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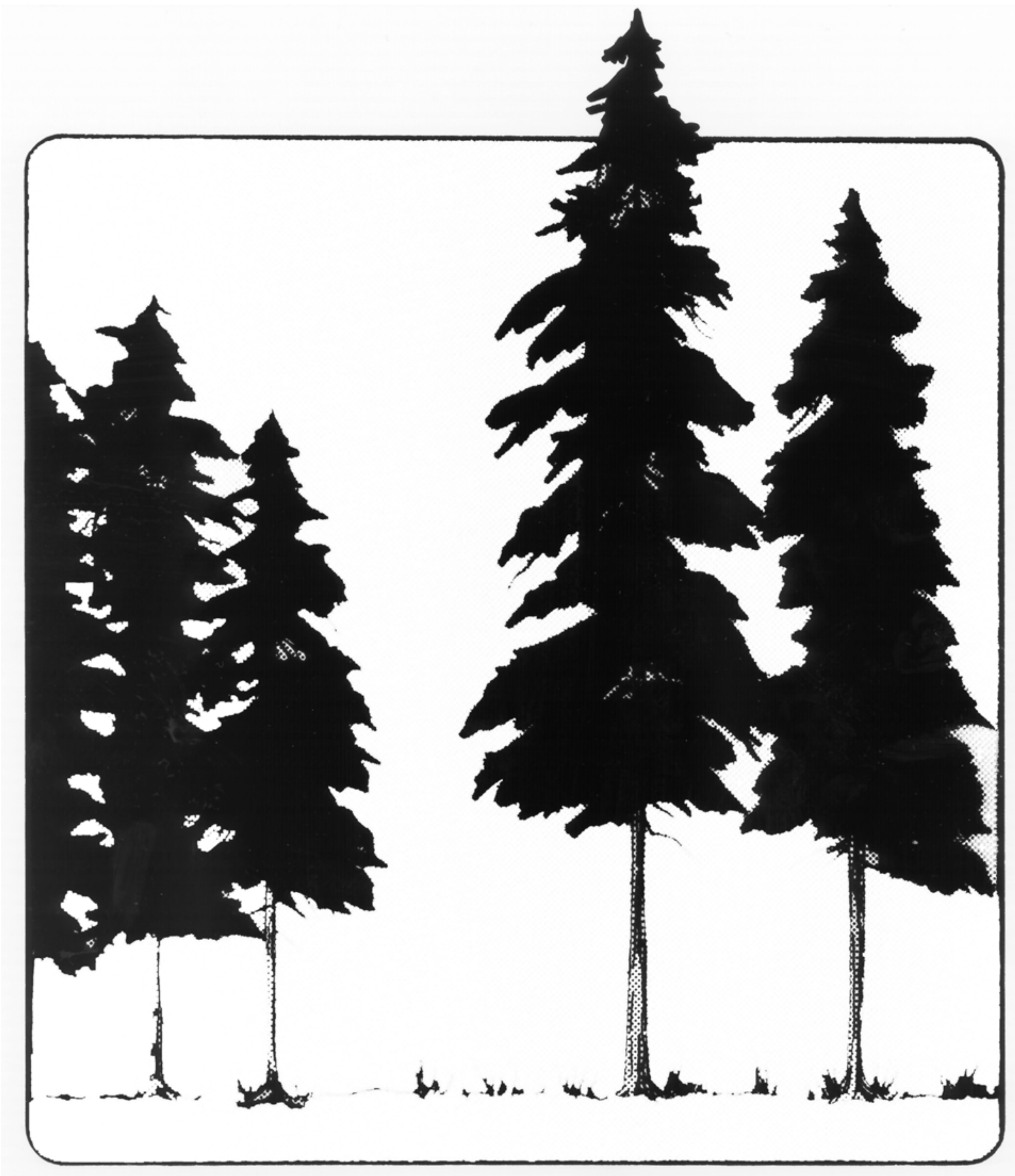
Levels-of-Growing-Stock Cooperative Study in Douglas-Fir: Report No. 17—The Skykomish Study, 1961–93; The Clemons Study, 1963–94

James E. King, David D. Marshall, and John F. Bell



Levels-of-growing-stock study treatment schedule showing percentage of gross basal area increment of control plots to be retained in growing stock after thinning.

	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 an initial 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 of 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.

Authors

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Abstract

King, James E.; Marshall, David D.; Bell, John F. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 17–the Skykomish study, 1961–93; the Clemons study, 1963–94. Res. Pap. PNW-RP-548. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 120 p.

Stand treatments were completed as prescribed with an initial calibration cut and five thinnings resulting in eight new regimes for management of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Measurements were continued for an additional 14 years to observe stability and yields of stands in a postthinning holding period. Detailed descriptions of each regime based on measurements at each thinning are summarized in stand development tables. Regimes with the most growing stock after the last thinning produced 30 to 38 percent more gross-cubic-volume yield (live and cumulative thinnings and mortality) per acre than regimes with the least growing stock. The complete regimes are compared at three stages of stand development followed by recommendations for applications.

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

Summary

The Skykomish and Clemons studies are part of the regional cooperative studies of levels-of-growing-stock (LOGS) in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). The Skykomish stand is mixed Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and the Clemons stand is a pure Douglas-fir plantation. These studies were carried out by Weyerhaeuser forestry research on site class II. The purpose of the LOGS studies is to develop information on growth and related characteristics in stands thinned to different levels of growing stock. Initial stands were thinned to the same level of growing stock so that all plots would have virtually the same growth potential except the unthinned controls. Treatment of these transformed plots was essentially a process of managing growth. The levels of growing stock were controlled by retaining prescribed amounts of basal area increment in each of five thinnings. These treatments produced eight different thinning regimes. The Skykomish and Clemons stands were 24 and 19 years old, respectively, when the studies were started. Stand treatments were completed at ages 42 and 36, and measurements were continued to ages 56 and 50. After 32 years at Skykomish and 31 years at Clemons, the basal area per acre in the eight regimes ranged from 119 to 244 square feet at Skykomish and 101 to 195 at Clemons. The corresponding gross yields (volume in remaining tree and cumulative volume in trees thinned and mortality) in cubic feet per acre were 8,709 to 13,579 at Skykomish and 6,329 to 9,072 at Clemons. Volumes in thinnings were 18 to 53 percent of the gross yield. Stand treatments included four regimes with different combinations of heavy and light thinning and four regimes with constant intensities of thinning. Variable regimes were found to have no consistent advantage over constant regimes. Within a given level of growing stock, the constant regimes are recommended for applications where wood production is the primary objective. A substantial increase in yield was produced in all regimes during the postthinning holding period. Based on standing volume after the last thinning, the holding period of 4 years produced about 30 percent more volume in all regimes. Extending the period to 9 years produced about 70 percent more volume, and at 14 years, the standing volume was more than double the volume remaining after the last thinning. This extra yield enhanced by the high quality of the stands makes the length of the holding period an important factor in scheduling the final harvest.

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

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

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

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

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

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

A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Growth for the first 7 years after thinning was greater than expected.

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). Info. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 46 p.

Describes the establishment and installation of the two LOGS studies on Vancouver Island at Shawnigan Lake and Sayward Forest.

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.

Growth data are presented for the first 12 years of management of young Douglas-fir growing at eight levels of growing stock. The second and third treatment periods are described.

Young Douglas-fir stands transfer growth from many to few trees. Some of the treatments have the potential to equal 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.

Tappeiner, John C.; Bell, John F.; Brodie, J. Douglas. 1982. Response of young Douglas-fir to 16 years of intensive thinning. Res. Bull. 38. Corvallis, OR: Forest Research Laboratory, School of Forestry, Oregon State University. 17 p.

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

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

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

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

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

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

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

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

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

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

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

Results of the Iron Creek study in the Gifford Pinchot National Forest, southern Washington, are summarized through age 42 (completion of the 60 feet of height growth composing the planned course of the experiment). Volume growth of this mid-site II plantation has been strongly related to growing stock; basal area growth much less so. Different growing-stock levels have produced marked differences in the size distribution and in crown dimension. Periodic annual volume increment at age 42 is two to three times mean annual increment in all treatments.

Hoyer, Gerald E.; Andersen, Norman A.; Marshall, David D. 1996. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 13—the Francis study: 1963–90. Res. Pap. PNW-RP-488. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 91 p.

Results of the Francis study, begun at age 15, are summarized together with results from additional first-thinning treatments started at age 25. To age 42, total cubic-foot volume growth on this mid-site II plantation has been strongly related to level of growing stock. Close dollar values among several alternatives suggest that diverse stand structure objectives can be attained at age 42 with little difference in wood product-value per acre.

Curtis, Robert O.; Marshall, David D.; Bell, John F. 1997. LOGS: a pioneering example of silvicultural research in coast Douglas-fir. Journal of Forestry. 95(7): 19–25.

Provides a general overview of the LOGS cooperative and presents the major results to date.

Curtis, Robert O.; Marshall, David D. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 14—Stampede Creek: 30-year results. Res. Pap. PNW-RP-543. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 77 p.

Results of the Stampede Creek study are summarized from establishment at age 33 through the final planned treatment period at age 63 in an estimated site class III stand in southwest Oregon. Results to date are generally similar to the higher site LOGS installations, although development is slower. Volume growth is strongly related to growing stock, but basal area growth relation is weaker. Thinning has resulted in marked differences in tree size distribution, and periodic annual increment is still two to three times greater than mean annual increment.

Marshall, D.D.; Curtis, Robert O. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 15—Hoskins: 35-year results. Res. Pap. PNW-RP-537. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 80 p.

Results of the Hoskins study are summarized at age 55, 19 years after the last thinning treatment, on this low site class I stand in western Oregon. Volume and diameter growth continue to be strongly related to growing stock with basal area growth becoming less strongly related to growing stock. The lightest thinning treatments have produced similar cumulative merchantable volumes as the unthinned controls. None of the treatments have reached their maximum mean annual increment to date.

Beddows, D. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 16—Sayward Forest and Shawnigan Lake. Info. Rep. BC-X-393. Victoria, BC: Canadian Forest Service, Pacific Forestry Centre. 67 p.

Results are summarized at age 51 for the site III Sayward Forest installation and at age 52 for the site IV Shawnigan Lake installation located on Vancouver Island, British Columbia, Canada. Results to date from both installations are similar to results from other cooperator installations. At both installations, volume growth has been strongly related to level of growing stock, as has basal area, although less so. Thinning has affected stand development through tree site distribution and live crown development. Volume periodic annual increment is still two to three times mean annual increment.

Contents

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

Introduction

The Pacific Northwest regional Douglas-fir levels-of-growing-stock (LOGS) study is a cooperative project started in 1962. The Skykomish and Clemons studies are part of this cooperative. They were carried out by Weyerhaeuser forestry research. Other cooperators are the USDA Forest Service, Oregon State University, Washington State Department of Natural Resources, the Canadian Forest Service, and the British Columbia Ministry of Forests. The total project includes nine installations spread from southern Oregon, USA, to Vancouver Island, British Columbia, Canada (fig. 1). These studies were designed to determine yields and related characteristics of stands that are repeatedly thinned to different levels of growing stock. To date, all the studies except Rocky Brook and Shawnigan Lake have completed the 60 feet of height growth, and reports have either been published or are in preparation. Although there has been no overall analysis yet, a significant amount of information has been published in the reports listed in the beginning of this report. When the cooperative project was started, the Pacific Northwest wood supply came largely from old-growth and advanced second-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Long-term plans for the next crop of timber indicated the need for new information on stand management. Some of the pertinent questions were about the length of rotations, the role of thinning, and the desirable levels of growing stock (Staebler 1967). Consequently, Staebler was motivated to initiate the regional LOGS studies. Young stands have become the major source of wood. The LOGS studies have been in progress for almost 40 years, and results from these studies are becoming available for management of young stands. Results from the combined regional LOGS installations will be a comprehensive source of new information on growth-growing stock and new thinning regimes. Completion of the LOGS studies will require a few more years. In the interim, the Skykomish and Clemons studies, and other installations soon to be completed, will provide new guidelines for stand management.

Since the LOGS studies were started in 1962, the goals of many forest landowners have expanded from primarily wood production to include various concurrent uses of forest resources such as wildlife habitat, recreation, and aesthetics. Even with diverse and expanded silvicultural objectives, results from the LOGS studies will be applicable wherever the managed forest includes a component of even-aged Douglas-fir. Unlike the other LOGS studies, which are predominately Douglas-fir, the Skykomish study was established in a mixed stand of Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). These elements of stand diversity provide a contrast to the Clemons study, which is in a Douglas-fir plantation.

Since the last measurement of the Skykomish study, the area was passed on to other ownership and then harvested. Additional measurements may be made at Clemons, but this report probably will be the final comprehensive summary of these two LOGS installations.

Objectives

The objectives of the LOGS studies are to determine how the amount of growing stock in repeatedly thinned stands affects cumulative wood production, tree size, and growth-growing stock ratios. The significance of these objectives along with the expected outcome and application of the LOGS studies was explained by Staebler (1967) as follows:

> The important results of thinning in terms of management objectives may be expected to show up in three ways—(a) size of tree produced—a corollary is width of the annual rings; (b) total yield, including that from thinnings and final harvest; and (c) growth/growing stock ratio, interest on the capital invested in growing stock at any given moment. Anyone involved in a forestry venture is concerned with all three elements.
>
> We don’t propose to pinpoint the optimum thinning schedule. We expect to show how the different schedules affect the three things I have just named. A forest owner would select the schedule that best met his objectives. Presumably that is the one that would be most profitable under his particular circumstances. If we don’t uncover the correct regime, we do expect to establish principles and the necessary factual data to permit a forester to formulate his own thinning schedule.

Methods

Description of Study Areas

General guidelines for selection of stands for the LOGS studies specified the following conditions:

1. Stands should be growing vigorously and of density such that competition has not yet unduly restricted individual tree development.
2. Stands should require only a comparatively light thinning to bring all plots to a uniform initial density.
3. Study areas should be located on soils typical of broad areas, avoiding soil types that are limited in extent.
4. Stands should be all Douglas-fir; however, other species will be allowed if they constitute less than 20 percent of the basal area after the initial thinning.
5. Stands should average less than 6 inches in diameter at breast height (d.b.h.) after the initial thinning with dominant heights of 20 to 40 feet.

Skykomish study area—This study area is located in the former Skykomish Tree Farm of Weyerhaeuser Company near Youngs River about 4 miles south of Sultan, Washington. The stand was regenerated naturally with an even-aged stand of about one-half Douglas-fir and one-half western hemlock. This study was based on the original LOGS plan by Staebler,[1] which did not include restriction on proportion of secondary species. This study was the first installation and prototype for the Regional Cooperative LOGS studies. Later studies were required to have at least 80 percent of basal area in Douglas-fir. Consequently, the Skykomish study is the only installation in a mixed Douglas-fir-western hemlock type. It also exceeded the recommended range in dominant height of 20 to 40 feet. The average initial height of crop trees was 46 feet. Topography of the study area varies from level to about a 35-percent gradient on a north-facing slope at about 500 feet elevation. Soils are the Oso series described by Webster and Steinbrenner (1974) as follows: "Common features of these soils are a dark grayish-brown, gravelly loam 15-to-20-inch-thick surface A horizon which grades into a weakly structured, gravely loam, dark yellowish-brown B horizon. Beneath this, C horizons containing 40 to 80 percent rock extend to fractured bedrock at 40 to 60 inches." Site index for the Douglas-fir is 130 feet (class II) (King 1966), and 118 feet for hemlock (Wiley 1978), both at index age of 50 years at breast height. The sample for site determination was 24 trees of each species on unthinned sample plots.

Clemons study area—The Clemons LOGS study is located on the Clemons Tree Farm of Weyerhaeuser Company near Blue Mountain about 11 miles west of Oakville, Washington. The stand was planted in spring 1947 with 2-0 Douglas-fir. The seed source is unknown. During the juvenile stage of the plantation, damage by rabbits, mountain beaver, and deer was prevalent. Other adversities were competition from heavy ground vegetation, particularly bracken fern (*Pteridium aquilinum* (L.) Kuhn), and later damage to the tops of several trees in the 1955 freeze (Duffield 1956, Reukema 1964). Apparently, the stand had fully recovered and was growing vigorously as demonstrated by 3- and 4-foot leaders at age 19 years when the study was established; however, some deformed trees remained and were cut in the first thinning. The study area is located on a broad ridge varying from 10 to 30 percent slope generally facing west

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

to northwest at about 800 feet elevation. The soils are Astoria series described by Steinbrenner and Duncan (1969) as follows: “Deep, friable, well drained, moderately fine textured yellowish-brown lateritics developed from coarse Miocene sandstones are characteristic of this series. The A horizons are dark brown, friable loams about 18 inches thick and the subsoils are yellowish-brown silt loams with a weak, fine, sub-angular blocky structure grading into yellowish, highly weathered, massive sandstones. Total depths are 40 to 60 inches with deeper soils more prevalent.” A sample of 25 trees on unthinned sample plots indicates an average site index of 127 feet (class II) based on index at 50 years breast-height age (King 1966).

Plot Establishment

At each location, the sample consists of twenty-seven 1/5-acre square plots. This size was chosen on the expectation that it would support a minimum of 10 trees after six thinnings at the lowest level of growing stock. Eight treatments and an unthinned control are each represented by three plots in a completely randomized design. The layout of plots for Skykomish is shown in figure 2A, and for Clemons in figure 2B. Plots were established in contiguous groups where stands were uniform, but some plots in each area were separated from the main group because of variable stand conditions. Buffer strips of about 11 acres were required for each study area.

To evaluate the effect of different levels of growing stock, it was necessary that individual plots not differ in other respects that might influence stand productivity. Accordingly the desired maximum difference in site index between plots was not to exceed 10 feet. Based on measurements of site trees on unthinned plots and estimates based on average heights on thinned plots, both areas were within these guidelines.

Another criterion for determining suitability of plots was uniformity of the stand. The availability and distribution of suitable crop trees on each plot was the basis for evaluating uniformity. These trees had to be well-formed, healthy dominants. On each plot, 16 (80 per acre) crop trees were selected at least 13.5 feet apart and distributed so that each quarter of a plot included at least three trees. If suitable crop trees were not available, the entire plot was rejected for nonuniformity and replaced with another plot.

The final phase of plot establishment was a preparatory thinning that removed small, defective trees and miscellaneous species to create a uniform density and structure on each plot. The purpose of this thinning was to calibrate or equalize the growth potential of the initial reserve stand on all plots except the unthinned controls. The procedure was to mark the trees to be retained in addition to the previously selected crop trees. This identified the total reserve stand, and all remaining trees were cut. Marking guides for identifying leave trees were (1) minimum d.b.h. of one-half the quadratic mean d.b.h. of the crop trees and (2) spacing as uniform as possible and determined from the following equation:

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

where S is the average spacing in feet and D is the quadratic mean d.b.h. in inches of the reserved trees on all plots combined. To initiate the marking, average d.b.h. was estimated. Trial marking with adjustments in tree selection was required to achieve the necessary uniformity among plots as specified.

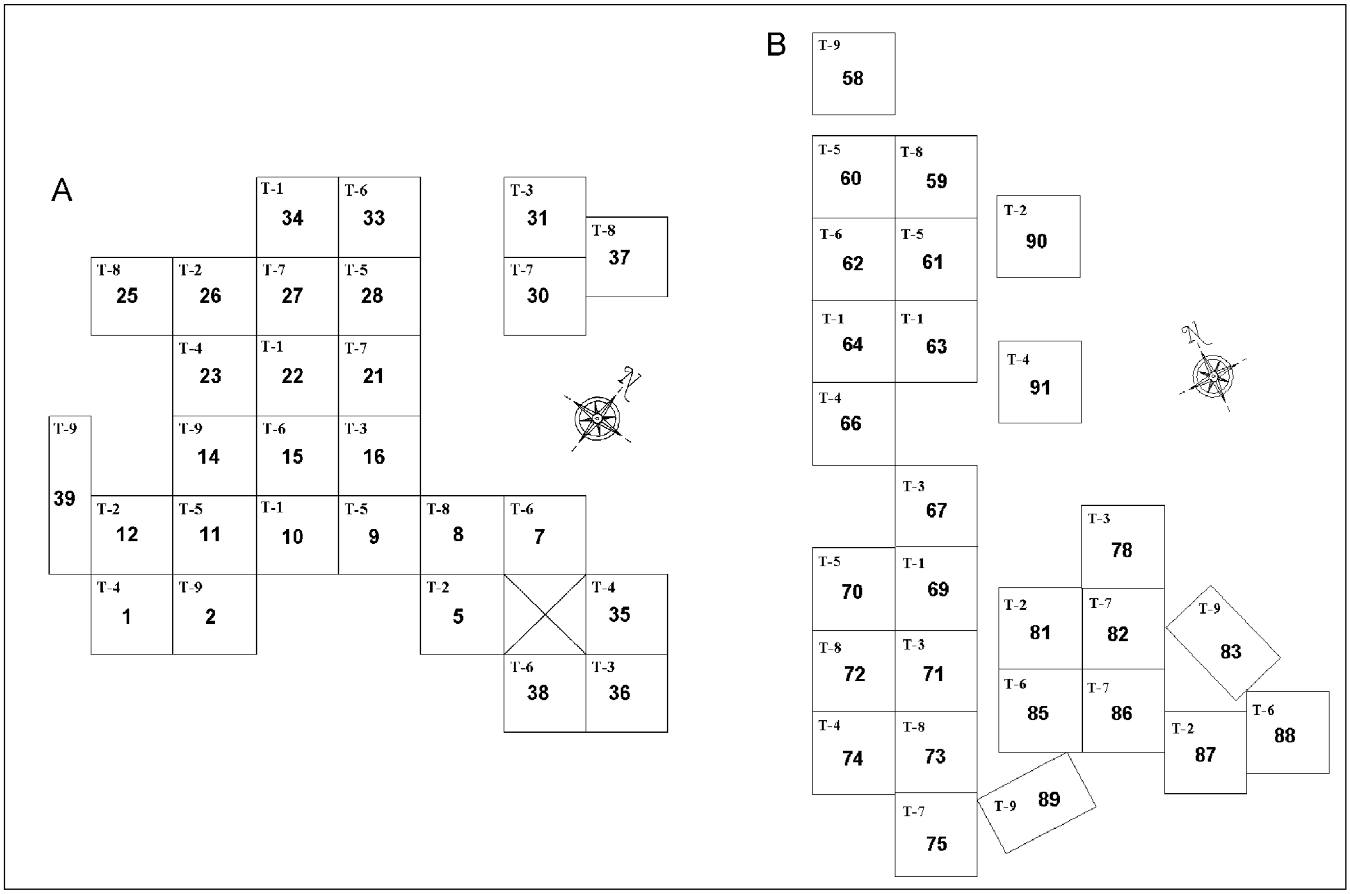

Figure 2—Layout of sample plots, (A) Skykomish and (B) Clemons, with treatment numbers (T-9 are the controls) and plot numbers. Plots are 0.2 acre.

The resulting reserved stands had the following specifications, for 1/5-acre plots with per-acre values given in parentheses.

	Skykomish	Clemons
Minimum d.b.h. (in)	3.2	2.3
Average d.b.h. (in)	5.2	4.1
Basal area (ft^2)	10.2 (51.0)	7.2 (36.1)
Standard deviation	0.16 (0.80)	0.70 (3.70)
Number of trees	71 (357)	79 (395)
Standard deviation	9 (44)	0.5 (2.5)
Average spacing (ft)	11.0	10.5

This provided a total sample in the three replications of each treatment of approximately 213 trees at Skykomish and 237 trees at Clemons. Area sampled in three sample plots was a total of 0.6 acre per treatment at each location.

The primary controlling factor for initial level of growing stock was either basal area where average d.b.h. was larger than 4.5 inches, or number of trees in stands with an average d.b.h. smaller than 4.5 inches. Accordingly, at Skykomish, basal area was the primary controlling factor, which allowed average diameter and number of trees to vary. At Clemons, number of trees was the primary controlling factor, so basal area and average diameter were allowed to vary from plot to plot. Maximum allowable deviation of a plot from the overall stand average d.b.h. was 10 percent where basal area was the controlling factor and 15 percent where number of trees was used. Data for the resulting initial stand on each plot are given in appendix 2 for Skykomish and appendix 3 for Clemons. All reserved trees were identified with numbered tags and pruned of all branches below 6 feet. Crop trees were pruned for one-third of their height for easy detection during later thinnings. Excess trees were cut and left on the ground, and a buffer strip was thinned around each installation.

With the close controls on soil series, site quality, stand structure, and uniformity of growing stock on all plots, each tree was left with abundant space and virtually the same opportunity for maximum growth until the next thinning, which started the development of different levels of growing stock.

Stand Treatments

Stand treatments were planned to produce a broad enough range in levels of growing stock so that results will show how to produce a stand to meet specific silvicultural objectives. The treatments were a series of thinnings planned to develop eight separate regimes with levels of growing stock expressed as basal area per acre. Each regime was represented by three plots thinned five times for a total of 15 plot thinnings per regime and 120 plot thinnings in each study area.

Severity of Thinning

The severity of thinning was controlled by cutting to a prescribed level of basal area in each plot. The prescribed level was the basal area at the beginning of the period plus a portion of the periodic growth. The amount of growth to be retained was equal to a percentage of the periodic gross (change in basal area including mortality) growth on control plots and varied from 10 to 70 percent as specified in table 1. The underlying assumption was that gross increment on unthinned plots approximates full production for the given stand and site. The experiment was designed to find out what proportion of the increment in basal area should be accumulated in the growing stock of the thinned stands to produce a given level of production. The range of 10 to 70 percent was expected to result in a practical array of thinning regimes that would include maximum volume production.

Treatments (regimes) 1, 3, 5, and 7 accumulated basal area in each periodic thinning at constant percentages of gross growth on control plots. Treatments 2 and 4 were variable percentages that increased by period, whereas treatments 6 and 8 were variable and decreasing (table 1). Thus, the eight treatments accumulated growing stock at different rates to create thinning regimes. All periodic growth of basal area in excess of the prescribed amount to be retained was removed in thinnings.

> Clearly, this range of treatments will explore the ability of Douglas-fir to respond to varying degrees of release as the stands pass through critical developmental stages. At the conclusion of the study, densities should range from near normal basal area to very low levels where all trees grow somewhat like open-grown trees. The range in yield, tree size, and growth-growing stock ratios should permit foresters to choose regimes that will satisfy any particular objective of management (Williamson and Staebler 1965).

Table 1—Levels-of-growing-stock study treatment schedule showing percentage of gross basal area increment of control plots to be retained in growing stock after thinning

	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

To determine the amount of basal area to be retained on a plot and the excess to be cut, the following steps were carried out for each thinning. An example of data from treatment 3, plot 71, at Clemons is given in parentheses. These data are from the fourth thinning at stand age 32 years (per-acre values are found in app. 3, table 53).

1. From the previous measurement, determine basal area on plot at beginning of period (12.60 square feet at age 29).
2. From current measurements (at age 32) determine:
   a. Total basal area (16.88 square feet)
   b. Average d.b.h. and equivalent basal area for noncrop trees (8.2 inches and 0.367 square feet) from field records.
3. From current and previous field measurements (including mortality), determine the average gross basal area growth for the third treatment period (ages 29 to 32) on the three control plots (4.77 square feet).
4. Calculate basal area to be retained in growing stock based on percentage in table 1 for treatment 3 and growth of controls (0.3 × 4.77 = 1.43 square feet).
5. Calculate basal area to be reserved on the plot after thinning; i.e., previous level plus amount to be retained (12.60 + 1.43 = 14.03 square feet).
6. Determine basal area to be cut by subtracting the amount to be reserved from the current level (16.88 - 14.03 = 2.85 square feet).
7. Estimate number of trees to be cut from total basal area to be cut and average basal area of noncrop trees (2.85 ÷ 0.367 = 7.8 or eight trees). The goal for this thinning was to cut eight trees with an average d.b.h. of 8.2 inches and distributed across the d.b.h. range of noncrop trees.

In this example, the actual cut was eight trees with a total basal area of 2.886 square feet, so the reserved level of growing stock was as prescribed. In about 80 percent of the thinnings, the combinations of trees selected for cutting resulted in minor discrepancies between prescribed and actual basal areas retained. The differences were generally less than 0.5 square feet of basal area.

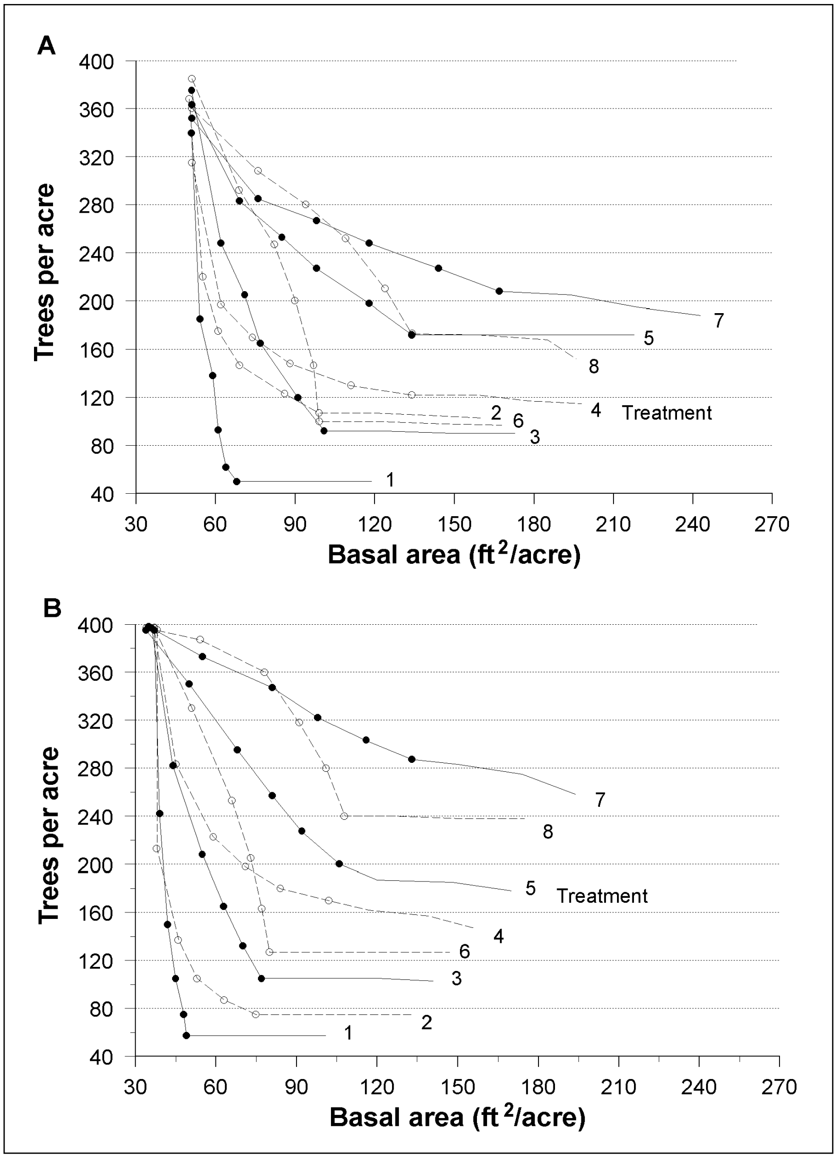

Figure 3—Trends in trees per acre in relation to basal area per acre by treatment, (A) Skykomish and (B) Clemons. Dots and circles mark basal area and corresponding numbers of trees retained after each thinning. Trend lines extending beyond last thinning show changes in numbers of trees resulting from mortality during 14 years after the final thinning.

Trends in numbers of trees per acre after thinning provide another perspective of the comparative severity of thinning in the eight regimes. As periodic thinnings progressed, the low percentages of basal area retained required substantial reductions in numbers of trees, as shown in figures 3A and 3B. For example, the 10-percent retention in treatment 1, which was the heaviest thinning, reduced the number of trees from 340 to 50 per acre in five thinnings at Skykomish. Treatment 1 at Clemons dropped from 395 to 57 per acre. This extremely heavy cutting reduced the trees in regime 1 to only 11 percent of the number of control trees at Skykomish, and 10 percent at Clemons.

In the lightest cut, regime 7, the remaining stand at Skykomish had 44 percent of the number of control trees, and at Clemons 51 percent. The close control of growing stock is evident by the similarity of trends in both study areas.

In the Skykomish study area, the prescribed treatments were applied as if the entire stand were Douglas-fir. A large proportion of the stand was hemlock, but the stand treatments did not favor either species. During the course of the experiment, however, each treatment developed a higher proportion of Douglas-fir as shown in the following tabulation:

	Proportion of basal area in Douglas-fir	
Treatment	**After calibration cut**	**After five thinnings**
	Percent	
1. Fixed 10%	46	67
2. Variable 10–50%	50	52
3. Fixed 30%	58	73
4. Variable 30–70%	59	66
5. Fixed 50%	43	52
6. Variable 50–10%	56	70
7. Fixed 70%	46	52
8. Variable 70–30%	47	58
9. Control	48	51
Mean	50	60

The development of higher proportions of Douglas-fir in all treatments probably resulted from a higher proportion of the larger trees being Douglas-fir. This resulted in most crop trees, which were not thinned, being Douglas-fir and a higher proportion of the noncrop trees being hemlock, which were removed in thinnings.

Method of Thinning

The method of thinning was not prescribed by commonly used quantitative definitions (Smith 1962), but was controlled by the following procedures on each thinned plot. These procedures were designated to provide uniform and consistent treatment in all regimes.

Thinnings were taken only from noncrop trees until only crop trees were left. When only crop trees remained, they were cut as necessary to satisfy the prescribed level of growing stock. If a crop tree died or became severely damaged, it was removed and another tree was selected for replacement.

1. As near as practicable, the average d.b.h. of trees removed in a single thinning (d) was equal to the average d.b.h. of all noncrop trees (D) before thinning; i.e., for noncrop trees, d/D = 1.0.
2. Trees removed in thinning were distributed as evenly as possible across the diameters of all trees available for cutting.

For a general definition of the thinning method, d/D ratios were calculated for each regime after the treatments were completed, based on the average d.b.h. (D) of the total stand. When crop trees were included, d/D ratios were 0.84 to 0.94 at Skykomish and 0.84 to 0.99 at Clemons. In both areas, about 70 percent of the thinnings would be

Table 2—Measurement and thinning schedule for Skykomish levels-of-growing-stock (LOGS) study area

Date	Stand age	Growth period	Average height of crop trees	Activity
Mo-Yr	*Years*		*Feet*	
09-61	24	—	46	Plots established, preparatory thinning
01-66	28	4	58	Measured, 1st LOGS thinning
02-69	31	3	67	Measured, 2nd LOGS thinning
02-72	34	3	76	Measured, 3rd LOGS thinning
03-76	38	4	86	Measured, 4th LOGS thinning
12-79	42	4	96	Measured, 5th LOGS thinning
01-84	46	4	106	Measured only
12-88	51	5	—	Measured only
12-93	56	5	—	Measured only

classified light to severe crown thinnings (Joergenson 1957, Vezina 1963, Warrack 1959). The extremes of d/D included both low and selection thinning. Within regimes, successive thinnings did not follow a trend but usually differed from period to period.

Interval of Thinning

Thinnings were made whenever crop trees on all plots had grown an average of 10 feet since the previous thinning. Time between thinnings was based on height increment in order to coordinate with the continuing need for additional growing space per tree. The timing of thinning based on 10 feet of height increment had been recommended for Douglas-fir plantations by the British Forestry Commission (Worthington and Staebler 1961). The determination of intervals between thinnings based on height growth was a procedure also recommended for other species (Hummel 1954, Joergenson 1957). Following the preparatory thinning at plot establishment, five treatment thinnings spanning 50 feet of height growth were specified by the study plan. This required a period of 19 years at Skykomish and 17 years at Clemons. The actual height interval between thinnings varied from 8 to 12 feet in order to coincide with the growing season.

Schedule of Measurements and Thinnings

The dates and stand ages when plots were measured and thinned are given in tables 2 and 3 for Skykomish and Clemons, respectively. The schedule through the fifth thinning and one additional measurement was determined by increase in average height of crop trees. Two subsequent measurements were made at 5-year intervals.

Results and Discussion

Preparatory Thinnings

The preparatory or calibration thinning was done at the time of plot establishment to minimize the variation in stocking so that all plots to be treated would have nearly the same growth potential. The extent to which this objective was achieved is indicated by the annual growth in basal area and volume during the calibration period (table 4).

These data show that the variability of growth in basal area was virtually the same in both thinned and unthinned stands at Skykomish. However, the volume increment in thinned plots was more uniform than in unthinned plots as indicated by the coefficients of variation of 10 percent and 15.2 percent, respectively. The opposite result was produced by preparatory thinning at Clemons where growth of thinned stands was substantially more variable than the unthinned stands.

Table 3—Measurement and thinning schedule for Clemons levels-of-growing-stock (LOGS) study area

Date	Stand age	Growth period	Average height of crop trees	Activity
Mo-Yr	*Years*		*Feet*	
09-63	19	—	31	Plots established, preparatory thinning
08-66	22	3	41	Measured, 1st LOGS thinning
10-70	26	4	52	Measured, 2nd LOGS thinning
10-73	29	3	62	Measured, 3rd LOGS thinning
10-76	32	3	70	Measured, 4th LOGS thinning
01-81	36	4	80	Measured, 5th LOGS thinning
11-84	40	4	89	Measured only
11-89	45	5	—	Measured only
10-94	50	5	—	Measured only

Table 4—Annual growth in basal area and volume during the calibration periods of 4 years at Skykomish and 3 years at Clemons

	Skykomish		Clemons	
Stand condition	Basal area	Volume	Basal area	Volume
	Ft²	*Ft³*	*Ft²*	*Ft³*
Thinned:[a]				
Mean	8.8	268	8.0	183
SD[b]	.9	26.8	1.2	30.1
CV (percent)[c]	9.9	10.0	15.4	16.4
Unthinned:[d]				
Mean	9.1	301	9.9	247
SD	1.0	45.6	.6	17.1
CV (percent)	10.4	15.2	6.1	6.9

[a] 24 plots in each area.
[b] SD = standard deviation.
[c] CV = coefficient of variation.
[d] 4 plots at Skykomish and 3 at Clemons.

The lower relative variability of growth at Skykomish and increased variability at Clemons resulted from different methods of determining growing stock in the preparatory thinning. The initial growing stock at Skykomish was prescribed by basal area, which only ranged from 49.6 to 52.6 square feet per acre. Using number of trees at Clemons resulted in greater variation in growing stock where basal area after thinning ranged from 32.2 to 42.8 square feet per acre, although number of trees varied only from 395 to 405 per acre. Use of basal area produced more uniform periodic annual growth even though Skykomish had a natural stand of mixed Douglas-fir and western hemlock. Using numbers of trees increased the variability at Clemons where more uniform growth was expected from the original stand of comparatively uniform pure Douglas-fir plantation.

Table 5—Skykomish: Analysis of variance results for periodic gross growth and gross growth percentage of total stem volume and basal area and net periodic annual growth in quadratic mean diameter

	P-value[a] and mean square errors				
	Volume		Basal area		Diameter
Source of variation	PAI[b]	Growth percent	PAI	Growth percent	PAI
Treatments:					
(A) Fixed vs. variable	0.34	0.50	0.96	0.69	0.32
(B) Fixed (linear)	.00**	.00**	.00**	.00**	.00**
(B) Fixed (quadratic)	.06	.20	.34	.69	.02*
(B) Fixed (cubic)	.19	.48	.04*	.05*	0.22
(C) Increasing vs. decreasing	.00**	.00**	.00**	.01*	.01*
(D) Among increasing	.00**	.01**	.00**	.01**	.99
(E) Among decreasing	.01**	.00**	.22	.00**	.01*
Error ‘a’ mean square	458.16	.50	.37	.35	1.0031
P - periods:	.00**	.00**	.00**	.00**	.00**
P × A	.00**	.02*	.87	.86	.06
P × B (linear)	.00**	.00**	.00**	.02*	.00**
P × B (quadratic)	.00**	.15	.00**	.05	.50
P × B (cubic)	.24	.01**	.14	.16	.77
P × C	.00**	.00**	.00**	.00**	.00**
P × D	.00**	.00**	.19	.19	.01**
P × E	.00**	.00**	.62	.90	.00**
Error ‘b’ mean square	215.61	.17	.11	.09	.0003

[a] P is the probability of a larger F, given that the null hypothesis of no difference among means is true. Significance levels: * is $0.01 < P \leq 0.05$; and ** is $P \leq 0.01$.
[b] PAI = periodic annual increment.

The objective of creating uniform growth potential was not achieved by preparatory thinning at Clemons, and at Skykomish the reduction in variability of growth in thinned plots compared to the unthinned was marginal. Although thinning to a uniform basal area was more effective than thinning to a uniform number of trees, the utility of preparatory thinning in these studies is questionable. In retrospect, four levels of growing stock similar to those established after the calibration period could have been initiated at the beginning of the study. They could have been based on levels relative to stocking of the original stands.

Comparison of Treatments by Analysis of Variance

The analysis of variance for five treatment periods is presented in tables 5 and 6 for the Skykomish and Clemons installations, respectively. This is a repeated measures analysis of variance (ANOVA) that tests for differences among overall means (table 7) of the eight treatments (not including the control). Seven orthogonal contrasts were used to test for differences among treatments. The results were generally consistent between the two installations and with other LOGS installations. The variables considered were periodic annual increment (PAI) of gross total stem volume and volume growth percentage, gross basal area PAI and growth percentage, and net quadratic mean diameter PAI (Curtis and Marshall 1989).

Table 6—Clemons: Analysis of variance results for periodic gross growth and gross growth percentage of total stem volume and basal area and net periodic annual growth in quadratic mean diameter

	P-value[a] and mean square errors				
	Volume		Basal area		Diameter
Source of variation	PAI[b]	Growth percent	PAI	Growth percent	PAI
Treatments:					
(A) Fixed vs. variable	0.94	0.35	0.99	0.99	0.82
(B) Fixed (linear)	.00**	.00**	.00**	.00**	.00**
(B) Fixed (quadratic)	.29	.63	.07	.89	.63*
(B) Fixed (cubic)	.60	.48	.25	.30	.60
(C) Increasing vs. decreasing	.00**	.02*	.03*	.01**	.01**
(D) Among increasing	.03*	.08	.04	.09	.06
(E) Among decreasing	.46	.01**	.99	.01**	.05*
Error ‘a’ mean square	1,302.15	1.42	1.07	1.34	1.012
P - periods:	.00**	.00**	.00**	.00**	.00**
P × A	.00**	.00*	.99	.34	.02*
P × B (linear)	.00**	.01**	.00**	.00*	.00**
P × B (quadratic)	.02*	.08	.07	.98	.13
P × B (cubic)	.44	.51	.25	.88	.39
P × C	.00**	.00**	.03*	.00**	.03*
P × D	.01**	.01**	.04*	.66	.31
P × E	.00**	.00**	.99	.94	.50
Error ‘b’ mean square	218.11	.34	.21	.28	.0005

[a] P is the probability of a larger F, given that the null hypothesis of no difference among means is true. Significance levels: * is 0.01 < P ≤ 0.05; and ** is P ≤ 0.01.
[b] PAI = periodic annual increment.

Differences among the four fixed percentage treatments (regimes 1, 3, 5, and 7) were significant. Trends with treatment (increasing growing stock) were linear for all variables tested, although the high density of the control was not included. The PAI for the two increasing treatments (regimes 2 and 4) were also significantly different from the two decreasing treatments (regimes 6 and 8). The differences between the two increasing and between the two decreasing treatments were significant for volume and basal area PAI and growth percentage at Skykomish. At Clemons, these differences were less clear. Diameter PAI was not significantly different between increasing and decreasing regimes at Clemons, but only the decreasing treatments at Skykomish were significantly different from each other. The lack of detectable difference between the increasing regimes at Skykomish might be because regime 4 experienced no mortality and had a greater proportion of hemlock to Douglas-fir growing stock. In general, basal area and volume PAI increased while diameter PAI decreased with increasing growing stock. Growth percentage values showed trends opposite to PAI.

The interactions of period × fixed (linear) percentage treatments and period × increasing vs. decreasing treatments were significant for both installations. These significant interactions disallow simple interpretation for differences among treatment means because

Table 7—Analysis of variance

Source of variation	Degrees of freedom (5 treatment periods)
Treatments:	(7)
(A) Fixed vs. variable percentage treatments	1
(B) Among levels of fixed percentage treatments:	(3)
Linear effects	1
Quadratic effects	1
Cubic effects	1
(C) Variable percentage treatments	1
(D) Between levels of increasing percentage treatments	1
(E) Between levels of decreasing percentage treatments	1
Error ‘a’ for testing treatments	16
P - periods	4
Treatment × period interaction:	(28)
P × A	4
P × B linear effects	4
P × B quadratic effects	4
P × B cubic effects	4
P × C	4
P × D	4
P × E	4
Error ‘b’ for testing treatments	64
Total	119

the differences change over time. This analysis also does not include information for the higher growing-stock conditions represented by the controls. This leads to the use of graphical and regression analysis to consider how the responses change over time.

Levels of Growing Stock

The fundamental outcome of the stand treatments was volume production, which provided for the quantitative expression of levels of growing stock for the eight regimes presented in table 1. All relations and parameters to be developed were dependent on the definition of these levels of growing stock and related stand conditions. Growing stock is expressed as basal area per acre. The levels of basal area accumulated in each regime after each of the five thinnings plus an additional holding period of 14 years are displayed in figures 4A and 4B.

By matching the percentages for a particular treatment in table 1 with the basal area trends for the same treatment in figures 4A and 4B, one can see that low percentages of retained growth correspond to heavy thinning and low levels of growing stock in residual stands. Conversely, high percentages correspond to light cuts and high levels. Also, the constant percentage treatments 1, 3, 5, and 7 produced consistently increasing trends of basal area. Treatments 2, 4, 6, and 8 have variable percentages, with 2 and 4 increasing and 6 and 8 decreasing, so that basal area trends increased at quite different rates in successive periods. Another important characteristic is that the eight regimes started with only four levels of growing stock after calibration. They occupied

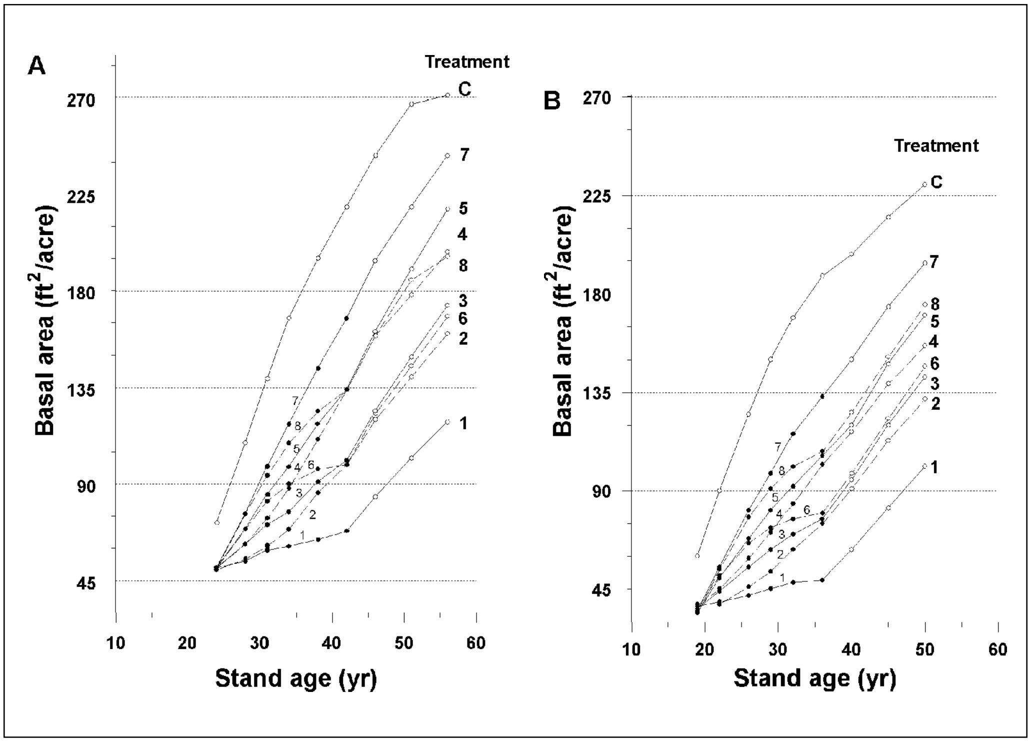

Figure 4—Levels of growing stock. Basal area after thinning by stand age and treatment for (A) Skykomish and (B) Clemons. Dots mark thinning, and circles mark measurement only.

eight levels at the second, third, and fourth thinnings, then converged again to four levels after the last thinning. Treatments 2 and 6 are variations of treatment 3, all averaging 30 percent retention of gross basal area growth of controls. Similarly, treatments 4 and 8 are variations of treatment 5, all with 50 percent retention.

The trend lines in figures 4A and 4B show basal area per acre after periodic thinning including the 14-year holding period after the last thinning. For comparison, the net basal area per acre in the unthinned stand is the upper line on each chart. This illustrates the large initial difference in levels of growing stock between the thinned and unthinned stands. After the preparatory thinning, the treated stands at Skykomish started with 30 percent less basal area than the controls. Stands at Clemons were 40 percent less than controls. These large differences in initial levels of growing stock were created by preparatory thinning to make the treated stands uniform. A consequence of this heavy initial cut was a substantial reduction in the amount of growing stock in all thinned stands. This is most pronounced in regime 1 where the heavy preparatory thinning followed by extremely heavy treatment thinnings reduced the growing stock to levels far below the possibility of full site occupancy during the entire period of this study.

The prescribed stand treatments were remarkably effective in controlling growth to produce a wide array of well-defined regimes starting at a common level after the calibration period. At Skykomish after five thinnings over a period of 18 years, the heaviest thinning, treatment 1, had only 67.7 square feet of basal area per acre, whereas the highest was 166.9 in treatment 7. At Clemons the comparable levels were 49.4 and 132.8. The applicability of this method of controlling growth over a wide range of stand conditions was demonstrated by development of a similar series of regimes at both Skykomish and Clemons, which started with markedly different species, stand origin, and stand structure. A minor deviation from the planned outcome at Clemons was the failure of regimes 2, 3, and 6 and 4, 5, and 8 to converge at the first and fifth thinnings. This was caused by initially using numbers of trees to determine growing stock, which allowed variation in basal area. At Skykomish, these treatments did converge at the last thinning and remained close in basal area during the 14 years after thinning.

Examples of stand conditions in the different levels of growing stock and stages of stand development are shown in figures 5A and 5B through 13A and 13B.

Basal Area Increment

Gross basal area increment in relation to basal area per acre in thinned stands is shown in figures 14A and 14B by periods. Thinnings were carried out in all periods except the last three in each study area. Data for the first growth period are not included because the range in growing stock was inadequate to calculate a regression. The sequence of periods shows a gradual reduction in growth rates as the stands advance in age from 28 to 56 years at Skykomish and 22 to 50 years at Clemons. The range in levels of growing stock; i.e., midperiod basal area, expanded with each thinning as shown by the length of regression lines in figures 14A and 14B. At Skykomish the range of midperiod levels at 28 and 31 years was only 28 square feet, but it expanded to 127 square feet in the period of 51 to 56 years. At Clemons the range was 21 square feet in the 22- to 26-year period and 99 square feet in the 45- to 50-year period. The reduction in growth rates with age resulted in a substantial increase in the amount of growing stock required to produce a given annual increment in basal area. For example, a PAI of 7 square feet was produced in the 28- to 31-year period at Skykomish with only 63 square feet of growing stock, but in the 42- to 46-year period, 164 square feet were required to produce the same increment. At Clemons, a PAI of 7 square feet was produced with a growing stock of 56 square feet in the 22- to 26-year period. When stand age advanced to the 29- to 32-year period, 87 square feet were required to produce a PAI of 7 square feet. Trends in growth-growing stock relations are discussed in more detail later in this report.

Gross PAI and mean annual increment (MAI) of basal area by midperiod age are displayed in figures 15A and 15B for Skykomish and figures 15C and 15D for Clemons, respectively. The purpose of these charts is to show the actual increments of basal area that were accumulated to develop the levels of growing stock in each regime. They also provide a comparison of treatments in terms of basal area allocated to cut and leave at each thinning and the trends in PAIs. In these charts, a single vertical bar represents the average growth on three plots in a treatment. The components of gross annual increment are the amount retained at each thinning and the amount cut including periodic mortality. In the last three periods when no thinning was done, the net increment and mortality are displayed. To facilitate comparisons between treatments, figures 15A through 15D are arranged in pairs from top to bottom of the page as follows. Treatments 1 and 7 had the lowest and highest basal area reserved (table 1), respectively. Large differences in reserve PAI are shown for all growth periods. The next pair, treatments 2 and 4, had variable increasing percentages of basal area reserved with higher levels in treatment 4. Treatments 3 and 5 had constant percentages at intermediate levels. Treatments 6 and 8 had variable decreasing percentages reserved with treatment 8 at the higher levels as shown by comparative amounts of basal area at each thinning. Comparable data for the control plots show net and gross PAI and the

Figure 5—Skykomish treatment 1 (plot 22). (A) After second thinning, stand age 31. (B) Stand age 56; growing stock per acre: basal area = 120, trees per acre = 45. Very severe thinning created large stand openings resembling shelterwood conditions with full cover of ground vegetation and regeneration.

Figure 6—Skykomish treatment 3 (plot 31). (A) Stand age 24 when study was established in 1961. George R. Staebler pruning crop tree, 9.1 inches d.b.h.; (B) Staebler by the same tree 31 years later. At stand age 56, one year after photo, tree d.b.h. was 19.8 inches. Growing stock per acre: basal area = 168, trees per acre = 85.

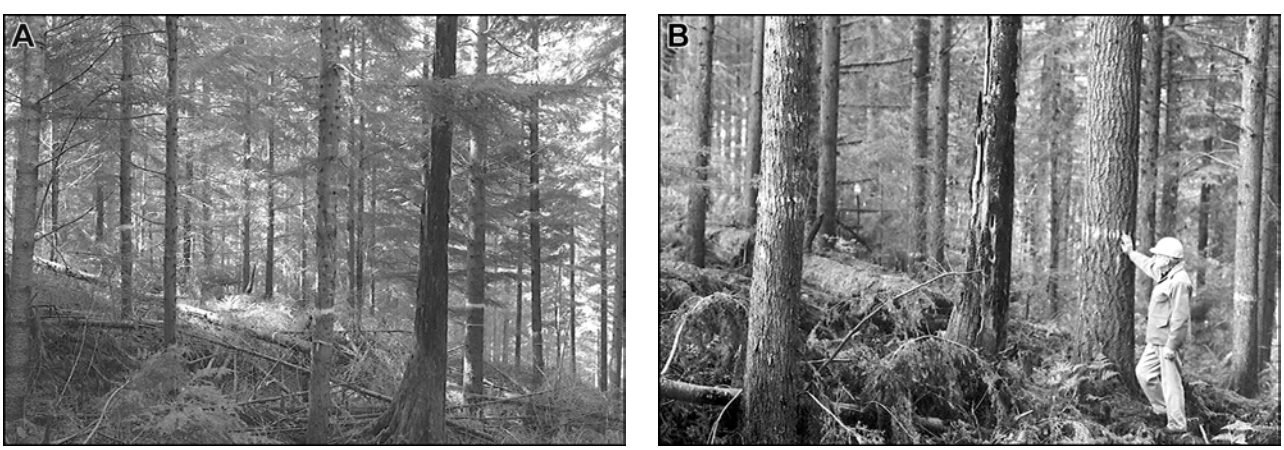

Figure 7—Skykomish treatment 5 (plot 9). (A) After second thinning, stand age 31. (B) Slightly different view with George R. Staebler by a crop tree in 1992. Growing stock per acre at age 56, 1993: basal area = 219, trees per acre = 210.

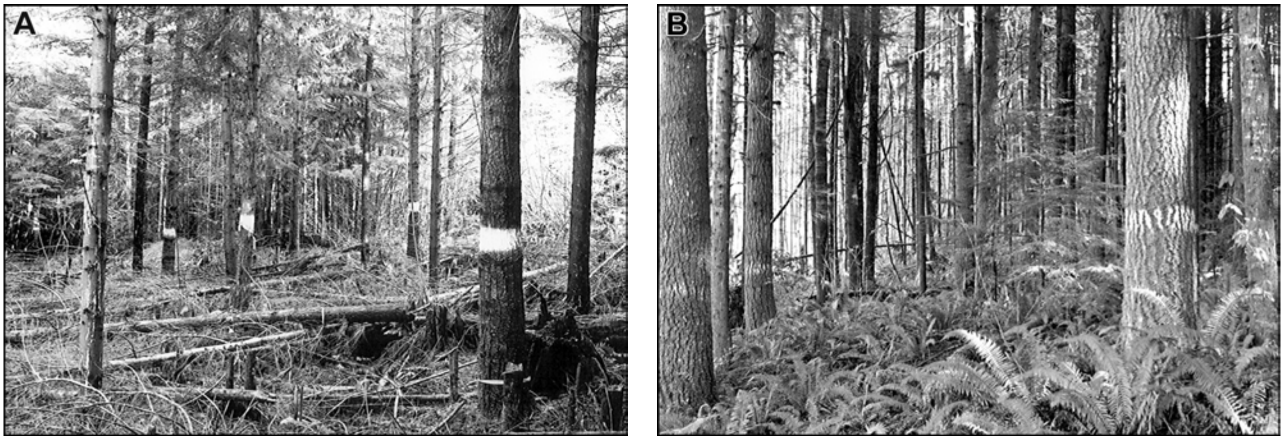

Figure 8—Skykomish treatment 7 (plot 30). (A) After second thinning, stand age 31. Heavy slash had accumulated because thinnings were not removed. (B) Stand age 56. Growing stock per acre: basal area = 239, trees per acre = 180: two times as much growing stock as plot 22 (fig. 5B).

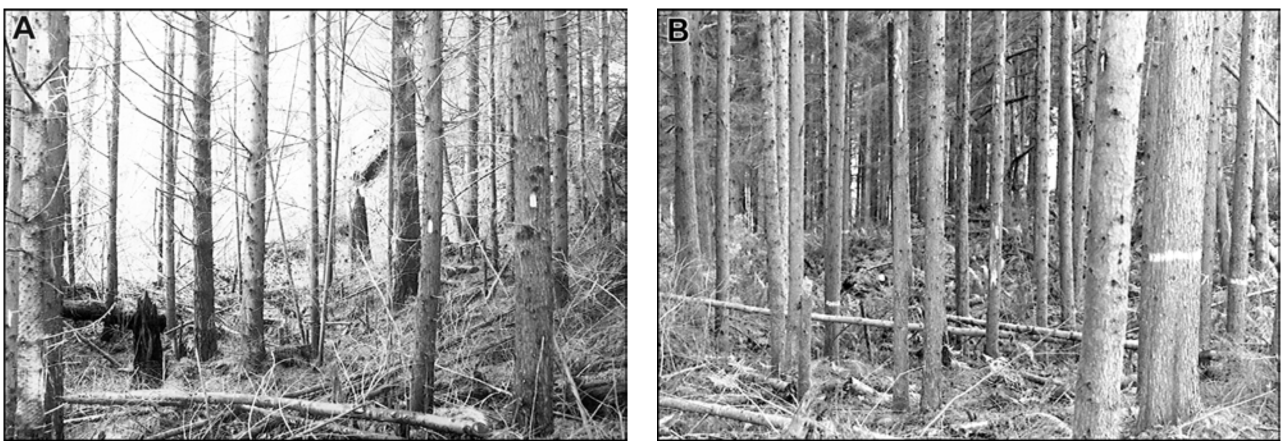

Figure 9—Skykomish control (plot 2). (A) Age 31, 784 trees per acre. (B) Age 56, growing stock per acre: basal area = 266, trees per acre = 380. From age 24 to 56 the volume lost to mortality was 2,660 cubic feet or 17 percent of the gross yield.

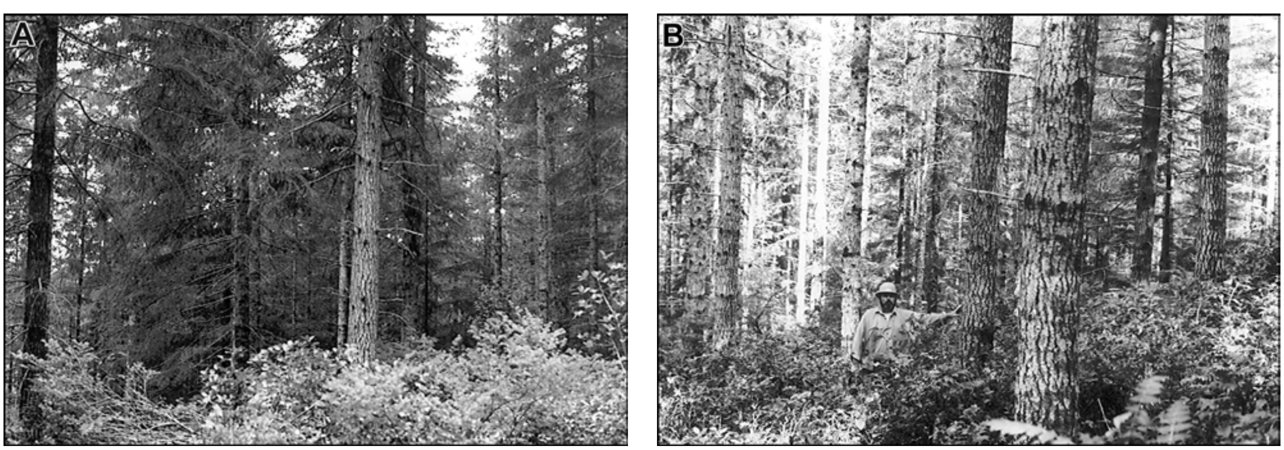

Figure 10—Clemons stand age 50. (A) Treatment 1 (plot 63). Growing stock per acre: basal area = 106, trees per acre = 55. (B) Treatment 3 (plot 71). Growing stock per acre: basal area = 144, trees per acre = 130. Treatment 1 has large stand opening similar to treatment 1 at Skykomish (fig. 5), but regeneration was precluded by a dense cover of salal.

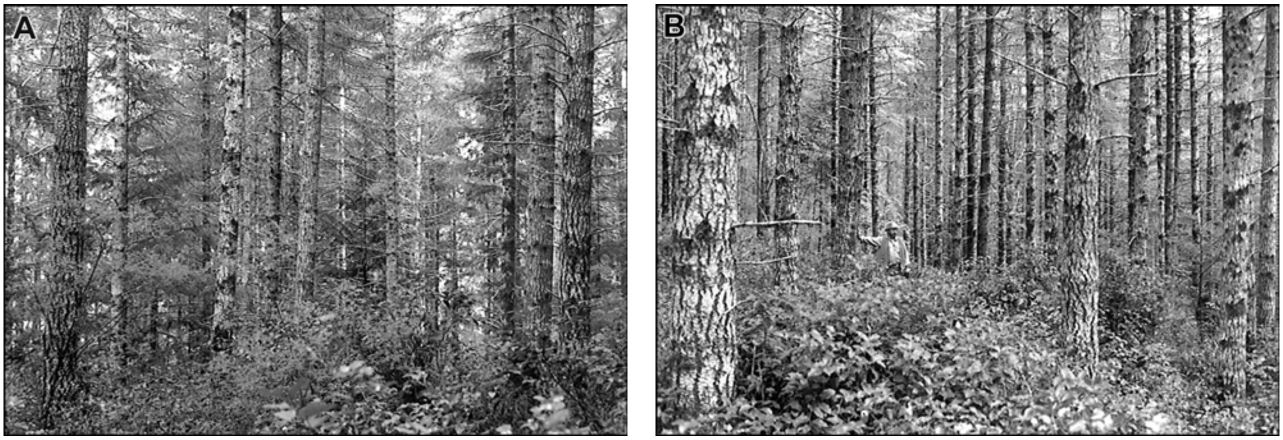

Figure 11—Clemons stand age 50. (A) Treatment 5 (plot 61). Growing stock per acre: basal area = 192, trees per acre = 155. (B) Treatment 7 (plot 86). Growing stock per acre: basal area = 204, trees per acre = 220. This treatment produced the highest level of growing stock.

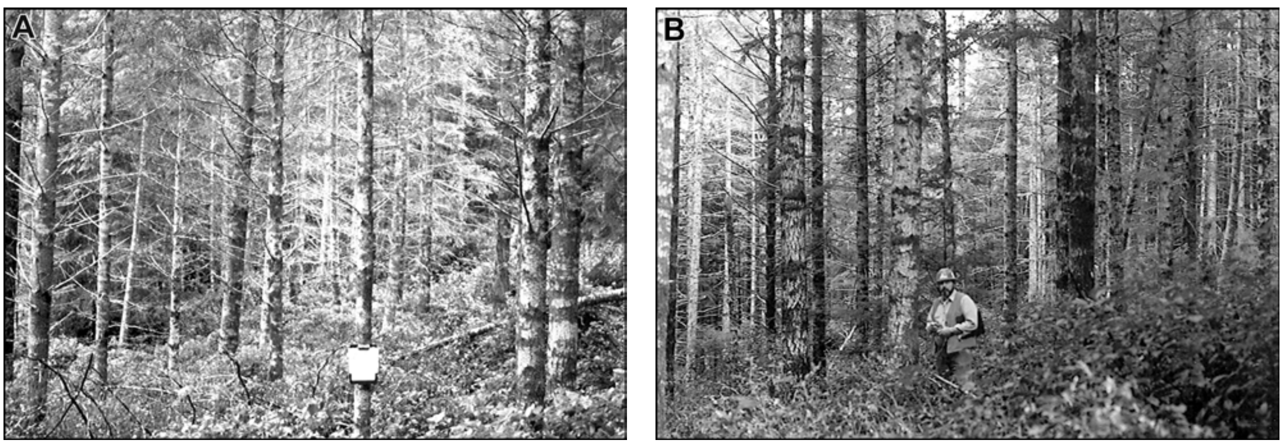

Figure 12—Clemons treatment 8 (plot 59). (A) Stand age 38, 2 years after last thinning. Growing stock per acre: basal area = 118, trees per acre = 200. (B) Stand age 50. Growing stock per acre: basal area = 178, trees per acre = 195. During the postthinning period, treatment 8 maintained a periodic annual increment of 269 cubic feet per acre, equal to treatment 5 (fig. 11A).

Figure 13—Clemons. (A) General view of stand after preparatory thinning, 396 trees per acre, 4.1 inches average diameter at breast height. (B) Unthinned control (plot 89) at stand age 50. Growing stock per acre: basal area = 252, trees per acre = 465. Ground cover remains sparse compared with heavy salal in all thinned stands.

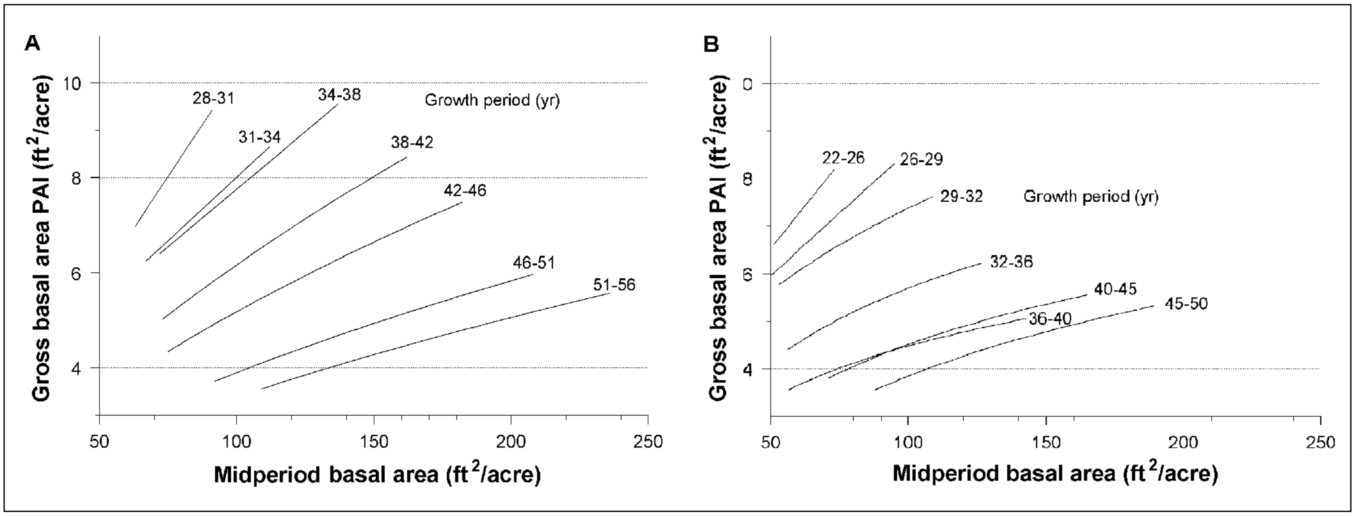

Figure 14—Gross periodic annual increment (PAI) in basal area in relation to midperiod basal area, by growth period for (A) Skykomish and (B) Clemons. Length of regression line shows range in level of growing stock for each growth period. Three oldest periods in each area were after last thinning.

difference between them, which represents mortality. In figure 15C, the first period of treatment 2 at Clemons shows no reserve basal area. This occurred because of an error at the time of thinning when the basal area that should have been reserved was included in the cut.

The sequence of gross-basal-area increments in both study areas show generally declining growth with advanced age. Most treatments show period-to-period irregularities, but growth in thinned stands was less than in unthinned controls in comparable periods. A major factor contributing to these differences was the reduced growing stock in the initial thinned stands after the preparatory thinning. Subsequent heavy thinning, as in treatment 1, further reduced gross growth.

Gross mean annual increments of basal area were steadily increasing in all regimes up to the last three or four periods when most were leveling off or slightly increasing. Treatments 1 and 2, with the most severe thinnings, produced the lowest MAIs in both study areas. However, the maximum total range in MAI for all treatments in a given period was only 1.4 square feet of basal area. The stability of gross PAI and MAI in all regimes, even with extreme variation in severity of thinning, indicates that a wide range of silvicultural regimes can be applied within the thinning parameters observed in these studies without jeopardizing potential yields.

Wood Production

The first major objective of the LOGS studies is to determine how the amount of growing stock in repeatedly thinned stands affects wood production. The aspects of wood production included in the analysis are (1) cumulative gross volume, i.e., yield, in relation to basal area and stand age; (2) thinning yields as a component of wood production; (3) gross volume increment in relation to basal area; and (4) gross PAIs and MAIs in relation to stand age. All volumes in the text of this report are given in cubic feet total stem (CVTS). Additional tables in the appendices include volume to a 6-inch diameter inside-bark top (CV6), Scribner board feet in 32-foot logs to a 6-inch top (SV632) and total stem volume in cubic meters.