^2 \\ &+ 0.78980*\ln((CR+0.2)/1.2) \\ &- 0.0000627105*BAL^2/\ln(DBH+1.0) \\ &- 0.075215*SBA^{1/2}] \end{aligned} \qquad [6\text{-}2]$$

where BAL is the basal area in trees larger than the subject tree and SBA is the total stand basal area.

6.1.2 Crown Change

Crown recession was predicted directly as the change in height to live crown (HLC) using a model form evaluated by Maguire and Hann (1990):

$$\ln(\Delta HLC) = -7.47573 + 0.17196*BAGE - 0.050726*HT + 8.64464*CR + 0.015184*SBA \qquad [6\text{-}3]$$

where BAGE is the breast height age and all values are at the start of the period. A total of 481 observations were used and $s^2 = 0.752$.

6.1.3 Mortality

No mortality was assumed to occur below 60 percent of a maximum stand density index (SDI) of 600 (SDI=360) at the start of the period (Long 1985). For the Hoskins plots, only 2 percent of the after calibration trees died when the plots were less than SDI of 360 (see chapter 2).

Stand level mortality was controlled by a self-thinning trajectory based on the approach to a maximum size-density line similar to Reineke (1931) where density is trees per acre and tree size is the quadratic mean DBH (QMD). The trajectory was modeled using (Smith and Hann 1984):

$$\ln(Y_i) = 6.10529 - 0.60348*\ln(X_i)$$
$$- 6.10529*(0.03848)$$
$$*EXP[-6.52874*(\ln(X_o) - \ln(X_i))] \qquad [6-4]$$

where

Y_i = average tree size (QMD) at time i.

X_i = trees per acre at time i.

X_o = the number of tree per acre when size-density mortality begins (when stand reaches and SDI of 360 at the start of the growth period).

The predicted self-thinning trajectory is shown in Figure 6-1. The 95 percent asymptotic confidence interval of the slope parameter (-0.60348) included the Reineke slope of -0.62305, but did not include a slope of constant basal area (-0.5). The slope was steeper than that found by Puettmann (1990) for Douglas-fir. The predicted maximum SDI was 545.

Individual tree mortality was allocated by the annual mortality rate equation of Shifley and Fairweather (1983):

$$PM = 1.0/(1.0 + EXP[1.2745$$
$$+ 13.207*DBH + 0.053176*DBH]) \qquad [6-5]$$

where PM is the annual probability of a tree dying.

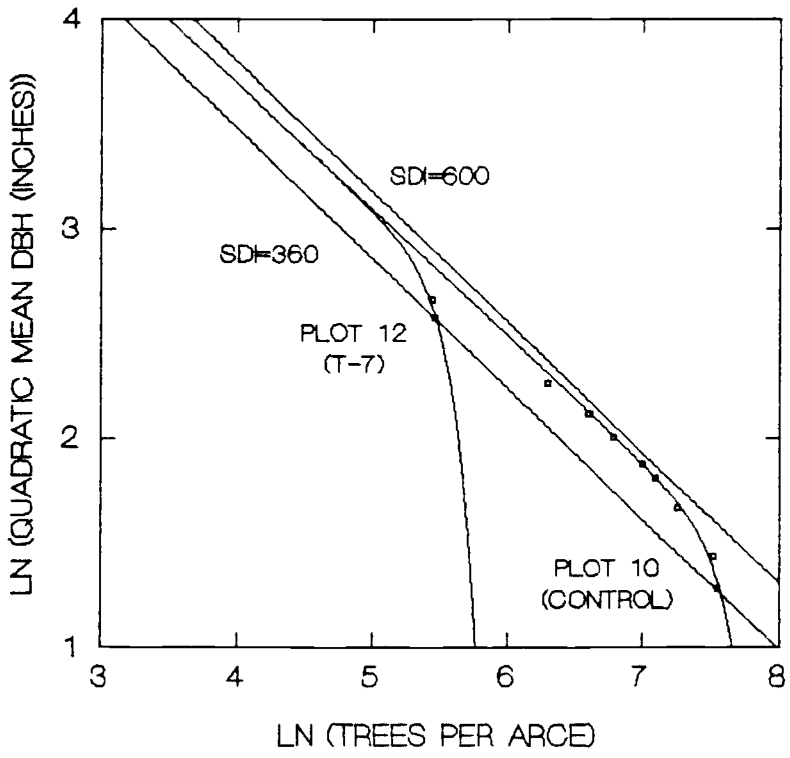


Figure 6-1: Predicted and actual self-thinning trajectories for plot 10 (control) and plot 12 (treatment 7).

The process for calculating mortality is similar to Hann and Wang (1990). After each projection, if the initial SDI was at least 360, the projected QMD was compared to the QMD predicted by the above self-thinning trajectory. If the projected QMD was less than the trajectory (calculated from equation 6-4) than no mortality was taken. If the QMD was greater however, the tree with the greatest PM (equation 6-5) was killed by setting EXPAN to zero and the stand diameter and trajectory QMD was iteratively computed and compared to the new stand QMD. The process was continued until the trajectory line was reached.

6.1.4 Tree Volume

The total stem cubic foot volume (CVTS) was calculated for each tree using the Bruce and DeMars (1974) equation for compatibility with previous LOGS results. Comparisons of several published taper models with felled tree records from the Hoskins treatment thinnings were made. The model by Walters and Hann (1986) performed the best and was used to calculate Scribner board foot volumes in 24-foot logs to a 6-inch top. This model also used CR information to modify tree taper. Shorter crown trees gave more cubic volume than longer crown trees with the same DBH and HT.

6.1.5 Log Grades

Using the taper equation of Walters and Hann (1986) each tree was "bucked" into 24-foot logs with 8-inch trim. A 0.5 foot stump and a 6-inch top diameter inside bark (dib) were used. Each log was graded for domestic grades as defined by the Northwest Log Scaling and Grading Bureaus (Northwest Log Rules Advisory Group 1980) for Douglas-fir. The grades considered were:

(1) Special Mill (SM) -- 16-inch minimum dib with allowance for 1 knot or indicator per foot, up to 1.5 inches and no more than 2 knots larger.

(2) #2 Sawlog (2S) -- 12 inch minimum dib with tight knots up to 2.5 inches in diameter and larger knots well distributed.

(3) #3 Sawlog (3S) -- 6 inch minimum dib with tight knots up to 3 inches with larger knots well distributed.

Grade determinations were made by predicting scaling diameters (small end dib). Logs were assumed to make knot and recovery requirements since no empirical data were available.

6.2 Results

6.2.1 Model Evaluation

The purpose of the model is to model the response of the plots as close as possible and then use it to simulate different thinning regimes. To test the model, each plot for treatments 1, 3, 5, and 7 and the control was projected for 25 years (total age 20 to 45). Thinnings was done by removing the same trees as were removed by the actual thinnings. To remove as much as possible of the mortality effect, trees that actually died on the plots were removed at the end of each period. Treatment 7 (in the last period) and control, contained the only plots with much mortality. To test the mortality predictions, a second set of runs were done by predicting mortality on these plots. Comparisons for all projections were made for the average DBH, HT, CR and trees per acre at the end of the projection. The actual treatment averages at age 45 and the predicted minus actual values are shown in Table 6-1.

Table 6-1: Average treatment values for the actual average stand diameter at breast height (DBH), total height (HT), crown ratio (CR) and trees per acre (TPA) at age 45 and the average differences between the 25 year projected and actual values.

	------ Actual ------				- Predicted-Actual -			
Treatment	DBH	HT	CR	TPA	DBH	HT	CR	TPA
	Projections with actual mortality							
1	20.0	107.4	0.58	51.7	-0.2	2.1	0.03	0
3	17.0	106.8	0.47	101.7	0.2	0.5	0.06	0
5	15.0	104.6	0.41	161.7	-0.2	-0.2	0.06	0
7	14.5	106.1	0.37	213.3	-0.7	-1.8	0.04	0
Control	10.2	94.8	0.21	488.3	-0.8	-0.5	0.03	0
	Projections with predicted mortality							
7	14.5	106.1	0.37	213.3	-0.9	-2.1	0.04	10.0
Control	10.2	94.8	0.21	488.3	-0.8	-0.9	0.00	85.0

For model runs with the mortality removed at the end of each period, diameters after 25 years of projection, were underpredicted by an average 0.3 inches. Heights were over predicted by 0.02 feet and predicted crown ratios were 0.045 greater. There did not appear to be any trends with treatment, although heights showed more overprediction on the heaviest thinning (treatment 1) plots. To assess the effects of removing mortality at the end of the period, a run on one of the control plots was made where the actual trees that died during a period were removed randomly during that period. For each tree that died during a period, a random number was obtained from a random number table to determine which year within the period a tree should be removed. This increased diameters by 0.1 inch, heights by 0.9 feet and crown ratios by 0.03.

Actual total mortality on the three plots in the control averaged a total of 1238 trees for 25 years (Chapter 2). The model predicted an average of 1153 trees dying for the three control plots during the same period (6.9 percent less). An average of 18 trees per acre died in treatment 7 while the model predicted 8 trees.

6.2.2 Predicted and Actual Development

The stand development was predicted for 25 years (Table 6-2). Results were very close to the actual with slight under predictions in diameters and volumes. Most of the mortality was unmerchantable and nearly all the thinnings removed 3S grade logs. The stand at age 45 showed the expected differences. Diameters on the heavy thinning were twice that on the controls (19.8 versus 9.7 inches). The reduced stocking of the heavy thinning, however, has reduced the standing cubic foot and board foot volumes by nearly 60 percent from treatment 7. The cubic foot volume on treatment 7 was about 10 percent lower than the control, but merchantable board foot volumes were 10 percent higher.

There were larger differences in the resulting mix of grades between the treatments. By scaling diameter, 30 percent of the board foot volume made the SM grade in treatment 1, whereas a negligible amount was in the SM grade in treatment 7 and the control. Treatment 7 was split between the two saw log grades whereas the control was primarily in the 3S grades.

Table 6-2: Per acre summary of the actual and predicted stand in 1988 (stand age 45 years), total thinnings, total mortality and total (1963-1988) growth.

	Live Stand 1988							Total Thinnings					Total Mortality			1963-1988 CVTS Growth	
Treatment	No. Trees	QMD	CVTS	SBF	Percent SM	2S	3S	No. Trees	CVTS	SBF	Percent 2S	3S	No. Trees	CVTS	SBF	Net	Gross
Actual																	
1	52	20.1	4442	20695	29	52	19	300	3001	5259	13	87	0	0	0	7202	7204
7	215	14.8	10809	49151	2	46	52	97	1217	2634	0	100	18	169	263	11269	11438
Control	488	10.5	12093	45080	1	15	84						1238	2809	744	9748	12555
Projected LOGS Thinnings																	
1	53	19.8	4538	20768	30	48	22	300	2951	5639	16	84	0	0	0	6320	6320
7	223	14.0	9924	42461	0	43	57	97	1225	2603	0	100	8	93	0	10393	10485
Control	573	9.7	11738	36339	0	8	92						1153	2309	0	9817	12126

CVTS = Total stem cubic foot volume

SBF = Scribner board foot volume (6-inch top, 24-foot logs).

6.2.3 Results of Alternative Thinning Regimes

One question that has often been asked is what would have happened if there had been no thinnings after the initial calibration thinning? To address this, the after calibration tree lists on the three plots in treatment 1 were projected without additional thinning. The projections are summarized in Table 6-3. The model predicted there would be roughly 300 trees per acre (mortality was almost 50 trees per acre) at age 45. This is almost 100 trees more than on treatment 7, the lightest thinning. The predicted stand diameter was 12.8 inches, 9 and 36 percent less than treatments 7 and 1, respectively. Cubic foot volume was only 4 percent less than the predicted control and merchantable board foot volume was 29 percent greater.

A second question is what would have happened if thinnings had been from below? Plots in treatments 1 and 7 were again projected with their after calibration tree lists. To simulate a thinning from below on each plot, the same percent of basal area (basal area before thinning/basal area removed) was removed at each thinning as the actual LOGS thinning would have, but by removing the trees with the smallest DBH. For treatment 1, the

Table 6-3: Per acre summary of projections for alternative regimes in 1988 (stand age 45 years), total thinnings, total mortality and total (1963-1988) growth. Projections are for no thinning after the calibration and for thinnings from below.

	Live Stand 1988							Total Thinnings					Total Mortality			1963-1988 CVTS Growth	
					Percent						Percent						
Treatment	No. Trees	QMD	CVTS	SBF	SM	2S	3S	No. Trees	CVTS	SBF	2S	3S	No. Trees	CVTS	SBF	Net	Gross
Projected No Thinning After Calibration																	
1	307	12.8	11273	46736	0	30	70	0	0	0	0	0	47	436	308	10536	10973
Projected Thinning from Below																	
1	32	22.2	3410	16105	56	32	12	322	3025	5550	0	100	0	0	0	5932	5932
7	175	15.6	9670	43181	0	49	51	152	1284	1882	0	100	0	0	0	10197	10197

CVTS = Total stem cubic foot volume

SBF = Scribner board foot volume (6-inch top, 24-foot logs).

average d/D ratio was 0.03 lower because the heavy thinning did not leave many trees to choose from (first thinning averaged 0.13 lower). In treatment 7, the average d/D ratio was 0.16 lower. A summary of projections are given in Table 6-3. The thinning reduced the trees per acre to only 32 trees on treatment 1, with an increase in diameter of 12 percent. Volumes were also greatly reduced because of the low stocking. Almost 60 percent of the log volume was in the special mill grade, although at that spacing, knots would be expected to reduce this greatly. Treatment 7 showed an increase in diameter of 11 percent with 22 percent fewer trees. The cubic foot volume was about 3 percent lower than the LOGS treatment and the board foot volume was about 2 percent greater. The grade composition was similar, with only slightly more in the 2S grade and no SM logs.

6.3 Discussion

Simulation offered a way to integrate results from previous chapters and to investigate questions that would otherwise take many years to answer. The model was tested against the plots and actual LOGS treatments. Performance was good for predicting average stand diameter, height and crown ratio. Mortality continues to be the weakest component of the growth modeling process, although the use of a self-thinning trajectory as an upper bound helped keep the differences in predicted mortality to less than 7 percent on the controls.

Twenty-five year projections of the actual LOGS thinnings were in close agreement with the actual results. Heavy thinnings gave the greatest increase in diameter and produced more volume in higher grades, but reduced standing volume and volume production. The lightest thinning, gave smaller trees than the heavy thinning, but produced larger trees than the control with similar standing cubic and board foot volumes at total stand age 45. The net cubic volume production (standing plus thinning volume) was greater in the light thinning than the control, whereas gross (net plus mortality) was only slightly reduced.

The grades were determined from scaling diameter only. In the heavy thinning (treatment 1), branches at the base of the live crown are greater than the 1.5 inch size limit for knots allowed for a SM grade. To minimize overestimates of grade, 24-foot logs were used so the first log of a tree would be below the live crown in the current stand. The percent of volume in SM are probably still a little optimistic. All trees removed in thinnings were at the lowest (3S) grade. Quality premiums for the better grades will increase the value towards heavier thinnings (Tappeiner et al. 1982). Sessions et al (1989) found that optimally bucking second growth, considering grades values, taper, knots, breaks, and other factors gave about a 12 percent increase in the value of a sample of second growth trees. The high growth rates also may have an impact on value, because the heaviest thinning treatments produced less than the accepted annual ring count of six rings per inch (Northwest Log Rules Advisory Group 1980).

There are many different thinning regimes that could be tested. A no thinning, after the calibration cut, regime increased the diameter and board foot volumes over the control. This demonstrates the desirability of precommercial thinning, albeit late in the life of the stand (Reukema 1975). Strict thinnings from below, to the same residual basal area (which increased with time) will create stand structures favoring the better growing trees (O'Hara 1988). The heavy thinning had to take many trees to obtain the amount of basal area required for the cut in small diameter trees. The lighter thinning (treatment 7), however, produced roughly an 1.5-inch diameter increase (most probably due to the thinning of smaller trees). The cubic foot volume production (standing in at age 45 plus all thinnings) was approximately 200 ft^3/acre less in the thinning from below than the projected LOGS thinning, whereas the board foot volume production was within 1 board foot.

Low thinning regimes maintained the best growing stock, but showed no volume gains at age 45 in simulated yields after intensive thinning. Crown thinning, as used in the LOGS studies, release crowns (and possibly the root system) for the growing stock that appears best able to use (or use more immediately) more growing space.

Chapter 7

Conclusions

The Hoskins Levels-of-Growing-Stock Study offers a 25-year record of a high site Douglas-fir stand grown at a wide range in growing stock. An initial calibration thinning, in this naturally regenerated stand at total stand age 20, reduced the trees per acre from 1727 (140 square feet per acre) to an average of 434 (approximately 50 square feet per acre). By age 45, five subsequent crown type thinnings reduced the trees per acre to a range of 50 to 230. Mortality was negligible on the treated plots (less than 2 percent of the number of trees after the calibration), but reduced the trees per acre on the control by 72 percent over the same time period.

The stand showed an immediate 131 percent increase in diameter growth after the initial thinning, emphasizing the desirability of precommercial thinning in dense stands. Diameter growth continued to show a strong relationship with the level of growing stock in each treatment. By age 45, the lightest thinning treatment (retained 70 percent of the gross basal area growth of the control) increased diameters by 40 percent, whereas the heaviest thinning (retained 10 percent) increased 90 percent. Height growth was more directly impacted by position than density.

Diameter growth decreased strongly with increasing density. Gross volume growth increased with the level of growing stock, but did not show a hypothesized plateau (Langsaeter 1941) at high densities even though basal area growth increased with thinnings. This is primarily due to the large amount of height growth in this young stand and low basal areas on the treatments. As density has increased in the later periods on the lightest treatments, gross volume growth has equalled the control, suggesting the possible formation of a plateau in the future. Heavy thinnings reduced net cubic yield by 39 percent from the control; the lightest thinning showed a reduction of only 1 percent. Merchantable board foot volume yields were decreased by 33 percent from the control on the heaviest thinning, but increased 18 percent on the light thinning. Thinnings also gave a greater proportion of volume in higher value grades, although knot sizes and number of rings per inch could reduce this advantage in the heavier thinnings.

The major factor affecting volume differences between treatments was the increased diameter growth for the treatments. However, trees on the control plots had significantly less taper in the upper stem. This was associated with the shorter crowns. For trees with the same diameter and height, volume was greater for the control.

These results are specific to a young, high site stand in western Oregon. However, similar results for stand growth and development have been found for other LOGS installations, which are primarily site II (Curtis and Marshall 1986). Extrapolation to young stands on low site and to older stands would be questionable due to differences in height growth pattern and its contribution to volume growth (chapter 3). Although the thinnings were early, some competition had occurred. Plantations of wide initial spacings would be expected to have larger diameter trees with longer crowns, giving greater release to thinning (and probably larger knots).

The use and type of thinning practices will continue to depend on many factors, including management objectives, harvesting options and markets. This study did not consider the economics of thinning. Tappeiner et al. (1982) found, using the Hoskins plots, that although thinnings provided low returns, the resulting increase in diameters gave substantially greater returns in the future. The large increases in diameter in the heaviest thinnings did not offset the resulting volume growth decrease, due to the depletion of growing stock levels. Returns were therefore lower than the lightest treatments that maintained higher levels of growing stock, but still resulted in diameter increases.

The effect of thinning on wood quality and value remain important considerations. Knot size and distribution and the amount of juvenile wood influence many wood properties and can have very negative affects on wood products (Senft et al. 1985). Knot size increases with spacing (Grah 1961) and the rapid growth of young, widely spaced trees will produce a higher percentage of juvenile wood if harvested at young ages (Briggs and Smith 1986). These characteristics are largely determined by the crown, which is greatly influenced by density.

Management implications of this, and the other LOGS studies, demonstrate the trade-offs between diameter and volume growth. Low densities give the greatest increases in individual tree diameter, but at the cost of reduced stand volume growth. Curtis and Marshall (1986) suggest that a general management guide would be to maintain stands between relative densities of 40 to 60. Maintaining stands below relative density 60 eliminated mortality losses. Below a relative density of around 40, volume yields are reduced for the low levels of growing stock. Increasing levels of growing stock with stand age can be expected to produce the highest amount of recoverable volume (O'Hara 1990). Intensity of thinning will depend on the frequency of thinnings and crown thinnings appear to give the greatest release to the residual stand, produce high volume growth rates and provide early economic returns (Berg 1970).

Thinning should become an even more important tool in meeting the increasing challenges of managing forests in the Northwest. The manipulation of stand density and structure through thinning offers a tool to meet multiple-use objectives in sensitive areas, creation and enhancement of wildlife habitat, and to maintain healthy forest for high timber production.

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Table A-1: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), stand height and crown height of the 40-largest diameter trees.

	START OF PERIOD							
TREATMENT	1963	1966	1970	1973	1975	1979	1983	1988
NUMBERS	20	23	27	30	32	36	40	45
				Height 40-largest (feet)				
1	40.0	49.5	62.1	71.0	75.0	86.5	97.9	108.2
2	38.5	48.5	62.9	73.2	78.5	89.3	100.8	111.6
3	38.5	48.8	61.2	72.5	77.3	89.1	99.1	111.2
4	39.6	50.8	63.8	74.0	79.3	90.7	103.4	112.3
5	39.9	50.1	62.4	71.7	77.4	88.9	104.7	115.5
6	39.9	49.0	62.4	72.3	76.9	87.8	98.8	110.6
7	38.8	49.1	62.4	72.9	77.5	88.7	102.1	113.7
8	40.7	50.5	64.2	74.8	79.4	87.5	99.4	112.7
Control	42.6	52.6	65.9	75.6	81.0	91.3	100.9	112.6
				Height to live crown 40-largest (feet)				
1	8.3	13.0	18.1	24.2	26.6	33.1	40.2	45.0
2	8.0	12.8	18.2	25.3	29.4	37.8	46.4	53.3
3	8.0	12.7	20.1	26.9	30.6	38.7	45.8	54.7
4	8.2	13.3	21.0	29.5	34.7	45.9	58.3	61.7
5	8.4	13.2	20.1	27.3	32.2	42.8	57.0	63.6
6	8.3	12.8	20.0	25.6	28.8	36.6	44.9	55.5
7	8.0	12.7	23.2	31.4	36.2	43.3	60.7	66.9
8	8.3	13.0	23.8	31.2	35.3	43.9	54.8	61.6
Control	8.6	20.8	30.2	38.1	43.5	54.8	66.8	79.6
				Live crown ratio 40-largest (percent)				
1	79.2	73.8	70.9	65.9	64.5	61.7	58.9	58.5
2	79.1	73.7	71.0	65.4	62.5	57.6	53.9	52.2
3	79.4	74.0	67.1	62.9	60.4	56.6	53.8	50.8
4	79.2	73.8	67.0	60.1	56.2	49.4	43.6	45.1
5	78.8	73.6	67.8	62.0	58.5	51.8	45.6	44.9
6	79.1	73.9	68.0	64.6	62.5	58.3	54.5	49.8
7	79.4	74.1	62.8	56.9	53.3	51.2	40.6	41.1
8	79.5	74.2	62.9	58.3	55.5	49.9	44.8	45.4
Control	79.8	60.4	54.2	49.5	46.3	39.9	33.7	29.2

Table A-2: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), trees per acre.

		Number of trees per acre													
		CALIBRATION PERIOD		TREATMENT PERIOD #1		TREATMENT PERIOD #2		TREATMENT PERIOD #3		TREATMENT PERIOD #4		TREATMENT PERIOD #5		MEASUREMENT PERIOD #6	
		1963	1966	1966	1970	1970	1973	1973	1975	1975	1979	1979	1983	1983	1988
Treatment	Plot	20	23	23	27	27	30	30	32	32	36	36	40	40	45
1	3	345	345	210	210	115	115	85	85	70	70	50	50	50	50
	8	380	375	225	225	120	120	80	80	70	70	50	50	50	50
	20	335	335	210	210	120	120	85	85	70	70	55	55	55	55
	AVE.	353	352	215	215	118	118	83	83	70	70	52	52	52	52
2	4	360	360	220	220	135	135	105	105	95	95	85	85	85	85
	15	325	325	185	185	100	100	75	75	70	70	65	65	65	65
	17	345	340	215	215	140	135	110	110	105	105	90	90	90	90
	AVE.	343	342	207	207	125	123	97	97	90	90	80	80	80	80
3	7	390	390	295	295	200	200	160	160	145	145	115	115	115	115
	11	340	340	240	240	160	160	125	125	105	105	85	85	85	85
	21	300	295	220	220	165	165	135	135	120	120	105	105	105	105
	AVE.	343	342	252	252	175	175	140	140	123	123	102	102	102	102
4	5	390	390	285	285	205	205	180	180	160	160	155	155	155	150
	18	320	320	245	245	185	185	165	165	150	150	145	145	145	140
	23	290	280	200	200	150	150	135	135	125	125	115	115	115	110
	AVE.	333	330	243	243	180	180	160	160	145	145	138	138	138	133
5	9	355	355	315	315	250	250	215	215	195	195	175	170	170	165
	24	345	345	280	280	230	230	200	200	180	180	165	160	160	160
	27	395	390	340	340	270	265	225	220	205	205	170	165	165	160
	AVE.	365	363	312	312	250	248	213	212	193	193	170	165	165	162
6	1	325	325	275	275	210	210	170	170	145	145	115	115	115	115
	2	360	360	300	300	225	225	180	180	150	150	115	115	115	115
	25	330	330	275	275	195	195	155	155	130	130	100	100	100	100
	AVE.	338	338	283	283	210	210	168	168	142	142	110	110	110	110
7	12	330	330	330	330	300	300	275	275	260	255	240	235	235	230
	14	325	325	310	310	270	270	245	245	230	230	210	210	210	190
	19	330	330	330	330	290	290	265	260	240	230	225	225	225	220
	AVE.	328	328	323	323	287	287	262	260	243	238	225	223	223	213
8	6	375	370	360	360	300	300	260	260	240	240	200	195	195	190
	13	330	330	320	320	270	270	240	235	220	215	190	185	185	180
	16	305	305	300	300	255	255	225	225	205	205	170	170	170	170
	AVE.	337	335	327	327	275	275	242	240	222	220	187	183	183	180
CONTROL	10	1885	1830	1830	1425	1425	1205	1205	1100	1100	885	885	735	735	540
	22	1610	1430	1430	1110	1110	965	965	800	800	695	695	600	600	435
	26	1685	1660	1660	1280	1280	1090	1090	915	915	720	720	625	625	490
	AVE.	1727	1640	1640	1272	1272	1087	1087	938	938	767	767	653	653	488

Table A-3: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), Basal area per acre.

		Basal area--sq.ft. per acre													
		CALIBRATION PERIOD		TREATMENT PERIOD #1		TREATMENT PERIOD #2		TREATMENT PERIOD #3		TREATMENT PERIOD #4		TREATMENT PERIOD #5		MEASUREMENT PERIOD #6	
		1963	1966	1966	1970	1970	1973	1973	1975	1975	1979	1979	1983	1983	1988
Treatment	Plot	20	23	23	27	27	30	30	32	32	36	36	40	40	45
1	3	49.6	88.4	55.9	102.1	60.3	86.0	64.7	77.7	65.5	88.8	68.6	88.3	88.3	113.4
	8	50.2	84.2	54.8	98.1	60.3	84.2	64.5	76.7	66.3	89.4	68.3	89.5	89.5	115.8
	20	48.3	84.0	54.8	98.1	60.6	85.2	63.9	76.6	66.5	90.1	70.2	89.6	89.6	112.8
	AVE.	49.4	85.5	55.1	99.4	60.4	85.1	64.4	77.0	66.1	89.4	69.0	89.1	89.1	114.0
2	4	50.3	87.3	56.0	102.2	66.1	93.5	77.0	93.0	84.3	112.3	102.0	129.2	129.2	161.0
	15	50.1	88.3	57.0	102.6	66.1	93.1	77.3	92.3	85.7	111.8	102.0	127.0	127.0	155.5
	17	49.7	85.8	54.7	96.7	66.4	91.3	75.0	89.0	84.2	110.1	100.6	126.2	126.2	154.2
	AVE.	50.0	87.1	55.9	100.5	66.2	92.6	76.5	91.4	84.7	111.4	101.5	127.5	127.5	156.9
3	7	48.6	83.0	65.2	113.1	81.8	112.5	92.3	109.2	97.7	127.3	107.8	135.5	135.5	168.6
	11	49.3	87.2	65.1	114.5	81.6	111.5	92.7	109.7	97.8	127.9	106.9	132.9	132.9	164.9
	21	49.1	84.7	62.5	106.8	81.4	109.9	92.2	107.8	97.3	123.4	107.9	130.3	130.3	155.4
	AVE.	49.0	85.0	64.2	111.5	81.6	111.3	92.4	108.9	97.6	126.2	107.5	132.9	132.9	163.0
4	5	50.7	88.4	66.9	116.2	86.6	117.8	105.8	124.1	115.3	145.6	140.6	170.5	170.5	200.6
	18	49.6	85.9	65.6	113.5	87.3	118.0	105.5	122.9	115.9	145.4	140.4	168.8	168.8	197.6
	23	51.0	85.8	64.4	108.3	87.0	115.7	105.3	122.3	116.3	144.7	139.4	166.1	166.1	193.3
	AVE.	50.4	86.7	65.6	112.6	87.0	117.2	105.5	123.1	115.8	145.2	140.2	168.5	168.5	197.1
5	9	48.2	83.5	75.0	126.5	103.0	136.9	121.3	139.2	130.5	163.6	147.4	174.1	174.1	204.5
	24	50.7	89.9	74.9	124.1	103.4	137.1	121.1	140.7	130.1	160.8	148.4	174.5	174.5	202.4
	27	48.7	84.5	74.8	128.9	104.5	138.8	120.8	140.6	130.5	168.6	147.8	177.7	177.7	215.4
	AVE.	49.2	86.0	74.9	126.5	103.6	137.6	121.1	140.1	130.4	164.3	147.9	175.4	175.4	207.4
6	1	50.2	87.2	75.2	125.9	98.1	131.1	107.9	126.4	112.1	141.6	115.4	143.7	143.7	175.0
	2	50.5	89.1	75.1	128.2	97.6	132.0	108.2	127.6	111.6	144.7	115.0	145.0	145.0	182.3
	25	48.8	87.6	75.0	128.1	97.9	131.6	108.9	127.8	111.6	143.0	114.4	140.3	140.3	169.1
	AVE.	49.9	88.0	75.1	127.4	97.8	131.5	108.3	127.3	111.8	143.1	114.9	143.0	143.0	175.4
7	12	49.2	83.7	83.7	136.7	124.6	161.0	150.3	169.4	162.3	196.5	185.8	219.0	219.0	255.8
	14	51.0	88.5	85.5	141.6	124.7	162.9	149.4	169.4	162.3	198.0	186.4	222.5	222.5	254.4
	19	50.0	85.5	85.5	139.8	124.1	161.0	150.3	170.7	162.3	192.3	186.5	221.7	221.7	257.7
	AVE.	50.1	85.9	84.9	139.4	124.5	161.6	150.0	169.8	162.3	195.6	186.2	221.1	221.1	256.0
8	6	51.2	88.8	86.7	141.5	118.8	154.4	137.0	154.9	145.7	179.9	154.7	187.7	187.7	226.0
	13	51.0	88.1	85.6	137.2	118.6	153.0	136.5	153.9	143.9	175.4	154.4	183.4	183.4	213.2
	16	49.0	86.6	85.2	139.1	118.6	155.4	137.4	157.9	144.1	180.1	153.7	188.4	188.4	228.4
	AVE.	50.4	87.8	85.8	139.3	118.7	154.3	137.0	155.6	144.6	178.5	154.3	186.5	186.5	222.5
CONTROL	10	134.1	178.4	178.4	218.8	218.8	243.5	243.5	250.0	250.0	261.1	261.1	274.6	274.6	269.4
	22	158.3	201.7	201.7	245.9	245.9	275.4	275.4	277.1	277.1	300.2	300.2	320.2	320.2	319.6
	26	121.9	174.0	174.0	221.2	221.2	249.9	249.9	255.9	255.9	272.7	272.7	290.5	290.5	300.1
	AVE.	138.1	184.7	184.7	228.6	228.6	256.3	256.3	261.0	261.0	278.0	278.0	295.1	295.1	296.3

Table A-4: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), quadratic mean diameter.

		Quadratic mean diameter--inches													
		CALIBRATION PERIOD		TREATMENT PERIOD #1		TREATMENT PERIOD #2		TREATMENT PERIOD #3		TREATMENT PERIOD #4		TREATMENT PERIOD #5		MEASUREMENT PERIOD #6	
		1963	1966	1966	1970	1970	1973	1973	1975	1975	1979	1979	1983	1983	1988
Treatment	Plot	20	23	23	27	27	30	30	32	32	36	36	40	40	45
1	3	5.1	6.9	7.0	9.4	9.8	11.7	11.8	12.9	13.1	15.3	15.9	18.0	18.0	20.4
	8	4.9	6.4	6.7	8.9	9.6	11.3	12.2	13.3	13.2	15.3	15.8	18.1	18.1	20.6
	20	5.1	6.8	6.9	9.3	9.6	11.4	11.7	12.9	13.2	15.4	15.3	17.3	17.3	19.4
	AVE.	5.1	6.7	6.9	9.2	9.7	11.5	11.9	13.0	13.2	15.3	15.7	17.8	17.8	20.1
2	4	5.1	6.7	6.8	9.2	9.5	11.3	11.6	12.7	12.8	14.7	14.8	16.7	16.7	18.6
	15	5.3	7.1	7.5	10.1	11.0	13.1	13.7	15.0	15.0	17.1	17.0	18.9	18.9	20.9
	17	5.1	6.8	6.8	9.1	9.3	11.1	11.2	12.2	12.1	13.9	14.3	16.0	16.0	17.7
	AVE.	5.2	6.8	7.1	9.5	9.9	11.8	12.2	13.3	13.3	15.2	15.4	17.2	17.2	19.1
3	7	4.8	6.2	6.4	8.4	8.7	10.2	10.3	11.2	11.1	12.7	13.1	14.7	14.7	16.4
	11	5.2	6.9	7.1	9.4	9.7	11.3	11.7	12.7	13.1	14.9	15.2	16.9	16.9	18.9
	21	5.5	7.3	7.2	9.4	9.5	11.1	11.2	12.1	12.2	13.7	13.7	15.1	15.1	16.5
	AVE.	5.1	6.8	6.9	9.1	9.3	10.8	11.0	12.0	12.1	13.8	14.0	15.6	15.6	17.2
4	5	4.9	6.4	6.6	8.6	8.8	10.3	10.4	11.2	11.5	12.9	12.9	14.2	14.2	15.7
	18	5.3	7.0	7.0	9.2	9.3	10.8	10.8	11.7	11.9	13.3	13.3	14.6	14.6	16.1
	23	5.7	7.5	7.7	10.0	10.3	11.9	12.0	12.9	13.1	14.6	14.9	16.3	16.3	17.9
	AVE.	5.3	7.0	7.1	9.3	9.5	11.0	11.1	11.9	12.2	13.6	13.7	15.0	15.0	16.6
5	9	5.0	6.6	6.6	8.6	8.7	10.0	10.2	10.9	11.1	12.4	12.4	13.7	13.7	15.1
	24	5.2	6.9	7.0	9.0	9.1	10.5	10.5	11.4	11.5	12.8	12.8	14.1	14.1	15.2
	27	4.8	6.3	6.4	8.3	8.4	9.8	9.9	10.8	10.8	12.3	12.6	14.1	14.1	15.7
	AVE.	5.0	6.6	6.7	8.6	8.7	10.1	10.2	11.0	11.1	12.5	12.6	14.0	14.0	15.3
6	1	5.3	7.0	7.1	9.2	9.3	10.7	10.8	11.7	11.9	13.4	13.6	15.1	15.1	16.7
	2	5.1	6.7	6.8	8.9	8.9	10.4	10.5	11.4	11.7	13.3	13.5	15.2	15.2	17.0
	25	5.2	7.0	7.1	9.2	9.6	11.1	11.3	12.3	12.5	14.2	14.5	16.0	16.0	17.6
	AVE.	5.2	6.9	7.0	9.1	9.3	10.7	10.9	11.8	12.0	13.6	13.9	15.5	15.5	17.1
7	12	5.2	6.8	6.8	8.7	8.7	9.9	10.0	10.6	10.7	11.9	11.9	13.1	13.1	14.3
	14	5.4	7.1	7.1	9.2	9.2	10.5	10.6	11.3	11.4	12.6	12.8	13.9	13.9	15.7
	19	5.3	6.9	6.9	8.8	8.9	10.1	10.2	11.0	11.1	12.4	12.3	13.4	13.4	14.7
	AVE.	5.3	6.9	6.9	8.9	8.9	10.2	10.3	11.0	11.1	12.3	12.3	13.5	13.5	14.9
8	6	5.0	6.6	6.6	8.5	8.5	9.7	9.8	10.4	10.5	11.7	11.9	13.3	13.3	14.8
	13	5.3	7.0	7.0	8.9	9.0	10.2	10.2	11.0	11.0	12.2	12.2	13.5	13.5	14.7
	16	5.4	7.2	7.2	9.2	9.2	10.6	10.6	11.3	11.4	12.7	12.9	14.3	14.3	15.7
	AVE.	5.3	6.9	7.0	8.9	8.9	10.2	10.2	10.9	11.0	12.2	12.3	13.7	13.7	15.1
CONTROL	10	3.6	4.2	4.2	5.3	5.3	6.1	6.1	6.5	6.5	7.4	7.4	8.3	8.3	9.6
	22	4.2	5.1	5.1	6.4	6.4	7.2	7.2	8.0	8.0	8.9	8.9	9.9	9.9	11.6
	26	3.6	4.4	4.4	5.6	5.6	6.5	6.5	7.2	7.2	8.3	8.3	9.2	9.2	10.6
	AVE.	3.8	4.6	4.6	5.8	5.8	6.6	6.6	7.2	7.2	8.2	8.2	9.1	9.1	10.6

Table A-5: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), total stem cubic volume per acre.

		Volume—cubic feet per acre													
		CALIBRATION PERIOD		TREATMENT PERIOD #1		TREATMENT PERIOD #2		TREATMENT PERIOD #3		TREATMENT PERIOD #4		TREATMENT PERIOD #5		MEASUREMENT PERIOD #6	
		1963	1966	1966	1970	1970	1973	1973	1975	1975	1979	1979	1983	1983	1988
Treatment	Plot	20	23	23	27	27	30	30	32	32	36	36	40	40	45
1	3	711	1544	985	2262	1347	2246	1693	2138	1806	2830	2191	3118	3118	4261
	8	783	1586	1044	2377	1487	2361	1809	2224	1925	2943	2248	3248	3248	4576
	20	738	1608	1053	2305	1434	2301	1733	2213	1922	2947	2295	3283	3283	4486
	AVE.	744	1579	1028	2314	1423	2303	1745	2192	1884	2906	2245	3216	3216	4441
2	4	733	1606	1031	2357	1530	2523	2084	2626	2380	3711	3367	4659	4659	6385
	15	745	1727	1135	2473	1631	2639	2206	2810	2610	3739	3410	4691	4691	6134
	17	709	1508	962	2230	1545	2460	2028	2595	2452	3609	3321	4695	4695	6272
	AVE.	729	1614	1043	2353	1568	2541	2106	2677	2481	3686	3366	4682	4682	6264
3	7	754	1544	1222	2605	1893	3096	2545	3158	2813	4263	3632	5034	5034	6910
	11	754	1605	1200	2714	1937	3080	2567	3187	2853	4252	3559	4843	4843	6721
	21	729	1586	1171	2456	1873	2998	2516	3177	2872	4151	3628	4848	4848	6317
	AVE.	746	1578	1197	2592	1901	3058	2543	3174	2846	4222	3606	4908	4908	6649
4	5	724	1554	1186	2571	1925	3017	2714	3333	3112	4499	4345	6038	6038	8083
	18	706	1593	1220	2712	2089	3241	2904	3661	3476	4940	4773	6461	6461	8220
	23	818	1723	1305	2704	2185	3398	3092	3857	3669	5155	4964	6378	6378	8032
	AVE.	749	1623	1237	2662	2066	3219	2904	3617	3419	4865	4694	6292	6292	8112
5	9	761	1644	1481	3150	2570	3883	3446	4262	4004	5647	5093	6748	6748	8682
	24	699	1576	1323	2824	2363	3677	3252	3975	3687	5344	4938	6656	6656	8457
	27	700	1476	1311	2911	2364	3647	3174	4035	3746	5435	4765	6602	6602	8736
	AVE.	720	1565	1371	2962	2432	3736	3291	4091	3812	5475	4932	6669	6669	8625
6	1	761	1601	1388	2927	2287	3543	2919	3681	3265	4683	3818	5279	5279	6999
	2	717	1571	1329	2873	2193	3449	2830	3556	3124	4671	3718	5275	5275	7326
	25	752	1626	1393	3057	2342	3672	3049	3818	3340	4796	3841	5057	5057	6917
	AVE.	743	1599	1370	2952	2274	3555	2933	3685	3243	4717	3792	5204	5204	7081
7	12	753	1552	1552	3233	2944	4402	4114	4996	4792	6626	6265	8196	8196	10590
	14	789	1666	1610	3314	2920	4458	4094	4930	4728	6637	6254	8381	8381	10793
	19	708	1503	1503	3257	2896	4348	4067	4952	4716	6423	6227	8670	8670	10936
	AVE.	750	1574	1555	3268	2920	4403	4092	4959	4745	6562	6249	8416	8416	10773
8	6	755	1607	1572	3231	2718	4184	3730	4462	4208	6084	5233	7080	7080	9398
	13	770	1588	1543	3156	2732	4103	3665	4346	4063	5775	5088	6614	6614	8883
	16	780	1706	1679	3486	2972	4496	3973	4811	4394	6218	5310	7207	7207	9527
	AVE.	768	1634	1598	3291	2807	4261	3789	4540	4221	6026	5210	6967	6967	9269
CONTROL	10	1823	3204	3204	4942	4942	6269	6269	7002	7002	8298	8298	9542	9542	10555
	22	2344	3787	3787	6019	6019	7843	7843	8529	8529	10521	10521	12533	12533	13746
	26	1780	3094	3094	5272	5272	6753	6753	7325	7325	9116	9116	10533	10533	12043
	AVE.	1982	3362	3362	5411	5411	6955	6955	7619	7619	9312	9312	10869	10869	12115

Table A-6: Hoskins LOGS--Basic data for all live trees, 1963-1988 (total stand age 20-45), Scribner board foot volume (6-inch top and 16-foot logs) per acre.

		Volume--Scribner board feet per acre													
		CALIBRATION PERIOD		TREATMENT PERIOD #1		TREATMENT PERIOD #2		TREATMENT PERIOD #3		TREATMENT PERIOD #4		TREATMENT PERIOD #5		MEASUREMENT PERIOD #6	
		1963	1966	1966	1970	1970	1973	1973	1975	1975	1979	1979	1983	1983	1988
Treatment	Plot	20	23	23	27	27	30	30	32	32	36	36	40	40	45
1	3	165	1739	1229	6265	3906	8336	6334	8680	7391	13064	10279	15738	15738	22621
	8	199	1600	1261	6288	4423	8667	7043	9270	7992	13729	10629	16539	16539	24707
	20	139	1752	1234	6224	4113	8419	6508	9061	8005	13740	10684	16519	16519	23898
	AVE.	168	1697	1241	6259	4147	8474	6628	9004	7796	13511	10531	16265	16265	23742
2	4	85	1559	1057	6306	4251	9118	7737	10631	9638	17029	15499	23093	23093	33665
	15	282	2534	2012	7970	5667	10876	9372	12718	11800	18268	16610	24309	24309	33243
	17	156	1741	1093	5976	4318	8886	7367	10332	9725	16157	15114	23209	23209	32878
	AVE.	174	1945	1387	6751	4745	9626	8159	11227	10388	17151	15741	23537	23537	33262
3	7	215	1368	1253	6083	4628	10115	8445	11685	10316	18185	15841	23995	23995	35344
	11	158	1972	1616	7504	5645	11337	9672	12990	11858	19716	16622	24166	24166	35793
	21	260	2138	1614	6732	5212	10675	9049	12547	11418	18505	16170	23298	23298	32270
	AVE.	211	1826	1494	6773	5162	10709	9056	12407	11197	18802	16211	23820	23820	34469
4	5	126	1462	1222	6183	4767	9820	8945	12131	11555	19019	18353	27953	27953	40442
	18	100	1970	1542	7666	5909	11607	10441	14382	13836	21940	21199	31110	31110	41912
	23	462	2948	2437	8377	7068	13197	12070	16212	15556	24031	23402	32118	32118	42456
	AVE.	230	2126	1734	7409	5915	11541	10485	14242	13649	21663	20985	30394	30394	41603
5	9	76	1628	1536	7533	6317	12650	11418	15568	14891	23909	21615	31496	31496	43492
	24	185	2034	1810	7526	6450	12608	11248	15013	14065	22981	21303	31537	31537	42516
	27	112	1270	1189	6518	5466	11230	9951	14404	13349	22384	20003	31108	31108	43953
	AVE.	124	1644	1512	7192	6078	12163	10873	14995	14101	23091	20974	31381	31381	43320
6	1	240	2125	1908	7983	6286	12287	10198	14037	12655	20450	16812	25382	25382	35848
	2	179	1844	1662	7347	5715	11577	9591	13348	11951	20397	16325	25351	25351	37745
	25	127	1816	1614	8146	6634	13242	11227	15324	13616	21762	17602	24720	24720	36168
	AVE.	182	1928	1728	7825	6212	12368	10339	14236	12741	20870	16913	25151	25151	36587
7	12	212	1881	1881	8041	7283	14036	13283	17726	17138	26951	25532	36884	36884	51310
	14	214	2170	2130	8786	7831	15179	14031	18310	17732	28076	26735	39225	39225	54704
	19	203	1846	1846	8353	7464	14206	13456	17936	17333	26818	25914	39714	39714	53809
	AVE.	210	1966	1952	8393	7526	14474	13590	17991	17401	27282	26060	38608	38608	53274
8	6	210	1913	1886	7989	6766	13258	12066	15828	15050	24440	21314	32270	32270	46110
	13	388	2205	2170	8209	7195	13641	12247	15838	14813	23547	20737	29745	29745	43792
	16	166	2250	2224	9480	8123	15573	13745	18189	16625	26621	22963	34018	34018	48108
	AVE.	255	2123	2093	8559	7361	14157	12686	16619	15496	24869	21671	32011	32011	46003
CONTROL	10	337	1083	1083	4341	4341	8556	8556	11164	11164	17960	17960	25563	25563	35895
	22	719	3240	3240	9829	9829	17182	17182	21719	21719	32453	32453	45389	45389	59013
	26	269	1816	1816	6901	6901	12581	12581	16573	16573	25497	25497	34440	34440	46990
	AVE.	441	2046	2046	7024	7024	12773	12773	16485	16485	25303	25303	35130	35130	47299

(*) Scribner volume is in 16-foot logs to a 6-inch top.

Table A-7: Hoskins LOGS--Periodic annual and total mortality for all trees. Year and total stand age are at the end of the treatment period.

	End of Period							Total
Treatment Numbers	1966 23	1970 27	1973 30	1975 32	1979 36	1983 40	1988 45	1963-1988 20-45
				Number of trees per acre				
1	.56	.00	.00	.00	.00	.00	.00	1.67
2	.56	.00	.56	.00	.00	.00	.00	3.33
3	.56	.00	.00	.00	.00	.00	.00	1.67
4	1.11	.00	.00	.00	.00	.00	1.00	8.33
5	.56	.00	.56	.83	.00	1.25	.67	13.33
6	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	.83	1.25	.42	2.00	18.33
8	.56	.00	.00	.83	.42	.83	.67	11.67
Control	28.89	92.08	61.67	74.17	42.92	28.33	33.00	1238.33
				Quadratic mean diameter--inches				
1	3.48	.00	.00	.00	.00	.00	.00	3.48
2	4.20	.00	4.28	.00	.00	.00	.00	4.24
3	4.11	.00	.00	.00	.00	.00	.00	4.11
4	4.08	.00	.00	.00	.00	.00	8.14	6.81
5	5.42	.00	7.61	8.01	.00	9.97	5.47	7.98
6	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	5.21	8.66	5.90	6.88	7.20
8	4.99	.00	.00	4.99	4.81	5.90	6.97	5.85
Control	2.08	2.52	3.04	4.00	4.28	4.90	6.15	3.90
				Basal area--sq.ft. per acre				
1	.04	.00	.00	.00	.00	.00	.00	.11
2	.05	.00	.06	.00	.00	.00	.00	.33
3	.05	.00	.00	.00	.00	.00	.00	.15
4	.10	.00	.00	.00	.00	.00	.36	2.11
5	.09	.00	.18	.29	.00	.68	.11	4.63
6	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	.12	.51	.08	.52	5.19
8	.08	.00	.00	.11	.05	.16	.18	2.18
Control	.68	3.18	3.10	6.46	4.29	3.70	6.80	102.99
				Volume--cubic feet per acre				
1	.58	.00	.00	.00	.00	.00	.00	1.75
2	.81	.00	.95	.00	.00	.00	.00	5.27
3	.90	.00	.00	.00	.00	.00	.00	2.70
4	1.63	.00	.00	.00	.00	.00	14.04	75.10
5	1.43	.00	4.57	8.26	.00	23.63	3.62	147.11
6	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	3.20	16.83	2.50	20.62	186.85
8	1.18	.00	.00	2.58	2.02	5.52	6.81	72.88
Control	8.85	60.59	68.82	166.14	126.00	120.17	249.20	3038.34
				Volume--Scribner board feet per acre (*)				
1	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00	.00	30.33	151.65
5	.00	.00	6.90	15.58	.00	84.92	.48	393.95
6	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	.00	53.35	.00	24.91	337.95
8	.00	.00	.00	.00	.00	.28	12.05	61.36
Control	.00	.00	.00	36.05	26.69	25.44	198.07	1271.00

(*) Scribner volume is in 16-foot logs to a 6-inch top.

Table A-8: Hoskins LOGS--Live trees cut by treatment period and total. Year and total stand age area at the start of the period.

Treatment Numbers	Start of Period 1966 23	1970 27	1973 30	1975 32	1979 36	1983 40	Total
			Number of trees per acre				
1	136.7	96.7	35.0	13.3	18.3	.0	300.0
2	135.0	81.7	26.7	6.7	10.0	.0	260.0
3	90.0	76.7	35.0	16.7	21.7	.0	240.0
4	86.7	63.3	20.0	15.0	6.7	.0	191.7
5	51.7	61.7	35.0	18.3	23.3	.0	190.0
6	55.0	73.3	41.7	26.7	31.7	.0	228.3
7	5.0	36.7	25.0	16.7	13.3	.0	96.7
8	8.3	51.7	33.3	18.3	33.3	.0	145.0
Control	.0	.0	.0	.0	.0	.0	.0
			Quadratic mean diameter--inches				
1	6.4	8.6	10.4	12.3	14.3	.0	8.6
2	6.5	8.8	10.5	13.6	13.4	.0	8.3
3	6.5	8.5	10.0	11.1	12.6	.0	8.7
4	6.7	8.6	10.3	9.4	11.8	.0	8.2
5	6.3	8.2	9.3	9.9	11.4	.0	8.6
6	6.6	8.6	10.1	10.3	12.8	.0	9.4
7	6.1	8.6	9.2	9.1	11.4	.0	9.2
8	6.6	8.6	9.8	10.5	11.5	.0	9.7
Control	.0	.0	.0	.0	.0	.0	.0
			Basal area--sq.ft. per acre				
1	30.4	39.1	20.8	10.9	20.4	.0	121.5
2	31.2	34.3	16.2	6.7	9.9	.0	98.3
3	20.7	29.9	18.9	11.3	18.7	.0	99.5
4	21.0	25.7	11.6	7.2	5.1	.0	70.6
5	11.1	22.9	16.5	9.8	16.4	.0	76.7
6	12.9	29.6	23.2	15.5	28.1	.0	109.3
7	1.0	14.9	11.6	7.5	9.4	.0	44.5
8	2.0	20.6	17.3	11.0	24.2	.0	75.1
Control	.0	.0	.0	.0	.0	.0	.0
			Volume--cubic feet per acre				
1	551.8	891.8	558.0	307.5	661.6	.0	2970.7
2	570.9	784.7	435.0	196.7	320.3	.0	2307.7
3	380.7	690.3	514.9	327.9	615.7	.0	2529.6
4	386.7	596.2	315.0	198.2	170.9	.0	1667.0
5	193.9	529.3	444.9	278.5	543.1	.0	1989.6
6	229.4	678.5	622.3	441.9	924.6	.0	2896.7
7	18.5	347.8	310.9	214.5	313.1	.0	1204.8
8	35.9	483.9	471.5	318.2	815.7	.0	2125.2
Control	.0	.0	.0	.0	.0	.0	.0
			Volume--Scribner board feet per acre (*)				
1	455.6	2112.0	1846.0	1208.1	2980.2	.0	8601.9
2	557.3	2005.3	1467.5	839.1	1410.2	.0	6279.4
3	331.8	1611.2	1653.3	1210.2	2591.3	.0	7397.8
4	392.9	1493.7	1056.0	592.9	678.2	.0	4213.7
5	132.5	1114.7	1290.1	893.5	2117.6	.0	5548.7
6	200.4	1613.7	2029.9	1495.6	3956.6	.0	9296.3
7	13.4	867.2	883.8	589.5	1221.3	.0	3575.2
8	29.3	1197.8	1471.0	1122.7	3198.2	.0	7018.9
Control	.0	.0	.0	.0	.0	.0	.0

(*) Scribner volume is in 16-foot logs to a 6-inch top.

Table A-9: Hoskins LOGS--Periodic annual net, survivor and total quadratic mean diameter growth.

	Diameter growth--inches/year							
TREATMENT NUMBERS	CALIBRATION (1963-1966) (20-23)	1ST PERIOD (1966-1970) (23-27)	2D PERIOD (1970-1973) (27-30)	3D PERIOD (1973-1975) (30-32)	4TH PERIOD (1975-1979) (32-36)	5TH PERIOD (1979-1983) (36-40)	6TH PERIOD (1983-1988) (40-45)	TOTAL (1963-1988) (20-45)
				NET GROWTH				
1	.54	.59	.60	.56	.54	.53	.47	13.52
2	.56	.60	.63	.57	.49	.46	.38	12.78
3	.55	.55	.52	.47	.42	.39	.33	11.23
4	.56	.55	.51	.44	.36	.33	.31	10.58
5	.54	.50	.45	.41	.34	.33	.27	9.85
6	.57	.53	.49	.46	.40	.40	.33	11.04
7	.55	.49	.42	.35	.30	.29	.28	9.27
8	.57	.48	.42	.35	.32	.34	.28	9.56
9	.24	.30	.28	.30	.25	.23	.29	6.76
				SURVIVOR GROWTH				
1	.54	.59	.60	.56	.54	.53	.47	13.51
2	.56	.60	.61	.57	.49	.46	.38	12.73
3	.55	.55	.52	.47	.42	.39	.33	11.22
4	.56	.55	.51	.44	.36	.33	.27	10.36
5	.54	.50	.45	.40	.34	.32	.25	9.64
6	.57	.53	.49	.46	.40	.40	.33	11.04
7	.55	.49	.42	.33	.29	.28	.23	8.92
8	.57	.48	.42	.34	.31	.32	.26	9.33
9	.22	.19	.16	.12	.13	.13	.13	3.84

Table A-10: Hoskins LOGS--Periodic annual net, gross and total basal area growth.

TREATMENT NUMBERS	CALIBRATION (1963-1966) (20-23)	1ST PERIOD (1966-1970) (23-27)	2D PERIOD (1970-1973) (27-30)	3D PERIOD (1973-1975) (30-32)	4TH PERIOD (1975-1979) (32-36)	5TH PERIOD (1979-1983) (36-40)	6TH PERIOD (1983-1988) (40-45)	TOTAL (1963-1988) (20-45)
	Basal area growth--sq.ft./acre/year							
	GROWTH	GROWTH	GROWTH	GROWTH	GROWTH	GROWTH	GROWTH	GROWTH
				NET GROWTH				
1	12.1	11.1	8.2	6.3	5.8	5.0	5.0	186.2
2	12.4	11.2	8.8	7.5	6.7	6.5	5.9	205.2
3	12.0	11.8	9.9	8.3	7.2	6.3	6.0	213.4
4	12.1	11.8	10.1	8.8	7.3	7.1	5.7	217.4
5	12.3	12.9	11.3	9.5	8.5	6.9	6.4	234.9
6	12.7	13.1	11.2	9.5	7.8	7.0	6.5	234.9
7	11.9	13.6	12.4	9.9	8.3	8.7	7.0	250.4
8	12.5	13.4	11.9	9.3	8.5	8.1	7.2	247.2
Control	15.5	11.0	9.2	2.4	4.2	4.3	.2	158.3
				GROSS GROWTH				
1	12.1	11.1	8.2	6.3	5.8	5.0	5.0	186.3
2	12.4	11.2	8.9	7.5	6.7	6.5	5.9	205.5
3	12.0	11.8	9.9	8.3	7.2	6.3	6.0	213.6
4	12.2	11.8	10.1	8.8	7.3	7.1	6.1	219.5
5	12.3	12.9	11.5	9.8	8.5	7.6	6.5	239.5
6	12.7	13.1	11.2	9.5	7.8	7.0	6.5	234.9
7	11.9	13.6	12.4	10.0	8.8	8.8	7.5	255.6
8	12.6	13.4	11.9	9.4	8.5	8.2	7.4	249.4
Control	16.2	14.2	12.3	8.8	8.5	8.0	7.0	261.3

Table A-11: Hoskins LOGS--Periodic annual net, gross and total stem cubic volume growth and growth percent.

TREATMENT NUMBERS	CALIBRATION (1963-1966) (20-23)		1ST PERIOD (1966-1970) (23-27)		2D PERIOD (1970-1973) (27-30)		3D PERIOD (1973-1975) (30-32)		4TH PERIOD (1975-1979) (32-36)		5TH PERIOD (1979-1983) (36-40)		6TH PERIOD (1983-1988) (40-45)		TOTAL (1963-1988) (20-45)
	Total cubic growth--cubic ft./acre/year														
	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH
							NET GROWTH								
1	278.4	24.0	321.7	19.3	293.4	15.8	223.5	11.4	255.6	10.7	242.8	8.9	244.9	6.4	6667.6
2	295.0	25.1	327.6	19.3	324.1	15.8	285.7	11.9	301.5	9.8	328.9	8.2	316.4	5.8	7842.5
3	277.5	23.9	348.6	18.4	385.4	15.5	315.6	11.0	344.0	9.7	325.5	7.6	348.2	6.0	8433.0
4	291.4	24.6	356.4	18.3	384.1	14.5	356.8	10.9	361.4	8.7	399.7	7.3	363.9	5.1	9029.4
5	281.9	24.7	397.5	18.4	434.4	14.1	400.1	10.8	415.7	9.0	434.1	7.5	391.3	5.1	9895.0
6	285.3	24.4	395.6	18.3	427.0	14.7	376.2	11.4	368.5	9.3	352.9	7.8	375.4	6.1	9234.2
7	274.7	23.6	428.1	17.8	494.3	13.5	433.8	9.6	454.2	8.0	541.7	7.4	471.5	4.9	11228.2
8	288.5	24.0	423.3	17.3	484.6	13.7	375.2	9.0	451.1	8.8	439.3	7.2	460.5	5.7	10626.4
Control	459.8	17.3	512.3	11.7	514.6	8.3	331.9	4.6	423.2	5.0	389.4	3.8	249.1	2.2	10132.5
							GROSS GROWTH								
1	279.0	24.0	321.7	19.3	293.4	15.8	223.5	11.4	255.6	10.7	242.8	8.9	244.9	6.4	6669.3
2	295.8	25.2	327.6	19.3	325.1	15.8	285.7	11.9	301.5	9.8	328.9	8.2	316.4	5.8	7847.8
3	278.4	24.0	348.6	18.4	385.4	15.5	315.6	11.0	344.0	9.7	325.5	7.6	348.2	6.0	8435.7
4	293.0	24.7	356.4	18.3	384.1	14.5	356.8	10.9	361.4	8.7	399.7	7.3	377.9	5.3	9104.5
5	283.3	24.8	397.5	18.4	439.0	14.3	408.4	11.1	415.7	9.0	457.7	7.9	394.9	5.2	10042.2
6	285.3	24.4	395.6	18.3	427.0	14.7	376.2	11.4	368.5	9.3	352.9	7.8	375.4	6.1	9234.2
7	274.7	23.6	428.1	17.8	494.3	13.5	437.0	9.7	471.1	8.3	544.2	7.4	492.1	5.1	11415.0
8	289.7	24.1	423.3	17.3	484.6	13.7	377.8	9.1	453.1	8.8	444.8	7.3	467.3	5.8	10699.3
Control	468.7	17.6	572.9	13.1	583.5	9.4	498.0	6.8	549.2	6.5	509.6	5.0	498.3	4.3	13165.7

Table A-12: Hoskins LOGS--Periodic annual net, gross and total Scribner board foot volume growth and growth percent.

	Scribner volume growth--bd.ft./acre/year													
TREATMENT NUMBERS	CALIBRATION (1963-1966) (20-23)		1ST PERIOD (1966-1970) (23-27)		2D PERIOD (1970-1973) (27-30)		3D PERIOD (1973-1975) (30-32)		4TH PERIOD (1975-1979) (32-36)		5TH PERIOD (1979-1983) (36-40)		6TH PERIOD (1983-1988) (40-45)		TOTAL (1963-1988) (20-45)
	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH	PCT	GROWTH
							NET GROWTH								
1	509.6	54.6	1254.5	33.5	1442.2	22.9	1187.8	15.2	1428.8	13.4	1433.6	10.7	1495.3	7.5	32175.7
2	590.1	56.3	1340.8	33.3	1627.0	22.8	1534.1	15.9	1690.8	12.3	1949.0	9.9	1945.0	6.9	39367.0
3	538.4	52.5	1319.6	32.0	1849.1	23.4	1675.9	15.6	1901.3	12.7	1902.2	9.5	2129.8	7.3	41655.8
4	632.3	55.0	1418.7	31.4	1875.4	21.6	1878.3	15.2	2003.6	11.4	2352.2	9.2	2241.9	6.3	45587.3
5	506.6	57.4	1420.2	32.7	2028.4	22.3	2061.2	16.0	2247.4	12.1	2601.7	10.0	2388.0	6.4	48744.4
6	582.0	55.3	1524.4	31.9	2052.3	22.1	1948.8	15.9	2032.3	12.1	2059.5	9.8	2287.2	7.4	45701.2
7	585.4	53.8	1610.2	31.1	2315.9	21.0	2200.4	13.9	2470.1	11.1	3136.8	9.7	2933.3	6.4	56639.6
8	622.6	52.6	1616.5	30.3	2265.2	21.1	1966.3	13.4	2343.4	11.6	2584.9	9.6	2798.5	7.2	52767.5
9	534.9	42.3	1244.3	28.1	1916.4	19.8	1856.2	12.9	2204.5	10.7	2456.8	8.2	2433.8	6.0	46857.8
							GROSS GROWTH								
1	509.6	54.6	1254.5	33.5	1442.2	22.9	1187.8	15.2	1428.8	13.4	1433.6	10.7	1495.3	7.5	32175.7
2	590.1	56.3	1340.8	33.3	1627.0	22.8	1534.1	15.9	1690.8	12.3	1949.0	9.9	1945.0	6.9	39367.0
3	538.4	52.5	1319.6	32.0	1849.1	23.4	1675.9	15.6	1901.3	12.7	1902.2	9.5	2129.8	7.3	41655.8
4	632.3	55.0	1418.7	31.4	1875.4	21.6	1878.3	15.2	2003.6	11.4	2352.2	9.2	2272.2	6.3	45739.0
5	506.6	57.4	1420.2	32.7	2035.3	22.4	2076.8	16.1	2247.4	12.1	2686.7	10.3	2388.5	6.4	49138.3
6	582.0	55.3	1524.4	31.9	2052.3	22.1	1948.8	15.9	2032.3	12.1	2059.5	9.8	2287.2	7.4	45701.2
7	585.4	53.8	1610.2	31.1	2315.9	21.0	2200.4	13.9	2523.5	11.3	3136.8	9.7	2958.2	6.4	56977.5
8	622.6	52.6	1616.5	30.3	2265.2	21.1	1966.3	13.4	2343.4	11.6	2585.2	9.6	2810.6	7.2	52828.9
9	534.9	42.3	1244.3	28.1	1916.4	19.8	1892.3	13.0	2231.2	10.8	2482.2	8.2	2631.9	6.5	48128.8

Table A-13: Hoskins LOGS--Net and gross yield, total stem cubic volume.

	Cubic volume growth--cubic ft./acre/year							
TREATMENT	1963	1966	1970	1973	1975	1979	1983	1988
NUMBERS	20	23	27	30	32	36	40	45
				NET YIELD				
1	744.02	1579.33	2866.18	3746.36	4193.33	5215.54	6186.94	7411.58
2	728.81	1613.73	2924.07	3896.40	4467.89	5673.81	6989.33	8571.32
3	745.64	1578.15	2972.37	4128.62	4759.84	6135.89	7437.82	9178.61
4	749.35	1623.45	3049.13	4201.36	4914.95	6360.66	7959.41	9778.76
5	719.69	1565.37	3155.40	4458.75	5259.00	6921.82	8658.24	10614.74
6	743.23	1599.09	3181.67	4462.74	5215.04	6688.86	8100.39	9977.44
7	749.81	1573.98	3286.41	4769.18	5636.69	7453.58	9620.45	11977.99
8	768.20	1633.76	3326.84	4780.52	5530.90	7335.20	9092.25	11394.57
Control	1982.46	3361.96	5411.10	6955.02	7618.82	9311.53	10869.25	12114.94
				GROSS YIELD				
1	744.02	1581.08	2867.93	3748.11	4195.08	5217.29	6188.69	7413.33
2	728.81	1616.15	2926.49	3901.67	4473.16	5679.08	6994.60	8576.59
3	745.64	1580.85	2975.07	4131.32	4762.54	6138.59	7440.52	9181.31
4	749.35	1628.35	3054.03	4206.26	4919.85	6365.57	7964.31	9853.86
5	719.69	1569.67	3159.70	4476.77	5293.54	6956.35	8787.28	10761.85
6	743.23	1599.09	3181.67	4462.74	5215.04	6688.86	8100.39	9977.44
7	749.81	1573.98	3286.41	4769.18	5643.10	7527.31	9704.18	12164.84
8	768.20	1637.28	3330.37	4784.04	5539.59	7351.95	9131.09	11467.45
Control	1982.46	3388.51	5679.99	7430.38	8426.47	10623.17	12661.59	15153.28

Table A-14: Hoskins LOGS--Net and gross yield, Scribner board foot volume.

	Scribner volume growth--bd.ft./acre/year							
TREATMENT	1963	1966	1970	1973	1975	1979	1983	1988
NUMBERS	20	23	27	30	32	36	40	45
				NET YIELD				
1	168.00	1696.94	6715.03	11041.73	13417.36	19132.69	24867.05	32343.74
2	174.35	1944.70	7307.90	12188.96	15257.06	22020.28	29816.46	39541.39
3	210.89	1826.11	7104.57	12651.76	16003.64	23608.70	31217.63	41866.70
4	229.55	2126.49	7801.45	13427.76	17184.35	25198.58	34607.54	45816.86
5	124.31	1644.05	7324.69	13409.75	17532.16	26521.91	36928.85	48868.71
6	182.25	1928.28	8025.76	14182.61	18080.24	26209.51	34447.36	45883.46
7	209.69	1965.88	8406.72	15354.28	19755.07	29635.53	42182.83	56849.28
8	254.75	2122.54	8588.43	15383.99	19316.54	28690.13	39029.78	53022.29
Control	441.48	2046.29	7023.58	12772.83	16485.23	25303.33	35130.34	47299.30
				GROSS YIELD				
1	168.00	1696.94	6715.03	11041.73	13417.36	19132.69	24867.05	32343.74
2	174.35	1944.70	7307.90	12188.96	15257.06	22020.28	29816.46	39541.39
3	210.89	1826.11	7104.57	12651.76	16003.64	23608.70	31217.63	41866.70
4	229.55	2126.49	7801.45	13427.76	17184.35	25198.58	34607.54	45968.51
5	124.31	1644.05	7324.69	13430.44	17584.01	26573.77	37320.39	49262.66
6	182.25	1928.28	8025.76	14182.61	18080.24	26209.51	34447.36	45883.46
7	209.69	1965.88	8406.72	15354.28	19755.07	29848.93	42396.23	57187.23
8	254.75	2122.54	8588.43	15383.99	19316.54	28690.13	39030.89	53083.65
Control	441.48	2046.29	7023.58	12772.83	16557.34	25482.21	35410.96	48570.29

Table A-15: Hoskins LOGS--initial 1963 (total age 20) control and after calibration treatment average stand table and treatment stand tables in 1988 (total age 45).

DBH Class	After Calibration 1963 (age 20) Control	Treatments	1988 (age 24) 1	2	3	4	5	6	7	8	Control
inches	trees/acre						trees/acre				
1.6 - 2.5	21										
2.6 - 3.5	482										
3.6 - 4.5	470	37									
4.6 - 5.5	357	91									8
5.6 - 6.5	225	108									38
6.6 - 7.5	113	70				2	3			2	53
7.6 - 8.5	48	31				2	7	2	2	8	68
8.6 - 9.5	5	5			2	2	5		5	5	62
9.6 -10.5	2	1			3	3	3		12	7	73
10.6 -11.5	2				2	2	8	2	23	12	50
11.6 -12.5	0				2	5	10	3	15	10	30
12.6 -13.5	2				5	2	8	5	13	10	48
13.6 -14.5				8	7	23	23	8	25	23	18
14.6 -15.5					7	15	17	7	30	20	8
15.6 -16.5			3	7	13	12	18	13	37	28	15
16.6 -17.5			5	10	13	18	20	30	22	28	3
17.6 -18.5			3	12	15	18	17	12	17	12	7
18.6 -19.5			8	15	18	17	10	8	10	7	2
19.6 -20.5			12	10	8	8	5	15	3	5	2
20.6 -21.5			8	7	5	2	7	3		3	2
21.6 -22.5			5	7	2	2		2			
22.6 -23.5			2	2		2					
23.6 -24.5			5								
24.6 -25.5				3							
25.6 -26.5											
Totals	1727	343	52	80	102	138	165	110	223	183	653