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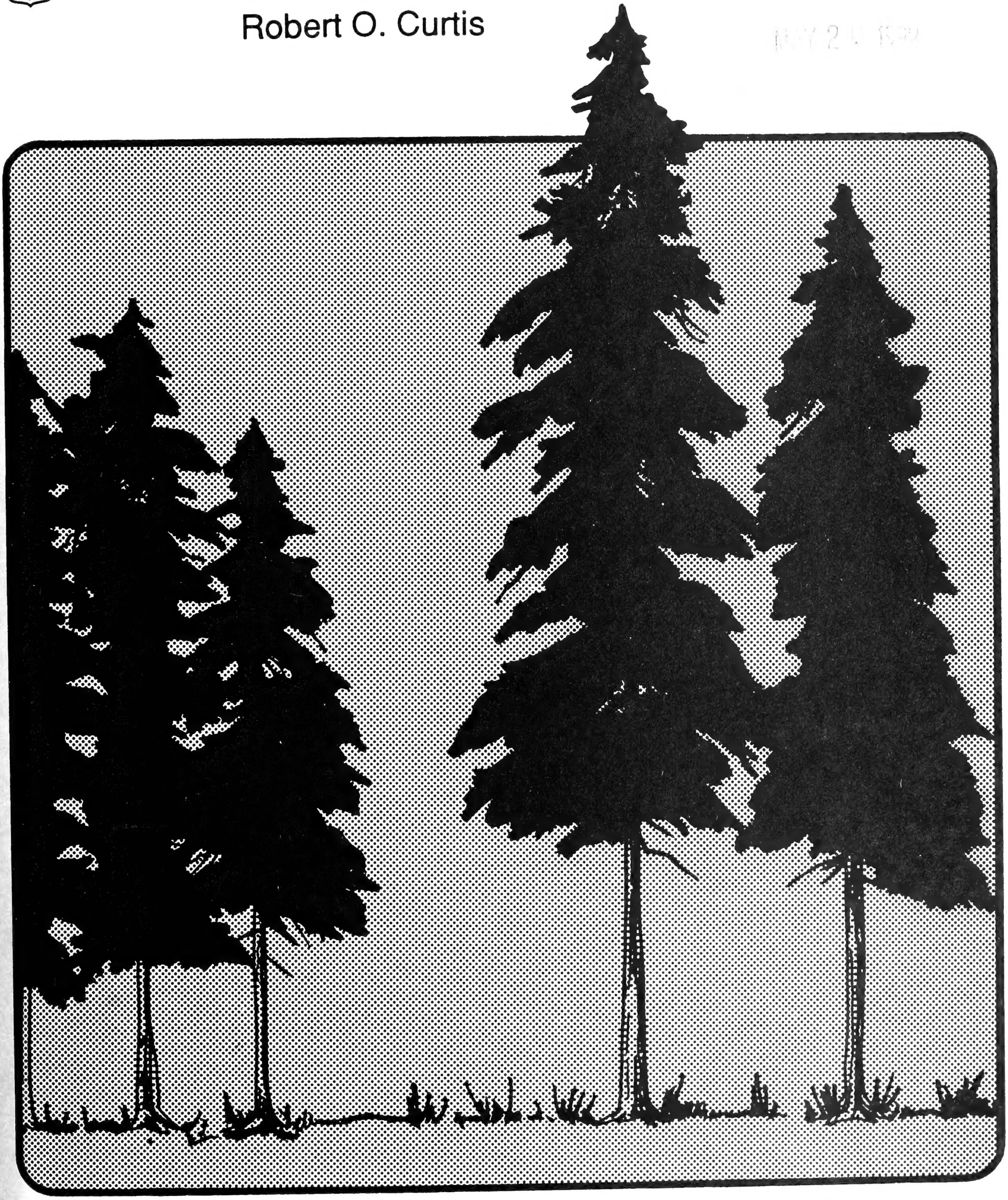
Levels-of-Growing-Stock Cooperative Study in Douglas-Fir:

Report No. 11—Stampede Creek: A 20-Year Progress Report

Robert O. Curtis



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
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Background

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

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

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

This is a progress report on this cooperative study.

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR:

Report No.11—Stampede Creek: a 20-year progress report.

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Research Paper PNW-RP-442
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Abstract

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

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

Summary

Results of the Stampede Creek levels-of-growing-stock (LOGS) study in the Umpqua National Forest in southwest Oregon are summarized through the third treatment period. Results are generally comparable with those obtained in the other LOGS installations. Height growth shows little reduction with increasing age.

Estimated site index (50-year base) is 110 (mid-site III). Growth is strongly related to level of growing stock. Gains from thinning would be minor if the 53-year-old stand were harvested now, but developing differences in size distributions indicate a much more favorable prospect for longer rotations. Periodic annual increment in cubic volume (all stems) is about twice the mean annual increment for all treatments, which indicates that the stand is still far from culmination and far short of rotation age as mandated by the National Forest Management Act of 1976.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Contents

Introduction

The Stampede Creek levels-of-growing-stock (LOGS) installation is one of nine in a regional thinning study established in young even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands according to a common work plan (Williamson and Staebler 1971; appendix 1 in this report). This study is a cooperative effort involving Weyerhaeuser Company, Oregon State University, Washington Department of Natural Resources, Forestry Canada, and the USDA Forest Service. The objective is to compare cumulative wood production, tree size development, and growth-growing stock relations under eight different thinning regimes, which were begun before the onset of severe competition. The original study plan was developed at Weyerhaeuser Company, Centralia, Washington. Procedural details to ensure consistency among cooperators were developed by the Pacific Northwest Research Station, USDA Forest Service, Portland, Oregon.

Descriptions of the program and detailed progress reports on individual installations are contained in the series of LOGS publications (listed in the front matter). Some supplementary information is given by Tappeiner and others (1982). Curtis and Marshall (1986) give an overall analysis of results for the first 20 years, concerned primarily with the higher site installations, which are at or near the end of the planned experiment.

Installations on poorer sites develop more slowly than those on good sites, and the poorer site installations are only now reaching a point where they can be expected to show substantial differences among treatments and possible differences in response from stands on good sites.

This is a progress report on the Stampede Creek LOGS installation, and presents summary data and some limited interpretations of results from establishment (1968) through completion of the third treatment growth period (1988). The installation has one more thinning and two growth periods (an additional 20 feet of height growth) remaining to completion of the experiment as originally planned, expected about 1998.

The Stampede Creek LOGS Installation

The Stampede Creek installation is located in the Tiller Ranger District, Umpqua National Forest, near Tiller in southwest Oregon (fig. 1) in Sec. 10, T.31S., R.1W., Willamette Meridian. It is the only LOGS installation in southwest Oregon (an area often considered ecologically distinct from the Douglas-fir type as found further north) and is within the mixed-conifer *(Pinus-Pseudotsuga-Libocedrus-Abies)* zone of Franklin and Dyrness (1973).

Like the other LOGS installations, the Stampede Creek study is a completely randomized experiment comparing eight thinning regimes (treatments 1-8) and unthinned control (C = treatment 9), with three replications each. An initial calibration thinning at age 33 reduced all treated plots to a common basal area level. Subsequent thinnings retain various percentages of the gross periodic basal area increment observed on the untreated control plots (inside front cover) and are expected to produce the basal area trends shown schematically in figure 2. The thinning interval is the time required for crop trees to grow 10 feet in height (averaged over all treatments). The principal features of the LOGS study plan are reproduced in appendix 1 and are more fully described in Curtis and Marshall (1986).

Figure 1—Locations of levels-of-growing-stock study installations.

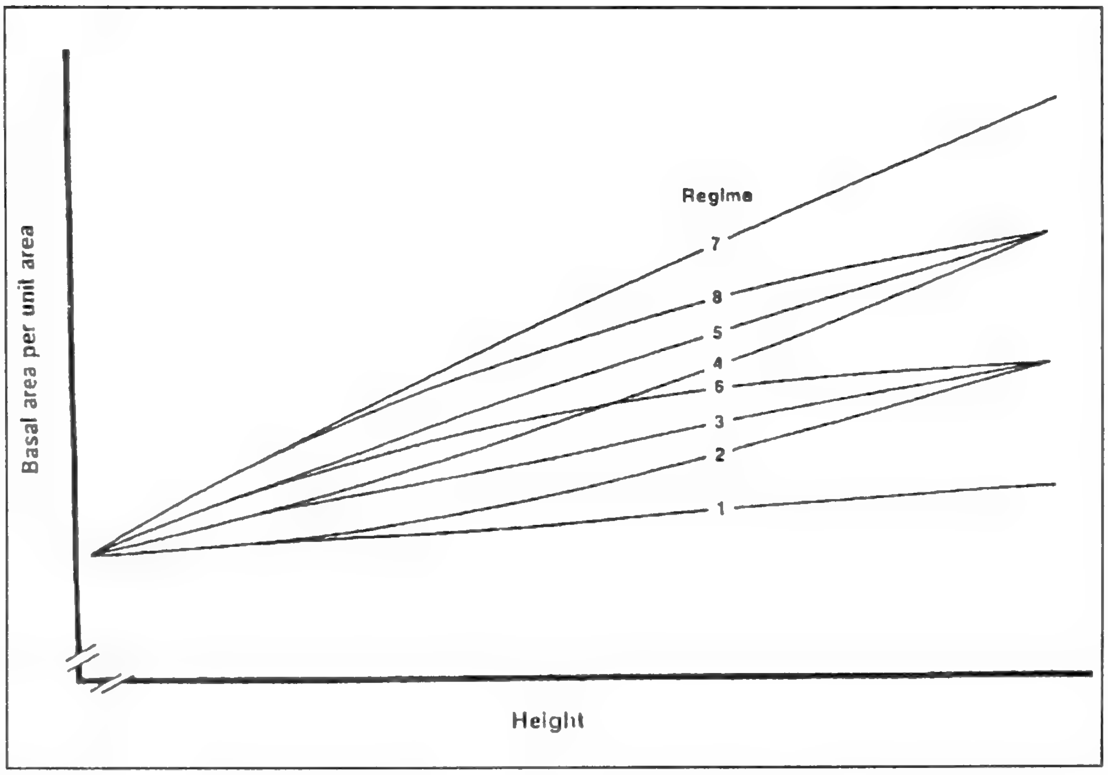

Figure 2—Idealized trends of basal area for the eight thinning regimes.

This predominantly Douglas-fir stand originated by natural seeding after a 1929 wildfire. When the study was established in 1968, the stand was older (age as estimated from borings was 33 years total, 25 years b.h. [breast height]) and taller than the initial conditions of other stands included in the LOGS study. Estimated total ages of dominant and codominant trees ranged from 29 to 36 years (age b.h. + 8). Field notes indicate delayed stand establishment after the fire, presence of well-developed madrone (*Arbutus menziesii* Pursh), chinkapin (*Castanopsis chrysophylla* (Dougl.) A.DC.), and brush species, and fairly uniform spacing. The number of trees and basal areas before thinning were about 83 percent of normal for the quadratic mean diameter (QMD) according to table 25 in McArdle and others (1961). This suggests relatively low early competition and is consistent with the observation that live crowns extended nearly to breast height at the time of study establishment.

The installation is on a broad minor ridge, at an elevation of 2,700 feet, with an average slope of about 25 percent and a generally north to east aspect. Soils are heavy loam over heavy clay loam and clay derived from well-weathered volcanic tuffs and breccias. Average (1972-78) growing season (May to September) temperature and precipitation were 54.9 °F and 7.71 inches, as determined from weather instruments located at the installation. Present ground cover is largely salal (*Gaultheria shallon*). The stand was classified as site IV at time of establishment, but subsequent development has led to a current site index estimate (50 years b.h.) of about 110 feet (site III), based on extrapolation of the height growth curve for the largest 40 stems per acre.

Before study establishment in 1968, about 100 large snags present on the area were felled. Thirty-nine plots were laid out in the stand. Of these, five were rejected as unsuitable, and the 27 judged most comparable were selected for use in the study; of the remaining seven, two were allocated as spare controls and five as spare thinning plots for use if major damage to plots in the experiment made substitution necessary.

The calibration thinning in 1968 adjusted the thinned plots to a common basal area. Subsequent treatment thinnings were made in 1973, 1978, 1983, and 1988; the corresponding growth periods will be referred to as the calibration period and treatment periods 1, 2, and 3 (TP0, TP1, TP2, and TP3 respectively).

The spare plots were measured in 1968 and 1973 only. In 1988, three of the spare thinned plots were remeasured and the other spares were abandoned. These three plots, not provided for in the original study plan, are designated as treatment 10 and will be remeasured in the future, with the intention of providing a supplementary comparison with the effects of a precommercial thinning without subsequent treatment.

Objectives

The objectives of this report are as follows:

1. Present revised data summaries showing development of the Stampede Creek LOGS stands through age 53 (end of third treatment period). These tables include the most recent measurements and replace those in Williamson and Curtis (1984).

2. Compare results to date of the different treatments.

3. Make some limited interpretations of these results in relation to results from the higher site LOGS installations and possible operational stand-management regimes.

Data

The data used as the basis for this report consist of the postcalibration thinning diameters and height sample from 1968 and the prethinning and postthinning measurements from 1973, 1978, 1983, and 1988.

Diameters (to nearest 0.1 inch) at breast height were measured on all trees 1.6 inches d.b.h. (diameter at breast height) and larger on each plot.

Total height (to nearest foot) was measured on a sample of at least 15 trees per plot, distributed throughout the diameter range, with about two-thirds of the sample trees larger than the stand quadratic mean diameter. When feasible, the same trees were remeasured at successive measurement dates. Additional trees were added to strengthen the sample and replace cut or damaged trees.

Height to live crown (defined as lowest whorl with live branches in at least three quadrants) was measured to the nearest foot at the 1973 (age 38) and subsequent measurements, on the same trees that were measured for total height.

Analyses

Tree and stand summary statistics discussed in this report were obtained by the following procedures:

1. Total volume, inside bark, was calculated for each sample tree by the volume equation of Bruce and DeMars (1974).

2. Total cubic volume was estimated for every tree, by regressions of logarithm of volume on logarithm of d.b.h. fit to the sample tree measurements for each plot and measurement date. Plot volume was then calculated as the sum of tree volumes.

3. Periodic gross volume (and basal area) growth was calculated as the difference between live volume (and basal area) at the start and end of the growth period, plus mortality and ingrowth (ingrowth present on unthinned plots only).

4. Periodic diameter increment was calculated for trees surviving to the end of each period (Curtis and Marshall 1989).

5. Height-diameter regressions of form $H = 4.5 + a*\exp(b/D)$, where H is height and D is d.b.h., were fit to combined measurements for each treatment at each measurement date. These are the bases for the top height (H40) and crop tree height estimates given.

6. Crown length regressions of form $CL = a*\exp(b/D)$ were fit to the combined measurements for each treatment, separately for 1973, 1978, 1983, and 1988, and are the bases for the estimates of crown length and height to live crown discussed.

Because the experiment is still incomplete, the analysis of variance prescribed in the study plan is not appropriate at this time. Rather, the intent of this paper is to present a summary description of development to date and developing trends, with similarities and differences from those observed in the installations that are at or close to completion. The presentation is by summary tables and graphic description, using treatment means. For simplicity, the constant-percentage treatments (1, 3, 5, 7) are emphasized. (Trends in the increasing and decreasing treatments are expected to change as the experiment progresses.)

Results and Discussion

Summary Tables[1]

Yield statistics by treatments are given in tables 1 (English units) and 2 (metric units). Note that trees removed in the calibration thinning (an estimated 896 cubic feet/acre) are not included in yields or MAI (mean annual increment) values for the thinned plots.

Plot statistics for the live stand at each measurement (number, quadratic mean diameter [QMD], basal area, volume) are summarized in tables 3-10.

Corresponding treatment means of periodic annual increments are given in tables 11 and 12.

Cumulative yields by tree size classes (live stand as of 1988 plus cumulative thinnings and mortality [excluding calibration cut]) for thinned treatments and comparable values for the 1988 live stand on the unthinned plots also were calculated.

Mean yield values for the three spare plots, which were measured only in 1968, 1973, and 1988, are given in tables 13 and 14. Height measurements on these plots are lacking for 1968 and 1973, and height-diameter measurements from adjacent plots were used to calculate volume and height statistics for 1968 and 1973.

Treatment mean values of top height (H40), which is the estimated height corresponding to D40 (QMD of the 40 largest stems per acre), and D40 are shown in tables 15-18. Tables 19-22 give the corresponding treatment mean values of average height of crop tees (Hcrop) and QMD of crop trees (Dcrop).

Height Development

Top height (H40) and crop tree height (Hcrop)—Early work used the arithmetic average of crop trees heights as the measure of stand development controlling thinnings. This has drawbacks as a general expression of stand development. First, over time there has been some substitution of crop trees because of injury or poor development of initially designated crop trees, so that this statistic does not represent a fixed set of trees. Second, in some treatments the number of trees has now been reduced below 80 per acre, so that average crop tree diameters and heights are affected by removal of individual crop trees. Third, more of the larger crop trees have been sampled for heights, so that means are biased. The crop tree heights given are estimated heights corresponding to the QMD of crop trees; they are roughly 3 to 5 percent lower than an arithmetic mean of the available crop tree heights.

Top height (H40) is an alternative expression of height development. This statistic is at least as stable as averages of crop trees and has greater generality for comparisons with other stands. For this reason, it is used as a basis for some of the later comparisons.

Volume growth is a joint function of growth in basal area (diameter) and growth in height. The pattern of height growth is therefore related to the pattern of volume growth and is of interest from this standpoint as well as being an indicator of site quality and (in this study) the factor determining timing of thinnings.

Height growth curve comparisons—Extrapolation of the trend of observed H40 values (table 15) to age 50 b.h. indicates a site index value of about 110 feet.

[1] Tables referred to are given in apprendix 2.

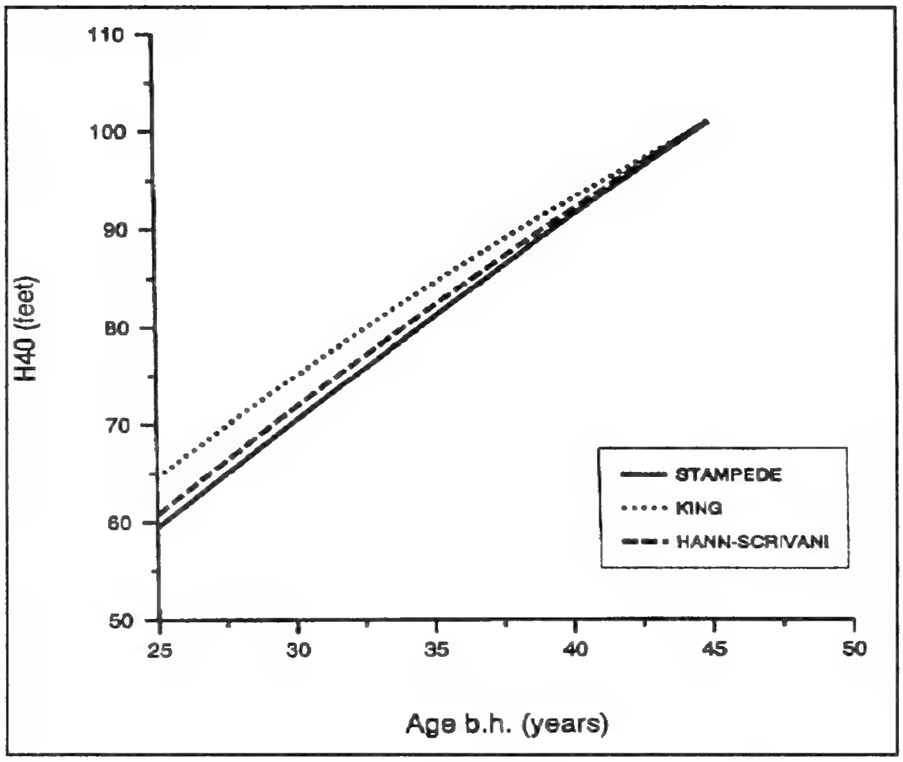

Figure 3—Observed trend in top height (H40) compared with height growth curves from King (1966) and Hann and Scrivani (1987).

The trend of H40 (mean of all plots) over age b.h. is compared in figure 3 with the curves of King (1966) and Hann and Scrivani (1987) having the same height at age 45 b.h. Although the site tree definitions used by King and by Hann and Scrivani are not identical with H40, no systematic age-related differences are expected, and past experience with the King curves is that substitution of H40 for site trees as defined by King has little effect on estimates. Height growth at Stampede Creek clearly conforms much more closely with the Hann and Scrivani curves (derived from southwest Oregon data) than with the King curves (western Washington data).

Extrapolation of mean crop tree heights (tables 19 and 20) indicates that the next remeasurement will be due in fall 1993.

Type of Thinning

The LOGS study plan specifies that (1) 80 crop trees per acre will be designated, (2) cutting will be confined to noncrop trees until all noncrop trees are cut, and (3) the average diameter of cut trees shall approximate the average diameter of all trees available for cutting. These specifications have sometimes been misinterpreted as a statement that average d/D (diameter of cut trees/diameter of all trees) is 1.0; which usually would be considered biologically undesirable. In fact, they correspond to crown thinning, with expected d/D considerably less than 1.0 until all noncrop trees have been removed.

Experience at Stampede Creek and Iron Creek suggests that the study plan specification of d/D = 1.0 after all noncrop trees have been removed will be realistic and achievable only on plots free from damage because root rot or other damage, when present, determines which trees will be cut.

At Stampede Creek, the overall average of d/D ratios (table 23) is about 0.82, although values differ considerably among plots and successive thinnings. This value is less than the averages for other LOGS studies (Curtis and Marshall 1986: 29). Although these differences may in part reflect differences in interpretation of the study plan, they are also related to differences in initial stand structure. Stampede Creek at time of establishment was older than other LOGS installations and of natural origin with some range in ages, and with a correspondingly greater range in initial diameters.

Average diameters of cut trees usually were comparable to average diameters of trees available for cutting according to the above rules, although there are of course considerable differences for individual dates within treatments.

Stand Density Trends Over Time

The different thinning treatments result in markedly different levels of stocking. Changes in live basal area over time are shown in figure 4. Corresponding changes in relative density (RD; Curtis 1982) are shown in figure 5. This expression of RD is a variation of Reineke's (1933) stand density index, which scales basal area by a power of average diameter. Because its maximum is nearly independent of age or site index, it has some advantages over basal area as an expression of relative density that is easily related to thinning guides and to stands in other stages of development.

The unthinned plot curve (fig. 5) suggests that the unthinned plots are close to a maximum RD of about 70-75. This is roughly the same as that observed in the Clemons and Skykomish installations and markedly less than values attained at Hoskins and Iron Creek (Curtis and Marshall 1986: fig. 13).

Net Yield Comparisons Among Treatments

Cumulative net volume yields, and attained QMDs (after thinning) taken from table 9 are shown in relation to age in figures 6 and 7, for treatments 1, 3, 5, 7, and control.

Note that in these graphs the initial differences in basal area and volume values between thinned plots and control represent trees removed in the calibration thinning and are not included in cumulative yields for the thinned plots.

Mortality has been negligible in all treatments except the unthinned controls and treatment 2 in TP3 (root rot); net and gross yields are virtually the same for the thinned plots.

Periodic Annual Increments in Relation to Age and Treatment

Net basal area periodic annual increment—Treatment means of periodic annual increment (PAI) in net basal area, for treatments 1, 3, 5, 7, and unthinned, are compared in figure 8. Values are plotted over midpoint ages (PAI is an estimate of current annual increment at the period midpoint age). The sharp decline with age for the unthinned treatment is caused by the rapid acceleration of mortality with increasing stand density. Mortality has been negligible in thinned plots, with the exception of some root rot mortality in treatment 2 in the most recent measurement period.

Net cubic volume PAI—Corresponding trends in net cubic volume PAI are shown in figure 9. The figure suggests a possible maximum in PAI in the second thinning period (age 43-48) for thinned plots, that is not evident in the unthinned control. Change in volume PAI is much less over the observed ages than is the case with basal area PAI.

(Text continues on page 19)

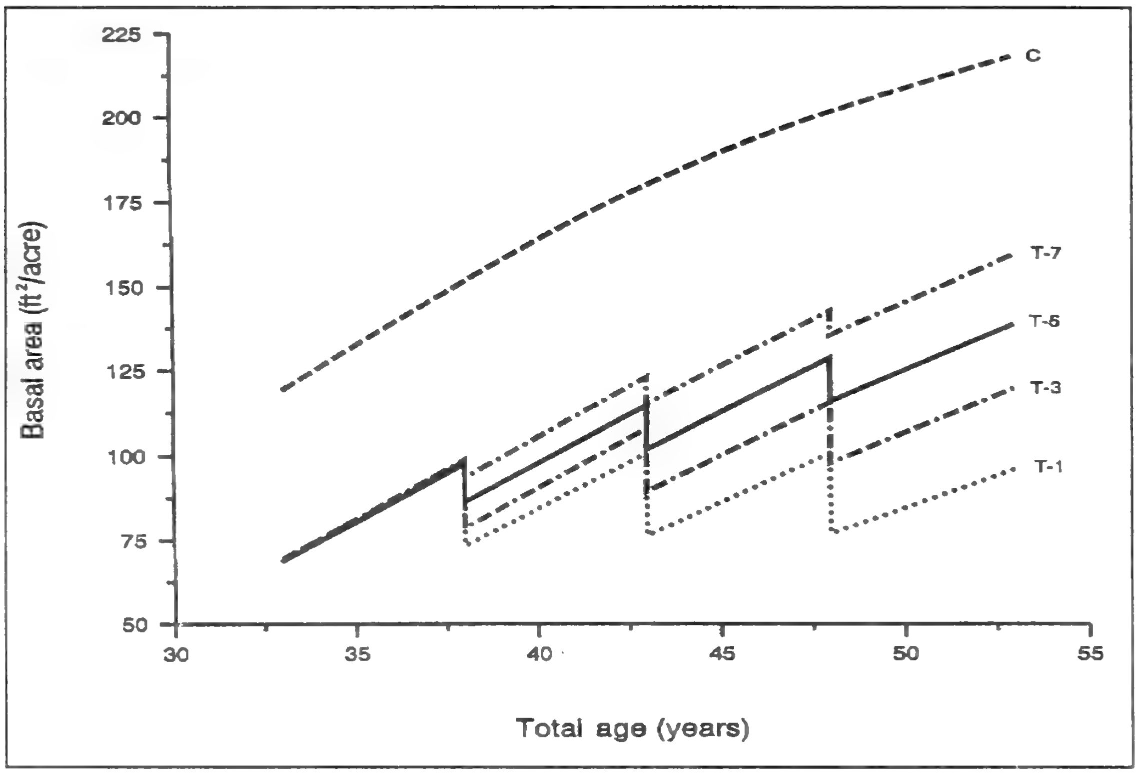

Figure 4—Live basal area (treatment means) in relation to age: treatments 1, 3, 5, and 7; and the control.

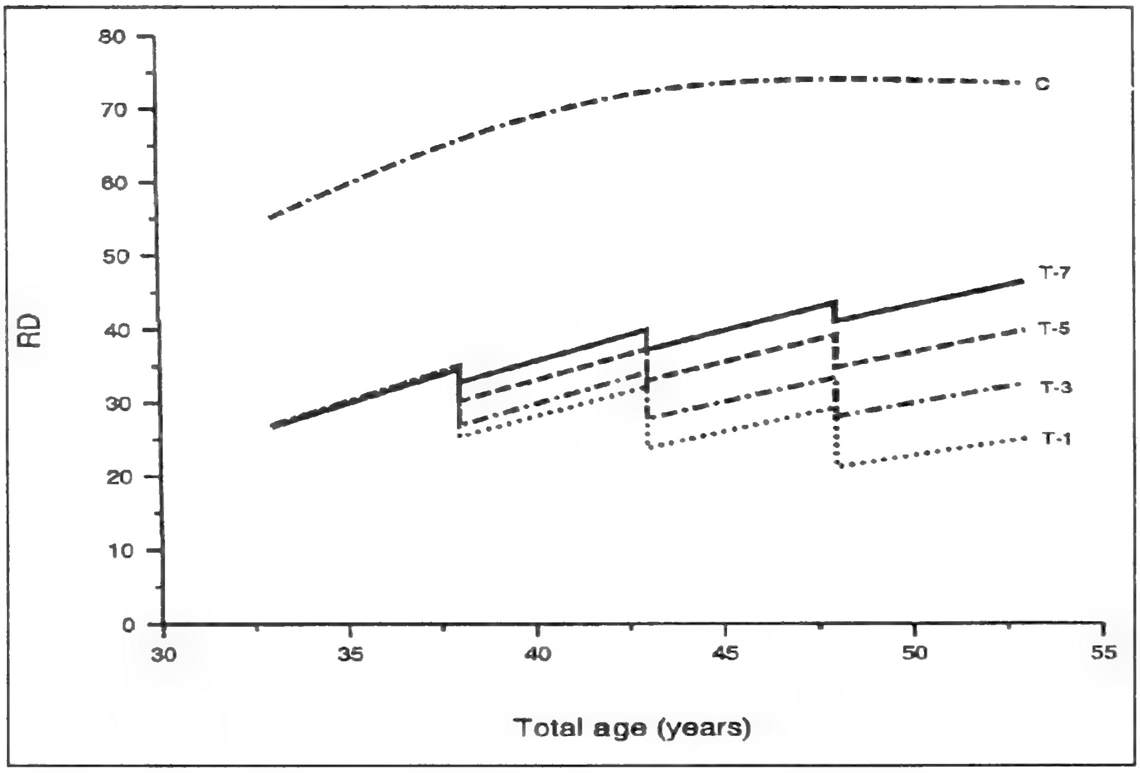

Figure 5—Relative density [RD = BA/SQRT(QMD)] in relation to age: treatments 1, 3, 5, and 7; and the control.

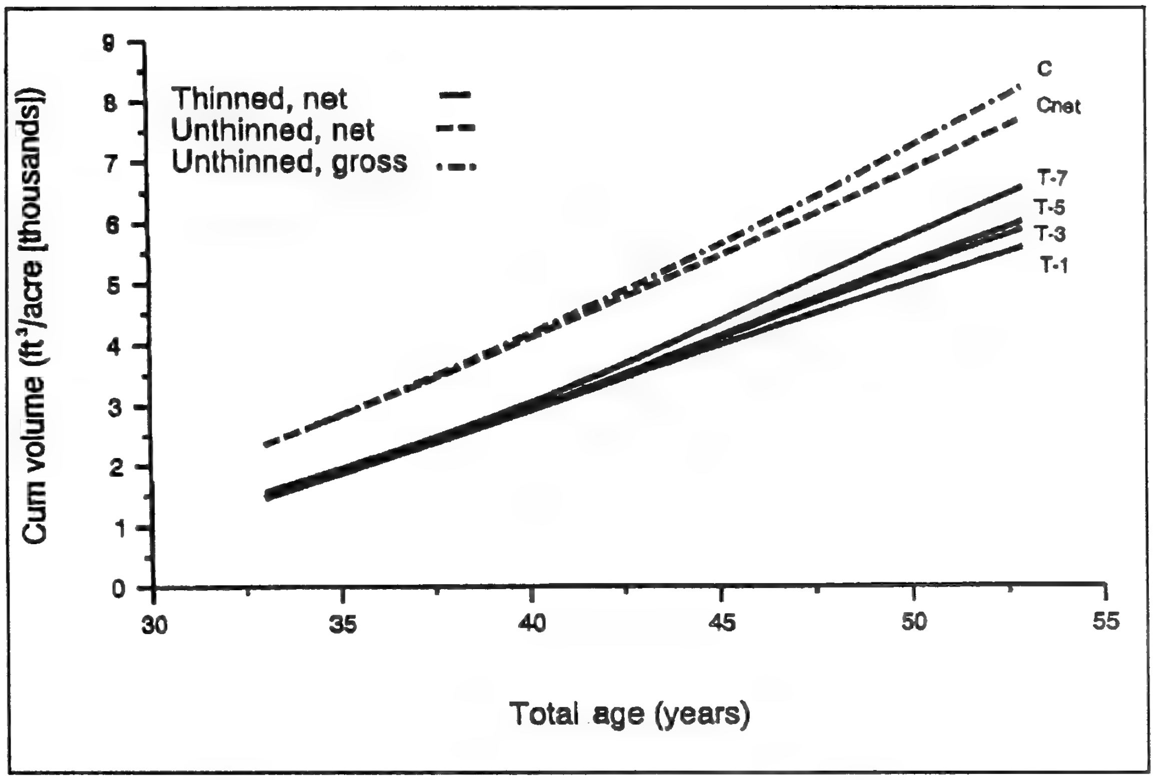

Figure 6—Cumulative net cubic volume yield (treatment means) in relation to age: treatments 1, 3, 5, and 7; and the control.

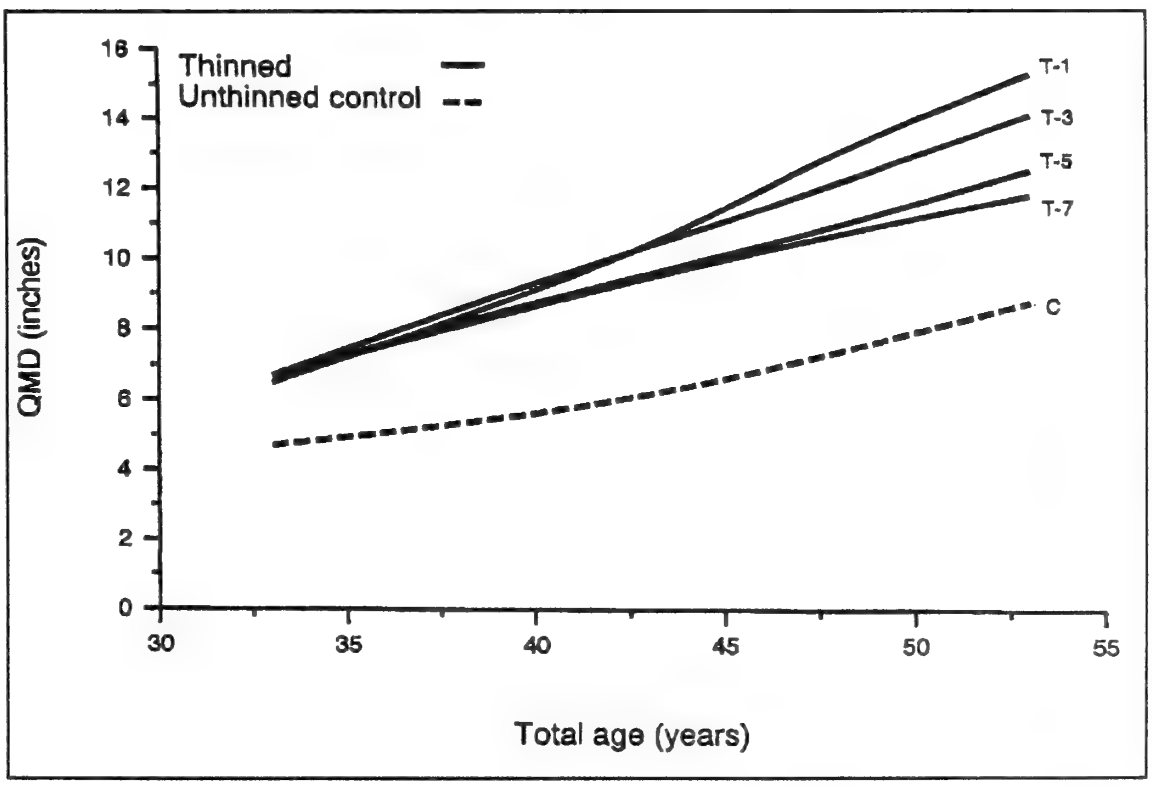

Figure 7—Attained quadratic mean diameters (treatment means, after thinning) in relation to age: treatments 1, 3, 5, and 7; and the control.

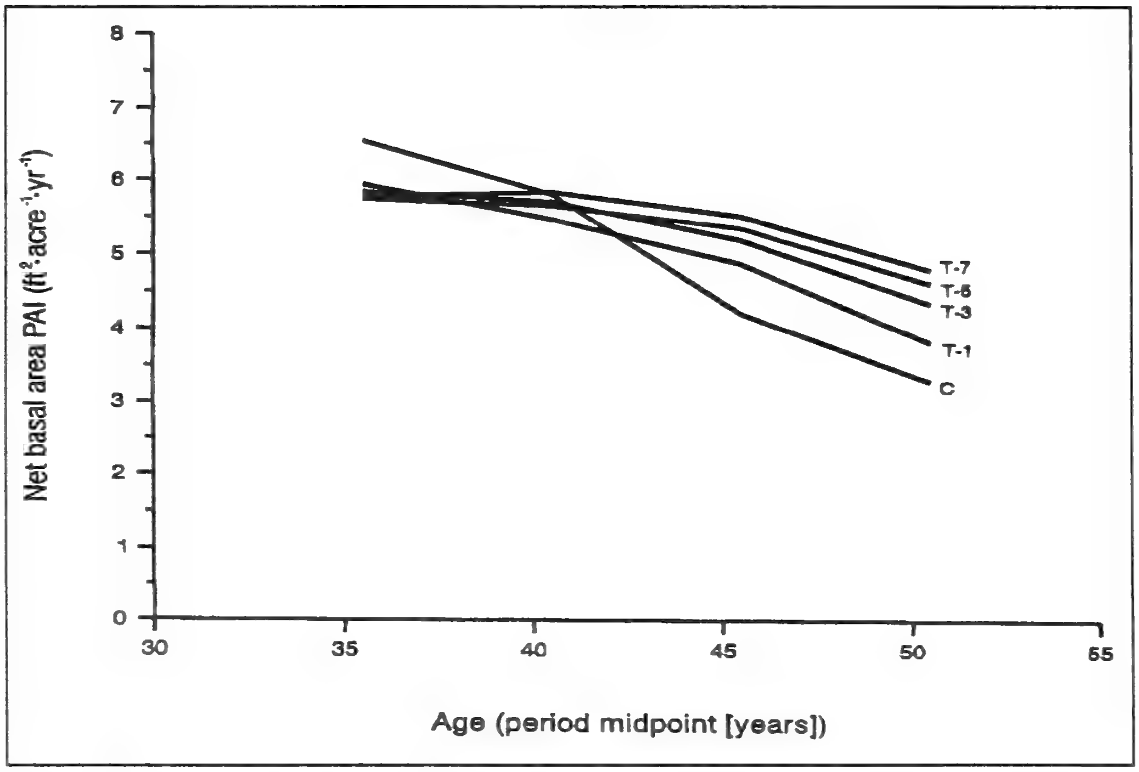

Figure 8—Trends of periodic annual net basal area increment (treatment means) in relation to age: treatments 1, 3, 5, and 7; and the control.

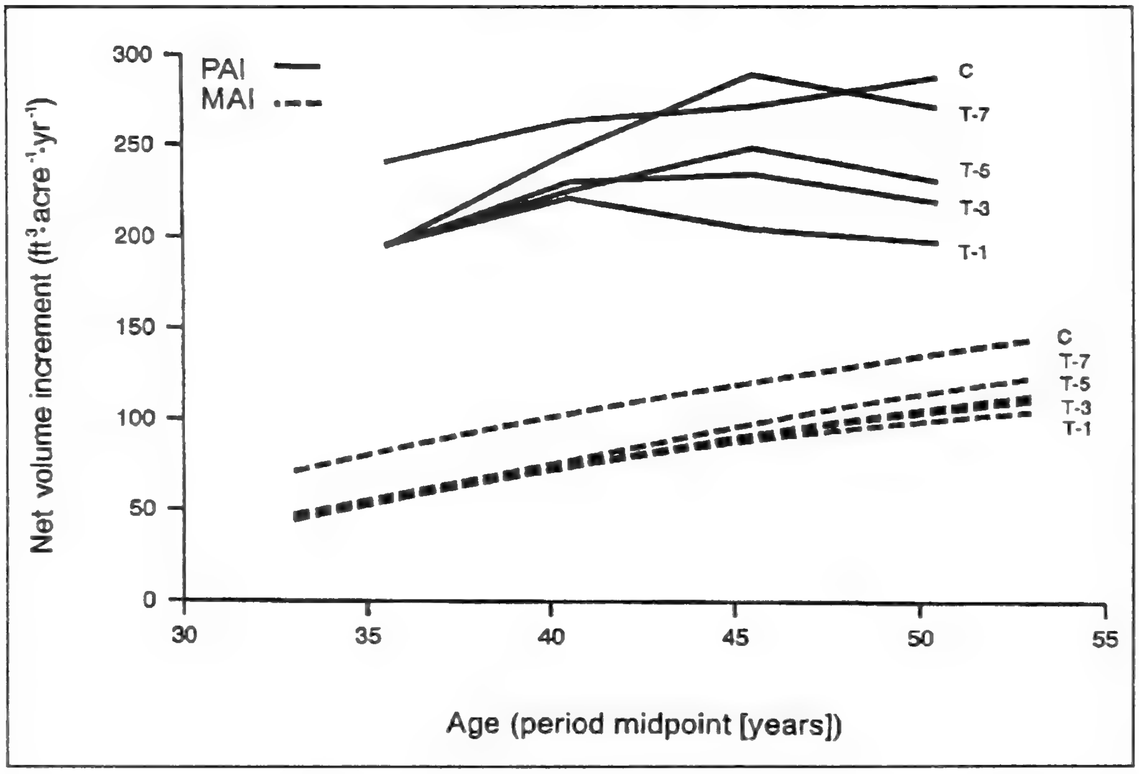

Figure 9—Trends of periodic annual net volume increment and of mean annual volume increment (treatment means) in relation to age for treatments 1, 3, 5, and 7, and the control.

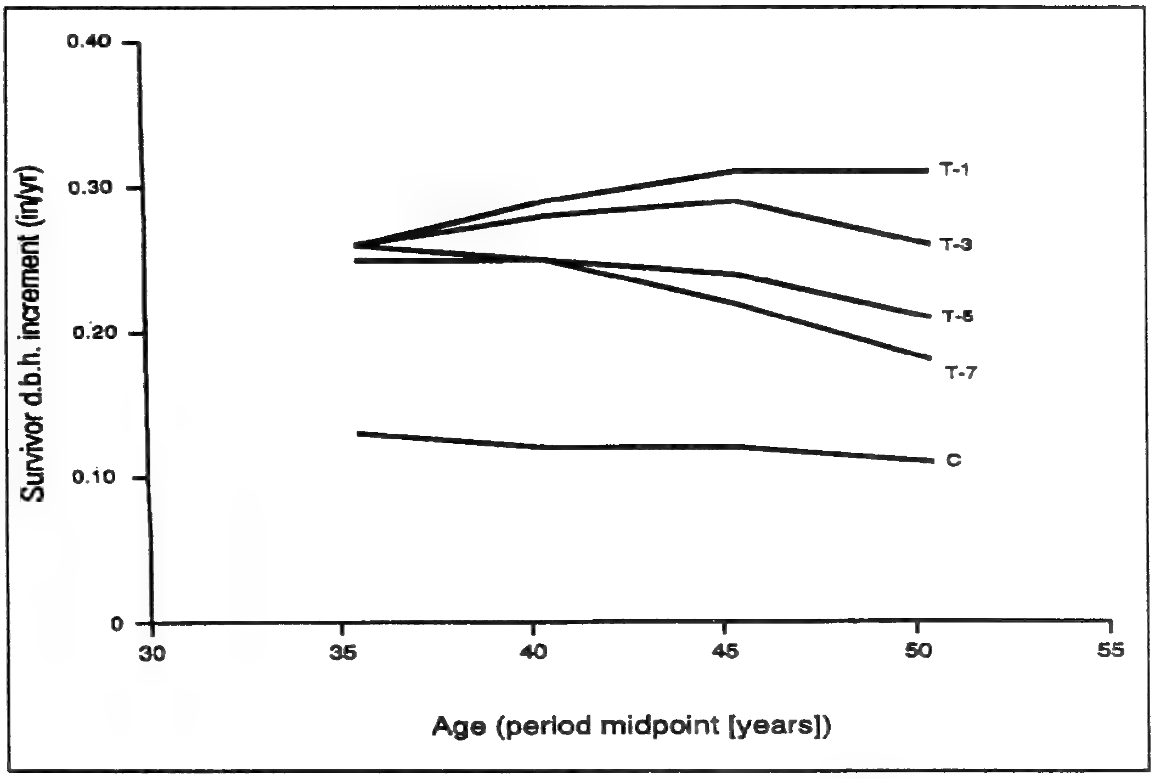

Figure 10—Trends of periodic annual survivor diameter increment (treatment means) in relation to age for treatments 1, 3, 5, and 7, and the control.

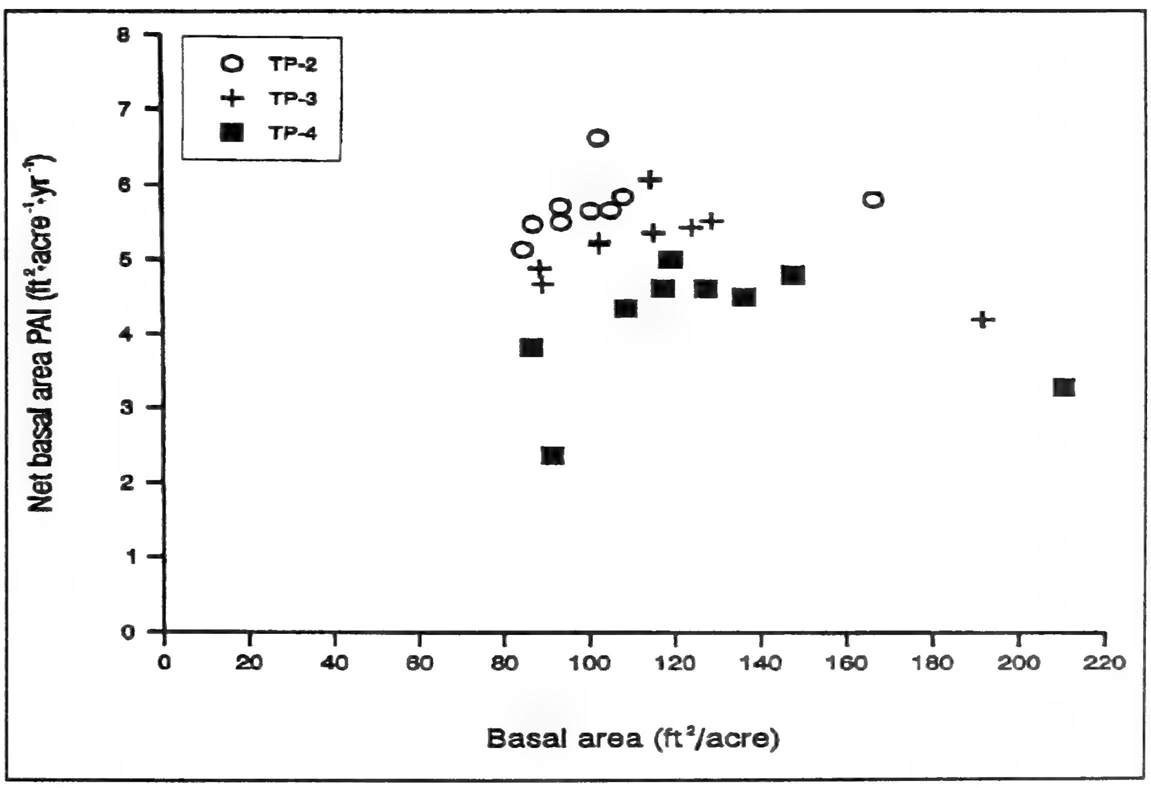

Figure 11—Relation of periodic annual net basal area increment (treatment means) to basal area (period midpoint), all treatments, treatment periods 2, 3, and 4.

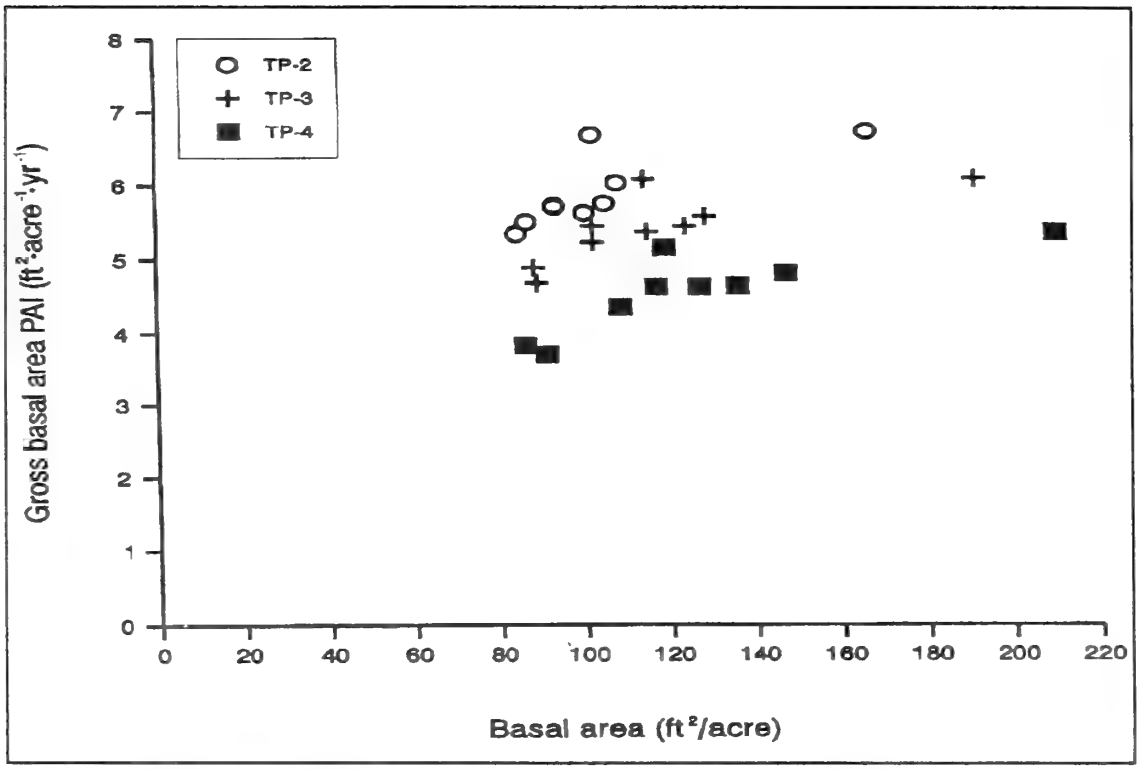

Figure 12—Relation of periodic annual gross basal area increment (treatment means) to basal area (period midpoint), all treatments, treatment periods 2, 3, and 4.

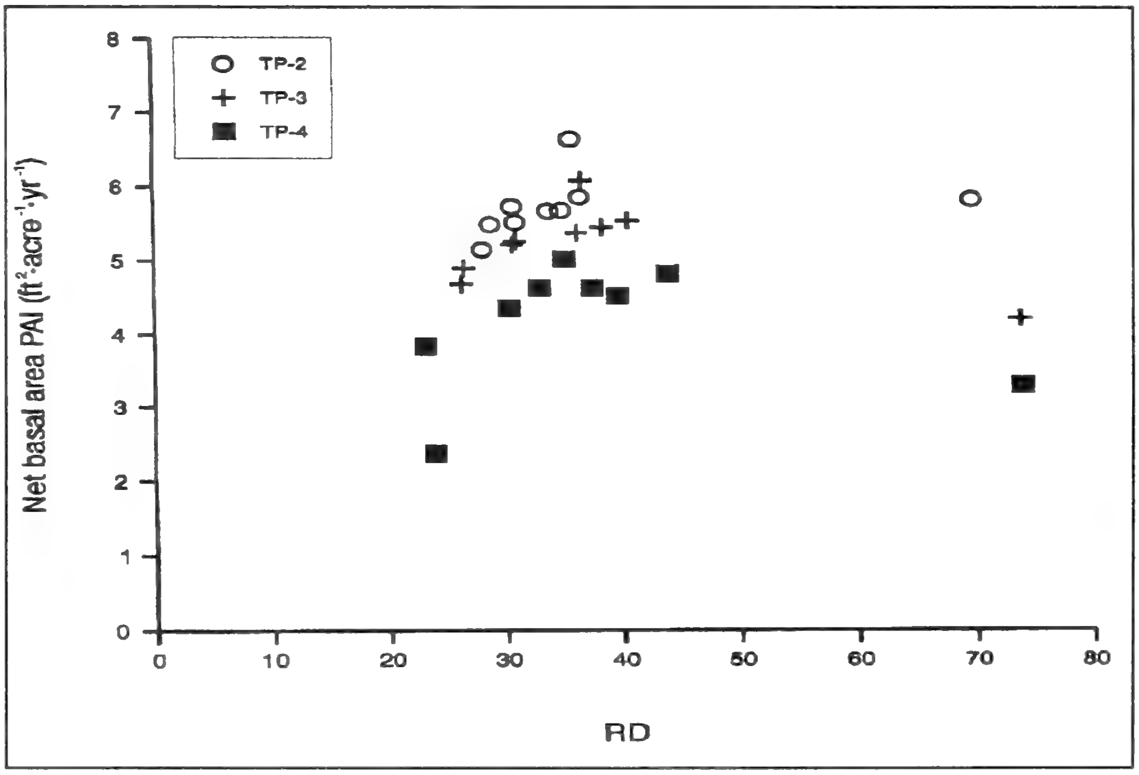

Figure 13—Relation of periodic annual net basal area increment (treatment means) to relative density (RD) at period midpoint, all treatments, treatment periods 2, 3, and 4.

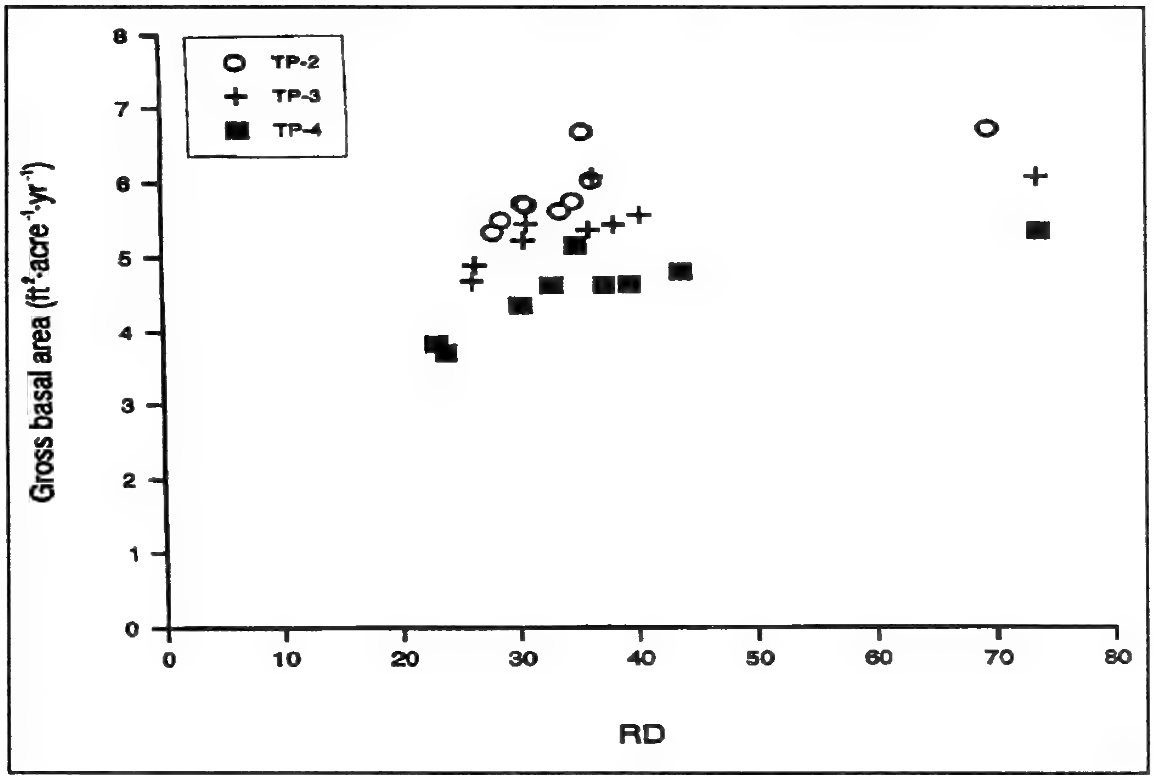

Figure 14—Relation of periodic annual gross basal area increment (treatment means) to relative density (RD) at period midpoints, all treatments, treatment periods 2, 3, and 4.

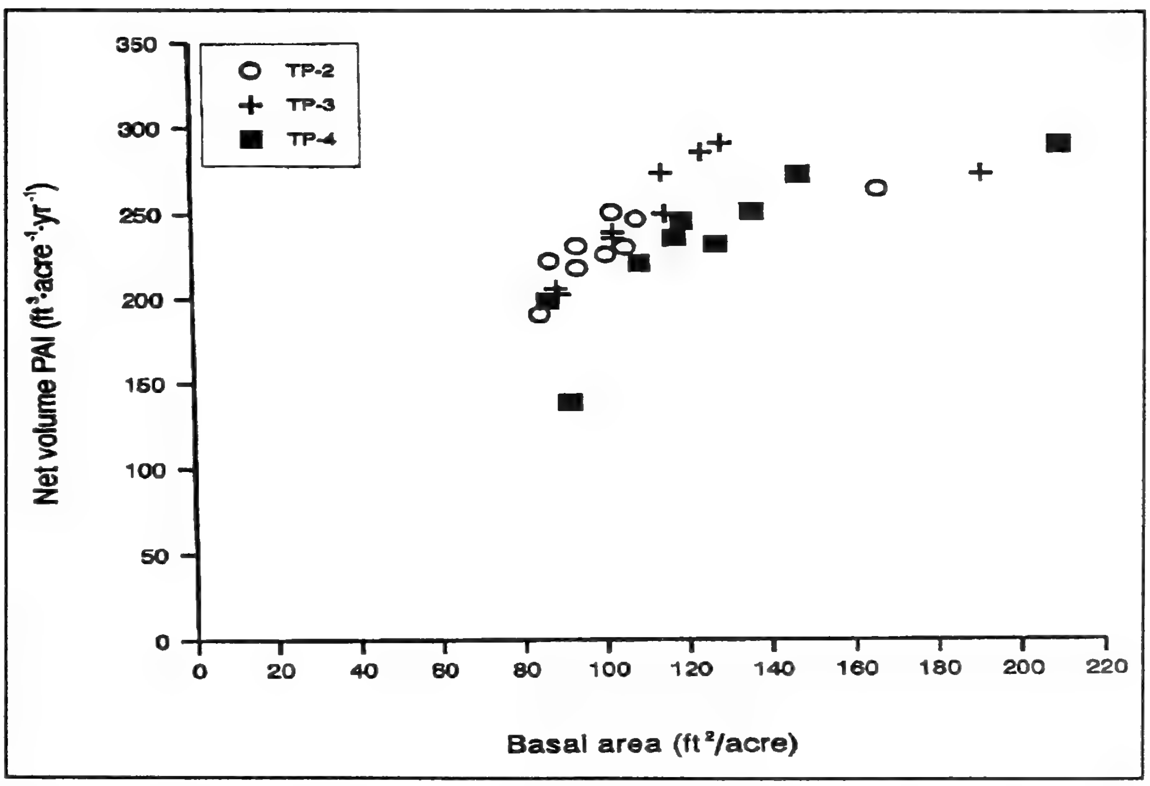

Figure 15—Relation of periodic annual net volume increment (treatment means) to basal area at period midpoints, all treatments, treatment periods 2, 3, and 4.

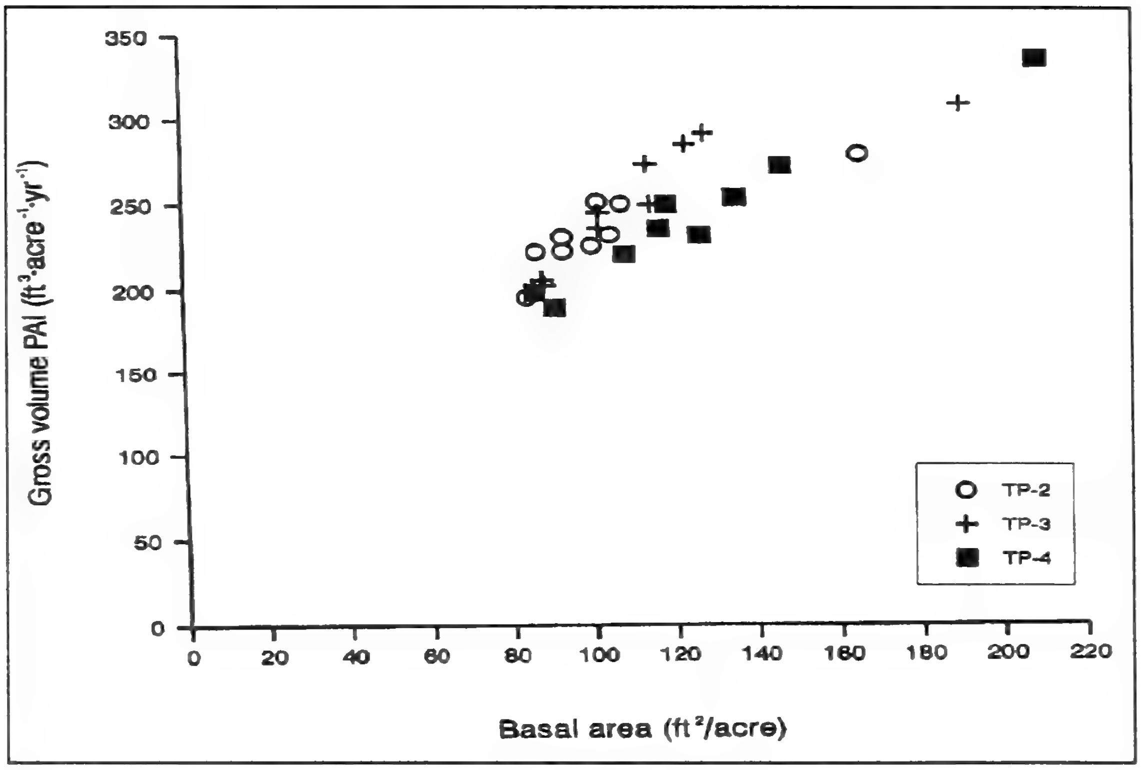

Figure 16—Relation of periodic annual gross volume increment (treatment means) to basal area at period midpoints, all treatments, treatment periods 2, 3, and 4.

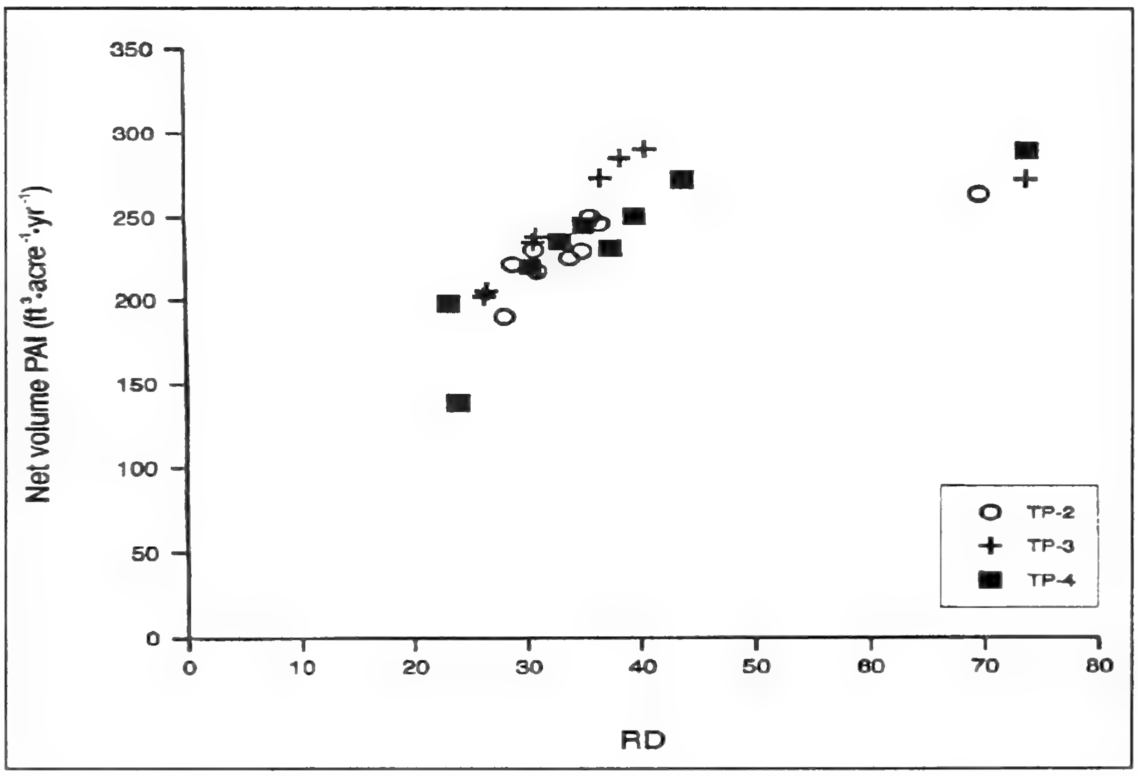

Figure 17—Relation of periodic annual net volume increment (treatment means) to relative density (RD) at period midpoints, all treatments, treatment periods 2, 3, and 4.

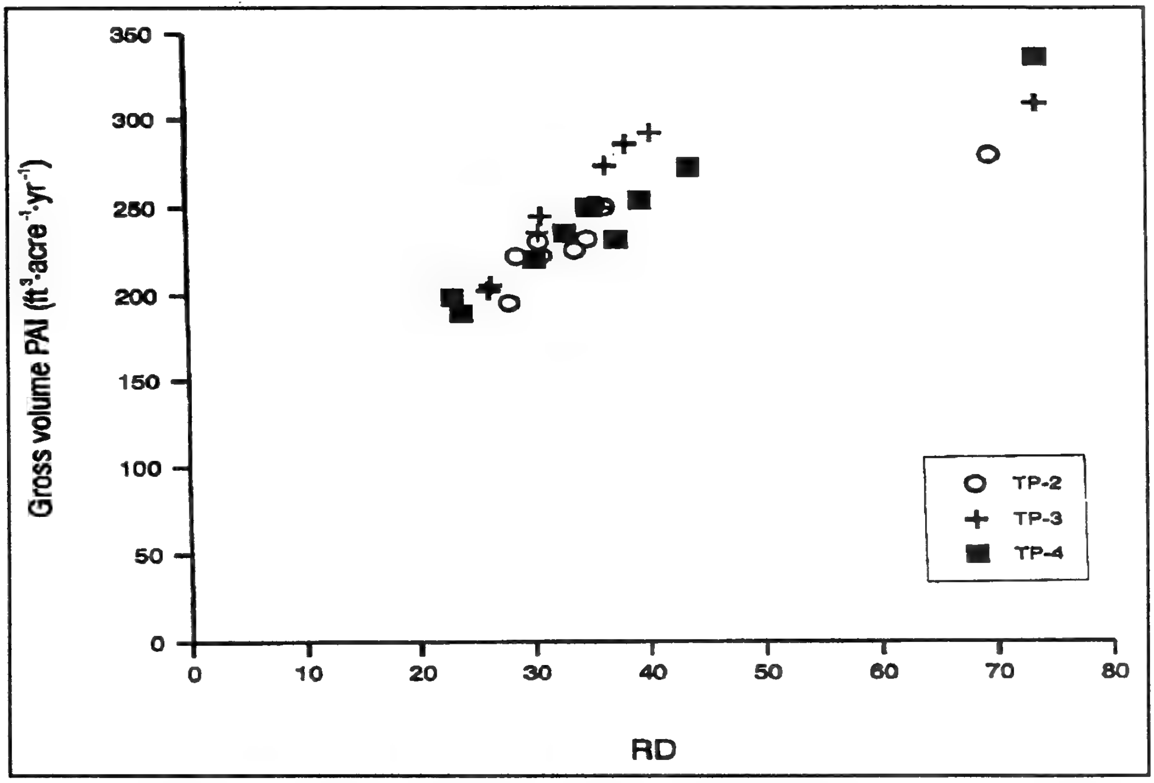

Figure 18—Relation of periodic annual gross volume increment (treatment means) to relative density (RD) at period midpoints, all treatments, treatment periods 2, 3, and 4.

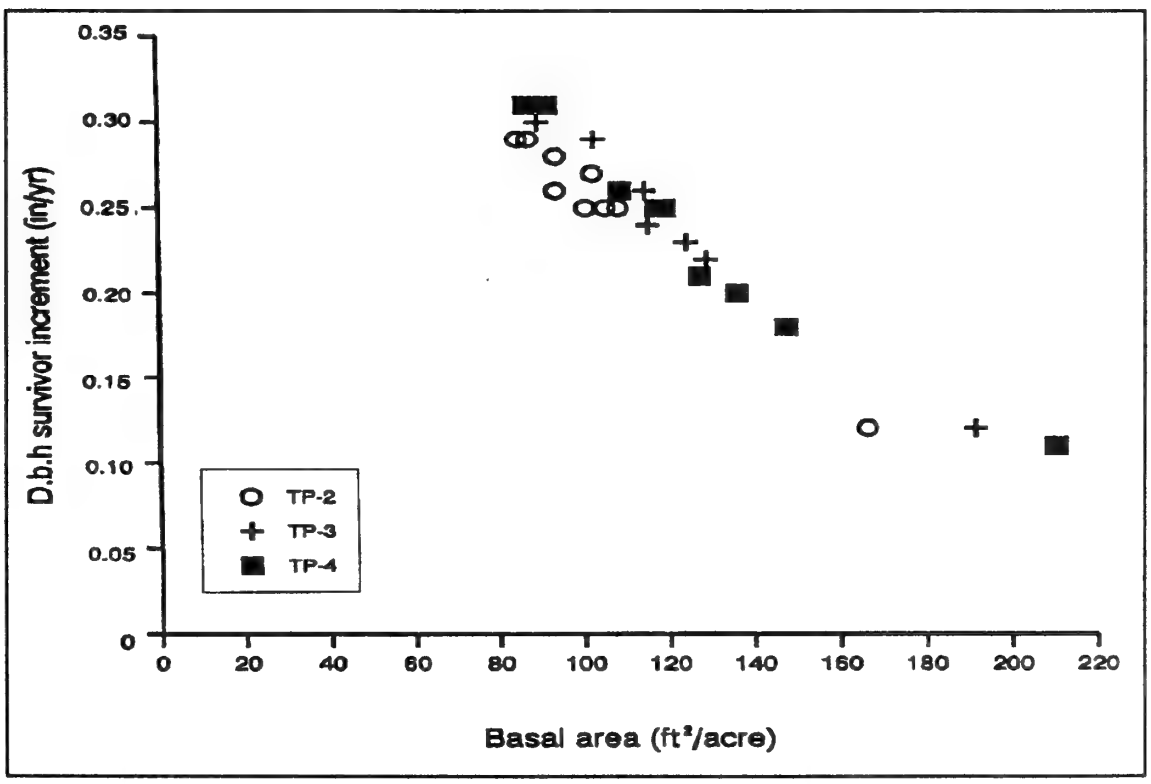

Figure 19—Relation of periodic annual increment in diameter of survivors (treatment means) to basal area at period midpoints, all treatments, treatment periods 2, 3, and 4.

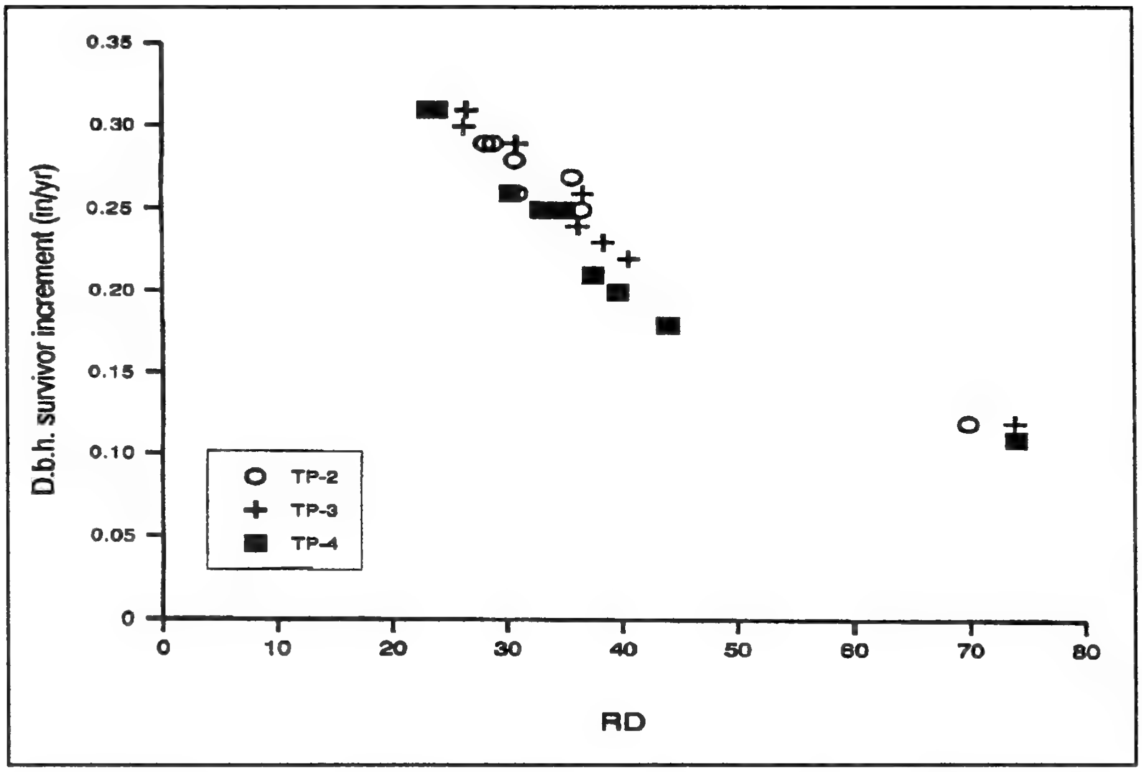

Figure 20—Relation of periodic annual increment in diameter of survivors (treatment means) to basal area at period midpoints, all treatments, treatment periods 2, 3, and 4.

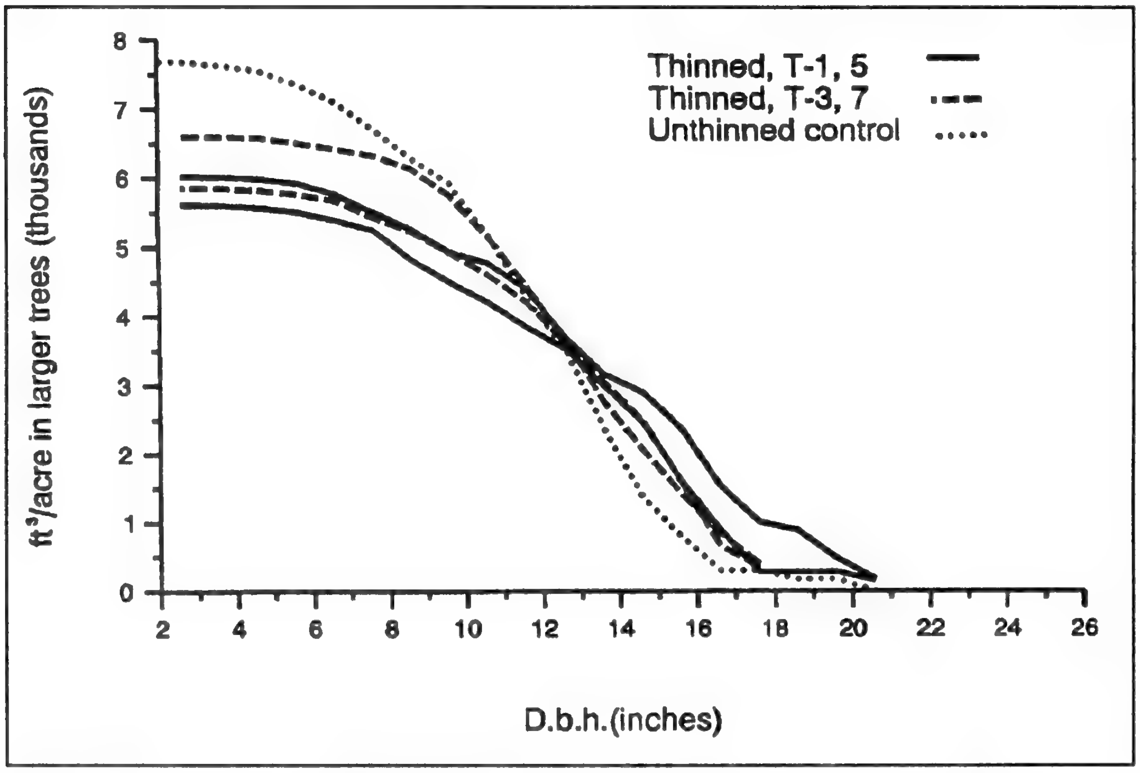

Figure 21—Cumulative volume distribution curves showing volumes in trees larger than indicated diameters, treatments 1, 3, 5, and 7 and the unthinned control. Values are 1988 live stand plus previous thinnings, omitting calibration cut.

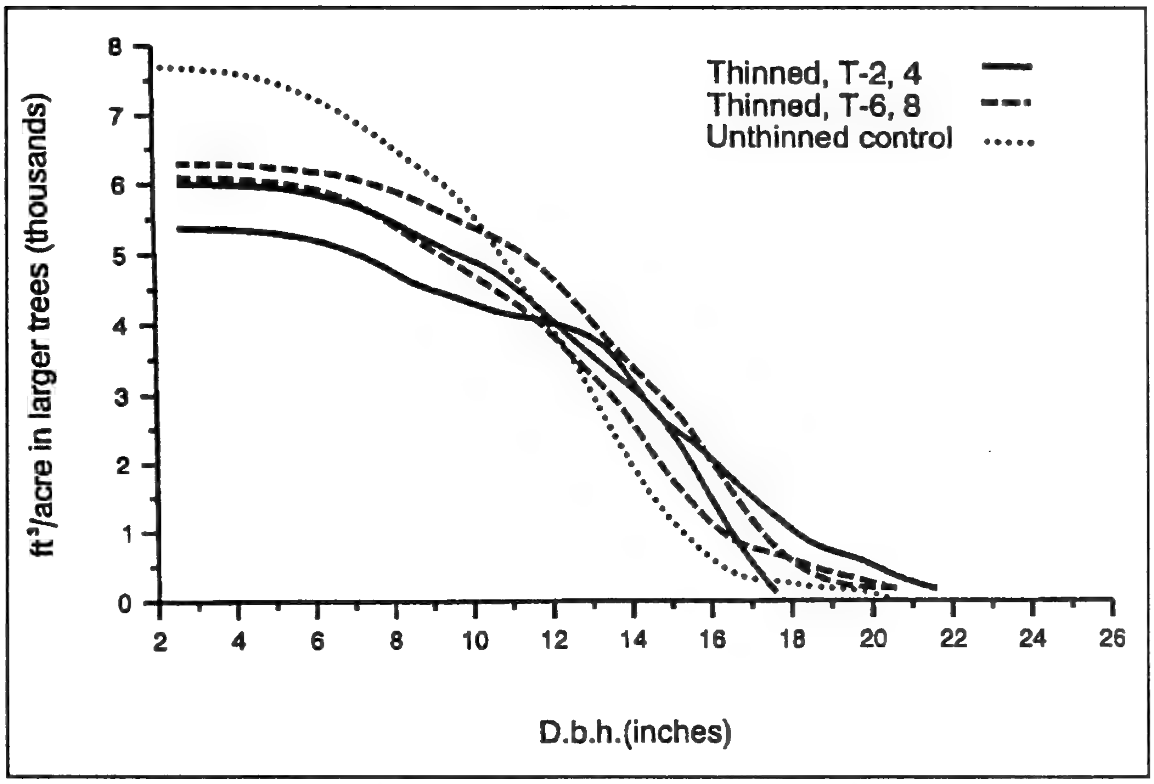

Figure 22—Cumulative volume distribution curves showing volumes in trees larger than indicated diameters, treatments 2, 4, 6, and 8 and the unthinned control. Values are 1988 live stand plus previous thinnings, omitting calibration cut.

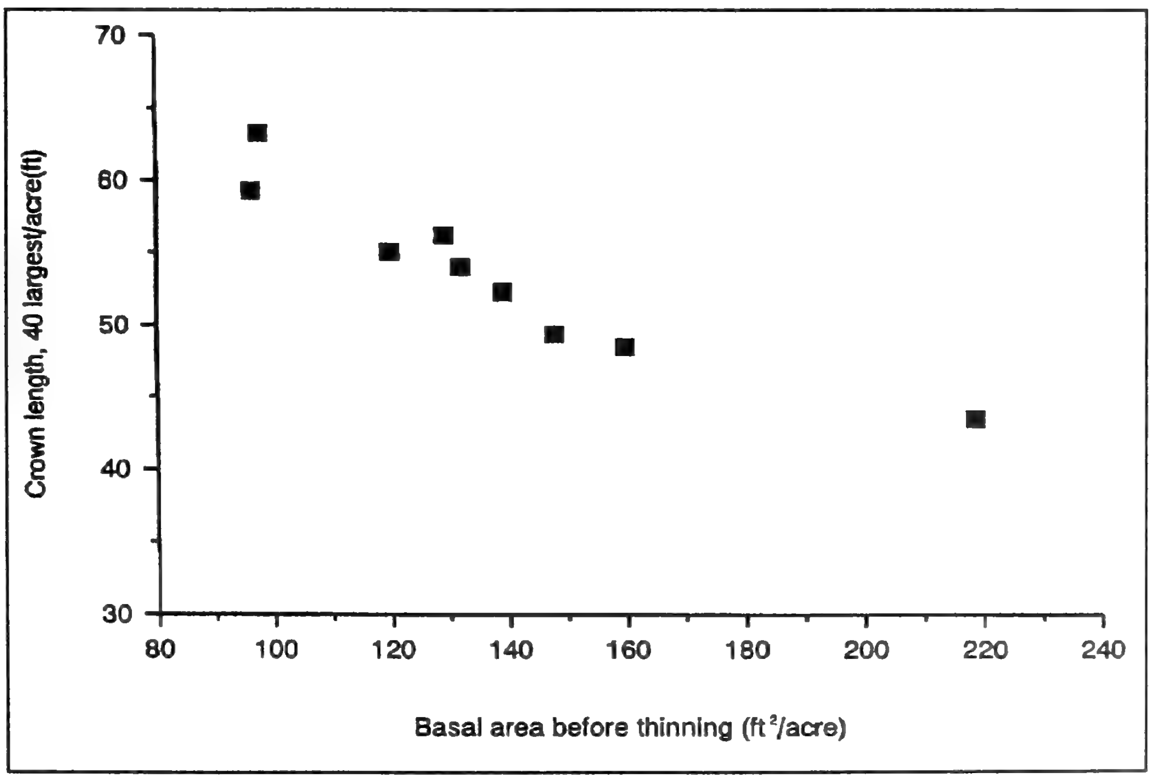

Figure 23—Live crown length of 40 largest trees per acre in relation to basal area at end of growth period, 1988.

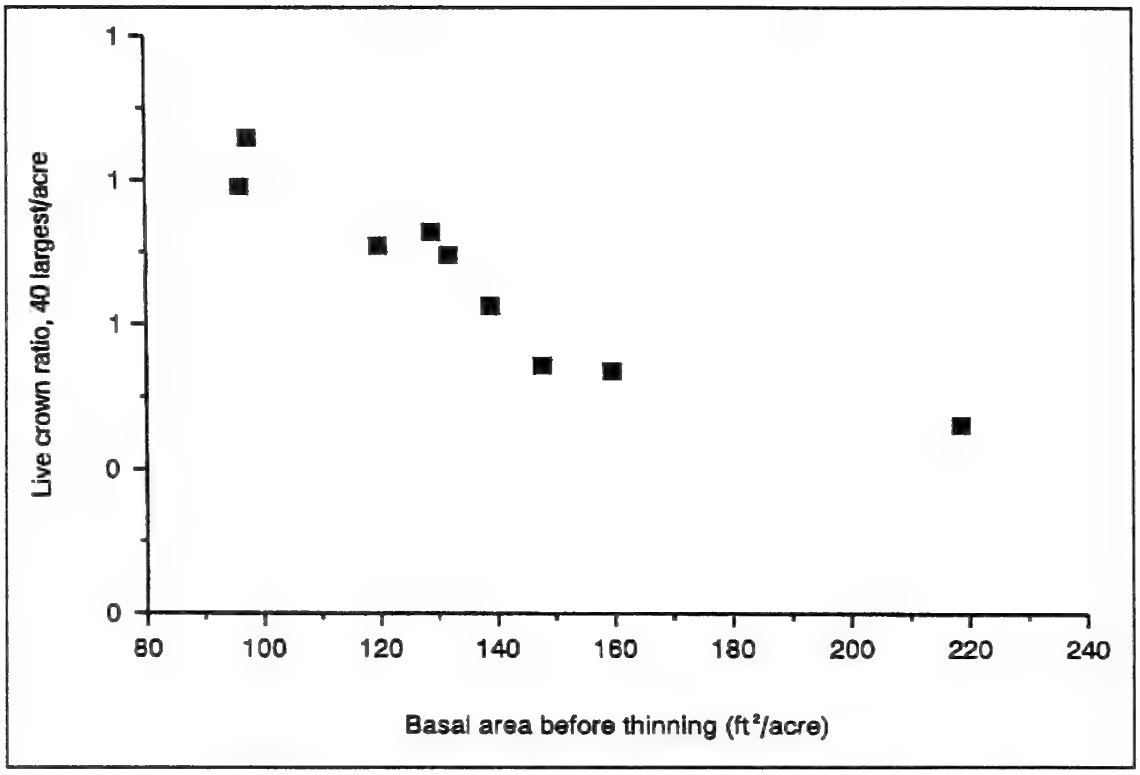

Figure 24—Live crown ratio of 40 largest trees per acre in relation to basal area at end of growth period, 1988.

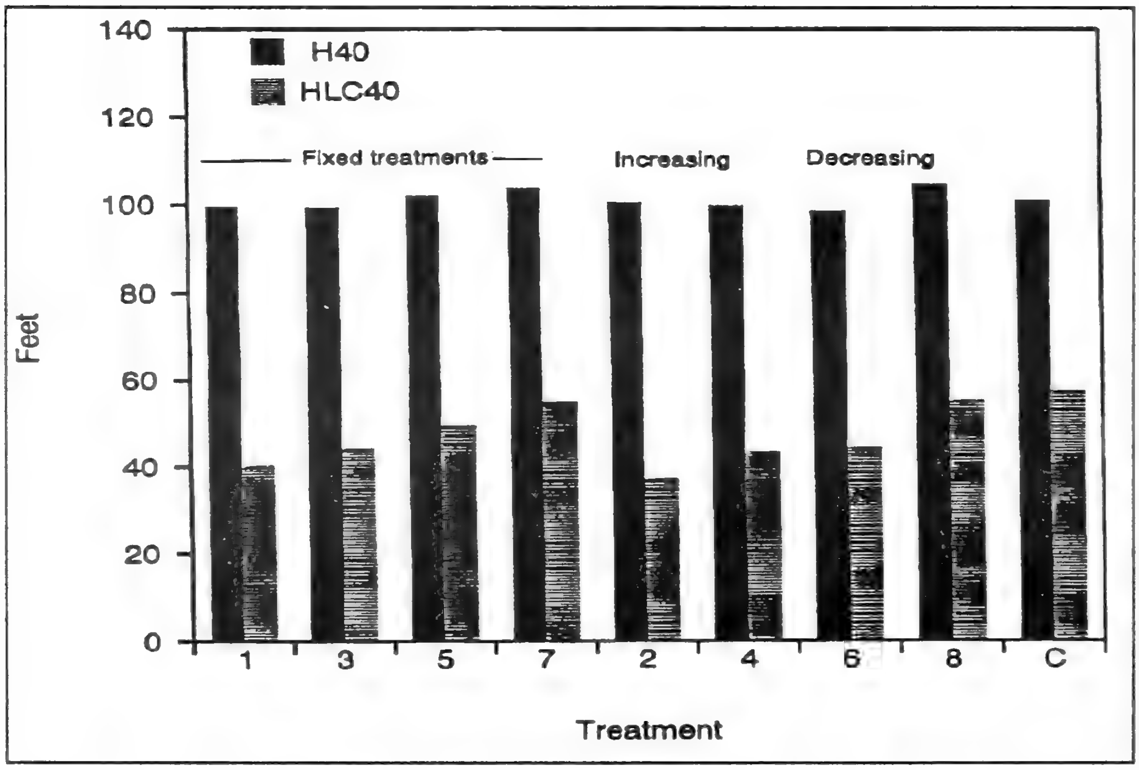

Figure 25—Total height (H40) and height to live crown (HLC40) of 40 largest trees per acre by treatment, at end of growth period, 1988.

Diameter PAI—Diameter increment can be expressed in several ways with somewhat different interpretations. Net periodic annual diameter increment, calculated as the difference between QMDs at start and end of the growth period divided by years in the period, can be misleading (Curtis and Marshall 1989) because suppression mortality in high-density stands markedly increases stand average diameter independent of growth of the surviving trees. Stand diameter growth therefore is expressed here as periodic annual diameter growth of trees surviving to the end of the growth period. For thinned plots, this is virtually the same as net diameter increment but is considerably less in the unthinned plots.

Trends in PAI of survivors are shown in figure 10. As would be expected, diameter growth rates decline with increasing age for the higher density treatments; however, they actually increase with treatment 1 and are nearly constant for treatment 3.

Periodic Annual Volume Increment and Mean Annual Volume Increment

Trends of mean annual increment (MAI) in net cubic volume (all trees) plotted over age at time of measurement are compared with the corresponding values of periodic annual increment in figure 9. For simplicity, the graph shows only treatment means for the uniform treatments—1, 3, 5, 7—and the unthinned control.

In the most recent growth period, age 48-53, PAI is still about twice MAI. Clearly, these stands are still far from culmination of MAI in total cubic feet.

Periodic Annual Increment and Stand Density

Basal area PAI—Net and gross basal area periodic annual increments are shown in figures 11 and 12, in relation to period midpoint values of basal area. Figures 13 and 14 show the corresponding relations to RD (Curtis 1982). Values are treatment means for treatment periods 1, 2, and 3. (Note: The extremely low net basal area increment value at about RD24 results from root rot mortality in treatment 2 in the most recent growth period (TP3) and has little effect on gross increment values.)

Basal area increment is related to stand density, whether expressed by RD or by basal area. Basal area increment increases with density up to a point somewhere in the range RD40-RD50, where gross basal area increment of thinned plots is about the same as that of the unthinned. The location of the maximum is not well defined, because relative densities between about RD50 and RD70 are not represented in the data. The figures also suggest that the gross basal area increment-stand density relation is becoming flatter with advancing age.

Net basal area increment is markedly less than gross basal area increment for the unthinned plots. The difference is mortality, negligible on the thinned plots except for the most recent period in treatment 2.

Cubic volume PAI—The corresponding relations for net and gross volume PAI to basal area for treatment periods 1, 2, and 3 are shown in figures 15 and 16, and those to RD in figures 17 and 18. Again, there are clear relations with gross increment increasing with stand density up to and including the unthinned (presumably near-maximum density) plots. Net increment relations are virtually the same as for gross increment on the thinned plots (excepting TP3 mortality in treatment 2); but because of mortality, net volume increment on the unthinned controls is about the same as on the higher density thinned plots.

The slopes of the volume increment-stand density relations are steeper than those of the corresponding relations for basal area.

Diameter PAI—Survivor diameter PAI is shown in relation to period midpoint basal areas and RD in figures 19 and 20, for treatment periods 1, 2, and 3. There is a very strong negative relation between survivor diameter increment and stand density, with average growth of surviving trees on the unthinned plots being only about one-third that of trees in the lowest density treatments.

Another and complementary relation is that between diameter increment of the 40 largest trees per acre (D40), or of designated crop trees, and stand density. Dominant trees are expected to be less affected by stand density than are averages of all trees. The 40 largest trees per acre are with few exceptions included among the designated crop trees, average diameters are little affected by removal of trees in thinning, and change over time can be interpreted as biological growth.

Change in average diameter of the 40 largest trees per acre and of designated crop trees from 1968 to 1988 can be expressed as ratios to corresponding values for the unthinned plots (table 24). These ratios show that although diameter growth of these dominant trees has been less influenced by stand density differences than has average diameter growth of all trees, they still have shown substantial increases in diameter growth compared to comparable trees on the unthinned plots.

Volumes by Tree Size Classes

Cumulative distribution curves showing volume in trees larger than specified diameters are given in figures 21 and 22. Volumes shown are totals of the 1988 live stand plus past thinnings (exclusive of calibration). As also shown in tables 9 and 10, both 1988 live stand and cumulative total production of thinned stands are less than the unthinned controls. Marked differences in the volume distribution curves are developing, however. The greater volume production in the unthinned stands is composed of relatively small trees, while the thinned stands have considerably larger volumes in the larger diameters. To date, results from treatment 8 combine relatively high total production with the highest volume in large-diameter trees. Treatments 7 and 5 are close seconds.

Crown Development

At establishment in 1968, crown dimensions were presumably the same in all treatments. Differences in stand density and concomitant differences in crown characteristics developed gradually under the influence of the different thinning treatments and can be expected to become considerably greater by the end of the experiment.

Live crown lengths and crown ratios in 1988 of the 40 largest trees per acre are strongly related to 1988 basal areas (figs. 23 and 24). Similar relations exist with RD.

Figure 25 compares 1988 heights to live crown and total heights of the 40 largest trees, by treatments. As expected, marked differences are developing that correspond to differences in stand density among treatments.

Similar comparisons were made with estimated crown dimensions corresponding to (1) average diameter of crop trees, and (2) average diameter of all trees. As would be expected, those for crop trees are very similar to those for the largest 40 per acre. Differences for all trees are considerably greater, which reflects the additional effect of the relatively large differences among treatments in average diameter of all trees.

Spare Plots

Initial average diameters and present heights of the spare plots (tables 13 and 14) suggest that these were in fact somewhat inferior in initial development to the plots included in the planned treatments; however, they still should provide some indication of development in the absence of later treatment thinnings. In retrospect, it is unfortunate that this was not included in the original study plan.

In 1988, the 40 largest trees per acre had average dimensions D40 = 14.5 inches, H40 = 93 feet, crown length = 42 feet, and live crown ratio 0.45. Average RD value of these plots was 51. Loss from suppression mortality has been negligible. Twenty years after the initial calibration thinning, they are in a condition that most people would consider favorable for an initial commercial thinning.

In 1988, H40 of the spares was about the same as average H40 attained by the planned treatments about 1984. From an interpolation of volumes in table 9, net yield at attainment of 93 feet top height was about 85 percent of that of the unthinned control at the same top height.

Conclusions

Stampede Creek differs from other LOGS installation in that (1) it represents a geographically (and ecologically) distinct region, (2) it was established at a somewhat later stage of development than the other installations, (3) it is a naturally regenerated stand with some range in ages, and (4) it is one of only two installations on site III (the other is the ecologically very different Sayward installation on Vancouver Island).

The stand has maintained a nearly constant rate of height growth since study establishment and is steadily increasing in height relative to heights predicted by the widely used curves of King (1966), consistent with Hann and Scrivani's (1987) finding that height growth trends in southwest Oregon differ from those in western Washington.

In other respects the results to date at Stampede Creek are consistent with those from the other LOGS installations.

At the time the LOGS study was begun, there was a widely held belief (based on European experience) that about the same volume growth rates could be obtained over a wide range of stocking, and that the effect of thinning would merely be to redistribute an approximately constant increment among fewer stems. One of the purposes of the LOGS study was to provide a test of this hypothesis.

Results at this and other LOGS installations have clearly shown that this belief (the so-called Langsaeter hypothesis) is not true for Douglas-fir stands within the age range considered here. Although trends of PAI in basal area are relatively flat in relation to measures of density (figs. 11-14), the corresponding trends in volume PAI show a continuing increase with stand density up to a point where mortality losses become limiting (figs. 15-18). The steeper slope of the volume increment-stand density relation, compared to that for basal area increment, is a consequence of continuing rapid height growth—as can be demonstrated by some fairly simple mathematics (Curtis and Marshall 1986: 80).

Douglas-fir is a very long-lived species, and the stands in the LOGS study are still at an early stage in the natural life cycle, as also shown by their continuing rapid height growth. As height growth and the height growth contribution to volume growth decline with advancing age, the volume growth-stand density relation should approach the shape of the basal area growth-stand density relation, which is much closer to the shape of the Langsaeter curve. But, this is still in the future.

The yield comparisons presented are based primarily on the fixed treatments (1, 3, 5, 7, C), because these are more readily interpretable at this point, midway in the course of the experiment.

Over the life of the experiment, comparisons among the fixed and variable treatments are expected to show that timing of removals also affects tree size and volume production. Variable density treatments 2 and 6 retain the same percentage of control gross growth as treatment 3, and variable density treatments 4 and 8 the same percentage as treatment 5. At the end of the third treatment period, however, the average percentages of gross growth retained in the variable treatments do not yet correspond directly to any of the fixed treatments (see table, inside front cover), and we can say only that cumulative yields increase as the average percentage of control gross increment retained increases—as with the fixed treatments.

The very short thinning cycle (10 feet of height growth) applied in the LOGS study was not intended to represent an operational thinning regime. Rather, it was designed to provide the continuous close control of stocking levels needed to facilitate analysis of growth-growing stock relations. This aim has been largely accomplished for the range in stand densities included in the experiment.

What can now be inferred from the Stampede Creek results with respect to operational thinning? The first and obvious conclusion is that rapid diameter growth obtained by low stocking is bought at the cost of some reduction in total production, at least up to the present (age 53) stage of development.

The Stampede Creek stand had moderate initial numbers of stems and considerable stand differentiation, and at age 53 mortality is only now becoming important in the unthinned plots. Net production to age 53 is higher on the unthinned plots (tables 9 and 10, fig. 6), and the diameters of the crop tree component are not drastically different. It would be hard to argue that thinning of any type was economically justified, if the stand were harvested today.

The picture is different if one considers longer rotations. The distributions of volume by tree size are changing rapidly as a result of thinning (figs. 21 and 22), and soon there will be substantial increases in value due to size-related change in log grades in addition to reduced handling costs. Several studies have found that yields are little influenced by moderate differences in thinning cycles, and the spare plots suggest that an interval of 30 to 40 feet of height growth since calibration has not resulted in serious mortality or crown reduction, while producing a stand that—compared to no thinning—is in better condition to respond to future thinnings.

An important result now appearing in this and other LOGS installations is the comparison of periodic annual increment and mean annual increment shown in figure 9. Even in terms of total cubic volume, Stampede Creek is obviously far from culmination in all treatments. (If increment were expressed in terms of value, differences would be even more pronounced.) Harvest at age 53 is not an option for this and similar stands on National Forest land, because the National Forest Management Act (1976) requires that rotations approximate culmination of mean annual increment. This is obviously well in the future.

For any ownership, harvest at age 53 would involve a large loss in potential volume production. The long-term timber supply problem in the region and increasing public pressures to reduce the area in clearcuts and related slash burns argue for relatively long rotations with multiple thinnings (and perhaps fertilization) to provide intermediate yields and production of high-value timber.

As yet no general analysis of the relations between crown development, thinning treatments, tree and stand increment, and the various measures of stand density has been done. With the continuing accumulation of crown measurements in this and some other LOGS installations, an examination of these relations should soon be possible and is highly desirable.

Metric Equivalents

1 centimeter = 0.3937 inch
1 meter = 3.2808 feet
1 square meter = 10.7643 square feet
1 cubic meter = 35.3107 cubic feet
1 hectare = 2.47105 acres
1 square meter per hectare = 4.3560 square feet per acre
1 cubic meter per hectare = 14.2913 cubic feet per acre

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Appendix 1: Description of Experiment

The following information is excerpted (and paraphrased) from Williamson and Staebler (1971).

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

Experimental Design

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

Crop Tree Selection

Well-formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees before initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees nor more than five—another criterion for stand uniformity.

Initial or "Calibration" Thinning

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

Average spacing in feet = 0.6167 (quadratic mean diameter) + 8 .

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

Treatments

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

Control of Thinning Interval

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

Control of Type of Thinning

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

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).

2. The quadratic mean diameter of cut trees should approximate that of trees available for cutting.

3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

Appendix 2: Tables

Table 1--Average per-acre stand statistics, by treatment[a]

Treatment, year, and age			TP[b]	After thinning: Trees left	QMD[c] all	QMD crop	Basal area	Total vol.	Removed in thinning: Trees cut	QMD	Basal area	Total vol.	Vol/tree	d/D[d]	Mortality: Trees dead	QMD	Basal area	Total vol.	Cum Yield: Net vol.	Gross vol.	MAI[e]: Net vol.
					Inches		Ft²	Ft³		In	Ft²	Cubic feet				In	Ft²		- Cubic feet -		
Fixed:																					
1	1968	33	0	295	6.5	8.3	68.9	1477	709	3.6	51.0	896	1.3	0.78	--	--	--	--	1477	1477	45
	1973	38	1	193	8.3	10.0	73.4	1872	100	6.8	25.2	580	5.8	.87	2	6.3	0.4	8	2452	2460	65
	1978	43	2	132	10.3	11.4	76.5	2309	60	8.6	24.4	673	11.2	.88	2	2.9	.1	1	3561	3571	83
	1983	48	3	82	13.2	13.5	77.0	2602	50	9.4	23.9	735	14.7	.79	0	0	0	0	4590	4599	96
	1988	53	4	62	15.4	15.4	79.2	2987	20	12.5	17.0	606	30.3	.85	0	0	0	0	5581	5590	105
3	1968	33	0	288	6.7	8.4	69.6	1466	709	3.6	51.0	896	1.3	.77	--	--	--	--	1466	1466	44
	1973	38	1	198	8.6	10.0	79.4	2019	90	6.4	20.1	437	4.9	.80	2	6.3	.4	7	2456	2463	65
	1978	43	2	152	10.4	11.7	89.6	2672	47	8.5	18.5	500	10.6	.85	0	0	0	0	3609	3616	84
	1983	48	3	122	12.2	13.3	98.0	3290	28	10.7	17.6	558	19.9	.90	2	3.4	.1	2	4785	4794	100
	1988	53	4	95	14.2	14.7	104.7	3881	27	10.1	15.0	511	18.9	.75	0	0	0	0	5887	5897	111
5	1968	33	0	285	6.7	9.1	68.9	1505	709	3.6	51.0	896	1.3	.77	--	--	--	--	1505	1505	46
	1973	38	1	237	8.2	10.8	86.5	2238	46	6.7	11.1	244	5.3	.84	2	3.7	.1	2	2483	2485	65
	1978	43	2	205	9.6	12.5	101.9	3014	32	8.6	12.9	353	11.0	.92	0	0	0	0	3611	3613	84
	1983	48	3	175	11.0	14.0	115.6	3882	30	8.9	12.9	381	12.7	.83	0	0	0	0	4859	4861	101
	1988	53	4	145	12.6	15.3	125.5	4621	30	9.1	13.5	419	14.0	.75	0	0	0	0	6018	6020	114
7	1968	33	0	280	6.7	8.4	69.4	1558	709	3.6	51.0	896	1.3	.77	--	--	--	--	1558	1558	47
	1973	38	1	260	8.1	10.1	93.3	2425	18	6.8	4.6	107	5.9	.85	2	3.1	.1	1	2532	2533	67
	1978	43	2	232	9.5	11.6	115.1	3440	20	8.5	7.9	218	10.9	.90	8	4.5	.9	17	3765	3783	88
	1983	48	3	212	10.8	13.0	135.7	4678	18	8.5	7.1	216	12.0	.80	2	4.8	.2	5	5218	5242	109
	1988	53	4	198	11.9	14.0	152.9	5789	14	9.5	6.8	252	18.0	.80	0	0	0	0	6582	6605	124
Increasing:																					
2	1968	33	0	287	6.6	8.8	67.5	1440	709	3.6	51.0	896	1.3	.78	--	--	--	--	1440	1440	44
	1973	38	1	190	8.3	10.6	71.8	1837	93	6.9	24.1	553	5.9	.87	4	5.9	.7	18	2389	2407	63
	1978	43	2	123	10.7	12.5	77.6	2301	63	7.4	19.0	489	7.8	.76	3	7.4	1.0	23	3342	3383	78
	1983	48	3	82	13.9	14.3	85.6	2893	41	8.3	15.4	420	10.2	.68	0	0	0	0	4354	4395	91
	1988	53	4	73	15.4	15.9	94.2	3467	3	14.2	3.3	119	39.6	.92	5	15.7	6.7	254	5047	5343	95
4	1968	33	0	295	6.6	8.3	69.7	1448	709	3.6	51.0	896	1.3	.77	--	--	--	--	1448	1448	44
	1973	38	1	207	8.4	10.1	79.9	2037	83	6.5	19.3	432	5.2	.82	5	4.7	.6	11	2470	2481	65
	1978	43	2	157	10.2	11.8	89.5	2643	47	8.4	18.0	482	10.2	.86	4	6.5	.9	24	3557	3593	83
	1983	48	3	134	12.1	13.5	105.9	3519	22	9.2	10.2	318	14.4	.79	2	10.3	1.0	31	4750	4817	99
	1988	53	4	120	13.7	15.0	121.9	4473	15	9.4	7.2	231	15.4	.71	0	0	0	0	5936	6003	112

Table 1 (continued)--Average per-acre stand statistics, by treatment[a]

Treatment	year	age	TP[b]	After thinning: Trees left	QMD[c] all	QMD crop	Basal area	Total vol.	Removed in thinning: Trees cut	QMD	Basal area	Total vol.	Vol/tree	d/D[d]	Mortality: Trees dead	QMD	Basal area	Total vol.	Cum Yield: Net vol.	Gross vol.	MAI[e]: Net vol.
					Inches		Ft^2	Ft^3		In	Ft^2	Cubic Feet				In	Ft^2		- Cubic feet -		
Decreasing:																					
6	1968	33	0	320	6.1	8.0	64.7	1318	709	3.6	51.0	896	1.3	.80	--	--	--	--	1318	1318	40
	1973	38	1	278	7.5	9.8	85.8	2031	39	6.3	8.6	180	4.6	.86	3	3.6	.2	4	2211	2215	58
	1978	43	2	218	9.1	11.5	99.6	2789	57	7.9	19.4	494	8.7	.89	3	3.6	.2	4	3464	3472	81
	1983	48	3	163	10.9	13.2	106.7	3470	55	8.8	23.3	686	12.5	.84	0	0	0	0	4831	4839	101
	1988	53	4	113	13.6	14.8	113.7	4155	50	8.2	18.1	544	10.9	.67	2	8.8	.7	21	6060	6089	114
8	1968	33	0	253	7.0	8.9	67.0	1488	709	3.6	51.0	896	1.3	.77	--	--	--	--	1488	1488	45
	1973	38	1	233	8.5	10.7	91.2	2425	19	6.0	3.7	77	4.0	.72	2	3.0	.1	1	2502	2503	66
	1978	43	2	207	9.9	12.3	110.6	3338	25	8.1	9.0	238	9.5	.83	2	6.8	.4	9	3652	3663	85
	1983	48	3	180	11.3	13.8	125.1	4368	27	9.3	12.7	396	14.7	.84	0	0	0	0	5079	5089	106
	1988	53	4	152	12.9	15.0	136.6	5275	25	9.0	11.1	349	14.0	.73	4	5.2	.6	14	6335	6359	120
Unthinned:																					
C	1968	33	0	997	4.7	8.7	119.2	2354	--	--	--	--	--	--	--	--	--	--	2354	2354	71
	1973	38	1	1010	5.3	10.1	152.0	3557	--	--	--	--	--	--	65	2.4	2.0	27	3557	3584	94
	1978	43	2	890	6.1	11.5	181.1	4878	--	--	--	--	--	--	120	2.6	4.6	75	4878	4981	113
	1983	48	3	685	7.4	12.7	202.2	6243	--	--	--	--	--	--	205	2.9	9.3	181	6243	6527	130
	1988	53	4	517	8.8	13.8	218.7	7691	--	--	--	--	--	--	168	3.4	10.3	232	7691	8207	145

[a] "Cut" values for calibration thinning estimated from means of controls vs. thinned plots. Calibration cut omitted from yet yield, gross yield, and net MAI for thinned plots.

[b] Treatment period

[c] Quadratic mean diameter.

[d] Diameter of cut trees/diameter of all trees

[e] Mean annual increment

Table 2--Average per-hectare stand statistics, by treatment[a]

Treatment	Year	Age	TP[b]	After thinning: Trees left	After thinning: QMD[c] all	After thinning: QMD crop	After thinning: Basal area	After thinning: Total vol.	Removed in thinning: Trees cut	Removed in thinning: QMD	Removed in thinning: Basal area	Removed in thinning: Total vol.	Removed in thinning: Vol/tree	d/D[d]	Mortality: Trees dead	Mortality: QMD	Mortality: Basal area	Mortality: Total vol.	Cum Yield: Net vol.	Cum Yield: Gross vol.	MAI[e]: Net vol.
					- - Cm - -		m^2	m^3		Cm	m^2	Cubic Feet				Cm	m^2		- Cubic Feet -		
Fixed:																					
1	1968	33	0	729	16.6	21.1	15.8	103.4	1752	9.2	11.7	62.7	0.04	0.78	0	0	0	0	103	103	3.1
	1973	38	1	477	21.2	25.3	16.9	131.0	247	17.3	5.8	40.6	.16	.87	5	16.0	.08	.5	172	172	4.5
	1978	43	2	326	26.2	29.0	17.6	161.5	148	21.9	5.6	47.1	.32	.88	5	7.4	.02	.1	249	250	5.8
	1983	48	3	203	33.4	34.3	17.7	182.1	124	23.8	5.5	51.4	.42	.79	0	0	0	0	321	322	6.7
	1988	53	4	153	39.0	39.0	18.2	209.0	49	31.7	3.9	42.4	.86	.85	0	0	0	0	391	391	7.4
3	1968	33	0	712	16.9	21.3	16.0	102.6	1752	9.2	11.7	62.7	.04	.77	0	0	0	0	103	103	3.1
	1973	38	1	489	21.8	25.5	18.2	141.3	222	16.3	4.6	30.6	.14	.80	5	16.0	.08	.5	172	172	4.5
	1978	43	2	376	26.4	29.7	20.6	186.9	116	21.6	4.2	35.0	.30	.85	0	0	0	0	252	253	5.9
	1983	48	3	301	30.9	33.7	22.5	230.2	69	27.3	4.0	39.1	.56	.90	5	8.6	.02	.2	335	335	7.0
	1988	53	4	235	36.1	37.3	24.0	271.6	67	25.7	3.5	35.7	.54	.75	0	0	0	0	412	413	7.8
5	1968	33	0	704	16.9	23.1	15.8	105.3	1752	9.2	11.7	62.7	.04	.77	0	0	0	0	105	105	3.2
	1973	38	1	586	20.8	27.5	19.9	156.6	114	16.9	2.6	17.1	.15	.84	5	9.4	.03	.1	174	174	4.6
	1978	43	2	507	24.3	31.6	23.4	210.9	79	21.9	3.0	24.7	.31	.92	0	0	0	0	253	253	5.9
	1983	48	3	432	28.0	35.6	26.5	271.6	74	22.6	3.0	26.6	.36	.83	0	0	0	0	340	340	7.1
	1988	53	4	358	32.0	39.0	28.8	323.3	74	23.1	3.1	29.3	.40	.75	0	0	0	0	421	421	7.9
7	1968	33	0	692	17.1	21.4	15.9	109.0	1752	9.2	11.7	62.7	.04	.77	0	0	0	0	109	109	3.3
	1973	38	1	642	20.7	25.6	21.4	169.7	44	17.3	1.0	7.5	.17	.85	5	7.9	.02	.1	177	177	4.7
	1978	43	2	573	24.2	29.5	26.4	240.7	49	21.6	1.8	15.3	.31	.90	20	11.4	.20	1.2	263	265	6.1
	1983	48	3	524	27.5	33.1	31.1	327.3	44	21.6	1.6	15.1	.34	.80	5	12.2	.05	.3	365	367	7.6
	1988	53	4	489	30.2	35.7	35.1	405.1	35	24.0	1.6	17.6	.51	.80	0	0	0	0	461	462	8.7
Increasing:																					
2	1968	33	0	709	16.7	22.4	15.5	100.8	1752	9.2	11.7	62.7	.04	.78	0	0	0	0	101	101	3.1
	1973	38	1	469	21.1	26.9	16.5	128.5	230	17.5	5.5	38.7	.17	.87	10	14.9	.17	1.2	167	168	4.4
	1978	43	2	304	27.3	31.7	17.8	161.0	156	18.9	4.4	34.2	.22	.76	7	18.7	.23	1.6	234	237	5.4
	1983	48	3	203	35.2	36.3	19.7	202.4	101	21.1	3.5	29.4	.29	.68	0	0	0	0	305	308	6.3
	1988	53	4	180	39.0	40.3	21.6	242.6	7	36.0	0.8	8.3	1.12	.92	12	39.8	1.54	17.8	353	374	6.7
4	1968	33	0	729	16.7	21.2	16.0	101.3	1752	9.2	11.7	62.7	.04	.77	0	0	0	0	101	101	3.1
	1973	38	1	512	21.4	25.6	18.3	142.5	205	16.6	4.4	30.3	.15	.82	12	11.9	.14	.8	173	174	4.5
	1978	43	2	388	26.0	29.9	20.5	184.9	116	21.4	4.1	33.7	.29	.86	10	16.6	.21	1.7	249	251	5.8
	1983	48	3	331	30.6	34.4	24.3	246.2	54	23.5	2.4	22.2	.41	.79	5	26.2	.22	2.2	332	337	6.9
	1988	53	4	297	34.7	38.1	28.0	313.0	37	23.8	1.6	16.2	.44	.71	0	0	0	0	415	420	7.8

Table 2 (continued)--Average per-hectare stand statistics, by treatment[a]

Trt	Year	Tot Age	TP[b]	After thinning: Trees left	QMD[c] all	QMD crop	Basal area	Total vol.	Removed in thinning: Trees cut	QMD	Basal area	Total vol.	Vol/ tree	d/D[d]	Mortality: Trees dead	QMD	Basal area	Total vol.	Cum Yield: Net vol.	Gross vol.	MAI[e]: Net vol.
					- - Cm	- -	m²	m³		Cm	m²	Cubic	Feet			Cm	m²		- Cubic	Feet -	
Decreasing:																					
6	1968	33	0	791	15.5	20.3	14.8	92.2	1752	9.2	11.7	62.7	.04	.80	0	0	0	0	92	92	2.8
	1973	38	1	687	19.1	24.8	19.7	142.1	96	16.1	2.0	12.6	.13	.86	7	9.1	.05	.3	155	155	4.1
	1978	43	2	539	23.2	29.3	22.9	195.2	141	20.1	4.5	34.6	.25	.89	7	9.0	.05	.3	242	243	5.6
	1983	48	3	403	27.8	33.5	24.5	242.8	136	22.4	5.3	48.0	.35	.84	0	0	0	0	338	339	7.0
	1988	53	4	279	34.4	37.5	26.1	290.7	124	20.7	4.2	38.1	.31	.67	5	22.4	.16	1.5	424	426	8.0
8	1968	33	0	625	17.7	22.6	15.4	104.1	1752	9.2	11.7	62.7	.04	.77	0	0	0	0	104	104	3.2
	1973	38	1	576	21.5	27.2	20.9	169.7	47	15.2	0.9	5.4	.11	.72	5	7.6	.02	.1	175	175	4.6
	1978	43	2	512	25.2	31.2	25.4	233.6	62	20.6	2.1	16.6	.27	.83	5	17.3	.10	.7	256	256	5.9
	1983	48	3	445	28.7	35.0	28.7	305.7	67	23.6	2.9	27.7	.42	.84	0	0	0	0	355	356	7.4
	1988	53	4	376	32.6	38.2	31.4	369.1	62	23.0	2.6	24.4	.40	.73	10	13.1	.13	1.0	443	445	8.4
Unthinned:																					
C	1968	33	0	2464	11.9	22.1	27.4	164.7	0	0	0	0	0	--	0	0	0	0	165	165	5.0
	1973	38	1	2496	13.3	25.7	34.9	248.9	0	0	0	0	0	--	161	6.0	.45	1.9	249	251	6.5
	1978	43	2	2199	15.5	29.2	41.6	341.3	0	0	0	0	0	--	297	6.7	1.05	5.3	341	348	7.9
	1983	48	3	1693	18.7	32.3	46.4	436.8	0	0	0	0	0	--	507	7.3	2.15	12.7	437	457	9.1
	1988	53	4	1278	22.4	35.1	50.2	538.2	0	0	0	0	0	--	415	8.5	2.36	16.2	538	574	10.2

[a] "Cut" values for calibration thinning estimated from means of controls vs. thinned plots. Calibration cut omitted from net yield, gross yield, and net MAI for thinned plots.

[b] Treatment period

[c] Quadratic mean diameter

[d] Diameter of cut trees/diameter of all trees

[e] Mean annual increment

Table 3--Number of trees per acre by treatment, plot, period, and year

Trtmt	Plot	Calibration: After cut 1968	Calibration: Before cut 1973	Period 1: After cut 1973	Period 1: Before cut 1978	Period 2: After cut 1978	Period 2: Before cut 1983	Period 3: After cut 1983	Period 3: Before cut 1988	After cut 1988
Fixed:										
1	41	300	295	200	195	125	125	75	75	60
	72	285	285	175	175	120	120	70	70	55
	126	300	300	205	205	150	150	100	100	70
3	51	295	295	195	195	150	150	115	115	85
	103	295	290	200	200	150	150	125	125	95
	121	275	275	200	200	155	150	125	125	105
5	92	280	275	210	210	175	175	130	135	95
	114	280	280	250	250	225	225	205	205	165
	125	295	295	250	250	215	215	185	185	175
7	62	275	270	250	245	220	215	190	190	175
	106	290	290	255	240	225	225	210	210	205
	107	275	275	275	270	250	250	235	235	215
Increasing:										
2	91	285	280	195	185	125	125	100	90	90
	112	300	300	220	220	140	140	80	80	70
	113	275	270	155	155	105	105	65	60	60
4	71	290	285	170	170	135	130	110	110	95
	82	320	315	245	240	175	175	145	145	125
	115	275	270	205	200	160	160	150	150	140
Decreasing:										
6	32	340	335	295	295	220	220	170	170	110
	101	290	290	235	235	185	185	135	135	95
	102	330	325	305	295	250	250	190	185	135
8	96	230	230	210	210	175	175	155	150	135
	111	275	270	240	240	235	235	200	195	165
	116	255	255	250	245	210	210	185	185	155
Unthinned:										
C	61	1005	965	965	860	860	675	675	495	495
	105	690	830	830	745	745	620	620	470	470
	122	1295	1235	1235	1065	1065	760	760	585	585

Table 4--Number of trees per hectare by treatment, plot, period, and year

		Calibration		Period 1		Period 2		Period 3		
Trtmt	Plot	After cut 1968	Before cut 1973	After cut 1973	Before cut 1978	After cut 1978	Before cut 1983	After cut 1983	Before cut 1988	After cut 1988
Fixed:										
1	41	741	729	494	482	309	309	185	185	148
	72	704	704	432	432	297	297	173	173	136
	126	741	741	507	507	371	371	247	247	173
3	51	729	729	482	482	371	371	284	284	210
	103	729	717	494	494	371	371	309	309	235
	121	680	680	494	494	383	371	309	309	259
5	92	692	680	519	519	432	432	321	334	235
	114	692	692	618	618	531	556	507	507	408
	125	729	729	618	618	531	531	457	457	432
7	62	680	667	618	605	544	531	469	469	432
	106	717	717	630	593	556	556	519	519	507
	107	680	680	680	667	618	618	581	581	531
Increasing:										
2	91	704	692	482	457	309	309	247	222	222
	112	741	741	544	544	346	346	198	198	173
	113	680	667	383	383	259	259	161	148	148
4	71	717	704	420	420	334	321	272	272	235
	82	791	778	605	593	432	432	358	358	309
	115	680	667	507	494	395	395	371	371	346
Decreasing:										
6	32	840	828	729	729	544	544	420	420	272
	101	717	717	581	581	457	457	334	334	235
	102	815	803	754	729	618	618	469	457	334
8	96	568	568	519	519	432	432	383	371	334
	111	680	667	593	593	581	581	494	482	408
	116	630	630	618	605	519	519	457	457	383
Unthinned:										
C	61	2483	2385	2385	2125	2125	1668	1668	1223	1223
	105	1705	2051	2051	1841	1841	1532	1532	1161	1161
	122	3200	3052	3052	2632	2632	1878	1878	1446	1446

Table 5--Quadratic mean diameters (all trees) by treatment, plot, period, and year

Trtmt	Plot	Calibration: After cut 1968	Calibration: Before cut 1973	Period 1: After cut 1973	Period 1: Before cut 1978	Period 2: After cut 1978	Period 2: Before cut 1983	Period 3: After cut 1983	Period 3: Before cut 1988	After cut 1988
		Inches								
Fixed:										
1	41	6.4	7.8	8.2	9.8	10.5	12.3	13.6	15.3	15.5
	72	6.8	8.2	8.9	10.5	10.9	12.5	14.2	15.8	16.3
	126	6.4	7.6	8.0	9.3	9.7	10.9	12.0	13.4	14.5
3	51	6.6	8.0	8.7	10.2	10.5	12.1	12.7	14.0	15.1
	103	6.6	7.9	8.5	10.0	10.5	11.8	11.9	13.2	14.2
	121	6.8	8.0	8.5	9.8	10.2	11.7	11.9	13.2	13.5
5	92	6.9	8.3	8.7	10.1	10.4	11.9	12.6	14.1	15.8
	114	6.5	7.8	8.0	9.1	9.2	10.2	10.2	11.1	11.4
	125	6.6	7.8	8.0	9.2	9.2	10.2	10.7	11.5	11.7
7	62	6.8	8.2	8.3	9.6	9.7	11.1	11.4	12.4	12.7
	106	6.7	8.0	8.1	9.6	9.6	10.7	10.8	11.7	11.6
	107	6.8	8.0	8.0	9.2	9.3	10.3	10.4	11.3	11.5
Increasing:										
2	91	6.6	7.8	8.2	9.6	10.4	11.8	12.6	13.9	13.9
	112	6.3	7.6	7.7	9.2	10.1	11.6	14.0	15.7	16.0
	113	6.8	8.3	9.2	10.7	11.9	13.6	15.4	16.7	16.7
4	71	6.7	8.1	9.2	10.9	11.1	12.9	13.2	14.7	15.3
	82	6.2	7.5	7.8	9.2	9.8	11.2	11.6	12.8	13.3
	115	6.9	8.2	8.5	9.7	10.0	11.2	11.4	12.5	12.7
Decreasing:										
6	32	6.0	7.2	7.3	8.6	9.1	10.4	10.7	12.0	13.7
	101	6.5	7.9	8.2	9.7	9.9	11.3	12.0	13.4	14.8
	102	5.8	7.1	7.2	8.5	8.6	9.8	10.2	11.4	12.6
8	96	7.4	8.8	9.0	10.3	10.7	12.0	12.1	13.3	13.5
	111	6.4	7.8	8.1	9.4	9.3	10.4	10.7	11.8	12.4
	116	7.1	8.4	8.4	9.6	9.8	11.0	11.2	12.2	12.8
Unthinned:										
C	61	4.7	5.4	5.4	6.3	6.3	7.6	7.6	9.3	9.3
	105	5.3	5.5	5.5	6.4	6.4	7.4	7.4	8.8	8.8
	122	4.3	4.9	4.9	5.7	5.7	7.1	7.1	8.4	8.4

Table 6--Quadratic mean diameters (all trees) by treatment, plot, period, and year.

Trtmt	Plot	Calibration After cut 1968	Calibration Before cut 1973	Period 1 After cut 1973	Period 1 Before cut 1978	Period 2 After cut 1978	Period 2 Before cut 1983	Period 3 After cut 1983	Period 3 Before cut 1988	After cut 1988
		Centimeters								
Fixed:										
1	41	16.3	19.9	20.7	24.9	26.7	31.2	34.5	38.8	39.3
	72	17.3	20.8	22.6	26.5	27.7	31.9	36.0	40.2	41.3
	126	16.3	19.2	20.4	23.6	24.5	27.7	30.5	34.0	36.7
3	51	16.9	20.2	22.1	26.0	26.8	30.8	32.2	35.5	38.2
	103	16.7	20.0	21.7	25.4	26.7	30.0	30.2	33.4	36.1
	121	17.1	20.4	21.5	24.8	25.8	29.8	30.3	33.6	34.3
5	92	17.5	21.2	22.0	25.7	26.3	30.3	32.0	35.7	40.1
	114	16.6	19.8	20.2	23.2	23.3	26.0	25.9	28.1	29.1
	125	16.7	19.7	20.4	23.2	23.4	26.0	27.1	29.3	29.6
7	62	17.2	20.8	21.0	24.4	24.7	28.1	28.9	31.5	32.3
	106	17.0	20.2	20.7	24.4	24.5	27.2	27.4	29.8	29.4
	107	17.2	20.3	20.3	23.3	23.6	26.1	26.4	28.6	29.2
Increasing:										
2	91	16.8	19.8	20.9	24.5	26.4	29.9	32.1	35.2	35.2
	112	16.0	19.3	19.7	23.3	25.6	29.6	35.6	39.8	40.5
	113	17.3	21.0	23.3	27.3	30.3	34.4	39.2	42.4	42.4
4	71	17.0	20.6	23.3	27.6	28.1	32.7	33.6	37.4	38.9
	82	15.7	19.1	19.8	23.3	24.8	28.5	29.4	32.5	33.9
	115	17.5	20.7	21.6	24.7	25.4	28.5	29.0	31.6	32.2
Decreasing:										
6	32	15.2	18.3	18.6	21.9	23.1	26.5	27.3	30.4	34.7
	101	16.5	20.0	20.7	24.6	25.2	28.7	30.6	34.0	37.5
	102	14.8	18.1	18.2	21.7	21.8	24.8	25.8	28.9	31.9
8	96	18.8	22.3	22.8	26.0	27.3	30.4	30.7	33.7	34.3
	111	16.3	19.9	20.4	23.7	23.6	26.3	27.3	30.1	31.4
	116	18.1	21.3	21.4	24.5	25.0	28.0	28.4	31.0	32.4
Unthinned:										
C	61	11.9	13.7	13.7	16.0	16.0	19.3	19.3	23.5	23.5
	105	13.4	14.0	14.0	16.2	16.2	18.9	18.9	22.4	22.4
	122	11.0	12.5	12.5	14.6	14.6	17.9	18.0	21.3	21.3

Table 7--Basal area per acre by treatment, plot, period, and year

Trtmt	Plot	Calibration		Period 1		Period 2		Period 3		
		After cut 1968	Before cut 1973	After cut 1973	Before cut 1978	After cut 1978	Before cut 1983	After cut 1983	Before cut 1988	After cut 1988
		Square feet								
Fixed:										
1	41	68	98	73	102	75	103	76	95	79
	72	72	104	76	104	78	103	77	96	79
	126	67	94	72	96	75	97	79	98	80
3	51	71	102	81	111	91	121	101	122	105
	103	70	98	79	109	90	114	97	118	105
	121	68	97	78	104	87	113	97	119	104
5	92	72	104	86	117	103	135	117	146	129
	114	65	92	86	113	103	128	116	137	118
	125	70	97	88	114	100	123	115	134	130
7	62	69	99	93	124	113	143	134	159	154
	106	71	100	92	121	114	141	134	158	150
	107	67	96	96	125	118	144	139	162	155
Increasing:										
2	91	68	93	72	94	74	95	87	94	94
	112	65	95	72	101	78	103	86	107	97
	113	70	100	71	97	82	105	84	91	91
4	71	71	102	78	109	90	117	105	130	122
	82	67	98	81	110	91	120	106	130	121
	115	71	98	81	103	87	110	106	127	123
Decreasing:										
6	32	67	95	86	119	99	131	107	132	112
	101	67	98	85	120	99	129	107	132	113
	102	61	90	86	117	101	130	107	131	116
8	96	69	96	92	120	110	137	124	144	135
	111	62	90	85	114	111	138	126	149	137
	116	71	98	97	124	111	139	126	150	138
Unthinned:										
C	61	121	154	154	186	186	212	212	232	232
	105	105	138	138	166	166	187	187	200	200
	122	132	164	164	191	191	207	207	224	224

Table 8--Basal area per hectare by treatment, plot, period, and year

Trtmt	Plot	Calibration: After cut 1968	Calibration: Before cut 1973	Period 1: After cut 1973	Period 1: Before cut 1978	Period 2: After cut 1978	Period 2: Before cut 1983	Period 3: After cut 1983	Period 3: Before cut 1988	After cut 1988
		- - - - - -	- - - - - -	- - - - - -	- - - - - -	Square meters	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Fixed:										
1	41	15.5	22.6	16.7	23.4	17.3	23.6	17.3	21.9	18.0
	72	16.5	23.8	17.3	23.9	17.9	23.6	17.6	22.0	18.2
	126	15.4	21.5	16.5	22.1	17.3	22.3	18.1	22.4	18.3
3	51	16.3	23.4	18.5	25.5	20.9	27.7	23.1	28.1	24.1
	103	16.0	22.5	18.2	25.0	20.7	26.1	22.2	27.1	24.1
	121	15.7	22.2	17.9	23.9	20.1	25.8	22.2	27.3	24.0
5	92	16.6	23.9	19.7	26.9	23.5	31.1	26.9	33.4	29.6
	114	14.9	21.2	19.8	26.0	23.7	29.4	26.6	31.5	27.0
	125	16.0	22.2	20.1	26.2	22.9	28.2	26.3	30.8	29.7
7	62	15.8	22.6	21.3	28.4	26.1	32.9	30.8	36.5	35.4
	106	16.2	23.0	21.2	27.8	26.2	32.3	30.7	36.2	34.4
	107	15.3	22.1	22.1	28.6	27.1	33.1	31.9	37.3	35.5
Increasing:										
2	91	15.6	21.3	16.5	21.5	16.9	21.7	20.0	21.6	21.6
	112	14.8	21.7	16.5	23.3	17.8	23.7	19.7	24.6	22.3
	113	16.1	23.1	16.4	22.4	18.7	24.1	19.3	20.9	20.9
4	71	16.2	23.5	18.0	25.1	20.8	26.9	24.1	29.9	27.9
	82	15.4	22.4	18.6	25.2	20.8	27.6	24.4	29.8	27.9
	115	16.4	22.4	18.5	23.7	20.0	25.2	24.4	29.2	28.2
Decreasing:										
6	32	15.3	21.9	19.9	27.4	22.7	30.0	24.5	30.4	25.8
	101	15.3	22.6	19.6	27.6	22.8	29.5	24.5	30.4	25.9
	102	13.9	20.6	19.7	26.9	23.1	29.9	24.5	30.0	26.7
8	96	15.7	22.1	21.1	27.6	25.2	31.4	28.4	33.0	30.9
	111	14.2	20.7	19.5	26.2	25.5	31.6	28.8	34.2	31.6
	116	16.2	22.5	22.2	28.5	25.5	31.9	29.0	34.5	31.6
Unthinned:										
C	61	27.8	35.3	35.3	42.8	42.8	48.7	48.7	53.3	53.3
	105	24.1	31.8	31.8	38.1	38.1	43.0	43.0	45.9	45.9
	122	30.2	37.7	37.7	43.9	43.9	47.6	47.6	51.5	51.5

Table 9--Total volume in cubic feet per acre (all trees) by treatment, plot, period, and year

		Calibration		Period 1		Period 2		Period 3		
Trtmt	Plot	After cut 1968	Before cut 1973	After cut 1973	Before cut 1978	After cut 1978	Before cut 1983	After cut 1983	Before cut 1988	After cut 1988
		Cubic feet								
Fixed:										
1	41	1470	2501	1878	3062	2309	3486	2593	3576	2940
	72	1599	2537	1894	3091	2358	3430	2608	3525	2949
	126	1362	2319	1846	2792	2259	3093	2602	3677	3072
3	51	1541	2567	2115	3393	2821	4120	3491	4566	3958
	103	1419	2387	1991	3079	2593	3666	3132	4159	3750
	121	1439	2367	1950	3043	2601	3759	3247	4450	3935
5	92	1650	2718	2293	3515	3112	4505	3999	5343	4857
	114	1368	2265	2143	3243	2985	4147	3782	4934	4310
	125	1498	2466	2279	3342	2944	4100	3865	4845	4696
7	62	1483	2556	2416	3675	3398	4859	4595	5960	5801
	106	1563	2527	2348	3558	3363	4800	4588	6005	5657
	107	1627	2513	2513	3741	3559	5022	4850	6158	5909
Increasing:										
2	91	1430	2324	1823	2590	2091	3002	2802	3398	3398
	112	1335	2295	1782	2801	2227	3287	2845	3894	3538
	113	1556	2549	1904	2977	2585	3649	3031	3465	3465
4	71	1491	2618	2075	3279	2728	4011	3609	4781	4483
	82	1357	2324	1941	3110	2627	3967	3525	4701	4425
	115	1497	2466	2095	2986	2575	3531	3447	4631	4511
Decreasing:										
6	32	1359	2228	2040	3300	2811	4241	3528	4792	4194
	101	1403	2289	2018	3384	2832	4125	3503	4788	4180
	102	1192	2119	2036	3167	2725	4103	3385	4517	4090
8	96	1537	2614	2511	3730	3464	4959	4522	5733	5420
	111	1340	2338	2239	3360	3261	4521	4175	5424	5084
	116	1588	2554	2526	3637	3289	4814	4409	5715	5320
Unthinned:										
C	61	2478	3659	3659	5236	5235	6950	6950	8505	8505
	105	2064	3347	3347	4620	4920	5909	5909	7034	7034
	122	2521	3665	3665	4779	4779	5870	5870	7535	7535

Table 10--Total volume in cubic meters per hectare (all trees) by treatment, plot, period, and year

		Calibration		Period 1		Period 2		Period 3		
Trtmt	Plot	After cut 1968	Before cut 1973	After cut 1973	Before cut 1978	After cut 1978	Before cut 1983	After cut 1983	Before cut 1988	After cut 1988
		- - - - - - - - - - - - - - Cubic meters - - - - - - - - - - - - - -								
Fixed:										
1	41	102.8	175.0	131.4	214.2	161.6	243.9	181.4	250.2	205.7
	72	111.9	177.5	132.5	216.3	165.0	240.0	182.5	246.7	206.4
	126	95.3	162.3	129.1	195.3	158.0	216.4	182.1	257.3	215.0
3	51	107.9	179.6	148.0	237.4	197.4	288.3	244.2	319.5	277.0
	103	99.3	167.0	139.3	215.5	181.4	256.5	219.1	291.0	262.4
	121	100.7	165.6	136.5	212.9	182.0	263.0	227.2	311.4	275.3
5	92	115.5	190.2	160.5	246.0	217.8	315.2	279.8	373.8	339.9
	114	95.7	158.5	150.0	226.9	208.9	290.2	264.6	345.2	301.5
	125	104.8	172.5	159.4	233.8	206.0	286.9	270.4	339.0	328.6
7	62	103.8	178.9	169.0	257.2	237.8	340.0	321.5	417.0	405.9
	106	109.4	176.8	164.3	249.0	235.3	335.9	321.0	420.2	395.9
	107	113.9	175.8	175.8	261.8	249.0	351.4	339.4	430.9	413.4
Increasing:										
2	91	100.1	162.6	127.6	181.3	146.3	210.1	196.1	237.8	237.8
	112	93.4	160.6	124.7	196.0	155.9	230.0	199.1	272.5	247.5
	113	108.9	178.3	133.2	208.3	180.9	255.3	212.1	242.5	242.5
4	71	104.3	183.2	145.2	229.4	190.9	280.7	252.6	334.5	313.7
	82	95.0	162.6	135.8	217.6	183.8	277.6	246.6	328.9	309.6
	115	104.7	172.6	146.6	208.9	180.1	247.1	241.2	324.1	315.6
Decreasing:										
6	32	95.1	155.9	142.7	230.9	196.7	296.8	246.8	335.3	293.4
	101	98.2	160.1	141.2	236.8	198.2	288.7	245.1	335.0	292.5
	102	83.4	148.3	142.5	221.6	190.7	287.1	236.9	316.1	286.2
8	96	107.5	182.9	175.7	261.0	242.3	347.0	316.4	401.2	379.3
	111	93.8	163.6	156.7	235.1	228.2	316.4	292.2	379.5	355.8
	116	111.1	178.7	176.7	254.5	230.1	336.8	308.5	399.9	372.2
Unthinned:										
C	61	173.4	256.0	256.0	366.4	366.3	486.3	486.3	595.1	595.1
	105	144.4	234.2	234.2	323.2	344.2	413.5	413.5	492.2	492.2
	122	176.4	256.4	256.4	334.4	334.4	410.7	410.7	527.2	527.2

Table 11--Periodic annual increments (PAI) in number, quadratic mean diameter, basal area, and volume, per acre per year, by treatment

Trt	Period	Total age, midperiod	Number PAI, mortality +ingrowth	D.b.h. PAI		Basal area PAI		Volume PAI	
				Net	Survivor	Net	Gross	Net	Gross
		Years		- - Inch - -		Square feet		Cubic feet	
Fixed:									
1	0	35.5	-0.4	0.26	0.26	6.0	6.0	195	197
	1	40.5	-.2	.30	.29	5.5	5.5	222	222
	2	45.5	0	.31	.31	4.9	4.9	206	206
	3	50.5	0	.31	.31	3.8	3.8	198	198
3	0	35.5	-.2	.26	.26	5.9	5.9	195	196
	1	40.5	0	.28	.28	5.7	5.7	231	231
	2	45.5	-.4	.30	.29	5.2	5.2	235	236
	3	50.5	0	.26	.26	4.4	4.4	220	220
5	0	35.5	-.4	.26	.25	5.8	5.8	195	196
	1	40.5	0	.25	.25	5.7	5.7	226	226
	2	45.5	0	.24	.24	5.4	5.4	250	250
	3	50.5	0	.21	.21	4.6	4.6	232	232
7	0	35.5	-.4	.26	.26	5.8	5.8	195	195
	1	40.5	-1.0	.27	.25	5.9	6.0	247	250
	2	45.5	-.4	.23	.22	5.5	5.6	291	292
	3	50.5	0	.18	.18	4.8	4.8	273	273
Increasing:									
2	0	35.5	-.8	.26	.26	5.7	5.8	190	193
	1	40.5	-.6	.29	.29	5.1	5.3	191	195
	2	45.5	0	.30	.30	4.7	4.7	202	202
	3	50.5	-1.0	.28	.31	2.4	3.7	139	190[a]
4	0	35.5	-1.0	.27	.26	5.9	5.7	204	207
	1	40.5	-.8	.29	.25	5.5	5.5	218	222
	2	45.5	-.2	.29	.29	5.3	4.6	239	245
	3	50.5	0	.25	.25	4.6	4.6	235	235
Decreasing:									
6	0	35.5	-.6	.26	.26	6.0	6.0	179	179
	1	40.5	-.2	.28	.27	6.6	6.7	250	251
	2	45.5	0	.26	.26	6.1	6.1	273	273
	3	50.5	-.4	.26	.25	5.0	5.2	245	250
8	0	35.5	-.2	.27	.27	5.6	5.6	203	203
	1	40.5	-.2	.25	.25	5.7	5.8	230	232
	2	45.5	0	.23	.23	5.4	5.4	285	285
	3	50.5	-.6	.22	.20	4.5	4.6	251	254
Unthinned:									
C	0	35.5	+2.6	.11	.13	6.6	7.0	241	246[b]
	1	40.5	-21.0	.17	.12	5.8	6.7	264	279
	2	45.5	-41.0	.25	.12	4.2	6.1	273	309
	3	50.5	-20.7	.29	.11	3.3	5.4	290	336

[a] Root rot mortality.

[b] Positive change in number in T-9 due to ingrowth, present only in unthinned plots.

Table 12--Periodic annual increments (PAI) in number, quadratic mean diameter, basal area, and volume, per hectare per year, by treatment

Trt	Period	Total age, midperiod	Number PAI mortality +ingrowth	DBH PAI Net	DBH PAI Survivor	Basal area PAI Net	Basal area PAI Gross	Volume PAI Net	Volume PAI Gross
		Years		Centimeter		Square meters		Cubic meters	
Fixed:									
1	0	35.5	-1.0	0.67	0.67	1.4	1.4	13.7	13.8
	1	40.5	-.5	.75	.74	1.3	1.3	15.5	15.5
	2	45.5	0	.79	.78	1.1	1.1	14.4	14.4
	3	50.5	0	.78	.78	.9	.9	13.9	13.9
3	0	35.5	-.5	.66	.66	1.3	1.4	13.6	13.7
	1	40.5	0	.72	.72	1.3	1.3	16.1	16.1
	2	45.5	-1.0	.76	.74	1.2	1.2	16.5	16.5
	3	50.5	0	.65	.65	1.0	1.0	15.4	15.4
5	0	35.5	-1.0	.66	.64	1.3	1.3	13.7	13.7
	1	40.5	0	.64	.63	1.3	1.3	15.8	15.8
	2	45.5	0	.60	.60	1.2	1.2	17.5	17.5
	3	50.5	0	.53	.53	1.1	1.1	16.2	16.2
7	0	35.5	-1.0	.67	.66	1.3	1.3	13.6	13.6
	1	40.5	-4.0	.68	.63	1.3	1.4	17.3	17.5
	2	45.5	-1.0	.57	.56	1.3	1.3	20.3	20.4
	3	50.5	0	.47	.47	1.1	1.1	19.1	19.1
Increasing:									
2	0	35.5	-2.0	.67	.66	1.3	1.3	13.3	13.5
	1	40.5	-1.5	.75	.73	1.2	1.2	13.3	13.7
	2	45.5	0	.77	.77	1.1	1.1	14.2	14.2
	3	50.5	-2.5	.72	.77	.5	.9	9.7	13.3[a]
4	0	35.5	-2.5	.68	.66	1.4	1.3	14.3	14.5
	1	40.5	-2.0	.73	.64	1.3	1.3	15.2	15.6
	2	45.5	-.1	.75	.75	1.2	1.1	16.7	17.1
	3	50.5	0	.64	.63	1.1	1.1	16.5	16.5
Decreasing:									
6	0	35.5	-1.5	.67	.65	1.4	1.4	12.5	12.6
	1	40.5	-1.5	.71	.69	1.5	1.5	17.5	17.6
	2	45.5	0	.67	.66	1.4	1.4	19.1	19.1
	3	50.5	-1.0	.65	.64	1.2	1.2	17.2	17.5
8	0	35.5	-.5	.69	.68	1.3	1.3	14.2	14.2
	1	40.5	-.5	.64	.64	1.3	1.3	16.1	16.2
	2	45.5	0	.58	.58	1.2	1.2	20	20.0
	3	50.5	-1.5	.56	.51	1.0	1.1	17.6	17.8
Unthinned									
C	0	35.5	+6.4	.29	.33	1.5	1.6	16.8	17.2[b]
	1	40.5	-59.3	.44	.31	1.3	1.5	18.5	19.5
	2	45.5	-101.3	.62	.29	1.0	1.4	19.1	21.6
	3	50.5	-83.0	.74	.28	.8	1.2	20.3	23.5

[a] Root rot mortality.

[b] Positive change in number in T-9 due to ingrowth, present only in unthinned plots.

Table 13--Per-acre stand statistics[a] for treatment 10 ("spare" plots 21, 81, and 123)

		After thinning				Removed in thinning						Mortality				Yield		MAI[c]
Year	Age	Trees left	QMD all	Basal area	Total vol.	Trees cut	QMD	Basal area	Total vol.	Volume per tree	d/D[b]	Trees dead	QMD	Basal area	Total vol.	Net vol.	Gross vol.	Net vol.
	Yr		In	Ft^2	Ft^3		In	Ft^2	Ft^3	Ft^2			In	Ft^2	- - Cubic feet - -			
1968	33	328	5.8	59.5	1180	709	3.6	51.0	896	1.3	0.81	--	--	--	--	1180	1180	36
1973	38	320	6.9	83.0	1920	0	--	--	--	--	--	8	5.5	1.4	23	1920	1943	51
1988	53	295	10	160.9	5326	0	--	--	--	--	--	25	5.1	3.5	163	5326	5489	100

[a] Because height measurements were lacking for 1968 and 1973, vol./d.b.h. curves from adjacent plots were used dates."Cut" values for calibration thinning estimated from difference between men means of thinned vs. unthinned plots. "Cut" values from calibration thinning omitted from net yield and net MAI.

[b] Diameter of cut trees/diameter of all trees

[c] Mean annual increment

Table 14--Per-hectare stand statistics[a] for treatment 10 ("spare" plots 21, 81, 123)

		After thinning				Removed in thinning						Mortality				Yield		MAI[c]
Year	Total Age	Trees left	QMD all	Basal area	Total vol.	Trees cut	QMD	Basal area	Total vol.	Volume per tree	d/D[b]	Trees dead	QMD	Basal area	Total vol.	Net vol.	Gross vol.	Net vol.
	Yr		Cm	m^2	m^3		Cm	m^2	m^3	m^2			Cm	m^2	- - Cubic feet - -			
1968	33	811	14.7	13.7	82.6	1752	9.2	11.7	4.40	0.04	0.81	--	--	--	--	83	83	2.5
1973	38	791	17.5	19.1	134.4	0	--	--	--	--	--	20	14.0	0.3	1.6	134	136	3.5
1988	53	729	25.4	36.9	372.7	0	--	--	--	--	--	62	12.9	.8	11.4	373	384	7.0

[a] Because height measurements were lacking for 1968 and 1973, vol./d.b.h. curves from adjacent plots were used for these dates. "Cut" values for calibration thinning estimated from difference between mean means of thinned vs unthinned plots. "Cut" values from calibration thinning omitted from net yield and net MAI.

[b] Diameter of cut trees/diameter of all trees

[c] Mean annual increment

Table 15--Heights of largest 40 trees per acre, by Treatments

Treatment	Total age, years				
	33	38	43	48	53
	Feet				
Fixed:					
1	59	69	80	89	99
3	59	69	80	90	99
5	62	73	84	93	102
7	60	71	82	94	104
Increasing:					
2	60	71	81	92	101
4	58	69	79	90	100
Decreasing:					
6	58	66	78	89	98
8	61	73	84	96	106
Unthinned:					
C	59	71	81	90	101
Spares	--	--	--	--	93
Mean, spares excluded	59.5	70.4	81.0	91.4	101.0

Table 16--Heights of largest 100 trees per hectare, by treatments

Treatment	Total age, years				
	33	38	43	48	53
	Meters				
Fixed:					
1	18.0	21.1	24.3	27.2	30.3
3	17.9	21.1	24.2	27.4	30.3
5	19.0	22.3	25.5	28.4	31.1
7	18.4	21.5	25.0	28.6	31.6
Increasing:					
2	18.3	21.8	24.8	28.0	30.6
4	17.6	21.2	24.2	27.3	30.4
Decreasing:					
6	17.7	20.2	23.7	27.2	30.0
8	18.5	22.4	25.6	29.4	32.3
Unthinned:					
C	18.0	21.5	24.7	27.4	30.8
Spares	--	--	--	--	28.3
Mean, spares excluded	18.1	21.5	24.7	27.9	30.8

Table 17--Average diameters of largest 40 trees per acre, by treatment

Treatment	Total age, years				
	33	38	43	4	53
	- - - - - - - - - Inches - - - - - - - - -				
Fixed:					
1	9.2	10.9	12.7	14.6	16.4
3	9.4	11.2	12.9	14.6	16.2
5	10.4	12.3	14.1	15.8	17.3
7	9.5	11.4	13.0	14.5	15.8
Increasing:					
2	10.4	12.3	14.1	15.8	17.4
4	9.1	10.9	12.8	14.6	16.1
Decreasing:					
6	9.1	10.9	12.8	14.6	16.3
8	10.2	12.1	13.8	15.4	16.8
Unthinned:					
C	9.7	11.1	12.6	14.0	15.3
Spares	--	--	--	--	14.5

Table 18--Average diameters of largest 100 trees per hectare, by treatments

Treatment	Total age, years				
	33	38	43	48	53
	- - - - - - - Centimeters - - - - - - -				
Fixed:					
1	23.2	27.8	32.3	37.1	41.5
3	23.9	28.3	32.8	37.2	41.1
5	26.5	31.3	35.8	40.1	43.8
7	24.2	28.8	33.0	36.9	40.2
Increasing:					
2	26.4	31.2	35.7	40.2	44.6
4	23.2	27.8	32.4	37.2	41.0
Decreasing:					
6	23.1	27.8	32.5	37.1	41.3
8	25.8	30.6	34.9	39.2	42.7
Unthinned:					
C	24.6	28.4	32.1	35.7	38.8
Spares	--	--	--	--	36.9

Table 19--Average heights of crop trees, by treatments

Treatment	Total age, years				
	33	38	43	48	53
	Feet				
Fixed:					
1	56	67	77	85	97
3	57	66	77	86	96
5	59	69	80	89	98
7	57	68	79	90	100
Increasing:					
2	56	67	77	87	97
4	55	67	77	85	97
Decreasing:					
6	55	63	74	86	95
8	57	70	80	92	101
Unthinned:					
C	57	68	78	87	98
Mean	56.3	67.2	77.7	87.9	97.5

Table 20--Average heights of crop trees, by treatments

Treatment	Total age, years				
	33	38	43	48	53
	Meters				
Fixed:					
1	17.1	20.3	23.5	26.0	29.4
3	17.2	20.1	23.4	26.3	29.2
5	17.9	21.1	24.3	27.3	29.9
7	17.5	20.7	24.0	27.5	30.4
Increasing:					
2	17.0	20.5	23.6	26.6	29.4
4	16.8	20.4	23.4	26.5	29.5
Decreasing:					
6	16.6	19.3	22.7	26.2	29.0
8	17.5	21.3	24.4	28.1	30.9
Unthinned:					
C	17.3	20.8	23.8	26.5	29.8
Mean	17.2	20.5	23.7	26.8	29.7

Table 21--Average diameters of crop trees, by treatments

Treatment	33	38	43	48	53
	Total age, years				
	Inches				
Fixed:					
1	8.3	10.0	11.7	13.5	15.4
3	8.4	10.0	11.7	13.3	14.7
5	9.1	10.8	12.5	14.0	15.3
7	8.4	10.1	11.6	13.0	14.0
Increasing:					
2	8.8	10.6	12.5	14.3	15.9
4	8.3	10.1	11.8	13.5	15.0
Decreasing:					
6	8.0	9.8	11.5	13.2	14.8
8	8.9	10.7	12.3	13.8	15.0
Unthinned:					
C	8.7	10.1	11.5	12.7	13.8

Table 22--Average diameters of crop trees, by treatments

Treatment	33	38	43	48	53
	Total age, years				
	Centimeters				
Fixed:					
1	21.1	25.3	29.7	34.3	39.0
3	21.3	25.5	29.7	33.8	37.3
5	23.1	27.5	31.6	35.6	39.0
7	21.4	25.6	29.5	33.1	35.7
Increasing:					
2	22.4	26.8	31.7	36.3	40.3
4	21.1	25.6	29.9	34.4	38.0
Decreasing:					
6	20.3	24.8	29.2	33.5	37.5
8	22.6	27.2	31.3	35.0	38.2
Unthinned:					
C	22.1	25.7	29.2	32.3	35.1

Table 23--Ratios of quadratic mean diameter of trees cut (d) to that of all trees before thinning (D), treatment means

Treatment	1973	1978	1983	1988
	- - - - - - - - d/D - - - - - - - - -			
Fixed:				
1	0.87	0.88	0.79	0.85
3	.80	.85	.90	.75
5	.84	.92	.83	.75
7	.85	.90	.80	.80
Decreasing:				
2	.87	.76	.68	.88
4	.82	.86	.79	.71
Increasing:				
6	.86	.89	.84	.67
8	.72	.83	.84	.73
Mean d/D	.83	.86	.81	.77

Table 24--Mean 20-year change in average diameter of 40 largest trees per acre (largest 100 per hectare) and of crop trees, by treatment

Treatment	Largest 40 per acre			Crop trees		
	△D40		Ratio to unthinned	△Dcrop		Ratio to unthinned
	In	Cm		In	Cm	
Fixed:						
1	7.2	18.3	1.29	6.8	17.3	1.33
3	6.8	17.3	1.21	6.3	16.0	1.23
5	6.8	17.3	1.21	6.2	15.7	1.22
7	6.3	16.0	1.13	5.8	14.7	1.13
Decreasing:						
2	7.0	17.8	1.25	7.0	17.8	1.36
4	7.0	17.8	1.25	6.6	16.8	1.29
Increasing:						
6	7.2	18.3	1.29	6.7	17.0	1.32
8	6.7	17.0	1.19	6.1	15.5	1.19
Unthinned:						
C	5.6	14.2	1.00	5.1	13.0	1.00

Appendix 3: The Nine Study Areas

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

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

Keywords: Thinning, silviculture, growth and yield, growing stock

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