2

3-YEAR GROWTH RESPONSE

Fertilization & Thinning Effects On a Douglas-Fir Ecosystem At Shawnigan Lake

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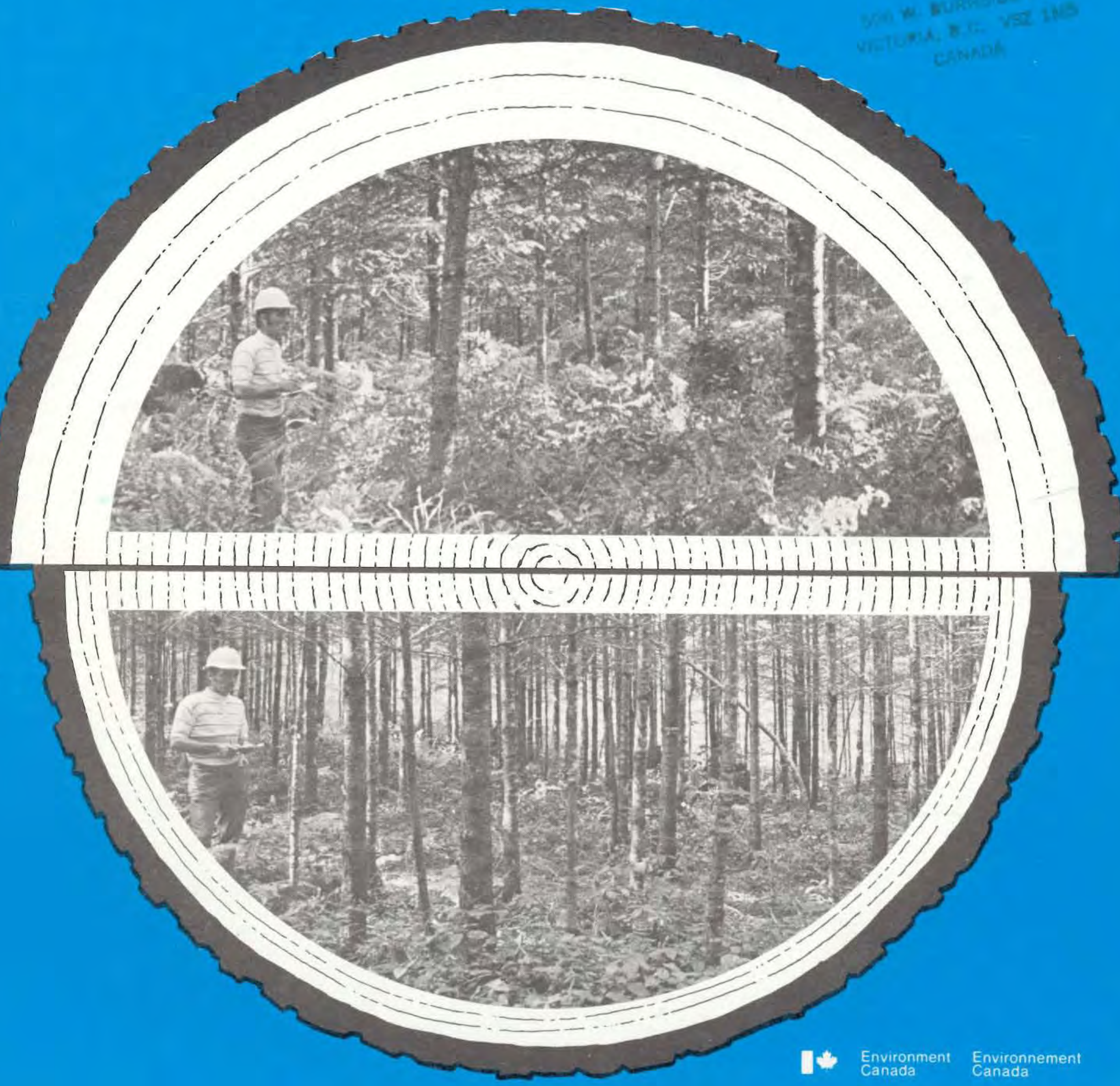

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ABSTRACT

Site specific growth data for the 3 years following fertilization and thinning are given for the Shawnigan research plots. The data base is documented and gross and merchantable volume, and cumulative dbh and height increments are given. Evaluation of treatment response is investigated using individual tree increments (dbh, ba, height and gross volume), stand structure analysis and crop tree analysis.

Significant early treatment responses are shown. By using covariance analysis with the 618 largest trees/ha as the crop trees, the percent gain in gross volume increment over the adjusted control treatment was 54, 110 and 188, respectively, for heavy thinning without fertilization, heavy fertilization with no thinning, and heavy thinning and heavy fertilization combined.

The analytical approaches used are compared and reader feed-back is solicited.

Key words: 3-year growth, individual trees, stand structure, crop trees, Pseudotsuga menziesii

RÉSUMÉ

Les parcelles de recherche à Shawnigan ont fourni des données spécifiques de croissance sur des stations pour les 3 années qui ont suivi leur fertilisation et leur éclaircie. Le fichier central est étoffé et indique l'accroissement des volumes brut et marchand, du dhp cumulatif et de la hauteur des arbres. Les auteurs évaluent les facteurs de la réponse aux traitements en utilisant les accroissements chez chaque arbre (du dhp, de la surface terrière, de la hauteur et du volume brut), l'analyse de la structure du peuplement et l'analyse des arbres du peuplement final.

Des réponses significatives et rapides sont ici présentées. En utilisant une analyse de covariance des 618 plus gros arbres par hectare comme arbres du peuplement final, le gain en pourcentage d'accroissement du volume brut par rapport aux arbres témoins (dont les caractéristiques avaient été ajustées) fut de 54, 110 et 188 respectivement pour les parcelles très éclaircies sans fertilisation, fertilisation pronouncé sans éclaircies et un traitment combiné des parcelles très fertilisées et très éclaircies.

On fait une comparaison des méthodes d'analyse, et à ce sujet les observations du lecteur seront appréciées.

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1.0 Introduction

Interest in forest fertilization and thinning is high in the Pacific Northwest. How best to measure and evaluate treatment response in the most "uniform" of heterogeneous forests is still an open question. Attention has recently been focussed on the development of procedures for handling variation in response (Anon, 1975), and on reporting gross volume growth (Miller and Pienaar, 1973). Early responses reported have been significant and the data produced will be invaluable as input into decision-making models for forest management. As research progresses, the need for regionally accepted analysis procedures will become important if results are to be readily interpreted.

Details of the site, experimental basis, and the multidisciplinary nature of the project at Shawnigan Lake, B.C. have been previously reported (Crown, Brett et al., 1975). The study area was established in 1970 in a young 24-year-old Douglas-fir stand, at 335 m elevation, on shallow, coarse textured soils (Orthic Dystric Brunisols). Site index was 21 m at 50 years. The basic experiment consisted of a 3 x 3 completely randomized factorial design comprising 3 levels of nitrogen fertilization [0 (F_0), 224 (F_1) and 448 (F_2), kg N per ha as urea] applied in the spring, and 3 levels of thinning in which zero (T_0), and about 1/3 (T_1) and 2/3 (T_2) of the basal area was removed. Treatments were replicated twice in each of 2 years (1971 and 1972) in plots of 0.04 ha surrounded by 10-m-wide buffer zones.

This report is based on only 3 years of growth following fertilization and thinning and results are site specific. Emphasis, therefore, is placed on the discussion of analysis procedures rather than on absolute response values. The report documents the data base, gives gross and merchantable volume growth on an area basis, cumulative increments for dbh and height, growth of individual trees in respect to dbh, ba, height, and gross volume, and results from individual trees. Stand Structure (Anon, 1975) and "Crop Tree" analyses are discussed. Many questions on analysis procedure are unanswered and reader feed-back is solicited.

2.0 Documentation of the data base

Data and analyses included in this report are based on measurements taken at the time of installation establishment and for the 3 years following treatment. It is recognized that 3-year results will give only initial treatment response. Reporting planned for 6, 9, 12 and 15 years' post treatment (coinciding with the measurement schedule in Appendix I) will provide increasingly more reliable estimations of the total response to fertilization and thinning. Analysis showed no significant difference between the response for the 1971 and 1972 installations and hence the data were pooled, giving 9 treatments each with 4 replications.

2.1 Units of Measurement

At the time of inception of this study, metric conversion appeared to be far in the future; consequently, the installation was established using Canadian yard/pound units. In conversion to metric units, some rather unconventional sizes exist. Examples are: —

i) plot size is 0.0404 ha (1/10 acre).
ii) breast height was defined as 1.372 m (4.5 ft)
iii) taper steps were at 2.54 cm dob (1 inch) intervals.
iv) diameter class intervals were 2.5 cm (approximately)
v) equations for dbh, basal area, height, height increment, gross volume and merchantable volume use Canadian yard/pound measures.

A number of initial analyses were also conducted using Canadian yard/pound measures.

The measurement of trees involved two distinct strategies, a plot basis and an individual tree basis.

2.2 Measurements on a plot basis

The plot basis is used to evaluate initial plot condition and to monitor changes at fixed time intervals through the course of the experiment.

The kind and frequency of measurements taken are:

a) dbh over bark (ob) and tree condition for all plot and buffer trees were recorded at the time of establishment and annually for the succeeding 3 years; future recordings will be at 3-year intervals; was measured using dbh tapes;

b) height of all plot trees and thinned buffer trees was measured with height poles at the time of plot establishment. Height of plot trees will be measured at 3-year intervals;

c) height to live crown was measured with height poles at the time of establishment; subsequent measurement will be made at 6 years following establishment and at 3-year intervals thereafter;

d) all plot and buffer trees were stem mapped at the time of establishment (prior to thinning). Tree locations were originally mapped using the azimuth-distance method and later checked using right angled prisms and tapes (now the preferred procedure); and

e) Competitive Stress Index at dbh (Arney, 1973) was calculated for all plot trees from dbh measurements and stem maps.

The total number of trees in all plots at plot establishment was 13,273. The number of plot trees currently being measured is 3,951.

2.3 Measurements on an individual tree basis

Measurements, taken on an individual tree basis, are designed to provide yearly trends in increment, estimates of volume and form changes and to provide a data base for related investigations.

Individual trees (volume sample trees), 231 and 233 for the 1971 and 1972 plots, respectively, were selected 3 years after treatment on the basis of initial dbh and competitive position in the stand as defined by Competitive Stress Index (CSI).

Measurements taken were:—

a) dbhob initially and annually thereafter.

b) total height annually from 3 years preceding establishment.

c) dob at 0.305 m and at 2.54 cm (approx) stem diameter taper steps measured to a 7.62 cm minimum dob for larger trees and to half height above dbh for the smaller trees; these measurements were taken 3 years after treatment and will be taken at 3-year intervals until the conclusion of the study.

2.4 Volume determination

To determine initial individual tree and initial plot volumes, a local volume equation was developed for the site. It was derived prior to metrification and hence is in Canadian yard/pound measures. One hundred and five healthy Douglas-fir trees, selected to cover the observed range of dbh (2.5 — 32.0 cm), were felled or climbed and measured for dob at 2.54-cm taper steps from the butt. Segment volumes were calculated using Newton's formula (Chapman and Meyer, 1949). A regression using dbh and height as independent variables and measured volume as the dependent variable was fitted, giving the following volume equation:

$$\log V = -2.48036 + 1.95882 \log D + 0.971352 \log H$$

where: V = volume in cu ft
D = dbhob in inches
H = total height in ft

$R^2 = 0.999$ SEE = 0.031 cu ft; No. of observations = 105

This equation was used to determine individual tree volumes at the time of establishment. However, in the case of the 1972 plots where tree heights were not available, it was necessary to estimate initial tree height from data collected on the thinned 1972 plot trees.

The regression selected for estimating initial tree height was:

Height = $-14.9985 - 3.27337\,D + 31.1521\sqrt{D}$

where: H = Initial height in feet

D = Initial dbhob in inches

$R^2 = 0.918$, SEE = 2.90 ft; No. of observations = 1636

Height increment by treatment was estimated from 1971 plot data. This estimate of height increment was based on regression analysis of height increment against initial height, initial dbh, and dbh increment. The regression form selected was:

$$\Delta H = a + b_1 D + b_2 D^2 + b_3 D^3 + b_4 \Delta D + b_5 H$$

where a, b_1, b_2, b_3, b_4 and b_5 are regression coefficients

D = Initial dbhob in inches.
ΔD = Dbh increment in inches.
ΔH = Height increment in feet.
H = Initial height in feet.

Regressions were derived for each of the 9 treatments in the 1971 plot series and applied to the corresponding treatments for the 1972 plot series. The equations derived are given in Appendix II.

To determine tree volume 3 years after treatment, it was decided that if no significant change in form quotient occurred between treatments, the initial condition volume equation would be used. The data used to test this hypothesis were taken from the detailed measurement of the volume sample trees for both the 1971 and 1972 plots. Analysis of variance and paired t tests failed to show any significant differences between form quotients for the different treatments. Consequently, the initial volume equation was applied to estimate total tree volume 3 years after treatment.

Merchantable tree volume (close utilization) was derived from merchantable volume curves developed by the B.C. Forest Service (unpublished). Regressions were fitted to these curves to facilitate determination of merchantable volume values for each individual tree. This procedure avoids the unrealistic merchantable volume increases that occur when dbh class values are applied to individual trees, especially where stands are just reaching merchantable sizes. Form of the regressions used was:

Merchantable Factor = $a + b_1/D + b_2 \log_e D + b_3 D$

where D = dbhob

This relationship was derived for Douglas-fir, western red cedar, western hemlock, balsam, western white pine and lodgepole pine (Appendix III).

2.5 Data recorded for all plot trees

The data recorded are as follows:

i) plot and tree number
ii) X and Y coordinates
iii) species
iv) treatment

Treatment codes used are:

T_0F_0 - CONTROL - No thinning, no fertilization

T_0F_1 - No thinning, 224 kg N/ha (urea)

T_0F_2 - No thinning, 448 kg N/ha (urea)

T_1F_0 - Intermediate thinning, no fertilizer

T_1F_1 - Intermediate thinning, 224 kg N/ha (urea)

T_1F_2 - Intermediate thinning, 448 kg N/ha (urea)

T_2F_0 - Heavy thinning, no fertilizer

T_2F_1 - Heavy thinning, 224 kg N/ha (urea)

T_2F_2 - Heavy thinning, 448 kg N/ha (urea)

v) mortality index records thinned trees, mortality, damage, or disease
vi) CSI at time of establishment, after thinning and thereafter at 3-year intervals
vii) total height at establishment and thereafter at 3-year intervals
viii) dbhob at treatment, annually for 3 years and thereafter at 3-year intervals

Diameter classes used in the analyses are as follows:

Diameter class	Class mid point (cm)	Range cm
1	3.75	2.50 - 4.99
2	6.25	5.00 - 7.49
3	8.75	7.50 - 9.99
4	11.25	10.00 - 12.49
5	13.75	12.50 - 14.99
6	16.25	15.00 - 17.49
7	18.75	17.50 - 19.99

ix) gross and merchantable volume at establishment and thereafter at 3-year intervals
x) height to base of live crown at establishment
xi) stem maps before thinning, after thinning and every 3 years thereafter

3.0 3-year growth response

Gross volume (G. Vol) and merchantable volume (M. Vol) per hectare are reported along with cumulative increment for dbh and height (Figs. 1, 2 and 3).

3.1 Volumes per hectare produced in the first 3 years following treatment

The data presented in this section are based on the mean treatment response per plot (4 replications per treatment) converted to a per hectare basis.

Gross Volume

The 3-year gross volume and the percent gain or loss in 3-year increment compared to control are given in Fig. 1a. The maximum 3-year gross volume increment of 70.67 m^3/ha occurred with the T_0F_2

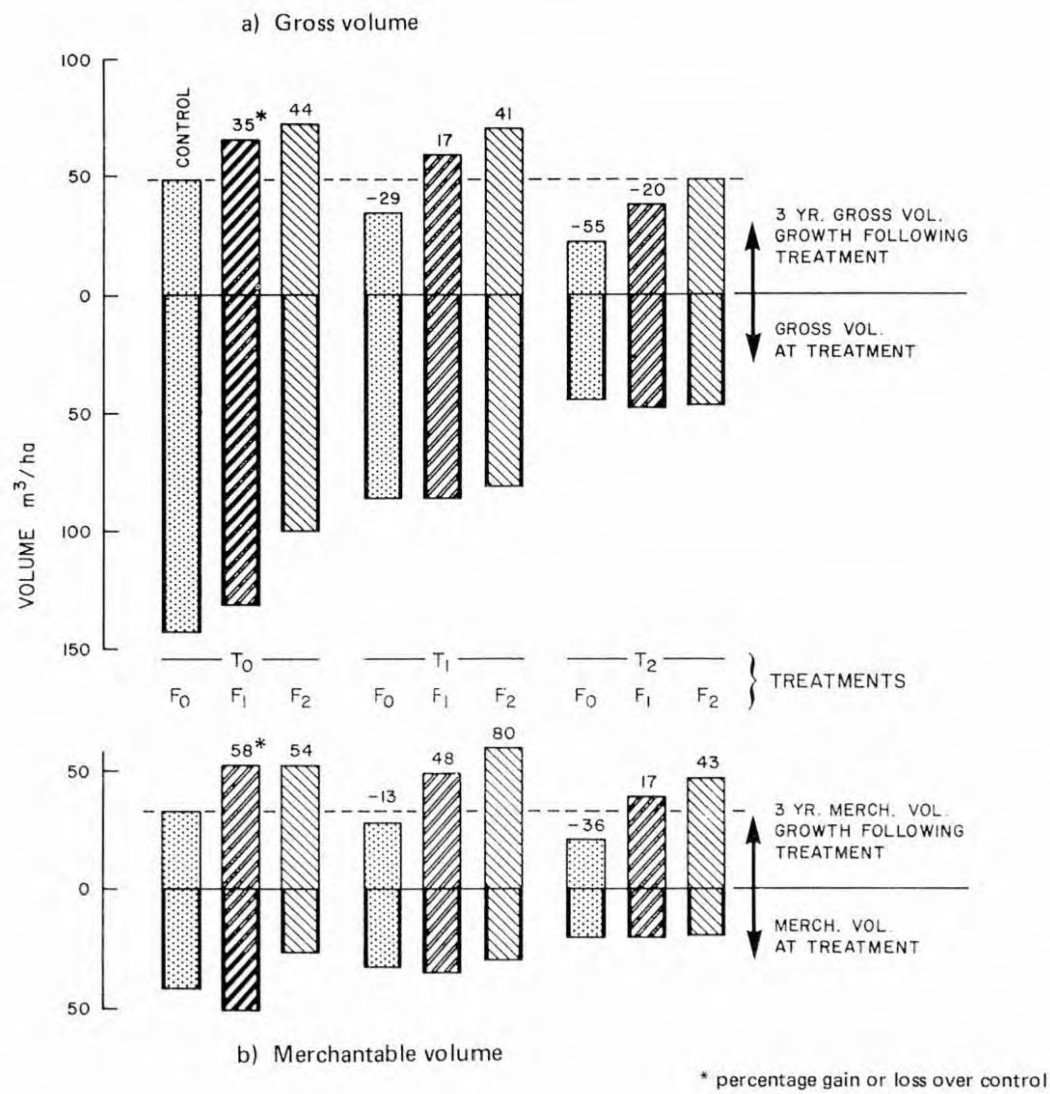


Figure 1. Gross and merchantable volume per hectare by treatments.

Figure 2. Cumulative dbh increment by treatments for dbh class 4.

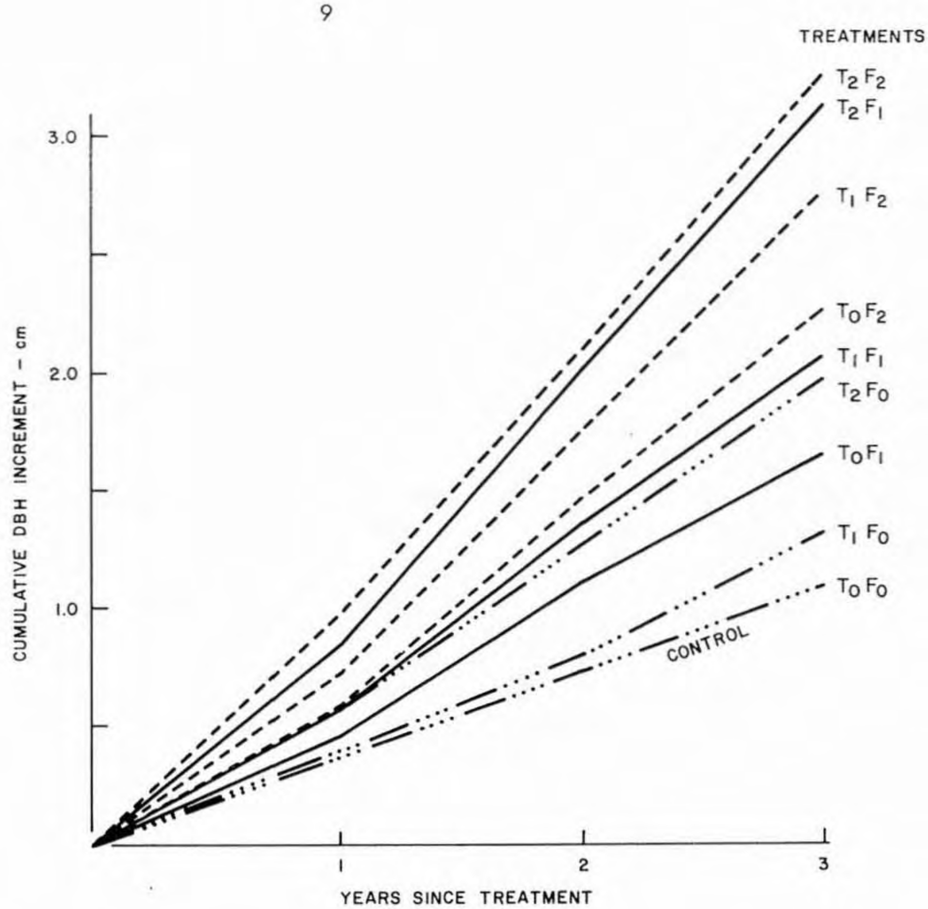
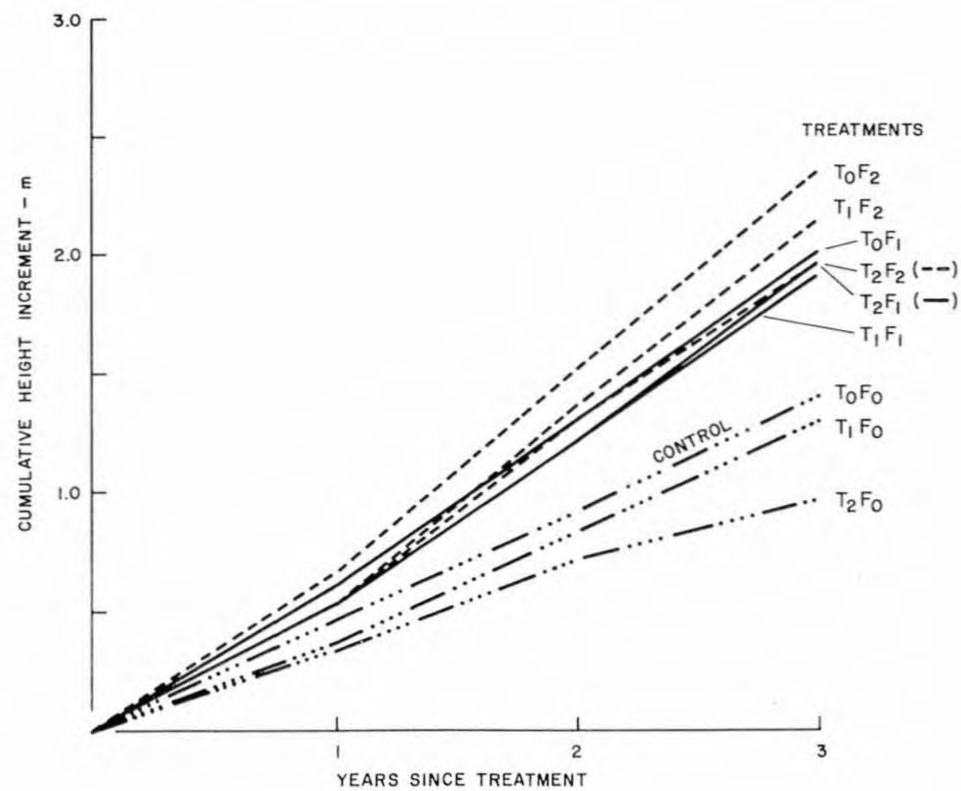


Figure 3. Cumulative height increment by treatments for dbh class 4.



treatment, and the smallest increment of 22.20m^3/ha occurred with the T_2F_0 treatment (Appendix IV). Fertilization has given a marked increase in Gross Volume increment. As might be expected, thinning alone has reduced the Gross Volume but this increment has accrued on a smaller number of larger trees. Fertilization with thinning has offset the volume increment reduction that resulted from thinning.

Merchantable Volume

The maximum 3-year merchantable volume increment of 58.81 m^3/ha occurred in the T_1F_2 treatment, and the smallest increment of 20.76 m^3/ha occurred with the T_2F_0 treatment (Appendix IV).

Fertilization increased growth at all thinning levels (Fig. 1b). Thinning alone reduced the response due to the reduction in number of trees. Fertilization of intermediate thinnings compensated for the increment reduction associated with thinning and resulted in increments similar to the unthinned treatments. Fertilization of heavy thinning treatments resulted in a substantial increase in increment that more than compensated for the thinning effect.

Initial stand differences (Appendix VI and Fig. 1) have profound and confounding effects on growth response. For example, the marked difference in number of trees and dbh distribution in the unthinned plots explains the higher initial volumes in the T_0F_0 (Control) as compared to the T_0F_2 treatment. Also, the higher initial merchantable volume of the T_0F_1 treatment results from the presence of a few larger trees (see Table 1).

3.2 Cumulative increment for dbh and height

Graphs of cumulative dbh and height increment against years since treatment are given for dbh class 4 to provide insight into annual changes in response (Figs. 2 and 3). These data were taken from the volume sample trees and hence do not coincide exactly with individual tree response determined by regression (Figs. 4 and 5).

The similarity of the dbh growth trends for the T_2F_2 and T_2F_1 treatments after 3 years is worthy of note, and future trends for these treatments will be of considerable interest. Divergence of height increment between fertilized and unfertilized treatments in these early measurements is very distinct and will be monitored closely in future.

4.0 Analysis of growth response of individual trees

In this analysis, individual tree Periodic Annual increment (PAI)* is used throughout. Comparison of the growth responses of individual trees between and within treatments provides a good basis for the evaluation of response to fertilization and thinning. It provides for a better understanding of plot response data and is input data for stand models. To make the comparisons, regressions using healthy Douglas-fir trees were fitted for dbh, ba, height and gross volume increment against initial dbh (Appendix V). These equations were solved for 6.25, 8.75, 11.25 and 13.75 cm initial dbh, the midpoints of the dbh classes 2 through 5. Insufficient data precluded use of dbh classes 1 and 6 through 11.

The PAI for control trees is compared to that of treated trees which had the same initial dbh (Figs. 4 through 7). Within treatments, trees of differing initial dbh are compared to provide some insight into changes in stand dynamics associated with treatment.

4.1 Dbh increment (cm/a)

Examination of the gain in dbh increment over that of the control indicates that increasing the levels of both fertilization and thinning resulted in increased increment (Fig. 4 and Appendix VII). In general, the greatest response for each fertilization level was associated with the heavy thinning treatments.

Comparisons of response to fertilization and thinning indicate a positive treatment interaction. For example, in dbh class 4, the dbh increment for control (T_0F_0) was 0.39 cm. The gain above control for heavy fertilization alone (T_0F_2) was 0.38 cm; for heavy thinning alone (T_2F_0) was 0.25 cm, and for heavy fertilization and thinning combined (T_2F_2) was 0.83, indicating a positive interaction of 0.20 cm.

In all cases, total dbh increment for a given treatment increased with increasing initial dbh (Appendix VII). When examining gain over control increment for a given treatment, the small dbh

* For the first 3 years following treatment.

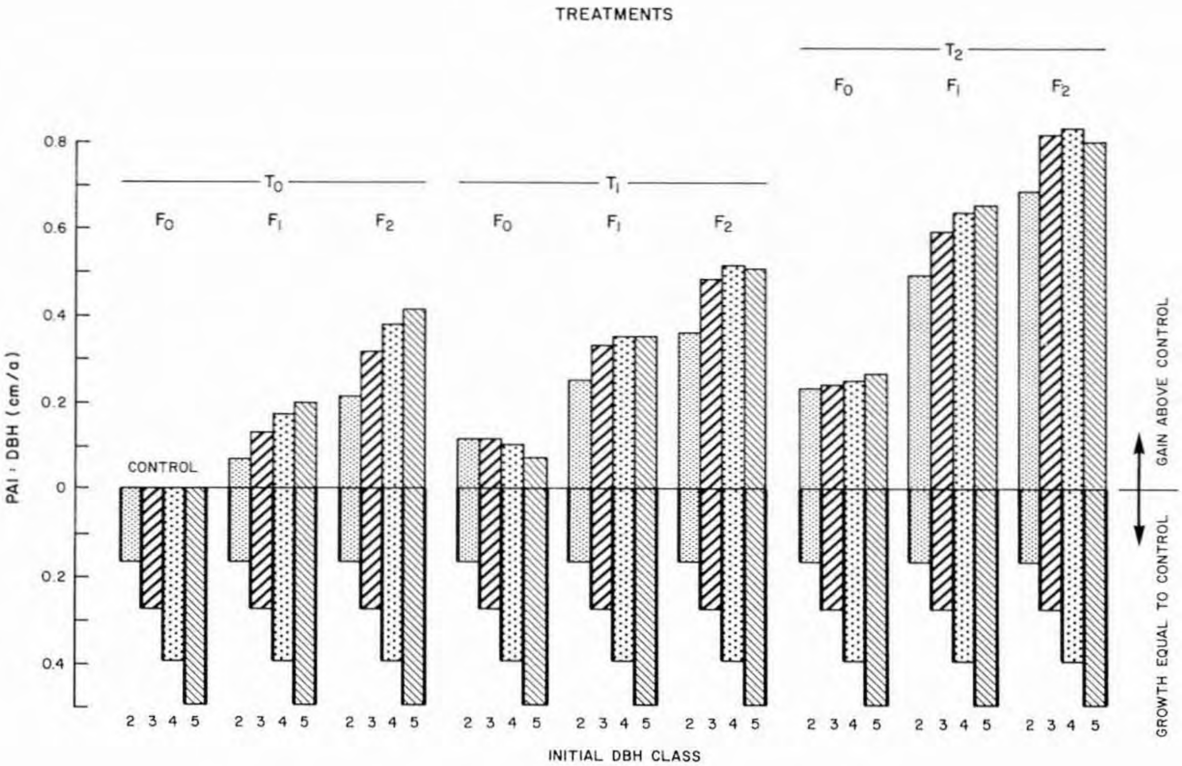


Figure 4. PAI for dbh by dbh classes and treatments. (cm/a)

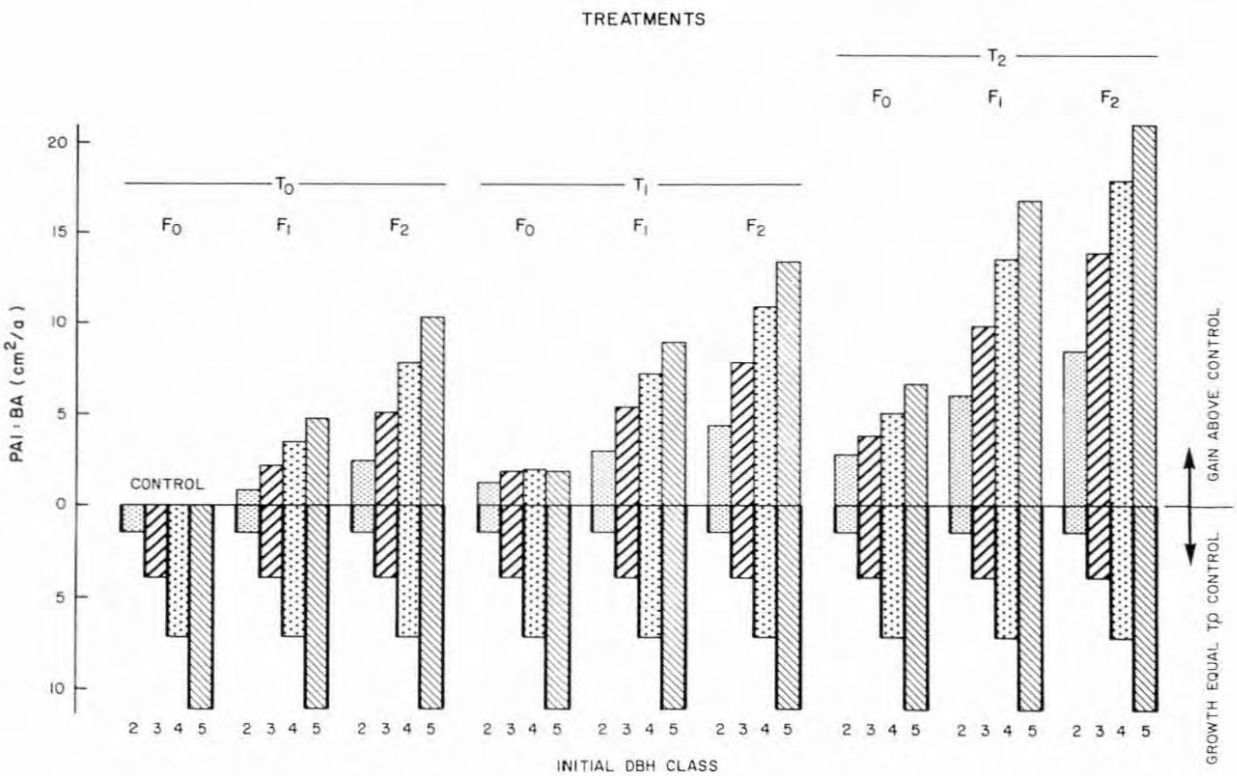


Figure 5. PAI for ba by dbh classes and treatments. (cm^2/a)

Note: - Total increment = Growth equal to control + Gain above control.

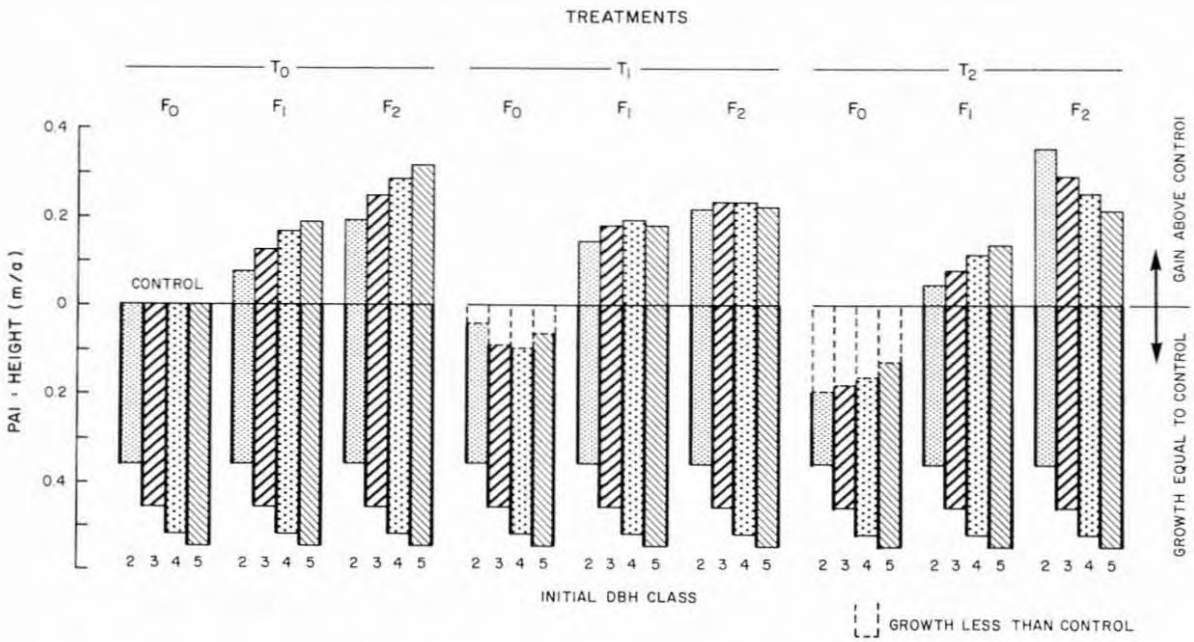


Figure 6. PAI for height by dbh classes and treatments.(m/a)

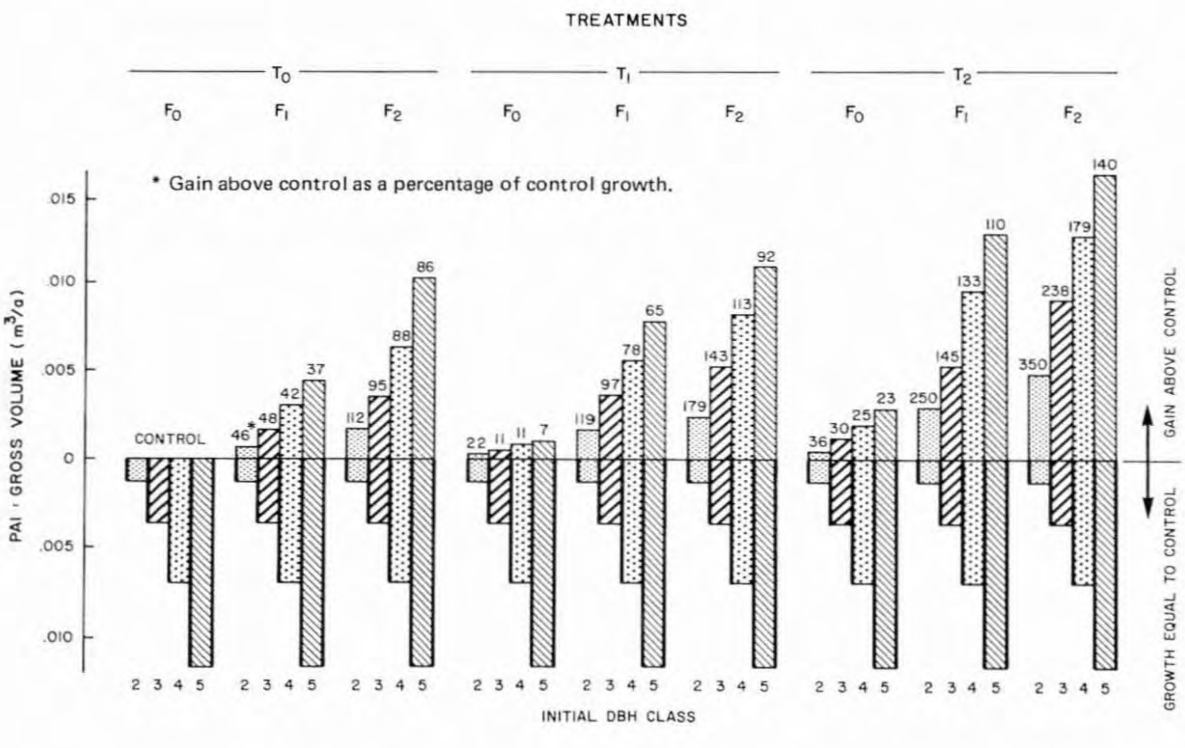


Figure 7. PAI for gross volume by dbh classes and treatments. (m^3/a)

Note: - Total increment = Growth equal to control + Gain above control.

classes occasionally exhibit a greater gain than the large dbh classes (i.e., T_1F_0) and with little or no difference between classes 4 and 5.

4.2 Ba increment (cm^2/a)

Ba response is essentially identical to dbh response (Fig. 5 and Appendix VIII). The only marked difference is that there is a more consistent increase in ba gain with increasing initial dbh. Treatment responses for dbh class 4 are as follows: Ba increment for control (T_0F_0) was 7.19 cm^2. The gain above control for heavy fertilization alone (T_0F_2) was 7.66 cm^2; for heavy thinning alone (T_2F_0) was 4.95 cm^2, and for heavy fertilization and heavy thinning combined was 17.75 cm^2, indicating a positive treatment interaction of 5.14 cm^2.

4.3 Height increment (m/a)

Height increment response differs markedly from dbh and ba response. The most striking feature was the decrease in height increment associated with increasing thinning intensity when no fertilizer was added. This is commonly termed "thinning shock" and is well illustrated in Fig. 6.

Fig. 6 and Appendix IX show that:

1) for those treatments having no fertilizer application, the periodic annual increment in height was less than that of the control, and decreased as thinning intensity increased (T_1F_0, T_2F_0)
2) for those treatments having no thinning, the periodic annual increment in height increased with fertilization (T_0F_1, T_0F_2).
3) fertilization reduces the degree of thinning shock; the heavier the fertilizer application, the less the shock.

4.4 Gross volume increment (m^3/a)

The gain in gross volume increment over that of the control provides the measure of the effect of fertilization and thinning. Increasing levels of both fertilization and thinning increased volume gain for all dbh classes (Fig. 7 and Appendix X).

Comparison of the volume increment response indicates a positive treatment interaction. For example, in dbh class 4, volume increment for control (T_0F_0) was 0.0071 m^3. Gain above control for heavy fertilization alone (T_0F_2) was 0.0062 m^3; for heavy thinning alone (T_2F_0) was 0.0018 m^3; and for heavy fertilization and heavy thinning combined (T_2F_2) was 0.0127 m^3, indicating a positive interaction of 0.0047 m^3.

Total volume increment and increment gain above control increased markedly for a given treatment with increasing initial tree size. However, it is interesting to note that gain above control expressed as a percentage of control growth for a given dbh class is inversely related to tree size, as shown by the percentage values in Fig. 7.

5.0 Methods of evaluating treatment response on a per hectare basis

How best to evaluate treatment response on a per hectare basis is still an open question. The very marked variation in the response of trees of different dbh class within treatments (Fig. 7) points up the importance of tree frequency distribution by dbh class when per hectare response is being considered.

Gross differences in tree frequency distribution result from the removal of trees in thinning. Other less obvious but important tree frequency distribution differences within thinning treatments result from variations in site, initial stand condition and mortality. The effect of the tree frequency distribution differences on the evaluation of treatment response (/ha) can be demonstrated, in general, by comparing the actual 3-year volume increment given in Fig. 1 with the results of the individual tree PAI for gross volume in Fig. 7. In Fig. 1, thinning within fertilization treatments shows a loss in 3-year volume increment, whereas in Fig. 7, a net gain in gross volume increment is shown. The large differences in tree frequency distribution created by the removal of trees in thinning (Appendix VI) mask the treatment response on a per hectare basis. Therefore, to evaluate treatment response, these important tree frequency distribution differences must be accounted for.

Two approaches are examined: 1) stand structure analysis, and 2) crop tree analysis.

5.1 Stand structure analysis

Stand structure analysis was used on the Shawnigan Lake data to evaluate gross volume response to treatment. The concept was described by the Regional Forest Nutrition Research Project (Anon., 1975).

Treatment responses were calculated as follows:

1) total gross volume increment was determined for each treatment
2) dbh frequency distributions were determined for each treatment
3) gross volume increments were determined for midpoints of each dbh class for control treatment
4) a 'control image' was created by applying control gross volume increments determined (3) to the dbh frequency distributions for each treatment (2)
5) the difference between the total gross volume increment and the gross volume increment for control image (4) was taken to represent treatment response
6) treatment response was then expressed as a percentage of the control image

Regression equations on healthy Douglas-fir (Appendix V) were used to define the control and treatment increment values for dbh classes 1-7. Classes 8 through 11 were not included because, in the initial stand condition, these dbh classes were not represented in all treatments. Using the tree frequency distribution for the healthy Douglas-fir as they exist for each treatment, the percentage of gain or loss in gross volume increment by treatment was calculated and is given in Fig. 8. Results from stand structure analysis can be compared to Fig. 8.

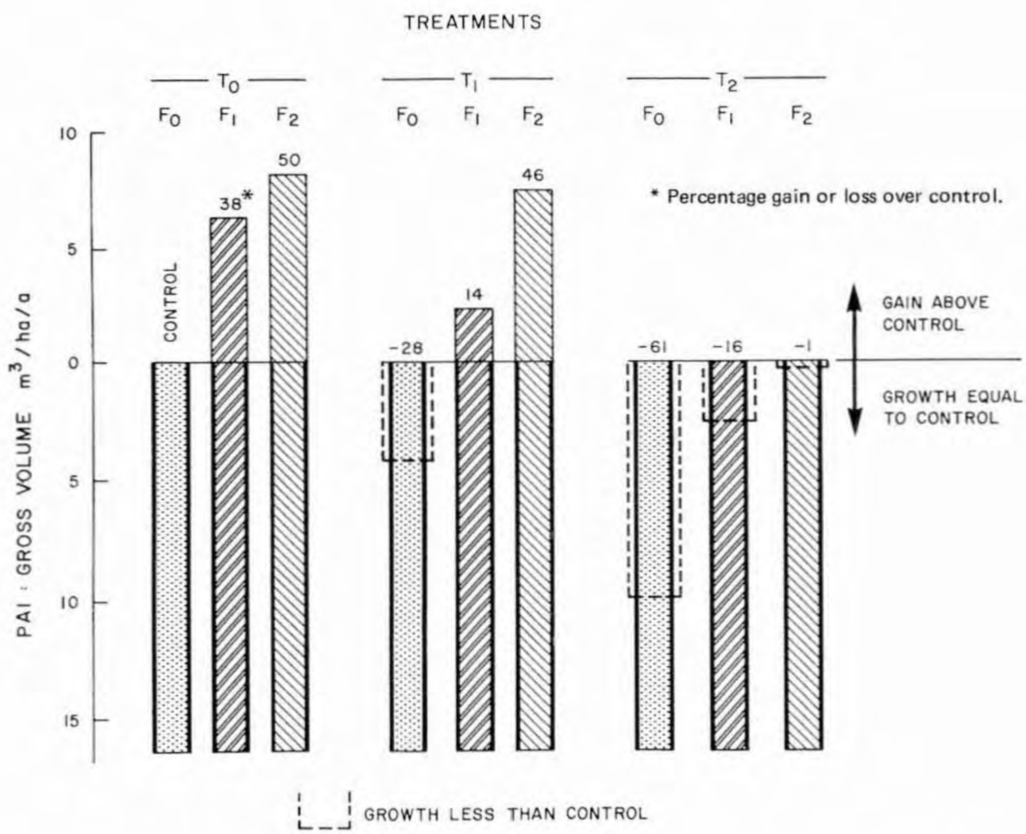


Figure 8. Calculated PAI for gross volume of healthy Douglas-fir on a per hectare basis.

The concept was applied using three sets of frequency distributions by dbh class as follows:

1) The actual tree frequency distributions by treatments as they occurred (Appendix X1a).
2) The mean tree frequency distribution for each thinning level (Appendix X1b).
3) A hypothetical tree frequency distribution equivalent to the individual plot that had the smallest number of trees after thinning (Appendix X1c).

The last two were tested in order to remove stand structure differences among thinning treatments.

1) Actual tree frequency distributions

In this analysis, comparisons were made using the actual tree frequency distributions as they occurred.

Figure 9 shows the treatment response (volume increment gain above control image) determined by stand structure analysis. This method of analysis gives a good estimation of both fertilization and thinning response. However, evaluation of the results is still confounded by different numbers of trees, both within and between thinning levels.

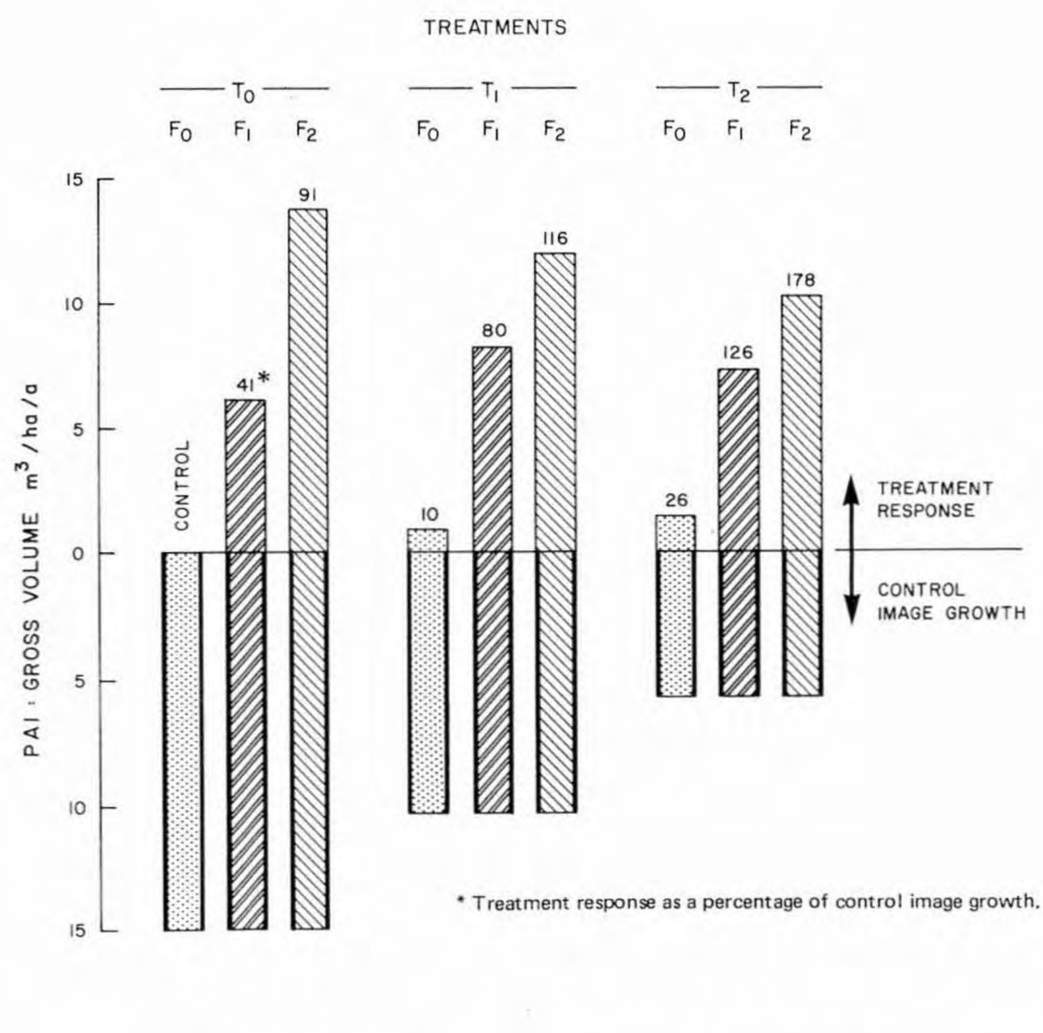


Figure 9. Treatment response by stand structure analysis using actual tree frequency distributions.

2) Mean tree frequency distribution for each thinning level

The use of mean tree frequency distribution calculated for each thinning level removes differences and gives a better basis for the evaluation of fertilizer effects within thinning levels (Fig. 10). This treatment of the data made little or no difference to the percentage calculations. However, it did affect treatment response; e.g. positive adjustment of the control image for the T_0F_2 treatment caused an increase in the treatment response.

3) Hypothetical tree frequency distribution

To compare results of both thinning and fertilization on the same basis, stand structure analysis was applied to a hypothetical distribution which coincided with that of the individual plot having the least number of trees (Fig. 11).

Use of the hypothetical distribution has the advantage of removing stand structure differences associated with thinning effects and initial stand conditions. The order of treatment response duplicates that found for individual tree gross volume gain (Fig. 7). The order of response, from highest to lowest, was as follows: T_2F_2, T_2F_1, T_1F_2, T_0F_2, T_1F_1, T_0F_1, T_2F_0, T_1F_0 and T_0F_0.

While the stand structure analysis provides a good base for evaluating response, it is somewhat limited in that it is not possible to include the larger trees because they do not exist in all treatments.

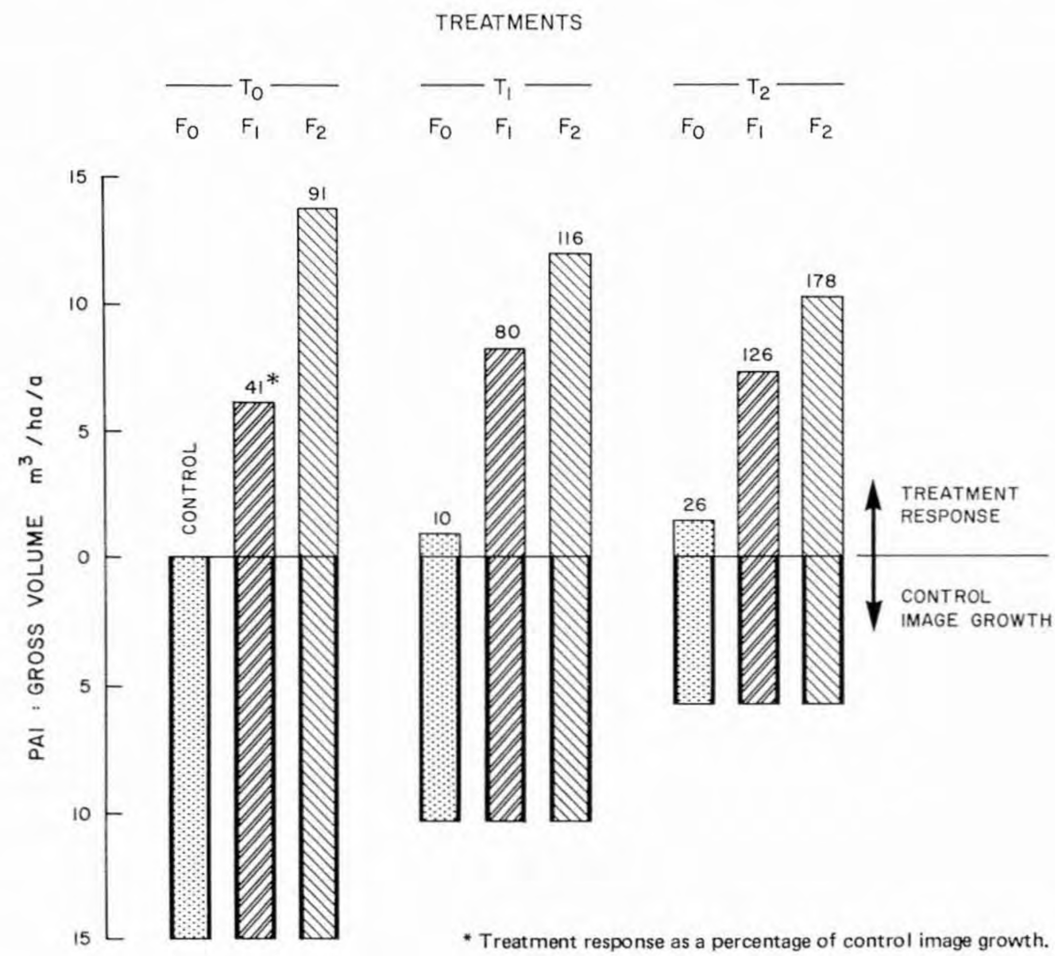


Figure 10. Treatment response by stand structure analysis using mean tree frequency distribution for each thinning level.

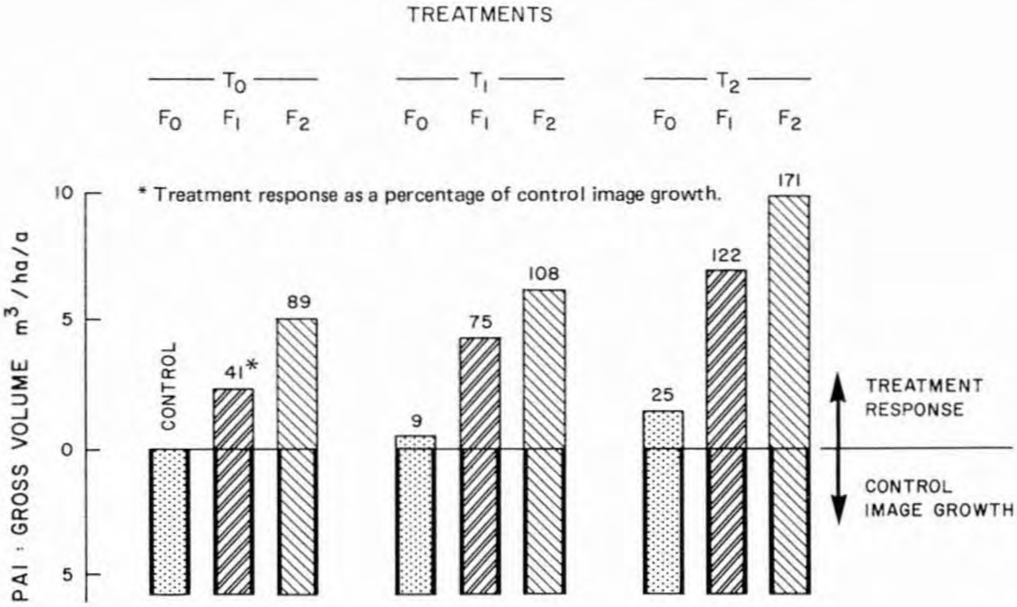


Figure 11. Treatment response by stand structure analysis using hypothetical tree frequency distribution.

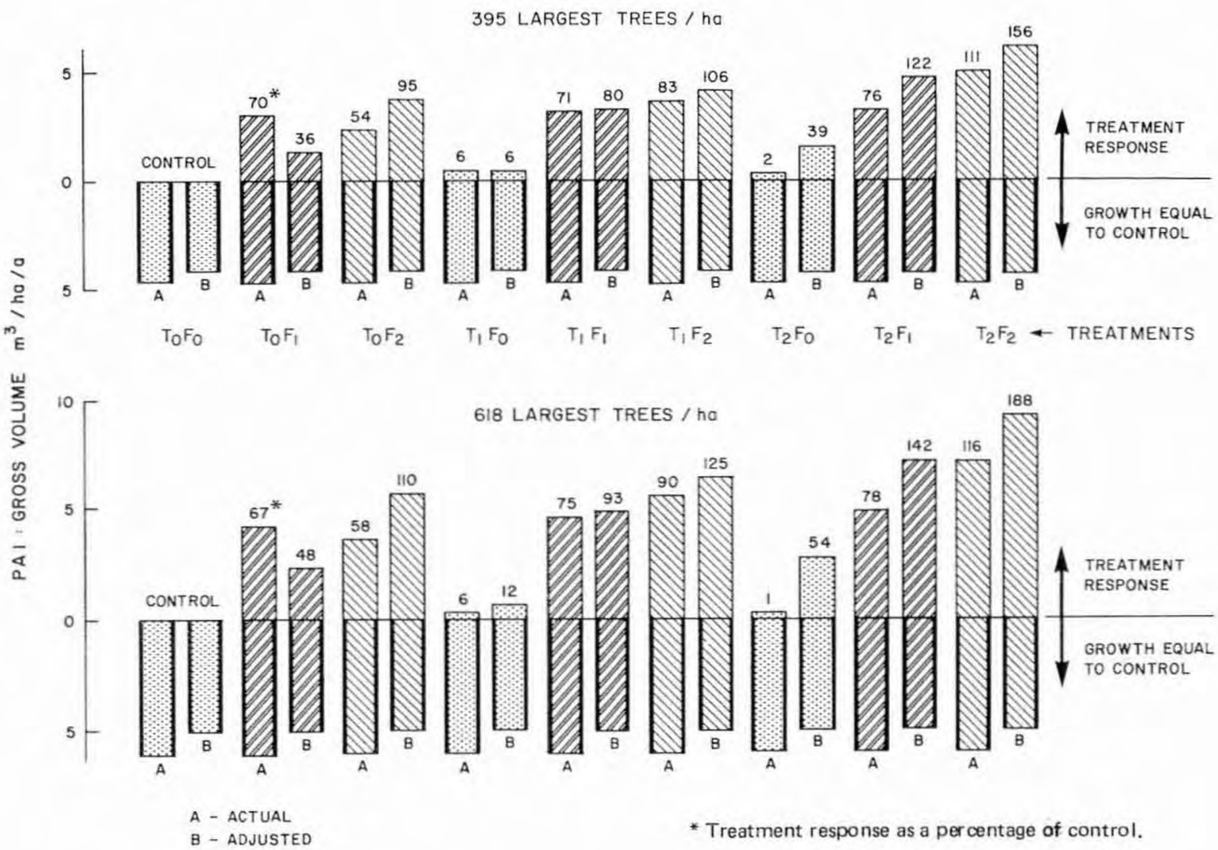


Figure 12. Actual and adjusted treatment response by covariance analysis using the 395 and 618 largest trees per hectare.

Table 1 - Initial mean dbh and height for the 395 and 618 largest trees per hectare.

	Treatment									
	T_0F_0	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2	General Mean
(a) 395 largest trees/ha.										
Initial dbh (cm)	13.40	14.76	12.53	13.49	13.50	13.19	12.56	12.40	12.65	13.16
Initial height (m)	12.03	12.30	11.02	11.92	11.62	11.40	10.99	11.31	11.11	11.52
(b) 618 largest trees/ha										
Initial dbh (cm)	12.74	13.67	11.93	12.70	12.76	12.48	11.59	11.62	11.71	12.36
Initial height (m)	11.77	11.83	10.70	11.54	11.36	11.03	10.60	10.98	10.67	11.16

Table 2 - Table of significance for fertilization, thinning and interaction using the 395 largest trees per hectare

		Dbh	Ba	Height	Volume
395 largest trees/ha	Thinning	***	***	ns	***
	Fertilization	***	***	***	***
	Interaction	**	**	***	*
618 largest trees/ha	Thinning	***	***	ns	***
	Fertilization	***	***	***	***
	Interaction	*	*	**	ns

where * = significant at the 5 percent level
** = significant at the 1 percent level
*** = significant at the 0.1 percent level
and ns = non significant.

5.2 Crop tree analysis

The primary management objective in fertilizing and thinning is to speed up the growth of the crop trees. Therefore, evaluation of treatment response of the potential crop trees would seem to be a logical analytical approach that would probably appeal to practicing foresters and that would appear to have some distinct advantages, e.g.:

1) the analysis is not complicated by the many small trees that will have little or no merchantable value.
2) it eliminates the problems associated with the variation in stand structure.
3) the analysis is based on trees that have a high probability of being harvested.

The 395 and 618 largest trees per hectare (160 and 250 trees per acre, respectively) were selected as representing the lower and upper limits of the range of density of potential crop trees (commercial thinning and final crop) for managed stands on sites similar to Shawnigan Lake. The response is similar to that shown for individual trees and stand structure, except where the trees are considerably smaller or larger than the general mean T_2F_0 and T_0F_1 treatments (Table 1, Fig. 12).

The difference in initial mean dbh and height necessitated the use of covariance analysis to evaluate the differences in response to fertilization and thinning. The analysis was based on individual trees, using initial dbh and initial height as covariates.

The results of the analyses (Fig. 12 and Appendix XII) generally confirm the results obtained from the individual tree and stand structure analyses.

The parameters showing statistical significance over control for fertilization and thinning and their interaction are given in Table 2.

6.0 Comparison of analytical approaches

The response of Douglas-fir at Shawnigan Lake to fertilization and thinning has been evaluated using:

1) response on hectare basis; 2) growth response of individual trees; 3) stand structure analysis, and 4) crop tree analysis.

With the exception of the response on a hectare basis, the analyses gave generally similar results. However, we feel that all of the approaches have application, albeit for different purposes. Some of the potentials and limitations of the approaches are listed below:

1) Response on a Hectare Basis

   a) Potentials

      i) provides a real measure of total volume and volume increment.

   b) Limitations

      i) growth response is confounded by differing number of stems within dbh classes, especially among thinning treatments.

2) Growth Response of Individual Trees

   a) Potentials

      i) provides a basis for elucidating stand dynamics and evaluating the effects of competition.
      ii) allows comparison of growth response of essentially identical individual trees.
      iii) provides an excellent basis for input into stand models.

   b) Limitations

      i) does not provide information on total stand response (area response) unless used in conjunction with the stand table, as in stand structure analysis.

3) Stand Structure Analysis

   a) Potentials

      i) has the greatest potential for determining response to thinning and fertlization in the mid-range diameters.

ii) is easily adaptable for application in developing managed stand tables.

iii) provides an excellent base for evaluating fertilization effects within (or in the absence of) thinning treatments.

b) Limitations

i) it is of restricted value at the upper and lower diameter limits because of few or missing trees.

4) Crop Trees Analysis

a) Potentials

i) has the greatest potential application for forest management, we believe, as it relates to that part of the stand that is of the greatest economic importance.

b) Limitations

i) ignores the large component of small trees.

7.0 Summary

The principal purpose of this paper is to present the 3-year fertilization and thinning response of a young stand of Douglas-fir at Shawnigan Lake and to compare analytical approaches to the evaluation of response.

The study area and experimental layout are described briefly and a detailed description of the data base, including the units of measurement, measurement on a plot basis, measurement on an individual tree basis and a description of the data currently being recorded, is given.

Regression equations are derived to estimate total tree volume and merchantable volume and initial height and dbh, ba, height and gross volume increment by treatments. Analysis of form quotient showed no significant differences between treatments.

3-year-treatment response is reported in terms of:

1) volume increment (gross and merchantable) on a hectare basis
2) cumulative increment for dbh and height
3) growth response of individual trees (dbh, ba, height and volume)
4) stand structure analysis using three dbh frequency distributions
5) crop tree response for the 395 and 618 largest trees per hectare (160 and 250 largest trees per acre).

1) Evaluation of treatment response, using volume increment on a per hectare basis indicated that fertilization within thinning levels resulted in increased increment, while thinning caused a reduction in increment. The reduction in response associated with thinning is attributable to fewer numbers of trees on the thinned plots. The different numbers of trees within thinning treatments distorted the magnitude of response to fertilization. The use of volume response on a per hectare basis is thought to be unsatisfactory for determining both the magnitude and order of response, because of differences in initial stand condition and differences in the tree frequency distributions by dbh class.

2) Examination of annual dbh and height increment trends provided some interesting indications of response. Dbh increment responded well to both fertilization and thinning over the 3-year period and appears to be maintaining the differential rates of increment. The similarity of growth response to the T_2F_2 and T_2F_1 treatments should be of special interest to the forest manager because of the high cost of fertilizer. The differential rates of height increment also appear to be continuing.

3) Both fertilization and thinning resulted in increased PAI for dbh, ba and volume on individual trees. Fertilization caused an increase in height increment regardless of thinning level, while increased levels of thinning reduced height increment. While the analysis of individual tree response cannot be used directly in determining response on a hectare basis, it provides a good basis for comparison of treatment response by diameter classes and has considerable promise for application in modelling.

4) The stand structure approach provided an excellent base for determining response to fertilization and thinning in the mid-range diameters, but has limited application for projecting final crop volumes because it is not possible to include the very

large trees.

5) The crop tree approach, which evaluates treatment response on the potential crop trees, is probably the most appealing to practicing foresters. However, it ignores a large component of small trees.

On the basis of the analyses conducted, it would appear that the magnitude of response recorded for fertilization and thinning depends to a large degree on the type of analysis used. Our intent has been to present a number of differing procedures and to solicit reader response to their application.

8.0 ACKNOWLEDGMENTS

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10.0 Appendices

Appendix I. Plot Measurement Schedule

Date to be measured	Kind of measurement 1971 plots	1972 plots
Spring '76		3
Fall '76	1, 3 & 4	2 & 5
Fall '77	2 & 5	1, 3 & 4
Fall '78	2 & 5	2 & 5
Fall '79	1, 3 & 4	2 & 5
Fall '80	2 & 5	1, 3 & 4
Fall '81	2 & 5	2 & 5
Fall '82	1, 3 & 4	2 & 5
Fall '83	2 & 5	1, 3 & 4
Fall '84	2 & 5	2 & 5
Fall '85	1, 3 & 4	2 & 5
Fall '86	–	1, 3 & 4

Kind of measurement:

1 = Dbh all trees in the plots.

2 = Dbh all volume sample trees.

3 = Original height or height every 3 years on all trees in the plots.

4 = Volume sample tree measurement (dbh, dob at taper steps, and height).

5 = Dbh all trees used in study PC-23-006 not measured in 1 or 2.

Appendix II. Regression equations for estimating 3-year height increment (ΔH) by treatment

		R^2	SEE(m)	OBS
T_0F_0	$\Delta H = -1.97482 + 2.47792\,D - .551474\,D^2 + .312579E{-}01\,D^3 + 5.22529\,\Delta D + .495936E{-}01\,H$	0.866	0.702	357
T_1F_0	$\Delta H = 3.97355 - .877774\,D + .372195\,D^2 - .302147E{-}01\,D^3 + 3.2275\,\Delta D - .597534E{-}01\,H$	0.607	0.909	154
T_2F_0	$\Delta H = -2.03794 + .921645\,D - .10313\,D^2 + .206027E{-}02\,D^3 + 3.61913\,\Delta D + .19291E{-}01\,H$	0.705	0.719	72
T_0F_1	$\Delta H = -3.90245 + 4.58555\,D - .967558\,D^2 + .604633E{-}01\,D^3 + 4.70053\,\Delta D + .2604E{-}01\,H$	0.899	0.802	267
T_1F_1	$\Delta H = -5.70565 + 7.13717\,D - 1.58054\,D^2 + .115326\,D^3 + 2.45037\,\Delta D - .635779E{-}02\,H$	0.689	0.985	139
T_2F_1	$\Delta H = 28.5185 - 19.0712\,D + 5.05678\,D^2 - .409218\,D^3 + 2.0468\,\Delta D - .106627\,H$	0.660	1.060	71
T_0F_2	$\Delta H = -5.00303 + 7.17189\,D - 1.99135\,D^2 + .17011\,D^3 + 5.24194\,\Delta D + .88662E{-}02\,H$	0.844	1.078	301
T_1F_2	$\Delta H = -2.8809 + 6.59\,D - 1.30415\,D^2 + .883537E{-}01\,D^3 + 2.17913\,\Delta D - .996329E{-}01\,H$	0.706	0.901	161
T_2F_2	$\Delta H = 15.6893 - 7.29265\,D + 1.71638\,D^2 - .128068\,D^3 + 4.01614\,\Delta D - .12022\,H$	0.382	1.396	69

Where D = Initial dbh ob in inches
ΔD = 3-year dbh increment in inches
H = initial height in feet
ΔH = 3-year height increment in feet

Appendix III. Merchantable Volume Factor Equations

		R^2	SEE	OBS
Douglas-fir:	$MVF = 5.03815 - 11.7506/D - 1.45218 \log_e D + .4295E{-}01D$	0.996	0.003	30
Western Red Cedar:	$MVF = 4.14084 - 9.23764/D - 1.48923 \log_e D + .3328E{-}01D$	0.992	0.003	30
Western Hemlock:	$MVF = 5.09995 - 11.6013/D - 1.48924 \log_e D + .4470E{-}01D$	0.990	0.004	30
Balsam:	$MVF = 2.01059 - 3.84346/D - 0.33031 \log_e D + 0.7052E{-}02D$	1.000	0	30
Western White Pine:	$MVF = 5.07592 - 11.5685/D - 1.47520 \log_e D + 0.4386E{-}01D$	0.990	0.004	30
Lodgepole Pine:	$MVF = 4.91080 - 11.0779/D - 1.41706 \log_e D + 0.41832E{-}01D$	0.989	0.003	30

where: MVF = Merchantable Volume Factor

D = dbh in inches

For dbh values greater than 30 inches (75 cm),the above relationships do not apply

Appendix IV. Actual gross and merchantable volume by treatments.

	Treatments								
	T_0F_0	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
1. Gross volumes (G. Vol).									
(a) G. Vol. just after treatment									
(1971 & 1972) (m^3/plot)	5.67	5.28	4.01	3.48	3.41	3.36	1.81	1.93	1.84
(1971 & 1972) (m^3/ha)	140.11	130.47	99.09	85.99	84.26	83.02	44.73	47.69	45.47
(b) G. Vol. 3 yrs after treatment									
(1973 & 1974) (m^3/plot)	7.66	7.96	6.87	4.90	5.74	6.17	2.71	3.53	3.82
(1973 & 1974)(m^3/ha)	189.28	196.70	169.76	121.08	141.84	152.46	66.97	87.23	94.39
(c) 3-yr. G. Vol. Increment (m^3/ha)	49.17	66.23	70.67	35.09	57.58	69.44	22.24	39.54	48.92
(d) G. Vol. PAI m^3/ha/a	16.39	22.08	23.56	11.70	19.19	23.15	7.41	13.18	16.31
(e) 3-yr G. Vol Increment expressed as a % of Initial G. Vol.	35	51	71	41	68	84	50	83	108
2. Merchantable volume (M. vol).									
(a) M. Vol. just after treatment									
(1971 & 1972) (m^3/plot)	1.70	2.05	1.09	1.37	1.42	1.20	0.75	0.82	0.80
(1971 & 1972) (m^3/ha)	42.01	50.66	26.93	33.85	35.09	29.65	18.53	20.26	19.77
(b) M. Vol. 3 yrs after treatment									
(1973 & 1974) (m^3/plot)	3.02	4.13	3.12	2.52	3.38	3.58	1.59	2.37	2.69
(1973 & 1974)(m^3/ha)	74.63	102.05	77.10	62.27	83.52	88.46	39.29	58.56	66.47
(c) 3-yr. M. Vol. Increment (m^3/ha)	32.62	51.39	50.17	28.42	48.43	58.81	20.76	38.30	46.70
(d) M. Vol. PAI m^3/ha/a	10.87	17.13	16.72	9.47	16.14	19.60	6.92	12.77	15.57
(e) 3-yr M. Vol increment expressed as a % at Initial M. Vol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix V. Regression equations by treatments for periodic annual increment* (dbh, ba, height and gross volume).

Treatment 1 - No thinning, no fertilizer - control (T_0F_0)

dbh increment	$= -.974146E{-}01 + .577276E{-}01\ D + .714099E{-}02\ D^2 - .210021E{-}03\ D^3$	$R^2 = 0.910$	SEE = 0.170 cm
ba increment	$= 1.97163 - 1.33575\ D + .312093\ D^2 - .343055E{-}02\ D^3$	$R^2 = 0.962$	SEE = 2.778 cm^2
ht increment	$= -2.17695 - .222983\ D + 1.85859\sqrt{D}$	$R^2 = 0.899$	SEE = 0.188 m
g. vol. increment	$= .207588E{-}02 - .140348E{-}02\ D + .274674E{-}03\ D^2 + .152464E{-}06\ D^3$	$R^2 = 0.976$	SEE = 0.00238 m^3

Treatment 2 - Intermediate thinning, no fertilizer (T_1F_0)

dbh increment	$= .236009 + .605829E{-}01\ D + .664385E{-}02\ D^2 - .239914E{-}03\ D^3$	$R^2 = 0.782$	SEE = 0.250 cm
ba increment	$= 2.85841 - 1.14992\ D + .370266\ D^2 - .702178E{-}02\ D^3$	$R^2 = 0.928$	SEE = 4.571 cm^2
ht increment	$= .133187 + .244382E{-}01\ D + .272323\sqrt{D}$	$R^2 = 0.638$	SEE = 0.225 m
g.vol.increment	$= .135467E{-}01 - .516787E{-}02\ D + .693547E{-}03\ D^2 - .138218E{-}04\ D^3$	$R^2 = 0.962$	SEE = 0.00352 m^3

Treatment 3 - Heavy thinning, no fertilizer (T_2F_0)

dbh increment	$= .660648 + .362881E{-}01\ D + .946352E{-}02\ D^2 - .26118E{-}03\ D^3$	$R^2 = 0.735$	SEE = 0.298 cm
ba increment	$= 6.78747 - 1.46103\ D + .421625\ D^2 - .511770E{-}02\ D^3$	$R^2 = 0.910$	SEE = 6.374 cm^2
ht increment	$= -1.99305 - .993987E{-}01\ D + 1.24963\sqrt{D}$	$R^2 = 0.704$	SEE = 0.196 m
g. vol. increment	$= .241986E{-}04 - .834813E{-}03\ D + .262510E{-}03\ D^2 + .198366E{-}05\ D^3$	$R^2 = 0.937$	SEE = 0.00520 m^3

Where D = initial dbh

* For healthy Douglas-fir trees only, during the first 3 years following treatment.

Appendix V. - (Continued)

Treatment 4 - No thinning, 224 kg N/ha (UREA) (T_0F_1)

dbh increment	$= -.540657 + .171747\ D + .590209E{-}02\ D^2 - .326519E{-}03\ D^3$	$R^2 = 0.902$	SEE = 0.284 cm
ba increment	$= .211955 - 1.78341\ D + .535733\ D^2 - .113177E{-}01\ D^3$	$R^2 = 0.956$	SEE = 5.196 cm^2
ht increment	$= -3.61150 - .326040\ D + 2.78185\sqrt{D}$	$R^2 = 0.904$	SEE = 0.241 m
g. vol. increment	$= -.204721E{-}02 - .746480E{-}03\ D + .327693E{-}03\ D^2 - .543608E{-}06\ D^3$	$R^2 = 0.970$	SEE = 0.00478 m^3

Treatment 5 - Intermediate thinning, 224 kg N/ha (UREA) T_1F_1)

dbh increment	$= -1.68019 + .694618\ D - .436668E{-}01\ D^2 + .112432E{-}02\ D^3$	$R^2 = 0.842$	SEE = 8.300 cm
ba increment	$= -13.5425 + 3.54797\ D + .120953\ D^2 + .850344E{-}03\ D^3$	$R^2 = 0.948$	SEE = 5.526 cm^2
ht increment	$= -3.41347 - .383012\ D + 2.93120\sqrt{D}$	$R^2 = 0.750$	SEE = 0.226 m
g. vol. increment	$= -.806577E{-}02 + .123582E{-}02\ D + .218784E{-}03\ D^2 + .3002E{-}05\ D^3$	$R^2 = 0.970$	SEE = 0.00430 m^3

Treatment 6 - Heavy thinning, 224 kg N/ha (UREA) (T_2F_1)

dbh increment	$= -.440710E{-}01 + .375256\ D - .805925E{-}02\ D^2 - .599618E{-}04\ D^3$	$R^2 = 0.663$	SEE = 0.420 cm
ba increment	$= 6.41071 - 2.04275\ D + .900910\ D^2 - .249876E{-}01\ D^3$	$R^2 = 0.882$	SEE = 9.292 cm^2
ht increment	$= -2.34037 - .190155\ D + 1.89764\sqrt{D}$	$R^2 = 0.601$	SEE = 0.282 m
g. vol. increment	$= .843273E{-}01 - .278389E{-}01\ D + .323514E{-}02\ D^2 - .920728E{-}04\ D^3$	$R^2 = 0.928$	SEE = 0.00731 m^3

Where D = Initial dbh

Appendix V. - (Continued)

<u>Treatment 7</u> - No thinning, 448 kg N/ha (UREA) (T_0F_2)

dbh increment	$= -.689723 + .28893\,D + .188379E{-}02\,D^2 - .35256E{-}03\,D^3$	$R^2 = 0.876$	SEE = 0.354 cm
ba increment	$= .305585 - 1.85377\,D - .699177\,D^2 - .164247E{-}01\,D^3$	$R^2 = 0.948$	SEE = 5.679 cm^2
ht increment	$= -2.95691 - .283620\,D + 2.54709\,\sqrt{D}$	$R^2 = 0.806$	SEE = 0.350 m
g. vol. increment	$= -.309193E{-}02 + .166963E{-}03\,D + .209036E{-}03\,D^2 + .102819E{-}04\,D^3$	$R^2 = 0.969$	SEE = 0.00448 m^3

<u>Treatment 8</u> - Intermediate thinning, 448 kg N/ha (UREA) (T_2F_2)

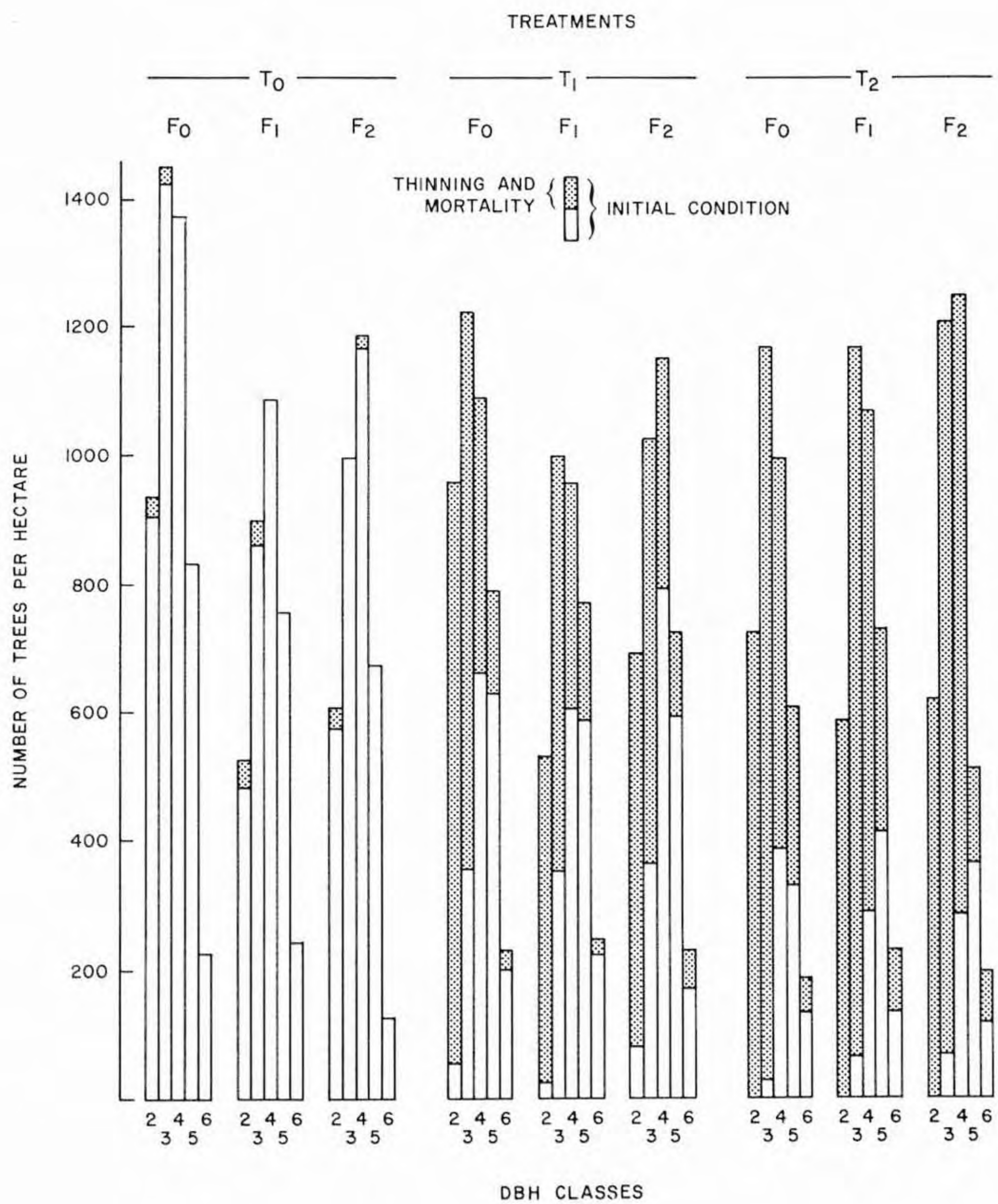
dbh increment	$= -1.37516 + .641372\,D - .307590E{-}01\,D^2 + .550762E{-}03\,D^3$	$R^2 = 0.758$	SEE = 0.456 cm
ba increment	$= -14.6545 + 3.46806\,D + .324712\,D^2 - .800922E{-}02\,D^3$	$R^2 = 0.912$	SEE = 8.518 cm^2
ht increment	$= -2.77389 - .354948\,D + 2.68469\,\sqrt{D}$	$R^2 = 0.694$	SEE = 0.240 m
g. vol. increment	$= -.112684E{-}01 + .186060E{-}02\,D + .282227E{-}03\,D^2 - .370685E{-}07\,D^3$	$R^2 = 0.952$	SEE = 0.00626 m^3

<u>Treatment 9</u> - Heavy thinning, 448 kg N/ha (UREA) (T_2F_2)

dbh increment	$= -1.76030 + 1.08279\,D - .748073E{-}01\,D^2 + .188795E{-}02\,D^3$	$R^2 = 0.564$	SEE = 0.494 cm
ba increment	$= -52.0512 + 16.9697\,D - .767295\,D^2 + .232243E{-}01\,D^3$	$R^2 = 0.874$	SEE = 11.460 cm^2
ht increment	$= .91745 - .958132E{-}01\,D + .729252\,\sqrt{D}$	$R^2 = 0.043$	SEE = 0.383 m
g. vol. increment	$= -.203059E{-}02 - .567197E{-}03\,D + .707374E{-}03\,D^2 - .152308E{-}04\,D^3$	$R^2 = 0.911$	SEE = 0.00989 m^3

Where D = Initial dbh

Appendix VI. Dbh frequency distributions by treatments showing initial condition and number of trees lost through thinning and mortality (cross hatched).



Appendix VII. PAI for dbh by dbh classes and treatments.

Initial dbh		Treatments								
Class	Midpoint (cm)	T_0F_0 Control	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
		a) Total dbh increment/tree* (cm)								
2	6.25	0.16	0.23	0.37	0.27	0.41	0.52	0.40	0.66	0.85
3	8.75	0.27	0.40	0.58	0.37	0.60	0.75	0.51	0.86	1.08
4	11.25	0.39	0.56	0.77	0.47	0.74	0.91	0.63	1.02	1.21
5	13.75	0.50	0.70	0.91	0.57	0.85	1.02	0.76	1.15	1.30
		b) Dbh increment gain above control (cm)								
2	6.25	0.00	0.06	0.20	0.11	0.25	0.36	0.23	0.49	0.68
3	8.75	0.00	0.13	0.31	0.10	0.33	0.48	0.24	0.59	0.81
4	11.25	0.00	0.17	0.38	0.09	0.35	0.52	0.25	0.64	0.83
5	13.75	0.00	0.20	0.41	0.07	0.35	0.52	0.26	0.65	0.80

*Derived from regression equations Appendix V.

Appendix VIII. PAI for ba by dbh classes and treatments

Initial dbh		Treatments								
Class	Midpoint (cm)	T_0F_0 Control	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
		a) Total ba increment/tree* (cm^2)								
2	6.25	1.66	2.41	4.01	2.81	4.52	5.92	4.29	7.58	9.90
3	8.75	3.96	6.01	8.87	5.48	9.11	11.73	7.62	13.59	17.75
4	11.25	7.19	10.61	14.85	8.93	14.30	18.02	12.14	20.62	24.94
5	13.75	11.23	15.85	21.43	12.93	20.11	24.53	17.70	27.90	32.20
		b) Ba increment gain above control (cm^2)								
2	6.25	0.00	0.75	2.35	1.15	2.86	4.26	2.63	5.92	8.24
3	8.75	0.00	2.05	4.91	1.52	5.15	7.77	3.66	9.63	13.79
4	11.25	0.00	3.43	7.66	1.74	7.11	10.83	4.95	13.44	17.75
5	13.75	0.00	4.62	10.20	1.70	8.88	13.30	6.47	16.67	20.97

*Derived from regression equations Appendix V.

Appendix IX. PAI for height by dbh classes and treatments

Initial dbh		Treatments								
Class	Midpoint (cm)	T_0F_0 Control	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
		a) Total height increment/tree (m)*								
2	6.25	0.36	0.44	0.55	0.32	0.51	0.57	0.17	0.41	0.71
3	8.75	0.46	0.59	0.70	0.38	0.64	0.69	0.28	0.54	0.75
4	11.25	0.52	0.68	0.80	0.44	0.70	0.74	0.36	0.63	0.76
5	13.75	0.55	0.74	0.86	0.49	0.73	0.77	0.42	0.69	0.77
		b) Height increment gain above control (m)								
2	6.25	0.00	0.08	0.19	–0.04	0.15	0.21	–0.19	0.05	0.36
3	8.75	0.00	0.13	0.24	–0.07	0.18	0.23	–0.18	–.08	0.29
4	11.25	0.00	0.17	0.28	–0.08	0.19	0.23	–0.16	0.11	0.25
5	13.75	0.00	0.19	0.31	–0.06	0.18	0.22	–0.12	0.14	0.22

* Derived from regression equations Appendix V.

Appendix X. PAI for gross volume by dbh classes and treatments.

Initial dbh		Treatments								
Class	Midpoint (cm)	T_0F_0 Control	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
		a) Total gross volume increment/tree (m^3)*								
2	6.25	0.0014	0.0020	0.0029	0.0017	0.0030	0.0038	0.0018	0.0047	0.0061
3	8.75	0.0036	0.0054	0.0071	0.0041	0.0072	0.0089	0.0047	0.0089	0.0123
4	11.25	0.0071	0.0101	0.0133	0.0078	0.0126	0.0151	0.0089	0.0165	0.0198
5	13.75	0.0117	0.0161	0.0218	0.0126	0.0194	0.0225	0.0144	0.0261	0.0281
		b) Gross volume increment gain above control (m^3)								
2	6.26	0.0000	0.0006	0.0015	0.0003	0.0016	0.0024	0.0005	0.0034	0.0048
3	8.75	0.0000	0.0017	0.0034	0.0004	0.0035	0.0052	0.0011	0.0053	0.0087
4	11.25	0.0000	0.0030	0.0062	0.0007	0.0055	0.0080	0.0018	0.0094	0.0127
5	13.75	0.0000	0.0044	0.0101	0.0009	0.0077	0.0108	0.0027	0.0129	0.0164

* Derived from regression equations Appendix V.

Appendix XI. Tree frequency distributions by dbh class and treatment used in stand structure analysis. (a) Actual tree frequency distributions by treatments as they occur.

Initial dbh		Number of trees by treatment								
Class	Midpoint (cm)	T_0F_0	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
1	3.75	36	20	24	2	2	3	0	0	0
2	6.25	58	35	40	14	14	15	1	2	3
3	8.75	56	44	47	27	24	32	16	11	12
4	11.25	34	30	27	26	24	24	13	17	15
5	13.75	9	10	5	8	9	7	5	5	5
6	16.25	1	2	2	2	2	2	1	1	2
7	18.75	1	2	0	0	0	0	0	0	0

(b) Mean tree frequency distributions for each thinning level.

Initial dbh		Number of trees by treatment								
Class	Midpoint (cm)	T_0F_0	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
1	3.75	26	26	26	2	2	2	0	0	0
2	6.25	44	44	44	14	14	14	2	2	2
3	8.75	49	49	49	28	28	28	13	13	13
4	11.25	30	30	30	24	24	24	15	15	15
5	13.75	8	8	8	8	8	8	5	5	5
6	16.25	2	2	2	2	2	2	1	1	1
7	18.75	1	1	1	0	0	0	0	0	0

Appendix XI (Continued)

(c) Hypothetical tree frequency distribution.

Initial dbh		Number of trees by treatment								
Class	Midpoint (cm)	T_0F_0	T_0F_1	T_0F_2	T_1F_0	T_1F_1	T_1F_2	T_2F_0	T_2F_1	T_2F_2
1	3.75	0	0	0	0	0	0	0	0	0
2	6.25	3	3	3	3	3	3	3	3	3
3	8.75	10	10	10	10	10	10	10	10	10
4	11.25	14	14	14	14	14	14	14	14	14
5	13.75	5	5	5	5	5	5	5	5	5
6	16.25	2	2	2	2	2	2	2	2	2
7	18.75	0	0	0	0	0	0	0	0	0

Appendix XII. Actual and adjusted PAI for gross volume by covariance analysis using the 395 and 618 largest trees per hectare (m^3)

Treatment	Actual	Gain over Actual Control	% Gain above Actual Control	Adjusted	Gain over Adjusted Control	% Gain above Adjusted Control
a) 395 largest trees/ha						
T_0F_0 (control)	4.525	0	0	4.040	0	0
T_0F_1	7.691	3.165	70.0	5.483	1.443	35.7
T_0F_2	6.958	2.433	53.8	7.875	3.835	94.9
T_1F_0	4.817	0.292	6.5	4.270	0.230	5.7
T_1F_1	7.724	3.199	70.7	7.286	3.246	80.3
T_1F_2	8.291	3.766	83.2	8.309	4.269	105.7
T_2F_0	4.627	0.102	2.2	5.598	1.558	38.6
T_2F_1	7.962	3.437	76.0	8.954	4.913	121.6
T_2F_2	9.560	5.035	111.3	10.340	6.300	156.0
b) 618 largest trees/ha						
T_0F_0 (Control)	6.116	0	0	5.095	0	0
T_0F_1	10.235	4.119	67.4	7.518	2.423	47.6
T_0F_2	9.683	3.567	58.3	10.702	5.607	110.0
T_1F_0	6.506	0.390	6.4	5.680	0.594	11.7
T_1F_1	10.690	4.574	74.8	9.855	4.760	93.4
T_1F_2	11.637	5.522	90.3	11.481	6.386	125.3
T_2F_0	6.185	0.069	1.1	7.862	2.767	54.3
T_2F_1	10.896	4.780	78.2	12.312	7.216	141.6
T_2F_2	13.226	7.110	116.3	14.660	9.565	187.7

Covariates = Initial mean height and initial mean dbh.