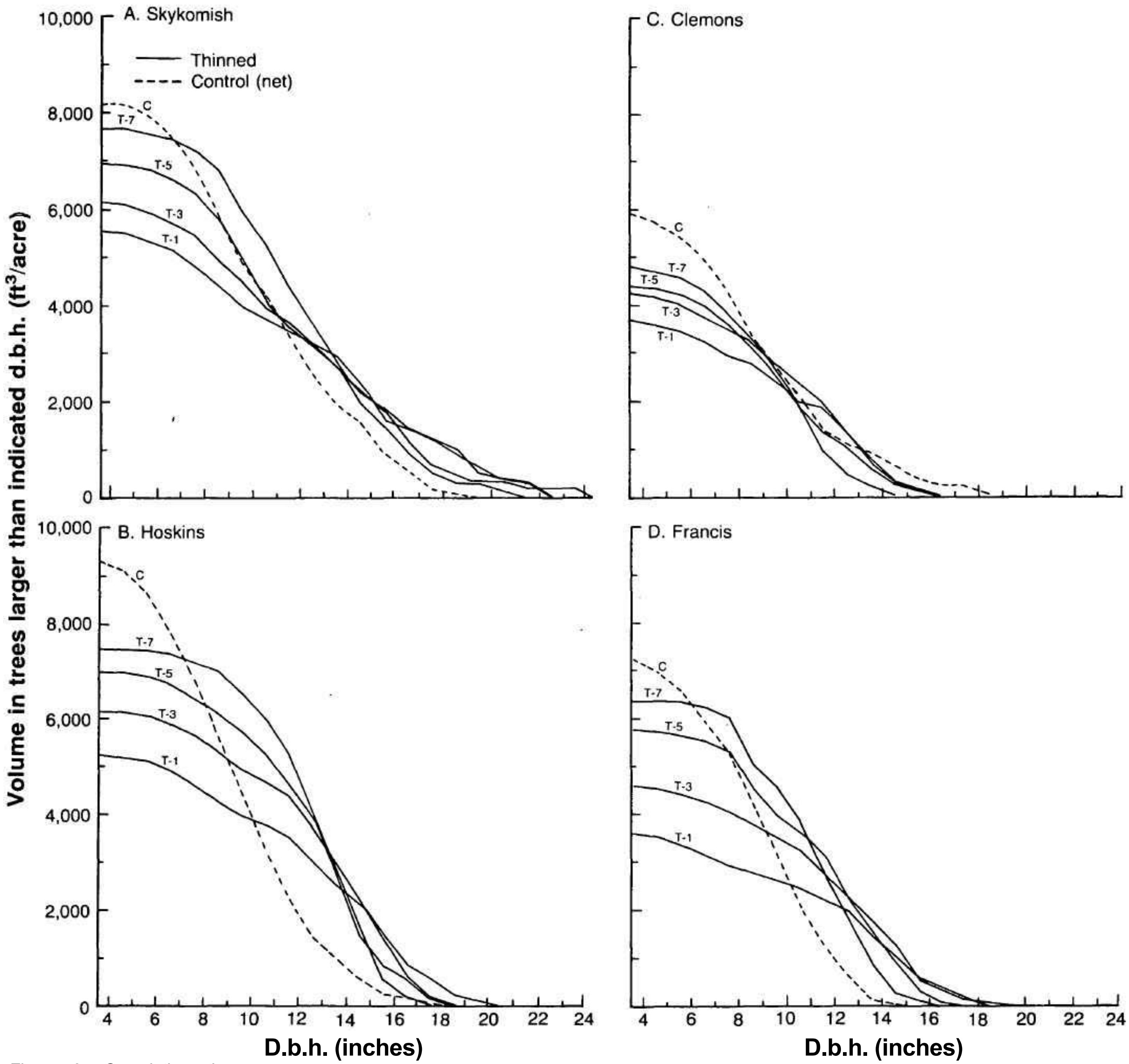


Figure 40.—Cumulative volume production (including thinnings) in trees larger than indicated diameters, to end of fourth treatment period: (A) Skykomish, to age 42; (B) Hoskins, to age 36; (C) demons, to age 36; and (D) Francis, to age 33. Material removed in calibration cut omitted. Values shown for fixed treatments (1,3, 5, and 7) and control only.

Discussion

Differences in Productivity

Volume and basal area production and diameters of trees at individual installations are expected to differ with differences in age and site index. These differences should be largely removed when height (H40) rather than age is used as the basis for comparison. The most advanced studies in the LOGS series—Skykomish, Hoskins, clemons, Francis, and Iron Creek—are similar in site index; the most recent SI_{50} estimates are 128, 132, 122, 125, and 125, respectively. These installations could, therefore, be expected to behave similarly in relation to H40 development.

Considerable differences do exist. The Skykomish and Clemons installations are clearly producing less volume, less basal area, and less diameter growth than expected for their site indexes and attained H40 values.

Evidence for differences.—

Controls.—The graphs of basal area, cumulative basal area production, cumulative volume production, and relative density in relation to H40 (figs. 10 through 13) all show much lower production for the Skykomish and Clemons controls than for controls in the other five installations compared. RD values do not appear to be approaching the same upper limit.

Clemons has produced much less basal area and volume for a given H40 than have the other installations (except Skykomish), even though the site index and initial height at Clemons were comparable to Hoskins, Francis, and Iron Creek. By the time the stands reached 90 feet in height, diameter of the Hoskins control exceeded that at Clemons despite the fact that Hoskins had nearly twice as many trees per acre (figs. 7,8,9, and 10). The Skykomish control has also produced much less basal area and volume for its H40 than did Hoskins, Francis, and Iron Creek, which have similar site indexes.

Thinning treatments.—Graphs of periodic annual increment in basal area and volume in relation to basal area, treatment, and period (figs. 15 and 16) show relationships that are qualitatively similar but quantitatively different. Clemons in particular has much less growth than the other site II installations. Cumulative production curves (fig. 32) show similar patterns, but with much less total production at Clemons. The same is true for attained diameters (fig. 33). The various curves relating periodic annual increment in basal area, volume, and diameter to measures of growing stock are likewise lower for Clemons.

Graphs comparing gross volume yields and attained diameters among installations by individual treatments (figs. 36 and 37) show differences similar to those for the controls; curves for Clemons and Skykomish are markedly lower than those for other installations.

Stands differed somewhat in height, average diameter, number of trees, and basal area at the start of the individual experiments, and it is not surprising that subsequent development has not been identical. To the extent that these initial differences have influenced subsequent basal area growth of controls, they must have influenced the definition of thinning treatments Basal area levels for a given treatment do differ considerably among installations (fig. 38), Differences in initial condition do hot .seem a sufficient explanation of the observed differences however.

Possible causes of differences.—

Skykomish.—This installation differs from others in that it was somewhat taller and had the most volume at the start of the experiment, the stand was and is about 50 percent hemlock by basal area, and trees on the control that were less than one-half the average diameter of crop trees were cut in the calibration thinning, unlike the procedure on other studies. The slightly later start of treatments could be a factor in the lower basal area growth and must affect comparisons of development in relation to H40. Removal of small trees from the control plots may have had some slight effect on subsequent development of the control plots and hence on treatment basal area levels. The major apparent difference from the other studies is species composition. The hemlock component has a substantially lower diameter growth rate and less height and average diameter (table 47) than did the Douglas-fir component which is used as the basis for site index and H40 estimates. Each of these factors probably contributes to observed differences, although they do not necessarily provide a complete explanation.

Clemons.—Initial stand values at demons were well within the range of those for Hoskins, Francis, and Iron Creek (table 2). Clemons had the smallest initial number of trees, was closely comparable to Hoskins and Iron Creek in initial H40, and was in between Hoskins and Iron Creek in average diameter (Francis had considerably smaller initial H40 and average diameter). The principal difference when compared to Hoskins and Iron Creek was lower initial basal area at Clemons (Francis had a still lower initial basal area, associated with smaller average diameter and lesser initial H40). This difference continued throughout subsequent development of control plots (fig. 10) and corresponding differences are evident for thinning treatments (figs. 36 through 38). The poor subsequent diameter and basal area growth, when compared to more heavily stocked and otherwise comparable installations, indicate that the difference in basal area is not a cause but a result of some inherent difference in stand productivity.

The original stand had considerable animal and freeze damage and many damaged trees were removed in the calibration thinning. The diameter distribution after calibration (table 5) suggests that more of the larger trees were removed than in the other studies; the 6-foot difference between mean H40 of controls and that for thinned plots suggest the same. Also, d/D at the second treatment thinning was unusually high (fig. 14), for reasons unknown (also true at Skykomish), and may have accentuated differences. These differences were still present at the end of the fourth treatment period, as shown by the volume distribution curves of figure 39 and the 10-foot difference in estimated site index of control plots vs. treated plots (table 8).

Several observers have commented that trees at Clemons appear less vigorous than those in other installations; the trees have a slight yellowish cast to the foliage and relatively thin crowns. Possible causes that have been suggested for this appearance and for differences in performance from the other site II installations include an unknown and possibly off-site seed source, some unrecognized nutritional problem, effects of a severe burn in the early 1940's, and heavy initial brush competition.

There is considerable evidence, much of it from Europe (Assmann 1970, Bradley and others 1966) that differences in stand productivity and stockability exist which are not fully accounted for by height growth or site index and which are often related to differences in soils or regional climate. Although such differences could be involved here, we have no reason to expect them for the soils and locations concerned. Differences in early damage and initial treatment, a possibly unadapted seed source (Clemons), and species composition (Skykomish) seem more likely explanations.

Definition of Thinning Regimes

Staebler's use of control plot growth to define residual stocking for the thinning regimes in the LOGS studies was based on the beliefs that local productivity differences exist and that definition of thinning regimes in relation to productivity of the individual stand, rather than in relation to regional averages, would be biologically meaningful. The differences discussed above appear to confirm the hypothesis of local productivity differences. It is arguable whether the attempt to define thinning regimes in relation to productivity of the individual stand has really simplified analysis and interpretation of the experiments.

The method used to define regimes has probably not achieved complete comparability of thinning regimes among installations. Basal area increment culminates early in dense stands, and time of culmination is influenced by initial density (Pienaar and Turnbull 1973). Installations differed considerably in initial number of stems, basal area, and height at the time the study was established, and such differences may well have introduced inconsistencies in defining thinning treatments.

The numerous small stems of associated species that are present in some installations distort summary values and growth trends for the number of trees and average diameter and introduce some confusion in comparisons among installations. In retrospect, it would have been preferable to have removed the small trees at the time of study establishment, as was done at Skykomish but not in the other installations. Alternatively, more nearly equal initial conditions might have been provided by thinning all controls to a fixed number of trees—a number large enough to allow early crown closure—at the time of study establishment.

Analyses of Variance

Differences among treatments.—The analyses of variance (tables 11-14) show no significant differences between averages of the fixed and variable treatments, which always have the same average amount of retained growing stock. Gross basal area growth and gross volume growth increased with growing stock; growth percents decreased with growing stock. Basal area growth, and basal area and volume growth percent have decreased over successive treatment periods. Diameter growth (both PAI and growth percent) has decreased with increasing growing stock and has shown decreases over successive periods except for PAI at the lowest level of growing stock.

So far, basal area and volume PAI have been greater for the decreasing treatments than for the increasing treatments. At the end of the fourth treatment period, the average percentage of control plot growth retained is 35 percent for the increasing treatments and 45 percent for the decreasing treatments. Average growing stock level of the latter is higher and would be expected to produce more growth. The experiment will not be completely developed until the end of the fifth treatment period, when the same average growing stock levels are expected for both increasing and decreasing treatments. Even through increasing and decreasing treatments differ at present, we cannot now conclude that they will be different at *the* end of the fifth treatment period.

Results for the contrasts between increasing treatments (D) and between decreasing treatments (E) (table 9) vary among installations. Where significant differences occur, they are consistent with results of the fixed percentage comparisons. Treatments 4 and 8 tend to have greater basal area and volume PAI in the increasing and decreasing groups, respectively. These retain more growing stock than the alternative treatments, 2 and 6. The opposite is true of growth percent, with treatments 2 and 6 having greater growth percents when there is a significant difference because growth is on fewer and larger trees. For quadratic mean diameter, treatments 2 and 6 have larger PAI and growth percents because of the greater radial growth response associated with less growing stock in these treatments.

The error mean squares (tables 10 through 15) show that demons has much higher variability than the other three installations discussed. Nonsignificance of most interactions at Clemons probably reflects less sensitivity associated with this greater variability.

Differences among installations.—The graphs of means for the fixed percentage treatments (figs. 15 through 18) show that trends are qualitatively similar among the four installations compared, but that there are considerable differences in productivity, as noted previously.

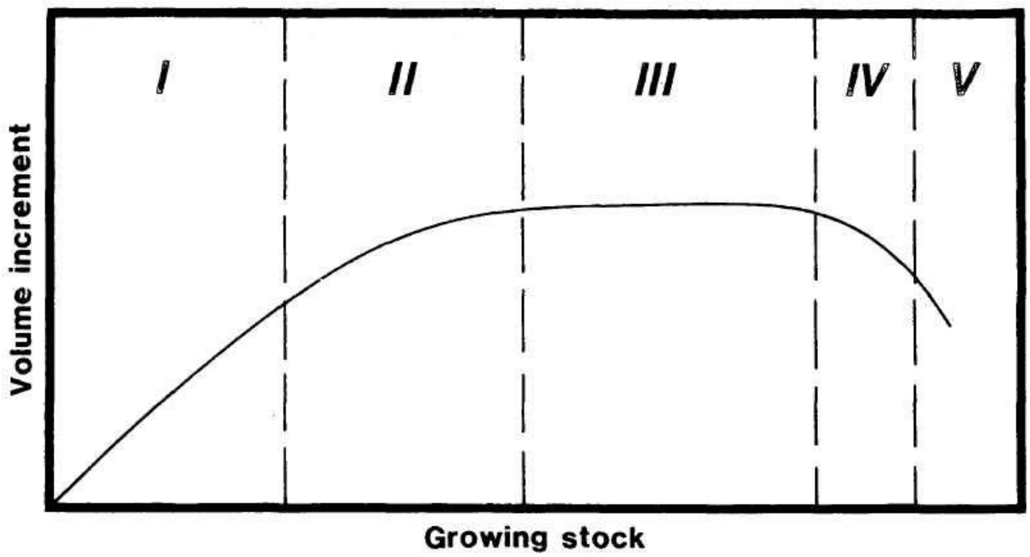
Relationships Between Growth and Growing Stock

Past observations and the Langsaeter curve.—Thinking at the time the LOGS studies were established was strongly influenced by the so-called Langsaeter curve (fig. 41), which portrayed a generalized relationship of growth to growing stock (Braathe 1957, Langsaeter 1941). The possible range of growing stock was subdivided into a free-growth zone (I) not influenced by competition, a transition zone (II), a zone (III) within which growth is nearly constant over a wide range of growing stock, and a zone (IV) in which growth is reduced by excessive competition. One purpose of the LOGS studies was to provide a quantitative definition of the rising portion of this curve, particularly zone II.

Subsequent to the widely quoted publications by Braathe (1957) and ManMoller (1954), the generalization has been frequently made that essentially the same total cubic volume production can be obtained over a wide range of stand densities. A considerable number of thinning studies in several species have seemed to support this, and Staebler (1960) based his theoretical thinning regime on the assumption that the same gross increment may be produced with widely differing combinations of growing stock and tree size.

There is considerable information for Douglas-fir that does not agree with the concept of constant gross growth over a wide range of densities. Curtis (1967) found that in untreated natural stands, gross increment in both basal area and volume increases with increasing stand density; there was no indication of a maximum within the range of his data. Reukema (1972) and Reukema and Bruce (1977) found, as did Curtis and others (1982), that thinning reduced gross volume increment. This is stem volume only, and mortality in unthinned stands may partially or completely offset this reduction in terms of recoverable volume. Also, the studies cited involve uncertainties arising from use of heterogeneous samples in regression and thinning practices that were influenced by merchantability considerations.

Figure 41.—Relation between volume increment and growing stock, as hypothesized by Langsaeter (adapted from Braathe 1957). Roman numerals denote Langsaeter's "density types."



The LOGS study results.—The LOGS studies constitute the most closely controlled and extensive series of thinning experiments in existence for young stands of Douglas-fir. In time, they should define the relationship of gross growth to growing stock in young stands that have been reduced to low stocking at an early age which was followed by consistent thinning to maintain a series of growing stock levels. Few data are yet available from the installations on poor sites, so we can say little about these; but relationships now seem fairly well established for the better sites.

We do not imply that the quantitative results would necessarily hold for thinnings begun at a later stage in stand development or for regimes that produce radically different stand structures. The close relationships of growth to growing stock found in the LOGS studies, in contrast to the results of the somewhat similar study reported by Oliver and Murray (1983), probably reflect the close control of initial conditions and kind of thinning that are a major feature of the LOGS studies. These specifications in turn imply development of a particular stand structure over time.

Gross growth.—Within the range of the thinned stands, gross growth in both basal area and volume increases with an increase in growing stock (figs. 19 and 23). For basal area growth, some of the curves suggest a possible maximum between the upper margin of the range of the thinned plots and the controls, with a zone of nearly constant growth in later periods. The volume growth curves appear much steeper and show little indication of any maximum or of any zone of constant growth.

Similar curves (figs. 20 and 24) with RD on the horizontal axis suggest that on these axes the curves are approximately proportional (and, therefore, parallel when transformed to logarithmic scales). Statistical and graphic comparisons indicated that curves for successive periods within an installation could be regarded as proportional and that this is also at least approximately true across installations (with the possible exceptions of Clemons and Rocky Brook).

These statements do not imply any theoretical basis for proportionality, nor do the statements necessarily hold over a wider range of ages and heights. For the limited range under consideration, proportional curves appear to be a sufficiently close approximation to reality to allow their use in summarizing relationships in an easily interpretable form.

Assuming such proportionality, relationships between growth and growing stock can be generalized as shown in figure 26 where the variable on the vertical axis is the ratio of growth rate to the growth rate expected at the “normal" density of RD70. The variable on the horizontal axis is the relative density expression, RD. For RD30, for example, about 66 percent of "normal" volume growth and about 77 percent of "normal" basal area growth would be expected.

The curves for individual periods (figs. 23 and 24) and the generalized curve in figure 26 do not support the idea that gross volume growth is the same over a wide range of stocking. The thinned stands in the LOGS study are clearly on the ascending portion of the Langsaeter curve (fig. 41) in Langsaeter's zones I and II. There is little indication of any plateau of gross growth.

Net growth.—Mortality on thinned plots was generally minor and, within the range of the thinning treatments, relationships between net growth and growing stock differ tittle from those for gross growth. Net growth increases with an increase in growing stock.

Suppression mortality is now substantial on the controls, and net growth of controls is considerably less than gross growth. The observed values, though erratic, indicate that by the third and fourth treatment periods net growth is about the same for the control and for treatment 7 (table 48, appendix). The accelerating suppression mortality on the control plots suggests that in the very near future net growth of the more heavily stocked thinning treatments is likely to exceed that of the controls.

Differences between basal area and volume increment curves.—The gross volume increment curves appear steeper than the basal area increment curves and, unlike the latter, show no indication of a maximum within the range of the data (fig. 26). The curve for gross basal area growth is much closer to the Langsaeter-Mdller concept of near-constant growth over a wide range of densities than is the curve for volume growth.

Douglas-fir characteristically has rapid height growth that is sustained over long periods of time. In this respect it differs markedly from many eastern and southern species. This rapid and sustained height growth is the probable explanation for the difference in shape of the basal area and volume growth curves and is a characteristic that has important implications for management of the species.

Height growth as a factor in volume increment and density control.—A generally applicable equation for stand volume is:

$$V = FGH;$$

in which:

V = cubic volume per unit area,

F = form factor,

G = basal area per unit area, and

H = stand height.

We used H40 as stand height and calculated the corresponding form factor as:

$$F = V/(G\ H).$$

Differentiating the volume equation with respect to time (t), we have (Hegyi 1969):

$$dV/dt = FG(dH/dt) + FH(dG/dt) + GH(dF/dt)\ ;$$

in which dV/dt, dH/dt, dG/dt, and dF/dt are the net rates of change in volume, height, basal area, and form factor; all can be approximated by the corresponding periodic annual net increments. Values of F, G, and H corresponding to these rates are approximated by the period means of these quantities. This relationship can also be expressed as a difference equation (Evert 1964).

As a numerical illustration, we take values from the Hoskins study, treatment 5, fourth treatment period. These values are:

Period means	Growth rates
	dV/dt = 416ft^3/acre/yr
F = 0.3770	dF/dt = -0.0013 per year
G = 147.4ft^2/acre	dG/dt = 8.475 ft^2/acre/yr
H = 83ft	dH/dt = 3.0 ft/yr

Substituting these values into the above equation for the derivative dV/dt:

$$dV/dt = 167 + 265 - 16 = 416\ ;$$

which agrees with the observed periodic annual increment.

The third term in the equation, GH(dF/dt), makes only a minor contribution to total volume growth.; The contribution of the second term, FH(dG/dt), is directly proportional to basal area growth rate. The. first term, FG(dH/dt), involves the product of basal area and height growth rate/The greater the rate of height growth, the greater the importance of this term. Differences in basal area levels will have.a greater effect on the magnitude of the FG(dH/dt) term-and on volume growth rate—in stands that are growing rapidly in height than in stands which are growing slowly in height:

Volume growth will be more closely related to basal area stocking in a species such as Douglas-fir, which characteristically maintains rapid height growth over long periods of time, than in species that do not have this height growth pattern. In the latter, the principal contribution to volume growth is from the second term, FH(dG/dt), which includes basal area only indirectly through its effect on basal area growth rate, dG/dt.

It is thus not surprising that the growth over growing stock curves for basal area and for volume differ in shape, and that the volume growth curves show growth increasing with growing stock up to fairly high levels of stocking. The importance of height growth also suggests the possibility of different patterns on poor sites and in older stands as compared to the young stands on good sites discussed here.

Staebler's Assumptions

Staebler (1960) based his method for calculating thinning schedules on three assumptions:

1. Gross yield in cubic feet of a normal (fully stocked), unmanaged stand represents the maximum production of which the site is capable.
2. Periodic gross increment for any age period in the life of a normal stand represents full capacity of the site to produce wood in a stand of the chosen age.
3. Approximately full increment may be produced with widely differing combinations of growing stock, tree size, and radial increment.

These concepts played an important role in planning the LOGS studies. In view of the results obtained to date, what can now be said? First, although the LOGS studies do not provide a clear test of assumptions (1) and (2), results to date do not conflict with them. Second, assumption (3) is contradicted by the LOGS study results. For the stand conditions and treatments represented, gross volume increment is different for the different observed combinations of growing stock, tree size, and radial increment.

Time Trends and Their Implications

Because all treatments start from a common base at the end of the calibration period, differences among growing stock levels and resulting differences in response develop gradually.

Yield curves (fig. 32) differ little in early growth periods, but diverge sharply in later periods. The same is true of diameters and diameter growth rates (fig. 33). The differences among treatments discussed here extend only to the end of the fourth treatment period for the four most advanced installations. We can expect these differences to become more striking by the planned completion of the experiment at the end of the fifth treatment period.

Comparison of periodic annual volume increments and mean annual volume increments (tables 48 and 49 (appendix); fig. 34) show that periodic annual volume increment has more or less stabilized in the third and fourth treatment periods. Mean annual volume increment is increasing rapidly, although by the fourth treatment period it is still only about one-half the value of the periodic annual increment. This pattern is mainly a consequence of the rapid and sustained height growth characteristic of the species and is accentuated by the low stocking level and resulting reduced volume growth in the early periods.

Comparison of periodic annual increment and mean annual increment shows that these stands are still far short of culmination of mean annual increment. This, plus the rapidly developing divergence of the yield curves and the increased values associated with large tree sizes, indicates that even the end of the fifth treatment period will not provide a full evaluation of the potential effects of the thinning treatments. Realization of the full gains attainable from thinning will clearly require rotations considerably longer than the ages represented by the LOGS studies.

Comparison of Thinning Treatments

Volume production by tree size classes.—Total cumulative production by tree size classes, as of the end of the fourth treatment period, has been summarized in tables 50 and 51 (appendix) and figures 35 and 40 for the Skykomish, Hoskins, Clemons, and Francis studies. Generally, the lowest levels of growing stock (regimes 1,2, and 3) have resulted in major reductions in both total volume production and production of the smaller merchantable material (7.6-11.5 inches d.b.h.), without corresponding gains in volume of large trees. The higher levels of growing stock in treatments 4, 5, 7, and 8 have produced volumes in trees 7.6 inches and larger that are more or less equal to those of the controls; volumes in trees 11.6 inches and larger are far greater than the controls and equal to or greater than those produced in the low-density treatments. Present trends leave little doubt that this superiority in net usable production will continue and will probably increase over time.

Again, Clemons is different. Not only is total production less than at the other three installations shown, but there has been less apparent response in volume growth to differences among thinning treatments (fig. 35). Figure 31 shows that there has, however, been a response in diameter growth. This seeming contradiction may be explained by the lower basal areas and the narrower range in basal areas in this installation, which are consequences of less basal area growth on the control. The fact that the Clemons control contains more large trees than do some of the thinning treatments probably reflects excessive removal of large trees in the calibration thinning.

Trends of basal area and RD in relation to H40.—Trends of basal area and of RD in relation to H40 and to age are shown in figures 42 and 43, for fixed treatments only, for Skykomish, Hoskins, Clemons, and Francis. Application of the study plan thinning specifications has resulted in much lower levels of basal area and RD, as well as volume growth, at Clemons. Differences among the other installations are smaller and probably attributable in part to associated differences in initial H40.

Quality.—To date, no comparisons of timber quality characteristics have been made in the LOGS studies. In none of the treatments have trees developed excessively large branches, even at the lowest density levels. Even treatment 1 contains fine looking trees. However, even if this impression of acceptable branch size were borne out by quantitative measurements, results would not necessarily extend to other stands established with initial numbers of trees comparable to those left in the calibration thinning; and certainly not to stands established with less trees. Although competition was not severe at the time the LOGS studies were established, crowns were in contact and lower branches were beginning to die. This has undoubtedly influenced later branch development.

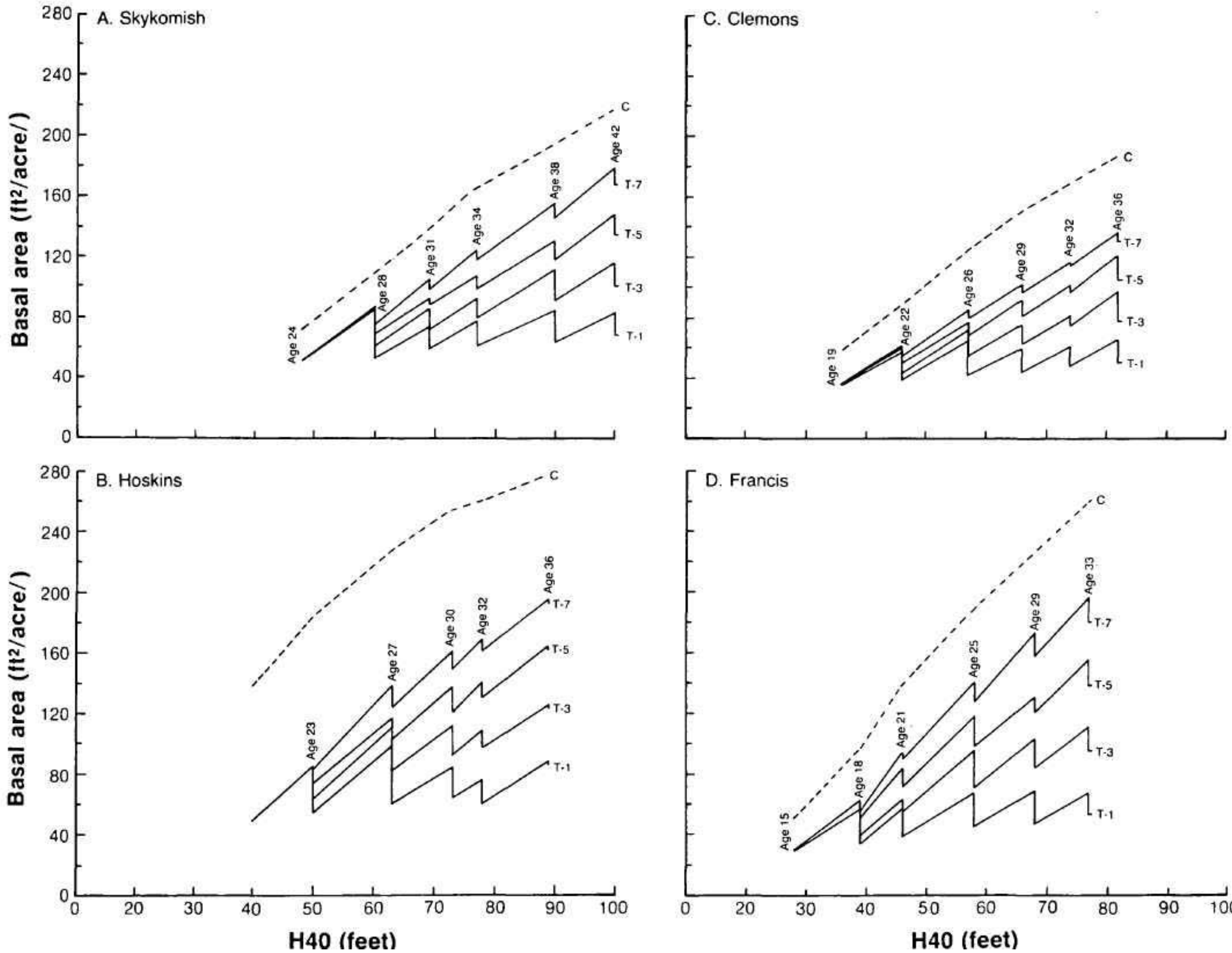


Figure 42.—Trends of basal area over H40, for fixed treatments (1, 3, 5, and 7) and control at: (A) Skykomish, (B) Hoskins, (C) Clemons, and (D) Francis.

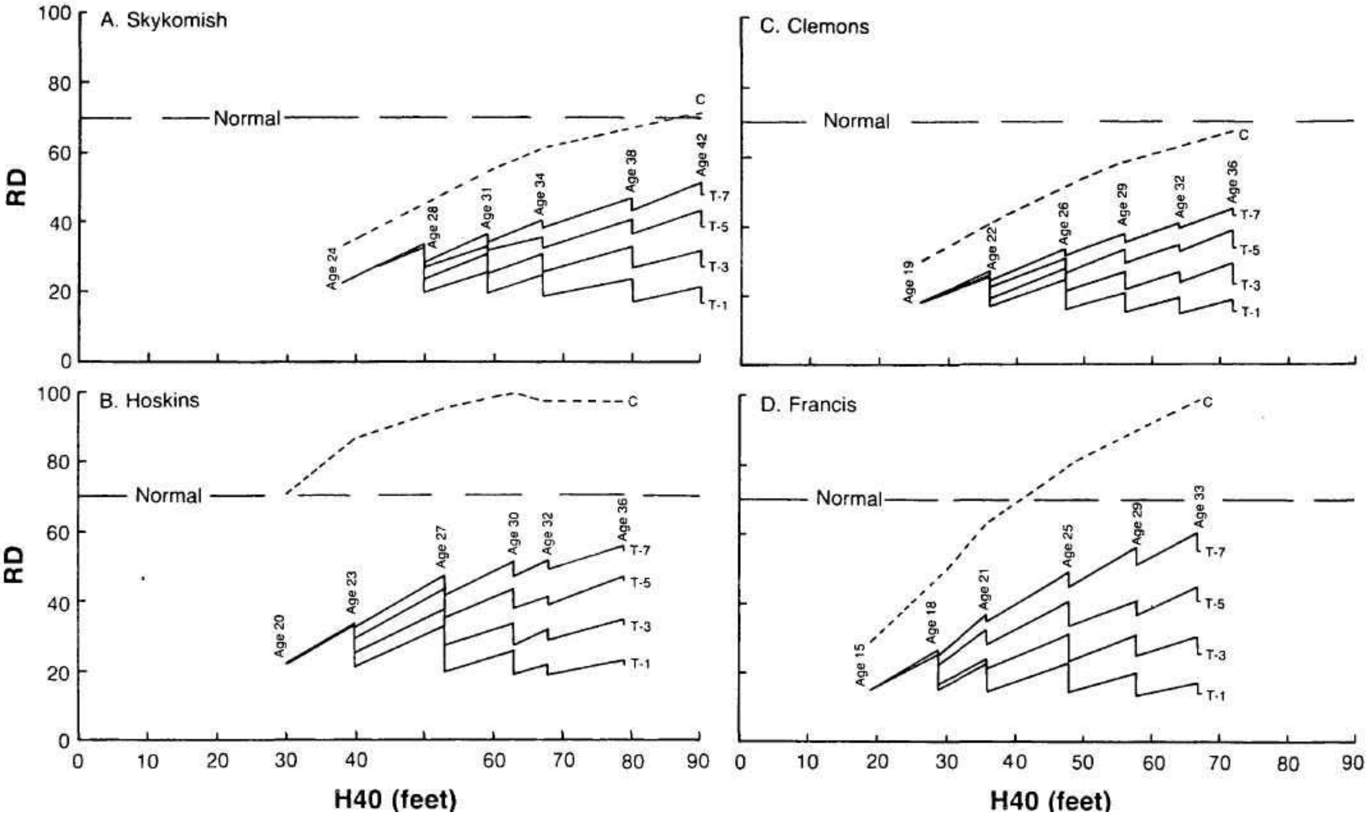


Figure 43.—Trends of RD over H40, for fixed treatments (1, 3, 5, and 7) and control at:
(A) Skykomish, (B) Hoskins,
(C) Clemons, and (D) Francis.

Value.—Although the thinning treatments have reduced total volume production, they have also sharply increased diameters. A ranking of treatments on the basis of value produced would differ considerably from a ranking by volume production.

Any value comparisons should ideally be made for some reasonable rotation age or range of rotation ages. These stands are still far short of such an age. Because the LOGS studies cannot be continued to rotation age, the appropriate point for a value comparison would seem to be the end of the fifth treatment period—the planned completion of the experiment. We have therefore made no attempt to include financial comparisons in this report.

Practical implications of LOGS results.—None of the LOGS studies is complete as of 1983, and little data are as yet available from the poorer sites. The LOGS studies were not designed as comparisons of operationally feasible regimes. Direct applications of current LOGS results to operational stand management are therefore limited.

The short thinning cycle used in the LOGS studies is not operationally realistic and should not be taken as an operational recommendation. There is, however, considerable evidence that for regimes with comparable average periodic growing stock or comparable initial conditions and thinning intensity (annual removal rate), moderate differences in thinning cycle have little effect on growth (Braathe 1957, Bradley 1963, Reukema 1972). Results generally similar to those of the LOGS regimes could probably be obtained with considerably longer cycles, provided trends of periodic mean growing stock and stand density over H40 correspond to those of the LOGS treatments (figs. 42 and 43).

It has been shown that volume increment is strongly related to growing stock for the conditions represented in the LOGS studies. Relatively high stand density is required for high cubic volume production. Conversely, diameter increment declines with increasing stand density.

Choice of any thinning regime is a compromise among conflicting desires for high volume production, large diameters, and relatively few thinning entries. Relative importance of volume growth and diameter growth varies with stage of stand development. Volume growth is a minor consideration when trees are small; the objective then is to get trees to merchantable size as rapidly as possible, consistent with acceptable stem quality. Once merchantable size is reached, volume growth becomes important. Timing of the change in emphasis depends on the diameters selected for beginning of commercial thinning or for harvest. The silviculturist must strike a balance between diameter growth and volume growth that is appropriate to the stage of stand development, to the site, and to management objectives.

The curves in figures 24 and 27 indicate that, for stand conditions comparable to LOGS, densities in the range RD20 to RD40 will produce high rates of diameter growth combined with substantially reduced volume production. Densities in the range RD40 to RD60 will produce high volume growth rates, with substantially reduced diameter growth and negligible suppression mortality. The point when emphasis should shift from diameter growth to volume growth will depend on the stand diameter at which thinning is judged financially and operationally feasible and on the choice of harvest age.

The LOGS regimes all maintain stands in an understocked condition during early treatment periods. In the first treatment period, stands were still close to the free-growth condition, in which volume growth is proportional to growing stock. Approximately the same diameters would probably have been produced if the first treatment thinning had been omitted and correspondingly fewer trees left at calibration.

Judged by results through the fourth treatment period, the LOGS low-density regimes (1 and 3) show somewhat higher diameter growth but considerably less total and merchantable volume production than the higher density regimes (5 and 7). The latter combine moderately fast diameter growth with relatively high volume production. At present, regimes analogous to the latter seem more attractive.

The low density regimes (1 and 3) have produced large, vigorous trees that are in excellent condition for future growth. If these stands are allowed time to build up to higher densities following the fifth treatment thinning, they might well develop greater volume, diameter, and value at final harvest.

Results of the LOGS studies to date appear generally consistent with previous stand management recommendations (Curtis and others 1981, Reukema and Bruce 1977). Consideration of possible analogous regimes and the information currently available from both LOGS and previous studies lead to some generalizations. These represent our best judgment rather than specific results of the LOGS studies.

It seems reasonable to reduce a stand at initial precommercial thinning to the number of stems required to produce an RD of about 50 at the time the stand reaches the average diameter selected for the initial commercial thinning. The only limitations on residual number appear to be the possibility of unacceptable wood quality when this target diameter is large and the number of trees correspondingly low; risks of sunscald, snowbreakage, and thinning shock if the initial thinning is delayed in high density stands; and possible brush problems.

Once the target diameter for the first commercial thinning is reached, successive thinnings that keep the period mean of RD in the range of 45-50 appear reasonable. d/D will usually be in the range, 0.85-0.95. Maximum RD should not be more than 55-60 (except immediately before final harvest), and the minimum should not be less than 30-35 at first commercial thinning and somewhat higher in later thinnings.[8/] Within these approximate limits, the upper portion of the density range will emphasize volume production while the lower portion will give somewhat greater diameter increment.

[8/] Change in RD can be estimated as:

$$RD = 0.005454N(D_2^{3/2} - D_1^{3/2});$$

where N is number of trees per acre (assuming negligible mortality); D, is stand diameter at start of growth period; and D_2 is estimated future stand diameter.

Critique of LOGS Study Design

Hindsight is proverbially clearer than foresight, so it may be useful to point out some difficulties and questions encountered in the LOGS studies, which may influence design of future studies.

Blocked vs. completely randomized treatments.—Treatments were randomized among the 27 plots per installation. According to the original study plan, complete randomization was chosen over a randomized block design because analysis of a completely random design can better accommodate the expected loss of some plots.

To date, only one of the nine installations (Rocky Brook) has lost plots. Major losses occurred at Rocky Brook immediately after calibration; those plots were replaced with spare plots. One plot has since been lost to root rot (1982). It appears that blocking, perhaps on the basis of characteristics such as slope position or tree dimensions at end of the calibration period, would have been a feasible alternative to complete randomization.

Plot size.—The 0.2-acre plots used are too small to allow continuation of thinning beyond the 60 feet of height increment originally planned. Thinning must cease at a stage when differences among treatments are increasing rapidly and when stands are still well short of any biologically reasonable rotation age. The result is a major gap in information. This is not a criticism of the LOGS study design; the study was not intended to extend to later stand development. Rather, it indicates that there was and is a need for concurrent studies addressing the later development of stands having early and continued stocking control.

Buffers.—Associated with the limitations of small plots is the question of possible effect of the lack of buffers. Some edge effects must exist. Although we think such effects are minor, they could have had some influence on the results. The possibility exists for future analysis of this question on those installations that have been stem-mapped or had trees on the inner 0.1 acre identified. Comparisons could also be made using the two Canadian Forestry Service installations, which do have buffers.

Crop Trees.—Well-spaced crop trees, selected after the calibration cut at the rate of 80 per acre, are retained through subsequent thinnings. The utility of this procedure and its possible effect on stand development have sometimes been questioned.

In general, crop trees have been fairly stable over time, although occasional substitutions have been made because of damage or poor growth of initially selected individual crop trees. Limited comparisons of diameters of crop trees with average diameters of the largest 80 trees per acre (see footnote 7), after the calibration thinning, showed that initial average diameter of crop trees was substantially smaller than that of the 80 largest trees per acre. Subsequent diameter growth at Hoskins, Skykomish, and Clemons was slightly greater for the 80 largest trees per acre than for the crop trees. This difference was larger on controls than on thinned plots, because in the later periods on thinned plots these were nearly the same trees.

Slightly larger trees and slightly more volume might have been produced by a more flexible choice of leave trees at each thinning. On the other hand, permanently marked crop trees simplify control of spacing in thinnings and make it easier to maintain comparability of treatments. Marked crop trees are most useful in early thinnings. Their usefulness declines with time, as substitutions are made necessary by individual tree damage and decline in vigor. Rigid adherence to the initial choice of crop trees is neither reasonable nor feasible.

Kind of thinning.—The LOGS study plan specifications produce d/D ratios of about 0.9 in the earlier treatment thinnings and higher growing stock levels, and d/D's near 1.0 after removal of all noncrop trees. Until all noncrop trees have been removed, these d/D ratios represent crown thinnings and appear entirely reasonable. Although strict, low thinning would have produced somewhat different stand structures and might have resulted in slightly more growth in the early years, removal of some of the larger trees is necessary if spacing is to be controlled and crop trees favored.

Justification for a d/D of 1.0 after removal of all noncrop trees is less clear. Low thinning is not possible at this stage because of the absence of lower crown classes, but differences are still evident in individual tree size and vigor that suggest that a d/D of somewhat less than 1.0 would be silviculturally preferable. The reasons for specifying a d/D of 1.0 at this stage are not now clear. They may have been in part simplicity; in part suggested by the requirements of Staebler's (1960) procedure for calculating numerical thinning schedules; and in part an expectation of a narrower range of crop tree diameters than has actually developed.

A d/D of 1.0 is usually attained only in the final thinning at the lowest growing stock levels, and this specification has probably not had much effect on the outcome of the experiment. It does not seem a desirable restriction, however, and we do not recommend it for future studies.

Thinning cycle.—The LOGS thinning cycle was defined as the time required for 10 feet of height growth. Definition in terms of height growth is biologically reasonable and facilitates work scheduling because height growth can be predicted fairly well from standard site curves. The short cycle, though not operationally realistic, is justified in the LOGS study as a means of maintaining close control over growing stock. The resulting light thinnings also avoid any possible exposure effects not directly related to growing stock level.

Height measurements.—Despite the detailed study plan and generally close quality control, some problems exist with height measurements. Inadequate sampling in some periods at Skykomish and Clemons has forced combining height measurements by treatment, thereby preventing adjustment of plot values for height differences or satisfactory assessment of among-plot site differences. The peculiar trend of volumes at Hoskins in treatment period 3 strongly suggests some systematic error in height measurements, despite apparently adequate sampling. These difficulties emphasize the critical importance of adequate sampling and careful measurement of heights.

Initial differences among controls.—Initial differences among controls in different installations, could have influenced control; plot growth and therefore, definition of thinning treatments: In retrospect; all controls should probably have been reduced to some standard number of stems at calibration.

Number of installations.—There is some difficulty in generalizing results because of the small number of locations represented. There are five LOGS installations on site II, two on site III, and one each on sites IV and V. Results to date show clearly that, among the site II studies, relationships between growth and growing stock are qualitatively similar but quantitatively considerably different. Five locations are insufficient to establish good regional averages or to identify causes of differences. This will be even more true of the poorer sites.

The combination of stringent uniformity requirements and the relatively large area required to accommodate three replications of nine treatments forced use of small plots and made it difficult to locate suitable areas, thereby limiting the number of installations. If future studies are to sample a wider range of site conditions and geographical areas, they must be less complex and less demanding in area and uniformity requirements to allow more installations. This will probably mean fewer treatments and use of blocking or covariates to reduce the effect of initial variation in site and stand conditions.

Analysis.—The study plan discussed analyses solely in terms of analyses of variance, and contemplated (but did not spell out) a combined ANOVA including all installations. A combined ANOVA does not appear feasible because of uncertain equivalence of thinning treatments in different installations and because of heterogeneous variances. The more meaningful analyses have been by graphic and regression methods. We think this will remain true for future analyses of these studies.

The most productive future use of the LOGS data and the most effective means of applying results to practical management will probably be their use, in combination with other data, in construction and refinement of stand simulators. The LOGS studies provide a unique set of high-quality data from young stands maintained at relatively low densities. This is a condition of crucial importance in evaluating stand management regimes for our future forests, and for which very little other data are now available. The LOGS studies provide basic information on the nature of relationships between growth and growing stock in such stands. The future use of this information in combination with other data should provide greatly improved predictive functions for stand simulation.

The Future of the LOGS Studies

The LOGS program is now over 20 years old and is an outstanding example of continuity and coordination achieved with a minimum of formal organization. Study installation and maintenance have been carried out by the individual cooperators. A number of the studies have now reached a stage where meaningful analyses can be made, and this report is a first effort in such analyses. As additional data become available within the next few years, the LOGS data will be widely recognized as a resource unique in its nature and quality and a "gold mine" for those engaged in growth modeling and stand management research. It is therefore important that there be no loss of interest and continuity and that the studies on the poorer sites—which are developing slowly and unspectacularly—be carried through to completion.

An immediate concern is disposition of the site II studies following completion of the fifth treatment period, which marks the end of the experiment as originally planned and which is now imminent for four LOGS studies. These stands are still well short of any reasonable final harvest age, and the thinning treatments will clearly influence stand development long after the originally planned completion of the experiment. The stands are unique in that they have developed under closely controlled and thoroughly documented conditions, including relatively low densities. Further thinning treatments are not feasible, because of the small size (0.2 acre) of the plots. There are simply too few trees left per plot to allow reasonable thinning.

The stands in the lower density treatments are still relatively open and will undoubtedly make excellent growth for a considerable period without further thinning. Indeed, an extended period of growth without further thinning seems a reasonable management alternative for stands in their present condition.

We recommend that, following completion of the fifth treatment period, these stands be allowed to grow without further treatment for at least two additional growth periods (20 feet of height growth) with remeasurements made after 10 and after 20 feet of height growth.

The present LOGS Committee should continue with all present cooperators, including those that have installations with all five treatments completed. A new version of this report should be prepared as soon as the committee feels sufficient additional data are available. Such a revision, or supplemental reports, should include additional analyses covering topics not treated here. Examples include values produced by thinning regimes; crown development; stem quality; effect of absence of buffer strips; and diameter distributions in relation to other stand characteristics and thinning regimes.

Metric Equivalents

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

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Appendix 1
Tables 22-51

Table 22—Skykomish study: means of periodic annual increment in gross basal area (all trees), (by treatment and period

Treatment	Period 1	2	3	4	Mean
	------ Square feet per acre per year ------				
Fixed:					
1	7.13	6.34	6.01	4.83	6.08
3	8.03	7.19	7.95	6.58	7.44
5	8.31	7.33	8.12	7.46	7.80
7	9.63	8.86	9.64	8.49	9.16
Mean	8.28	7.43	7.93	6.84	7.62
Increasing:					
2	7.26	6.32	7.15	6.46	6.80
4	7.74	7.42	8.08	6.78	7.51
Mean	7.50	6.87	7.62	6.62	7.15
Decreasing:					
6	8.93	7.71	8.31	6.88	7.96
8	8.83	8.09	8.62	7.37	8.23
Mean	8.88	7.90	8.46	7.12	8.09
Variable:					
Mean	8.19	7.39	8.04	6.87	7.62
Mean, all treatments	8.24	7.41	7.98	6.86	7.62

increment in gross basal area (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	------ Square feet per acre per year ------				
Fixed:					
1	11.08	8.23	6.33	5.83	7.87
3	11.80	9.90	8.23	7.15	9.27
5	12.90	11.50	9.83	8.49	10.68
7	13.62	12.39	10.03	8.85	11.22
Mean	12.35	10.51	8.61	7.58	9.76
Increasing:					
2	11.15	8.87	7.50	6.68	8.55
4	11.76	10.07	8.78	7.35	9.49
Mean	11.45	9.47	8.14	7.01	9.02
Decreasing:					
6	13.08	11.24	9.47	7.83	10.40
8	13.36	11.87	9.42	8.52	10.79
Mean	13.22	11.56	9.44	8.18	10.60
Variable:					
Mean	12.34	10.51	8.79	7.60	9.81
Mean, all treatments	12.34	10.51	8.70	7.59	9.78

Table 24—demons study: means of periodic annual increment in gross basal area (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - - Square feet per acre per year - - - - - -				
Fixed:					
1	6.05	5.96	5.79	4.59	5.75
3	7.11	6.67	6.66	5.58	6.50
5	7.58	8.03	7.60	6.64	7.46
7	7.78	7.94	7.10	5.79	7.16
Mean	7.28	7.15	6.77	5.65	6.72
Increasing:					
2	7.02	6.16	5.82	4.51	5.88
4	7.33	6.93	6.97	5.72	6.74
Mean	7.18	6.54	6.39	5.11	6.31
Decreasing:					
6	8.16	7.57	7.00	5.38	7.03
8	7.38	7.71	7.31	5.77	7.04
Mean	7.77	7.64	7.16	5.58	7.04
Variable:					
Mean	7.48	7.09	6.78	5.34	6.67
Mean, all treatments	7.38	7.12	6.78	5.50	6.69

Table 25—Francis study: means of periodic annual increment in gross basal area (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - - Square feet per acre per year - - - - - -				
Fixed:					
1	8.33	7.55	6.38	4.98	6.81
3	8.73	9.92	8.19	6.62	8.37
5	10.69	11.62	8.97	8.20	9.87
7	12.27	12.74	11.43	9.50	11.48
Mean	10.00	10.46	8.74	7.32	9.13
Increasing:					
2	7.92	7.80	6.88	5.92	7.13
4	9.26	10.40	9.75	8.49	9.47
Mean	8.56	9.10	8.32	7.21	8.30
Decreasing:					
6	11.29	11.21	9.16	7.72	9.84
8	11.28	11.52	9.56	8.23	10.15
Mean	11.28	11.37	9.36	7.98	10.00
Variable:					
Mean	9.94	10.23	8.84	7.59	9.15
Mean, all treatments	9.97	10.35	8.79	7.46	9.14

Table 26—Skykomish study: means of gross basal area growth percent (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	Percent				
Fixed:					
1	11.1	9.2	8.3	6.6	8.8
3	10.9	8.8	8.3	6.3	8.6
5	10.2	7.6	7.1	5.6	7.6
7	10.7	8.0	7.0	5.3	7.7
Mean	10.7	8.4	7.7	5.9	8.2
Increasing:					
2	11.1	9.0	8.6	6.5	8.8
4	10.6	8.7	7.7	5.4	8.1
Mean	10.8	8.9	8.2	6.0	8.4
Decreasing:					
6	10.9	8.2	7.8	6.2	8.3
8	9.9	7.6	6.8	5.3	7.4
Mean	10.4	7.9	7.3	5.7	7.8
Variable:					
Mean	10.6	8.4	7.7	5.9	8.2
Mean, all treatments	10.7	8.4	7.7	5.9	8.2

Table 27—Hoskins study: means of gross basal area growth percent (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	Percent				
Fixed:					
1	14.3	11.3	9.0	7.5	10.5
3	13.4	10.3	8.2	6.4	9.6
5	12.8	9.5	7.5	5.8	8.9
7	12.1	8.7	6.3	4.9	8.0
Mean	13.2	9.9	7.7	6.1	9.2
Increasing:					
2	14.2	11.2	8.9	6.8	10.3
4	13.2	9.9	7.7	5.6	9.1
Mean	13.7	10.5	8.3	6.2	9.7
Decreasing:					
6	12.9	9.8	8.0	6.1	9.2
8	11.9	8.7	6.4	5.3	8.1
Mean	12.4	9.2	7.2	5.7	8.6
Variable:					
Mean	13.0	9.9	7.8	6.0	9.2
Mean, all treatments	13.1	9.9	7.8	6.0	9.2

Table 28—demons study: means of gross basal area growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	12.8	11.6	10.8	8.0	10.8
3	12.3	10.2	9.1	6.5	9.5
5	11.5	10.0	8.2	6.0	8.9
7	11.0	8.6	6.6	4.6	7.7
Mean	11.9	10.1	8.7	6.3	9.2
Increasing:					
2	13.4	11.2	9.4	6.2	10.0
4	12.3	10.0	8.5	6.0	9.2
Mean	12.8	10.6	8.9	6.1	9.6
Decreasing:					
6	12.1	9.9	8.4	6.2	9.1
8	10.7	8.6	7.2	5.1	7.9
Mean	11.4	9.3	7.8	5.6	8.5
Variable:					
Mean	12.1	9.9	8.4	5.9	9.1
Mean, all treatments	12.0	10.0	8.5	6.1	9.2

Table 29—Francis study: means of gross basal area growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	18.1	14.2	11.2	8.6	13.0
3	17.4	13.1	9.3	6.7	11.6
5	15.6	12.0	7.6	5.9	10.3
7	16.3	11.0	7.6	5.4	10.0
Mean	16.9	12.6	8.9	6.6	11.2
Increasing:					
2	17.2	13.4	9.6	6.7	11.7
4	17.8	12.8	9.0	6.5	11.5
Mean	17.5	13.1	9.3	6.6	11.6
Decreasing:					
6	16.8	12.3	8.8	7.0	11.2
8	16.0	10.7	7.2	5.5	9.9
Mean	16.4	11.5	8.0	6.3	10.5
Variable:					
Mean	16.9	12.3	8.6	6.5	11.1
Mean, all treatments	16.9	12.4	8.8	6.6	11.2

Table 30—Skykomish study: means of periodic annual increment in gross volume (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	- - - - - - Cubic feet per acre per year - - - - -				
Fixed:					
1	245	251	260	243	250
3	258	288	349	308	301
5	295	302	413	408	355
7	314	338	440	454	387
Mean	278	295	366	353	323
Increasing:					
2	242	254	323	337	389
4	254	319	377	330	320
Mean	248	286	350	334	305
Decreasing:					
6	296	322	360	361	335
8	320	336	417	349	355
Mean	308	329	389	355	345
Variable:					
Mean	278	309	369	344	325
Mean, all treatments	278	301	367	349	324

Table 31—Hoskins study: means of periodic annual increment in gross volume (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	- - - - - Cubic feet per acre per year - - - - -				
Fixed:					
1	322	293	223	256	274
3	349	385	316	344	348
5	398	439	408	416	415
7	428	494	437	471	458
Mean	374	403	346	372	374
Increasing:					
2	328	325	286	301	310
4	356	384	357	361	365
Mean	342	355	321	331	337
Decreasing:					
6	396	427	376	368	392
8	423	485	378	453	435
Mean	409	456	377	411	413
Variable:					
Mean	376	405	349	371	375
Mean, all treatments	375	404	348	371	374

Table 32—demons study: means of periodic annual increment in gross volume (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - - Cubic feet per acre per year - - - - -				
Fixed:					
1	188	190	198	189	191
3	196	232	263	238	232
5	206	250	286	259	250
7	233	293	277	257	265
Mean	206	241	256	236	235
Increasing:					
2	187	216	212	206	205
4	201	232	264	234	233
Mean	194	224	238	220	219
Decreasing:					
6	228	256	283	234	250
8	217	279	273	260	257
Mean	222	267	278	247	254
Variable:					
Mean	208	246	258	234	236
Mean, all treatments	207	243	257	235	236

Table 33—Francis study: means of periodic annual increment in gross volume (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - Cubic feet per acre per year - - - - -				
Fixed:					
1	168	196	194	180	184
3	188	274	260	258	245
5	239	331	334	360	316
7	272	369	417	408	367
Mean	217	292	302	301	278
Increasing:					
2	184	222	225	233	216
4	208	290	336	343	294
Mean	196	256	281	288	255
Decreasing:					
6	249	312	311	304	294
8	256	342	366	371	334
Mean	252	327	338	338	314
Variable:					
Mean	224	292	310	313	285
Mean, all treatments	221	292	306	307	281

Table 34—Skykomish study: means of gross volume growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	14.7	12.6	10.9	9.0	11.8
3	14.5	13.0	11.7	8.4	11.9
5	14.8	11.3	11.1	8.3	11.4
7	13.8	11.0	10.3	8.0	10.8
Mean	14.4	12.0	11.0	8.4	11.5
Increasing:					
2	15.1	13.1	12.1	9.4	12.4
4	14.3	13.4	11.2	7.4	11.6
Mean	14.7	13.3	11.7	8.4	12.0
Decreasing:					
6	14.4	12.2	10.6	9.0	11.6
8	14.3	11.2	10.3	7.0	10.7
Mean	14.3	11.7	10.4	8.0	11.1
Variable:					
Mean	14.5	12.5	11.0	8.2	11.6
Mean, all treatments	14.5	12.2	11.0	8.3	11.5

Table 35—Hoskins study: means of gross volume growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	19.3	15.8	11.4	10.7	14.3
3	18.4	15.5	11.0	9.7	13.7
5	18.4	14.2	11.0	9.0	13.1
7	17.8	13.5	9.6	8.3	12.3
Mean	18.4	14.8	10.8	9.4	13.3
Increasing:					
2	19.3	15.8	11.9	9.8	14.2
4	18.3	14.5	10.9	8.7	13.1
Mean	18.8	15.2	11.4	9.2	13.7
Decreasing:					
6	18.3	14.6	11.4	9.3	13.4
8	17.3	13.7	9.0	8.8	12.2
Mean	17.8	14.2	10.2	9.0	12.8
Variable:					
Mean	18.3	14.7	10.8	9.2	13.2
Mean, all treatments	18.4	14.7	10.8	9.3	13.3

Table 36—demons study: means of gross volume growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	18.4	16.0	14.1	11.1	14.9
3	17.3	15.2	13.4	9.1	13.7
5	16.6	14.1	12.4	8.4	12.9
7	16.1	13.2	9.5	6.9	11.4
Mean	17.1	14.6	12.3	8.9	13.2
Increasing:					
2	17.8	16.5	12.6	9.4	14.1
4	17.2	14.4	12.3	8.4	13.1
Mean	17.5	15.5	12.5	8.9	13.6
Decreasing:					
6	17.4	14.5	12.8	8.9	13.4
8	15.9	13.3	10.2	7.9	11.8
Mean	16.6	13.9	11.5	8.4	12.6
Variable:					
Mean	17.1	14.7	12.0	8.6	13.1
Mean, all treatments	17.1	14.7	12.2	8.8	13.2

Table 37—Francis study: means of gross volume growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	23.6	19.0	14.7	11.8	17.3
3	23.4	18.1	12.6	9.9	16.0
5	21.4	17.0	11.7	9.2	14.8
7	22.9	16.2	11.7	8.5	14.8
Mean	22.8	17.6	12.7	9.8	15.7
Increasing:					
2	23.0	17.9	12.5	9.5	15.7
4	23.9	17.5	12.8	9.5	15.9
Mean	23.4	17.7	12.7	9.5	15.8
Decreasing:					
6	22.6	17.0	12.5	10.2	15.6
8	22.2	15.8	11.4	8.9	14.6
Mean	22.4	16.4	12.0	9.5	15.1
Variable:					
Mean	22.9	17.0	12.3	9.5	15.4
Mean, all treatments	22.9	17.3	12.5	9.7	15.6

Table 38—Skykomish study: means of periodic annual increment in quadratic mean diameter (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - - - - -	- -	Inches per year	- -	- - - - - - - - -
Fixed:					
1	0.445	0.443	0.499	0.489	0.469
3	.404	.377	.431	.400	.403
5	.375	.322	.345	.314	.339
7	.409	.349	.356	.301	.354
Mean	.408	.373	.408	.376	.391
Increasing:					
2	.411	.387	.440	.397	.409
4	.439	.419	.442	.362	.415
Mean	.425	.403	.441	.379	.412
Decreasing:					
6	.397	.350	.392	.376	.379
8	.362	.318	.329	.293	.326
Mean	.380	.334	.361	.334	.352
Variable:					
Mean	.402	.369	.401	.357	.382
Mean, all treatments	.405	.371	.404	.367	.387

Table 39—Hoskins study: means of periodic annual increment in quadratic mean diameter (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	- - - - - - - - -	- -	Inches per year	- -	- - - - - - - - -
Fixed:					
1	0.588	0.603	0.559	0.537	0.572
3	.545	.519	.472	.416	.488
5	.498	.449	.398	.341	.422
7	.488	.415	.333	.287	.381
Mean	.530	.497	.440	.395	.465
Increasing:					
2	.601	.610	.570	.487	.567
4	.548	.506	.442	.363	.465
Mean	.575	.558	.506	.425	.516
Decreasing:					
6	.527	.492	.456	.396	.468
8	.476	.416	.340	.306	.385
Mean	.502	.454	.398	.351	.426
Variable:					
Mean	.538	.506	.452	.388	.471
Mean, all treatments	.534	.501	.446	.392	.468

Table 40—demons study: means of periodic annual increment in quadratic mean diameter (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	Inches per year				
Fixed:					
	0.407	0.465	0.527	0.471	0.468
3	.384	.392	.415	.342	.383
5	.344	.357	.338	.282	.330
7	.330	.305	.261	.203	.275
Mean	.366	.380	.385	.324	.364
Increasing:					
2	.456	.485	.492	.389	.455
4	.394	.391	.382	.304	.368
Mean	.425	.438	.437	.346	.411
Decreasing:					
6	.375	.373	.365	.306	.355
8	.308	.292	.277	.223	.275
Mean	.342	.332	.321	.265	.315
Variable:					
Mean	.383	.385	.379	.305	.363
Mean, all treatments	.375	.383	.382	.315	.364

Table 41—Francis study: means of periodic annual increment in quadratic mean diameter (all trees), by treatment and period

Treatment	Period 1	Period 2	Period 3	Period 4	Mean
	Inches per year				
Fixed:					
1	0.551	0.589	0.624	0.580	0.586
3	.543	.540	.485	.422	.497
5	.477	.472	.372	.325	.411
7	.482	.412	.340	.272	.376
Mean	.513	.503	.455	.400	.468
Increasing:					
2	.589	.625	.579	.483	.569
4	.565	.535	.469	.398	.491
Mean	.577	.580	.524	.440	.530
Decreasing:					
6	.519	.495	.440	.420	.468
8	.455	.385	.311	.271	.356
Mean	.487	.440	.375	.346	.412
Variable:					
Mean	.532	.510	.450	.393	.471
Mean, all treatments	.523	.507	.452	.396	.469

Table 42—Skykomish study: means of quadratic mean diameter growth percent (all trees), by diameter and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	5.57	4.65	4.17	3.31	4.42
3	5.48	4.42	4.20	3.17	4.32
5	5.15	3.83	3.56	2.82	3.84
7	5.38	3.99	3.54	2.64	3.89
Mean	5.40	4.22	3.87	2.98	4.12
Increasing:					
2	5.57	4.52	4.32	3.29	4.42
4	5.32	4.38	3.89	2.72	4.08
Mean	5.44	4.45	4.10	3.01	4.25
Decreasing:					
6	5.48	4.14	3.93	3.11	4.16
8	4.98	3.81	3.43	2.66	3.72
Mean	5.23	3.98	3.68	2.88	3.94
Variable:					
Mean	5.34	4.21	3.89	2.94	4.20
Mean, all treatments	5.37	4.22	3.88	2.96	4.11

Table 43—Hoskins study: means of quadratic mean diameter growth percent (all trees), by treatment and period

Treatment	Period 1	2	3	4	Mean
	Percent				
Fixed:					
1	7.32	5.70	4.49	3.77	5.32
3	6.84	5.16	4.10	3.21	4.83
5	6.51	4.78	3.76	2.89	4.48
7	6.16	4.35	3.14	2.46	4.03
Mean	6.71	5.00	3.87	3.08	4.66
Increasing:					
2	7.28	5.62	4.47	3.42	5.20
4	6.71	4.96	3.85	2.82	4.58
Mean	6.99	5.29	4.16	3.12	4.89
Decreasing:					
6	6.57	4.93	4.02	3.08	4.65
8	6.02	4.37	3.22	2.64	4.06
Mean	6.29	4.65	3.62	2.86	4.36
Variable:					
Mean	6.64	4.97	3.89	2.99	4.62
Mean, all treatments	6.68	4.98	3.88	3.04	4.64

Table 44—demons study: means of quadratic mean diameter growth percent (all trees), by treatment and period

	Period				
Treatment	1	2	3	4	Mean
	Percent				
Fixed:					
1	6.49	5.87	5.45	4.03	5.46
3	6.24	5.13	4.58	3.26	4.80
5	5.85	5.01	4.11	3.01	4.49
7	5.58	4.33	3.30	2.29	3.87
Mean	6.04	5.08	4.36	3.15	4.66
Increasing:					
2	6.80	5.63	4.71	3.14	5.07
4	6.26	5.01	4.28	2.99	4.63
Mean	6.53	5.32	4.49	3.06	4.85
Decreasing:					
6	6.15	4.98	4.22	3.09	4.61
8	5.40	4.32	3.60	2.58	3.97
Mean	5.77	4.65	3.91	2.83	4.29
Variable:					
Mean	6.15	4.99	4.20	2.95	4.57
Mean, all treatments	6.10	5.04	4.28	3.05	4.62

Table 45—Francis study: means of quadratic mean diameter growth percent (all trees), by treatment and period

	Period				
Treatment	1	2	3	4	Mean
	Percent				
Fixed:					
1	9.22	7.24	5.68	4.35	6.62
3	8.88	6.68	4.68	3.38	5.90
5	7.93	6.11	3.92	2.96	5.23
7	8.26	5.58	3.80	2.68	5.08
Mean	8.57	6.40	4.52	3.34	5.71
Increasing:					
2	8.74	6.83	4.82	3.39	5.94
4	9.06	6.52	4.56	3.28	5.85
Mean	8.90	6.67	4.69	3.34	5.90
Decreasing:					
6	8.53	6.23	4.42	3.54	5.68
8	8.12	5.43	3.64	2.78	4.99
Mean	8.33	5.83	4.03	3.16	5.34
Variable:					
Mean	8.61	6.25	4.36	3.25	5.62
Mean, all treatments	8.59	6.32	4.44	3.29	5.66

Table 46—Gross cubic volume yield in trees 1.6 inches d.b.h. and larger (material removed in calibration cut excluded), by treatment and age, for the Skykomish, Hoskins, demons, Francis, and Iron Creek studies

			Gross volume yield by treatments								
			Fixed				Increasing		Decreasing		
	Age	H40	T-1	T-3	T-5	T-7	T-2	T-4	T-6	T-8	Control
	Years	Feet	Cubic feet per acre								
Skykomish	24	48	960	918	932	976	888	895	947	934	1,271
	28	60	2,081	1,897	1,903	2,151	1,914	1,921	2,001	2,010	2,460
	31	69	2,816	2,671	2,788	3,091	2,641	2,684	2,890	2,970	3,682
	34	77	3,569	3,534	3,696	4,107	3,402	3,641	3,856	3,977	5,023
	38	90	4,609	4,932	5,347	5,868	4,696	5,147	5,296	5,646	6,863
	42	100	5,581	6,166	6,980	7,686	6,045	6,468	6,739	7,041	8,854
Hoskins	20	40	744	746	720	750	729	749	743	768	1,982
	23	50	1,581	1,581	1,570	1,574	1,616	1,628	1,599	1,637	3,389
	27	63	2,868	2,975	3,160	3,286	2,926	3,054	3,182	3,330	5,680
	30	73	3,748	4,131	4,477	4,769	3,902	4,206	4,463	4,784	7,430
	32	78	4,195	4,763	5,294	5,643	4,473	4,920	5,215	5,540	8,310
	36	89	5,217	6,139	6,956	7,527	5,679	6,366	6,689	7,352	10,618
Clemons	19	36	477	470	438	492	524	507	459	469	854
	22	46	1,028	1,016	920	1,044	1,156	1,067	1,021	951	1,599
	26	57	1,780	1,800	1,743	1,976	1,905	1,872	1,933	1,819	2,766
	29	66	2,350	2,495	2,491	2,856	2,554	2,567	2,699	2,656	3,907
	32	74	2,942	3,283	3,349	3,688	3,189	3,350	3,649	3,476	4,949
	36	82	3,700	4,236	4,386	4,716	4,014	4,296	4,484	4,516	6,242
Francis	15	29	304	318	350	281	382	361	329	283	543
	18	39	802	867	895	793	994	918	881	779	1,328
	21	46	1,307	1,432	1,613	1,609	1,547	1,542	1,627	1,547	2,439
	25	58	2,091	2,528	2,937	3,083	2,437	2,703	2,875	2,917	4,123
	29	68	2,866	3,570	4,311	4,753	3,338	4,047	4,119	4,379	5,958
	33	77	3,585	4,602	5,757	6,387	4,272	5,420	5,357	5,867	7,666
Iron Creek	19	39	600	648	733	734	735	771	629	763	1,115
	23	50	1,389	1,488	1,606	1,619	1,673	1,721	1,454	1,678	2,342
	26	58	2,039	2,227	2,486	2,618	2,392	2,506	2,286	2,618	3,561
	30	68	2,889	3,327	3,766	4,039	3,338	3,662	3,559	3,952	5,329
	33	77	3,471	4,187	4,881	5,267	4,070	4,672	4,537	4,997	6,768

T-n = treatment "n."

Table 47—Quadratic mean diameters (after thinning), by treatment and age, for the Skykomish, Hoskins, demons, Francis, and Iron Creek studies

			Quadratic mean d.b.h. (after thinning), by treatment								
			Fixed				Increasing		Decreasing		
	Age	H40	T-1	T-3	T-5	T-7	T-2	T-4	T-6	T-8	Control
	Years	Feet	Inches								
Skykomish 1/	24	48	5.3 (6.4) 1/	5.0 (5.6)	5.1 (6.2)	5.2 (6.0)	5.0 (5.7)	5.5 (6.2)	4.9 (5.6)	5.1 (6.2)	4.7 (5.6)
	28	60	7.3 (8.8)	6.8 (7.4)	6.7 (8.3)	7.0 (7.9)	6.8 (7.4)	7.6 (8.4)	6.6 (7.3)	6.7 (7.9)	5.8 (6.8)
	31	69	8.8(10.4)	8.0 (8.8)	7.8 (9.7)	8.2 (9.3)	8.0 (8.4)	8.9 (9.9)	7.8 (8.6)	7.9 (9.1)	6.6 (7.7)
	34	77	10.9(12.3)	9.4(10.4)	8.9(11.0)	9.3(10.4)	9.3 (9.8)	10.4(11.4)	9.1(10.1)	8.9(10.2)	7.2 (8.4)
	38	90	13.8(14.8)	11.8(13.0)	10.4(13.1)	10.8(12.2)	11.3(12.0)	12.5(13.5)	11.2(12.8)	10.4(12.2)	8.2 (9.8)
	42	100	15.8(17.1)	14.2(15.4)	12.0(15.0)	12.1(13.9)	13.0(14.0)	14.2(15.2)	13.5(15.2)	11.9(14.1)	9.3(11.2)
Hoskins	20	40	5.1	5.1	5.0	5.2	5.2	5.3	5.2	5.3	3.8
	23	50	6.9	6.9	6.7	6.9	7.1	7.1	7.0	7.0	4.6
	27	63	9.7	9.3	8.7	8.9	9.9	9.5	9.3	8.9	5.8
	30	73	11.9	11.0	10.2	10.3	12.2	11.1	10.9	10.2	6.6
	32	78	13.2	12.1	11.1	11.1	13.3	12.2	12.0	11.0	7.2
	36	89	15.7	14.0	12.6	12.3	15.4	13.7	13.9	12.3	8.2
Clemons	19	36	4.1	4.1	4.0	4.0	4.2	4.2	4.1	4.0	4.0
	22	46	5.4	5.4	5.2	5.2	5.8	5.4	5.4	5.1	4.9
	26	57	7.2	7.0	6.6	6.6	7.9	7.1	6.9	6.3	5.9
	29	66	8.9	8.5	7.7	7.5	9.7	8.3	8.1	7.3	6.6
	32	74	10.7	9.8	8.7	8.4	11.6	9.5	9.4	8.2	7.2
	36	82	12.6	11.8	10.0	9.3	13.6	10.8	10.8	9.1	7.9
Francis	15	29	3.6	3.7	3.7	3.5	3.9	3.8	3.6	3.4	3.3
	18	39	5.2	5.3	5.3	5.1	5.9	5.4	5.3	4.9	4.0
	21	46	7.0	7.0	6.8	6.6	7.9	7.1	6.9	6.3	4.8
	25	58	9.7	9.4	8.8	8.3	10.8	9.3	9.1	7.9	5.7
	29	68	12.2	11.6	10.4	9.6	13.2	11.3	11.1	9.2	6.4
	33	77	14.7	13.6	11.7	10.7	15.2	12.9	13.2	10.4	7.0
Iron Creek	19	39	4.8	5.0	5.1	5.1	5.1	5.1	4.8	5.1	4.1
	23	50	6.7	6.8	6.9	6.7	7.0	7.0	6.6	6.9	4.5
	26	58	8.3	8.3	8.3	8.0	8.5	8.5	8.0	8.3	5.1
	30	68	10.6	10.1	9.9	9.4	10.6	10.4	9.6	9.8	5.7
	33	77	12.2	11.4	10.8	10.3	11.9	11.6	10.9	10.9	6.2

T-n = treatment "n."

1/ Values for Douglas-fir only given in parentheses.

Table 48—Periodic annual gross volume increment (PAI) by treatment and period, for all trees 1.6 inches d.b.h. and larger, for the Skykomish, Hoskins, Clemons, Francis, and Iron Creek studies

Study	Period ages	Period H40	Periodic annual gross volume increment, by treatment									
			Fixed				Increasing		Decreasing			
			T-1	T-3	T-5	T-7	T-2	T-4	T-6	T-8	Control	Control, net
	Years	Feet	Cubic feet per acre per year									
Skykomish	24-28	48-60	280	245	243	294	257	256	264	269	297	297
	28-31	60-69	245	258	295	314	242	254	296	320	407	401
	31-34	69-77	251	288	303	338	254	319	322	336	447	439
	34-38	77-90	260	349	413	440	323	377	360	417	460	381
	38-42	90-100	243	308	408	454	337	330	361	349	498	422
Hoskins	20-23	40-50	279	278	283	275	296	293	285	290	469	460
	23-27	50-63	322	349	398	428	328	356	396	423	573	512
	27-30	63-73	293	385	439	494	325	384	427	485	583	514
	30-32	73-78	223	316	408	437	286	357	376	378	1/ 440	1/ 276
	32-36	78-89	256	344	416	471	301	361	368	453	577	451
Clemons	19-22	36-46	184	182	161	184	211	187	187	161	248	247
	22-26	46-57	188	196	206	233	187	201	228	217	292	289
	26-29	57-66	190	232	249	293	216	232	256	279	381	374
	29-32	66-74	198	263	286	277	212	264	283	273	347	303
	32-36	74-82	189	238	259	257	206	234	234	260	323	290
Francis	15-18	29-39	166	183	182	171	204	186	184	165	262	258
	18-21	39-46	168	188	239	272	184	208	249	256	370	366
	21-25	46-58	196	274	331	369	222	290	312	342	421	412
	25-29	58-68	194	261	343	418	225	335	311	366	459	437
	29-33	68-77	180	258	360	408	233	343	310	372	427	415
Iron Creek	19-23	39-50	197	210	218	221	234	238	206	229	307	303
	23-26	50-58	216	246	293	333	240	262	277	320	406	394
	26-30	58-68	212	275	320	355	237	289	318	328	442	415
	30-33	68-77	213	293	372	424	266	345	331	360	480	322

T-n = treatment "n."

1/ Includes one plot with unexplained very low volume growth in this period; this was excluded from regression analyses.

Table 49—Mean annual increment (MAI) in gross volume,[1] by treatment and period, for all trees 1.6 inches d.b.h. and larger, for the Skykomish, Hoskins, demons, Francis, and Iron Creek studies

				Mean annual gross volume increment, by treatment								
				Fixed				Increasing		Decreasing		
Study	Period	Midperiod age	Midperiod H40	T-1	T-3	T-5	T-7	T-2	T-4	T-6	T-8	Control
		Years	Feet	Cubic feet per acre per year								
Skykomish	C	26	54	58	54	54	60	54	54	57	57	72
	1	29.5	65	83	77	80	89	77	78	83	84	104
	2	32.5	73	98	95	110	111	93	97	104	118	134
	3	36	84	114	118	126	138	112	122	127	138	165
	4	40	95	127	139	154	169	134	145	150	159	196
Hoskins	C	21.5	45	54	54	53	54	54	55	54	56	125
	1	25	57	89	91	95	97	91	94	96	99	181
	2	28.5	68	116	125	134	141	120	127	134	142	230
	3	31	76	128	143	158	168	135	147	156	166	254
	4	34	84	138	160	180	194	149	166	175	190	278
Clemons	C	20.5	41	37	36	33	37	41	38	36	35	60
	1	24	51	58	59	55	63	64	61	62	58	91
	2	27.5	61	75	78	77	88	81	81	84	81	121
	3	30.5	70	87	95	96	107	94	97	102	100	145
	4	34	78	98	111	114	124	106	113	118	118	165
Francis	C	16.5	34	34	36	38	32	42	39	37	32	57
	1	19.5	43	54	59	64	62	65	63	64	60	97
	2	23	52	74	86	99	102	87	92	115	97	143
	3	27	63	92	113	134	145	107	125	130	135	187
	4	31	72	104	132	162	180	123	153	153	165	220
Iron Creek	C	21	45	47	51	56	56	57	59	49	58	82
	1	24.5	54	70	76	84	86	83	86	76	88	120
	2	28	63	88	99	112	119	102	110	104	118	159
	3	31.5	73	101	119	137	148	118	132	128	142	192

T-n = treatment "n."

1/ Computations based on age at midpoint of growth period.

Table 50—Volumes produced in trees larger than 11.6, 7.6, 9.6,11.6, and 13.6 inches d.b.h., at end of 4th treatment period, for the Skykomish and Hoskins studies

Treatment	Size class	Skykomish		Hoskins	
		Live stand	Total production 1/	Live stand	Total production 1/
	Inches d.b.h.	Cubic feet per acre			
1	1.6+	3,172	5,581	2,906	5,218
	7.6+	3,172	4,827	2,906	4,640
	9.6+	3,172	3,972	2,906	3,986
	11.6+	3,085	3,476	2,906	3,549
	13.6+	2,693	2,924	2,423	2,528
2	1.6+	4,262	6,045	3,686	5,679
	7.6+	4,262	5,395	3,686	5,235
	9.6+	4,018	4,438	3,671	4,627
	11.6+	3,260	3,436	3,487	3,935
	13.6+	2,312	2,449	2,993	3,109
3	1.6+	4,219	6,166	4,222	6,138
	7.6+	4,175	5,479	4,222	5,675
	9.6+	3,941	4,509	4,047	4,924
	11.6+	3,457	3,658	3,912	4,383
	13.6+	2,687	2,733	2,714	2,949
4	1.6+	5,142	6,468	4,865	6,366
	7.6+	5,103	5,960	4,855	5,948
	9.6+	4,959	5,330	4,731	5,331
	11.6+	4,255	4,299	4,485	4,770
	13.6+	3,614	3,614	3,138	3,240
5	1.6+	5,720	6,980	5,475	6,956
	7.6+	5,594	6,369	5,374	6,433
	9.6+	4,564	4,885	5,137	5,754
	11.6+	3,424	3,484	4,381	4,653
	13.6+	2,721	2,781	2,655	2,763
6	1.6+	4,673	6,738	4,717	6,688
	7.6+	4,616	5,989	4,694	6,333
	9.6+	4,205	4,860	4,623	5,702
	11.6+	3,336	3,565	4,224	4,646
	13.6+	2,413	2,503	3,127	3,230
7	1.6+	6,576	7,686	6,562	7,527
	7.6+	6,255	7,001	6,411	7,212
	9.6+	5,514	5,947	6,080	6,561
	11.6+	4,155	4,363	5,136	5,237
	13.6+	2,820	2,820	2,773	2,773
8	1.6+	5,638	7,040	6,026	7,352
	7.6+	5,467	6,411	5,886	7,042
	9.6+	4,664	5,214	5,490	6,269
	11.6+	3,802	4,096	4,714	5,157
	13.6+	2,803	2,928	2,458	2,458
Control	1.6+	8,192	--	9,312	--
	7.6+	6,909	--	6,955	--
	9.6+	4,867	--	4,555	--
	11.6+	3,315	--	2,335	--
	13.6+	1,908	--	1,044	--

-- = not applicable.

1/ Live stand + thinnings + mortality.

Table 51—Volumes produced in trees larger than 1.6, 7.6, 9.6,11.6, and 13.6 inches d.b.h., at end of 4th treatment period, for the Clemons and Francis studies

		Clemons		Francis	
Treatment	Size class	Live stand	Total production 1/	Live stand	Total production 1/
	Inches d.b.h.	Cubic feet per acre			
1	1.6+	2,081	3,700	1,884	3,585
	7.6+	2,081	2,942	1,884	2,951
	9.6+	2,059	2,442	1,864	2,606
	11.6+	1,724	1,850	1,804	2,234
	13.6+	695	744	1,343	1,484
2	1.6+	2,569	4,015	2,931	4,273
	7.6+	2,569	3,250	2,931	3,736
	9.6+	2,423	2,694	2,931	3,356
	11.6+	2,209	2,297	2,906	3,087
	13.6+	1,278	1,278	2,705	2,845
3	1.6+	3,098	4,236	3,134	4,601
	7.6+	3,044	3,517	3,134	4,074
	9.6+	2,592	2,754	3,003	3,547
	11.6+	1,994	1,994	2,564	2,803
	13.6+	696	696	1,797	1,797
4	1.6+	3,218	4,296	4,293	5,421
	7.6+	3,034	3,596	4,282	4,930
	9.6+	2,470	2,771	4,731	4,582
	11.6+	1,741	1,811	3,608	3,800
	13.6+	701	701	2,003	2,061
5	1.6+	3,516	4,387	4,610	5,757
	7.6+	3,147	3,604	4,557	5,322
	9.6+	2,404	2,590	4,002	4,451
	11.6+	1,307	1,350	3,057	3,132
	13.6+	591	591	1,581	1,581
6	1.6+	3,063	4,483	3,590	5,358
	7.6+	2,943	3,828	3,573	4,924
	9.6+	2,382	2,658	3,395	4,106
	11.6+	1,452	1,542	2,732	2,918
	13.6+	372	372	1,503	1,555
7	1.6+	4,194	4,716	5,645	6,386
	7.6+	3,640	3,898	5,459	6,035
	9.6+	2,531	2,581	4,310	4,575
	11.6+	969	969	2,662	2,768
	13.6+	238	238	873	873
8	1.6+	3,752	4,517	4,930	5,867
	7.6+	3,194	3,535	4,657	5,352
	9.6+	2,158	2,290	3,783	4,120
	11.6+	910	910	1,889	1,978
	13.6+	251	251	646	646
Control	1.6+	5,941	--	7,468	--
	7.6+	4,387	--	5,265	--
	9.6+	2,713	--	3,184	--
	11.6+	1,418	--	1,287	--
	13.6+	929	--	151	--

-- = not applicable.

1/ Live stand + thinnings + mortality.

Appendix 2
The Nine Cooperative Study Areas

Study Area	Cooperate?
Skykomish	Western Forestry Research Dept. Weyerhaeuser Company Tacoma, Washington
Hoskins Rocky	College of Forestry Oregon State University Corvallis, Oregon
Brook	USDA Forest Service Pacific Northwest Research Station and Pacific Northwest Region Portland, Oregon
Clemons	Western Forestry Research Dept. Weyerhaeuser Company Tacoma, Washington
Francis Iron	Washington State Department of Natural Resources Olympia, Washington
Creek	USDA Forest Service Pacific Northwest Research Station and Pacific Northwest Region Portland, Oregon
Stampede Creek	USDA Forest Service Pacific Northwest Research Station and Pacific Northwest Region Portland, Oregon
Sayward Forest	Canadian Forestry Service Department of the Environment Victoria, British Columbia
Shawnigan Lake	Canadian Forestry Service Department of the Environment Victoria, British Columbia

Glossary

Age—Total age (years from seed).
Age b.h.—Age at breast height (years since attaining breast height).
ANOVA—Analysis of variance.
B.h.—Breast height (4.5 feet above ground).
C—Symbol representing control treatment.
CT—Commercial thinning.
CVTS—Cubic volume of bole including stump and tip.
Dg—Quadratic mean diameter at breast height.
D.b.h.—Diameter at breast height.
d/D—Ratio of quadratic mean diameter of cut trees to quadratic mean diameter of all trees before cutting.
dD—Periodic annual increment in d.b.h.
dG—Periodic annual increment in basal area
dH—Periodic annual increment in height.
dV—Periodic annual increment in volume (CVTS).
G—Basal area.
g/G—Ratio of basal area of cut trees to basal area of stand before cutting.
H—Height.
H40—Mean height of the 40 largest (by diameter) trees per acre.
Hi/Hm—Ratio of plot value of H40 to installation mean value of H40.
In—Natural logarithm (logarithm to base e).
LOGS—Acronym for Levels-Of-Growing-Stock.
MAI—Mean annual increment.
n/N—Ratio of number of trees cut to number of trees before cutting.
PAI—Periodic annual increment.
PCT—Precommercial thinning.
RD—**A** measure of relative density, defined as $G/Dg^1/2$.
RDn—A relative density value of n.
R^2—Coefficient of determination; equals the proportion of total sum of squares accounted for by regression.
SEEy—Standard error of estimate of the variable y.
SI_{50}—Site index value based on reference age 50 years b.h.
Tn—Treatment n.
TPn—Treatment period n.
V—Volume (equals CVTS as used in this report).

Curtis, Robert O.; Marshall, David D. 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; **1986.** 113 p.

This progress report reviews the history and status of the cooperative levels-of-growing-stock study in coast Douglas-fir, begun in 1961, in Oregon, Washington, and British Columbia. It presents new analyses, including comparisons among some installations. Data now available are primarily from the site II installations. which are approaching completion of the study Growth is strongly related to growing stock. Thinning treatments have produced marked differences in volume distribution by tree sires. During the fourth treatment period, current annual increment was still about double the mean annual increment, and differences in volumes and size distributions among treatments have been increasing rapidly There are considerable differences in productivity among installations, beyond those accounted for by site index differences. The LOGS study design is evaluated.

Keywords: Thinnings, (-stand volume, growing stock, (-increment/yield, Douglas-fir, *Pseudotsuga menziesii,* series—Douglas-fir LOGS.

Pacific Northwest Research
Station 319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208