AN ABSTRACT OF THE THESIS OF

Abdel Azim Zumrawi for the degree of Doctor of Philosophy in Forest Resources presented on March 1, 1990

Title: Examining Bias in Estimating the Response Variable and Assessing the Effect of Using Alternative Plot Designs to Measure Predictor Variables in Diameter Growth Modeling

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David W. Hann

Diameter growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) estimated from increment cores was compared with that obtained from repeated measurements of tree diameter on permanent plots located in two Douglas-fir study areas in the central Coast Range of Oregon. Growth was measured for a 6-year period (1979-1985). Diameter growth measured from two increment cores taken opposite to each other, provided an unbiased estimate of the stand average diameter-growth as determined from repeated measurements of diameter. However, a statistically significant trend was found in the differences in individual tree diameter-growth between the two methods of measurements. A nonlinear model was used to characterize these differences. The practical significance of the observed trend and the use of the developed model as a calibration tool, depend upon the reliability desired by the particular user.

The second part was a simulation study to examine the effect upon growth model predictions of using alternative sample plot designs to measure predictor variables. Five forest stands were generated through computer simulation by use of field data and random spatial distributions. Two variable-radius plot designs and four fixed-radius circular plots were used to sample simultaneously the generated stands . Sample data then were used to simulate diameter and gross-basal-area growth in both a single-tree/distance-independent growth model and a whole-stand/diameter-free growth model. In comparing the growth predictions of each model, the plot design used to develop the model was the standard against which alternative plot designs were evaluated. Both fixed and variable area plots provide, with varying degree of precision, unbiased estimates of stand-level predictor variables. For both models, average gross basal area growth-rate predictions from 50 samples of each alternative design were not significantly different from the standard design. However, large differences in individual predictions may occur as a result of using a different plot design. The magnitude of these differences depend on the stand size and density.

EXAMINING BIAS IN ESTIMATING THE RESPONSE VARIABLE AND ASSESSING THE EFFECT OF USING ALTERNATIVE PLOT DESIGNS TO MEASURE PREDICTOR VARIABLES IN DIAMETER GROWTH MODELING.

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GENERAL INTRODUCTION

In growth and yield modeling, a diameter-growth equation is a basic component of all single-tree (Munro 1974) growth and yield models (Wykoff et al. 1982, Holdaway 1984, Wensel et al. 1987, Hann and Larsen 1990). Diameter-growth predictions are essential to estimate volume growth and yield of a stand and to provide information on tree size and timber quality. The performance of a single-tree growth-and-yield model therefore is expected to be influenced greatly by the diameter-growth equation.

Diameter growth of individual tree is usually modeled as a function of the characteristics of both the stand and the tree. Precise estimation of the stand-level predictor variables used in diameter-growth equations thus is essential for reliable predictions of growth and yield. In developing diameter-growth equations, the dependent variable is often derived from measurements of increment cores , under the assumption that radial-growth measurements from increment cores are reliable estimates of diameter or basal area growth (Amidon and Dolph 1979, Wykoff et al. 1982, Ritchie and Hann 1985, Dolph 1988, Hann and Larsen 1990)

I examined possible trends in Douglas-fir diameter growth measured on increment cores from standing trees, when compared with that measured from repeated measurements of diameter over time. Regression analysis was used to develop a calibration equation to predict actual growth in diameter from radial growth measured on increment cores.

A computer simulation study was conducted to assess the effect of using alternative plot designs, to measure independent variables, upon predicted tree diameter and stand basal-area growth rates. Six plot designs, including both fixed-radius and variable-radius plots, were used to sample the computer-generated stands in this study. Predictions of individual tree diameter-growth rate and gross growth rate of stand basal area, from the ORGANON single-tree/distance-independent growth and yield model (Hester et al. 1989) and predictions of gross growth rate in stand basal area from the DFSIM whole-stand/diameter-free model (Curtis et al. 1981) were used as basis in this assessment.

SECTION I

EXAMINING BIAS IN ESTIMATING DIAMETER GROWTH FROM INCREMENT BORINGS.

ABSTRACT

Diameter growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) trees, estimated for 6 years from increment cores, was compared with that from repeated measurements of tree diameter, on permanent plots located in two Douglas-fir study areas in the central Coast Range of Oregon. Increment cores provided a means of obtaining unbiased estimates of the actual diameter-growth of the stand as determined from repeated measurements of diameter with a diameter tape. However, a statistically significant trend between the two methods was found for the diameter growth of the individual trees. Measurements from increment cores overestimated actual diameter-growth in slow growing trees and underestimated it for fast growing trees. A nonlinear calibration-model was used to characterize the differences in diameter growth as measured by the two methods. The practical significance of the observed differences and the use of the developed model to correct the bias in increment-cores measurements, depend upon the reliability desired by the particular user.

INTRODUCTION

Measurements of tree diameter growth play an important role in the practice of forestry. Use of diameter-growth measurements to make simple stand-table projections has a long history (Wahlenberg 1941, Avery and Burkhart 1983). Diameter-growth measurements also are essential for developing all of the different types of modern growth-and-yield models described by Munro (1974). When converted into an estimate of basal area growth and divided by an estimate of the sapwood area of the tree at crown base, diameter growth can provide a useful measure of tree vigor (Waring et al. 1980).

Diameter-growth measurements can come from repeated measurements of diameter on permanent plots, from stem analysis, or from increment cores. Avery and Burkhart (1983) ranked the first two as being more reliable than the last. Unfortunately, permanent sample plots do not always exist in adequate number to meet needs; stem analysis techniques can be difficult and costly to perform. As a result, measurement of diameter growth through the use of increment cores was used widely (Amidon and Dolph 1979, Wykoff et al. 1982, Ritchie and Hann 1985, and Hann and Larsen 1990).

There have been several previous studies directed at determining the number and position of radial-growth increments, that would minimize the variation in estimating either mean inside bark radial-increment or mean inside bark basal-area increment. Amidon and Dolph (1979) found that, when compared to one core, two increment cores at right angles to each other reduced within-tree variability in estimating average inside bark radial-growth. Matern (1962) examined the number and placement of radial-growth measurements on disks removed in stem analysis and concluded that two measurements opposite of each other produced better estimates of average radial-increment than two at right angles or four positioned randomly. Biging and Wensel (1988) found that an unbiased estimate of basal-area growth could be determined by measuring one or two radial increments along the minor axis.

Given an unbiased measurement of inside bark radial-increment, outside bark diameter-growth then can be estimated by use of either a direct measurement of bark thickness on the tree or an indirect estimate from an equation such as given in Ritchie and Hann (1984). However, outside-bark diameter itself frequently is determined by use of a diameter-tape to measure the circumference of the tree, and to convert the circumference into a diameter based on the assumption that the bole of the tree is circular. Measurement of diameter growth by repeated application of a diameter-tape , therefore, could produce an estimate that differs from that obtained from an increment core (or cores). If a difference in the estimates existed, then use of a diameter-growth estimate from an increment core(s) to estimate the future outside-bark diameter as determined from a diameter-tape could produce a biased estimate of that diameter, which could lead to biased estimates of volume.

Therefore, the first objective of this study was to compare estimates of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) diameter-growth from increment cores to actual growth in diameter obtained from repeated measurements of tree diameter over time to determine if significant differences existed between the two methods. If significant systematic differences were found, then the second objective was to develop a method for reducing or eliminating the differences.

DATA

The data used in this study were collected in the summer 1988 from Douglas-fir plots on the Burnt Woods and Black Rock Experimental Forests located in the central Coast Range of Oregon. The plots were established between 1952 and 1962 at Black Rock and in 1959 at Burnt Woods as part of thinning study conducted by Oregon State University. In 1988, the Black Rock plots were 64 to 72 years old, breast height age, and the Burnt Woods plots were 56 years old. King's (1966) site class on Black Rock ranges from II to IV, with most of the area in class III. Burnt Woods is in King's (1966) site class I. The treatments consisted of light, moderate, and heavy repeat thinnings and controls. The last thinnings occurred in 1970 at Burnt Woods and in 1976 at Black Rock.

For this study, radial-growth data were collected from all trees on all of the eight one-tenth acre plots on the Burnt Woods Experimental Forest and on six of the one-quarter acre plots and one of the one-acre plots (plot 32) on the Black Rock Experimental Forest. The selected plots covered all of the stand conditions resulting from the past thinning treatments. Two increment cores were extracted from each tree, with the first boring being on the side of the tree facing the plot center and the second on the opposite side. On each core, six-year radial growth for the period 1979 to 1985 was measured in the field to the nearest 1/40 of an inch with the aid of a ten-power hand lens. Six-year Diameter growth ranged from 0.0 to 2.7 inches in the Burnt Woods area and from -0.1 to 3.2 inches in the Black Rock area (Table I.1). These data then were combined with diameters at breast height measured in 1979 and 1985 by use of a diameter tape. Previously collected bark-thickness data for Douglas-fir in the Burnt Woods study area were extracted from the files at Oregon State University.

Table I.1: Summary of the Douglas-fir 6-year diameter growth data.

Study Area	Species	No. of Obser.	Diameter (Inches)			Diameter growth (Inches)		
			Min.	Mean	Max.	Min.	Mean	Max.
Burnt Woods	Douglas fir	175	6.1	12.3	20.2	0.00	0.99	2.70
Black Rock	Douglas fir	245	4.5	17.3	29.2	-0.10	1.22	3.20

ANALYSIS AND RESULTS

The following hypotheses were tested in this analysis:

1. A pair of inside bark radial-growth measurements can provide an unbiased estimate of outside bark diameter-growth as obtained from repeated measurements of diameter using a diameter-tape (RDGRO).
2. Differences between the two methods of measuring outside bark diameter-growth are random and are not related to tree size or rate of growth.

Inside bark diameter growth (IDGRO) was computed as the sum of the two radial growth measurements, and this value then was converted to an estimate of outside bark diameter growth (BDGRO) using the following:

$$BDGRO = IDGRO/a_1$$

Where,

a_1 = The regression coefficient from the relationship:

$$DIB = a_0 + a_1(DOB) \tag{1}$$

DIB = Diameter at breast height inside bark

DOB = Diameter at breast height outside bark

For the Black Rock area, existing Douglas-fir parameter estimates for equation (1) were used (Khan 1966). For the Burnt Woods area, bark-thickness data from the area were used to estimate the parameters of equation (1). From this fit, a_1 was estimated as being 0.92186 and the resulting adjusted coefficient of determination for equation (1) was 0.998.

The first hypothesis was tested by applying a paired t-test to the difference RDGRO minus BDGRO for each of the plots (table I.2). Of the 15 plots, the null hypothesis that the mean difference equaled zero was not rejected on 13 of the plots ($P = 0.01$). Because of this, the data were combined across all plots for the remainder of the analysis.

Table I.2: Paired *t*-tests for the mean of RDGRO-BDGRO by plot.

			Differences			
Installation	Plot	Number of Trees	Mean	Standard Error of Mean	*t*-Statistic	*p*-Value
Burnt Woods	1	27	0.0622	0.0343	1.8152	0.0814
	2	32	0.0540	0.0339	1.5921	0.1216
	3	12	0.0826	0.0403	2.0478	0.0638
	4	24	-0.1036	0.0428	-2.4184	0.0244
	5	17	0.0450	0.0416	1.0834	0.2952
	6	27	-0.1094	0.0290	-0.3768	0.7142
	7	14	0.0059	0.0536	0.1103	0.9138
	8	22	-0.1274	0.0343	-3.7109	0.0012
Black Rock	181	26	0.0969	0.0468	2.0704	0.0484
	182	19	0.0284	0.0799	0.3547	0.7300
	191	59	-0.0200	0.0190	-1.0551	0.2934
	192	47	0.0723	0.0300	2.4101	0.0204
	201	25	0.1209	0.0603	2.0060	0.0564
	202	28	0.1118	0.0404	2.7669	0.0098
	32	41	0.0275	0.0376	0.7318	0.4694

To test the second hypothesis, the differences, between RDGRO and BDGRO, were plotted over DOB at the start of the growth period (SDOB) and RDGRO in figures I.1 and I.2, respectively. A nonlinear trend in these differences was observed over RDGRO. In figure I.2, it can be seen that BDGRO overestimated RDGRO for trees with low RDGRO rates and underestimated RDGRO for trees with higher RDGRO rates.

To develop a bias-reduction formula, regression analysis then was used to model the differences in diameter-growth rate between the two methods of measurement as a function of RDGRO. RDGRO was chosen as the independent variable because it is considered to be the more reliable standard against which the alternative method (BDGRO) is being calibrated (Draper and Smith 1981). Based on the trends found in figure I.2, the following nonlinear model was developed:

$$\mathrm{BDGRO} = \mathrm{RDGRO} + b_0 + b_1\mathrm{EXP}(b_2\mathrm{RDGRO}) \qquad (2)$$

In this formulation, b_0 is the estimated difference between BDGRO and RDGRO when RDGRO is large, and b_0 plus b_1 is the estimated difference when RDGRO is zero.

Weighted, nonlinear least-squares regression analysis (Draper and Smith 1981) was used to estimate the parameters of the model. Because the variance increased with RDGRO, a weight of 1.0/RDGRO was used to homogenize the variance. All parameters in equation (2), are highly significant. The parameter estimates and their standard errors are presented in table I.3. The equation explains about 46 percent of the variation in the differences between the two methods of measurement.

Table I.3 Parameters estimates and their standard errors (*S*.*E*.) for equation (2).

Parameter	Estimate	*S*.*E*.	*t*-Statistic	*p*-value
B_0	-0.093874	0.017800	-5.2738	< 0.00001
B_1	0.313132	0.020288	15.4343	< 0.00001
B_2	-2.68221	0.459721	-5.8344	< 0.00001

Mean square error = 0.035305 Adj. $R^2 = 0.4616$

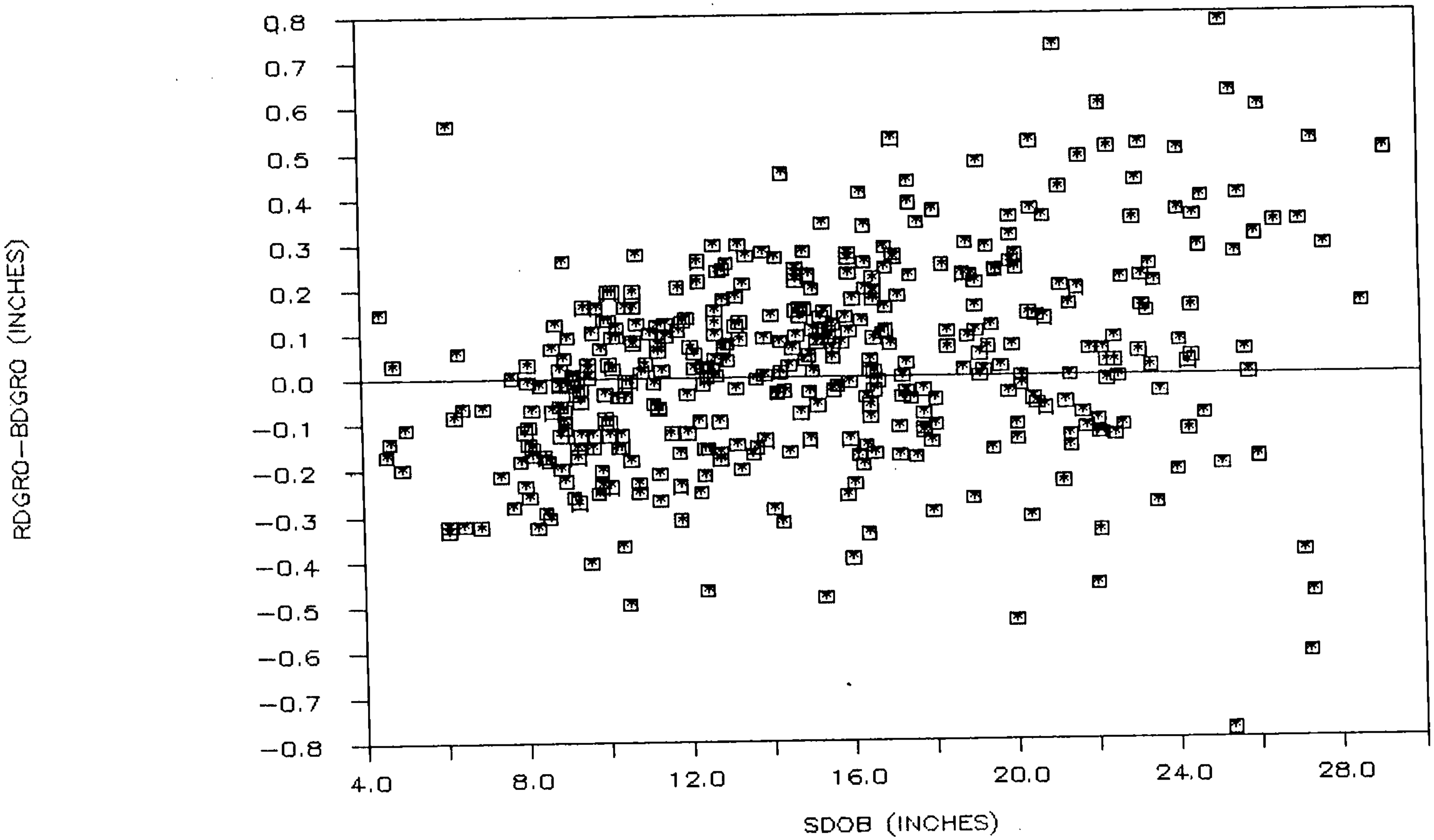

Figure I.1: Differences in tree diameter growth between increment borings (BDGRO) and repeated diameter measurements (RDGRO) plotted over tree diameter at breast height at the start of growth period (SDOB).

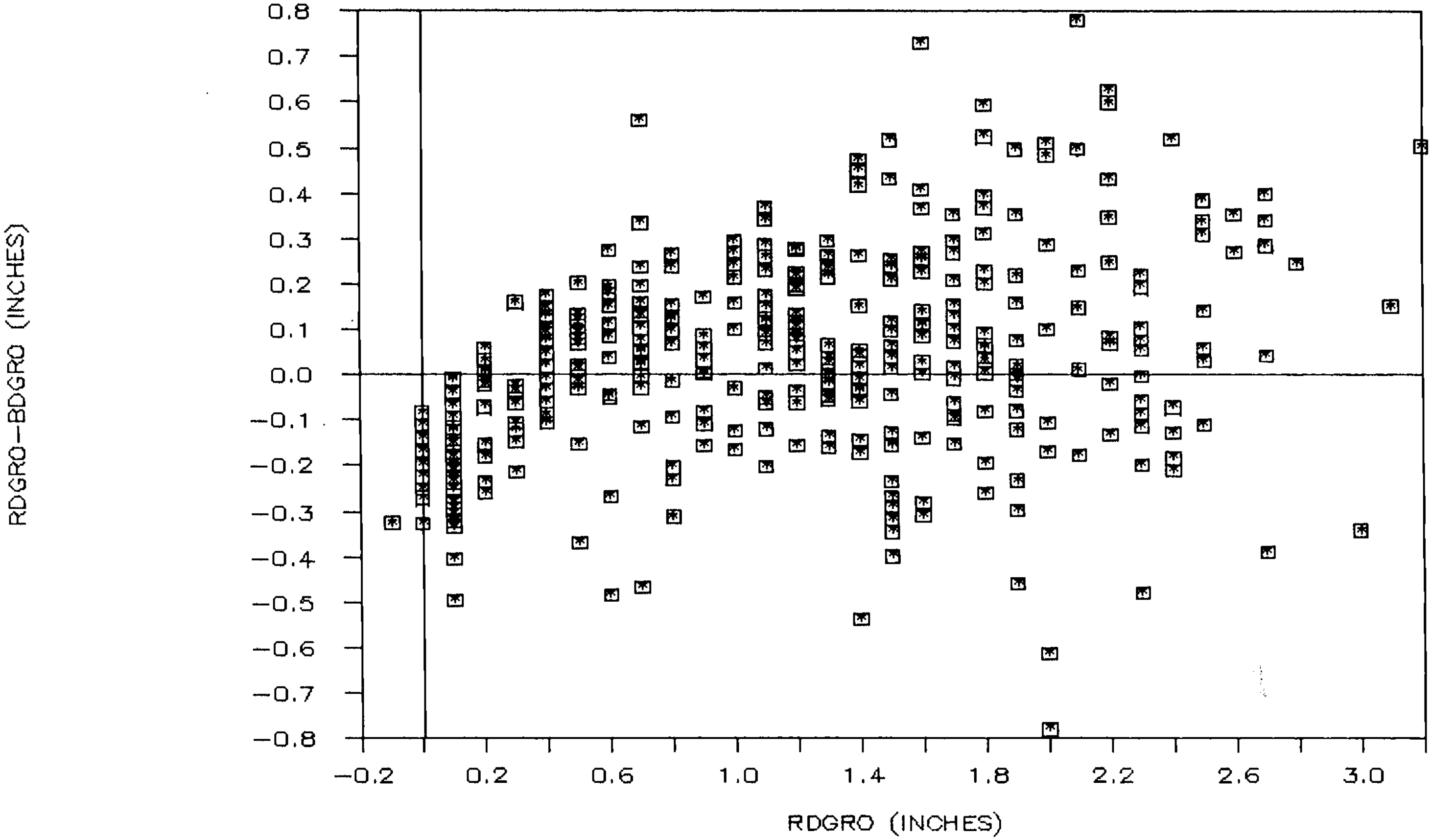

Figure I.2: Differences in tree diameter growth between increment borings (BDGRO) and repeated diameter measurements (RDGRO) plotted over RDGRO.

Given the calibration equation (2), it would be of interest to predict RDGRO from a measured value of BDGRO. If the relationship between BDGRO and RDGRO was linear, then one means of predicting RDGRO would be to algebraically invert the equation to express RDGRO as a function of BDGRO (Draper and Smith 1981). Unfortunately, equation (2) cannot be manipulated algebraically to give such a relationship. There are, however, solutions to this problem:

1. Use an iterative procedure on a computer or programmable calculator that screens across possible values of RDGRO to find one such that its use in equation (2) produces a prediction similar to the measured value of BDGRO
2. Develop a separate equation that can closely approximate the inverse of equation (2).

To develop an approximation equation for the inverse of equation (2), equation (2) was first used to predict BDGRO from RDGRO, with RDGRO being increased from zero to five inches by tenth-inch units. These predicted pairs of RDGRO and BDGRO values ($\widehat{RDGRO}$ and $\widehat{BDGRO}$) then were used to develop the following equation:

$$\widehat{RDGRO}=\widehat{BDGRO}-b_0-b_1EXP\{c_1[\widehat{BDGRO}-(b_0+b_1)]^{c2}\} \quad (3)$$

For convenience, nonlinear regression was used to estimate the parameters c_1 and c_2 (-3.40416 and 0.700566, respectively), even though both $\widehat{RDGRO}$ and $\widehat{BDGRO}$ are without error. In equation (3), the values for b_0 and b_1 are the estimates of the parameters in equation (2).

To ascertain the validity of the inverse approximation equation, the differences between the values of $\widehat{RDGRO}$ used to develop equation (3) and the $\widehat{RDGRO}$ values estimated from equation (3) were computed and plotted across the values used to develop the equation (figure I.3). All of the differences were within 0.002 inches, indicating that the inverse approximation equation was good.

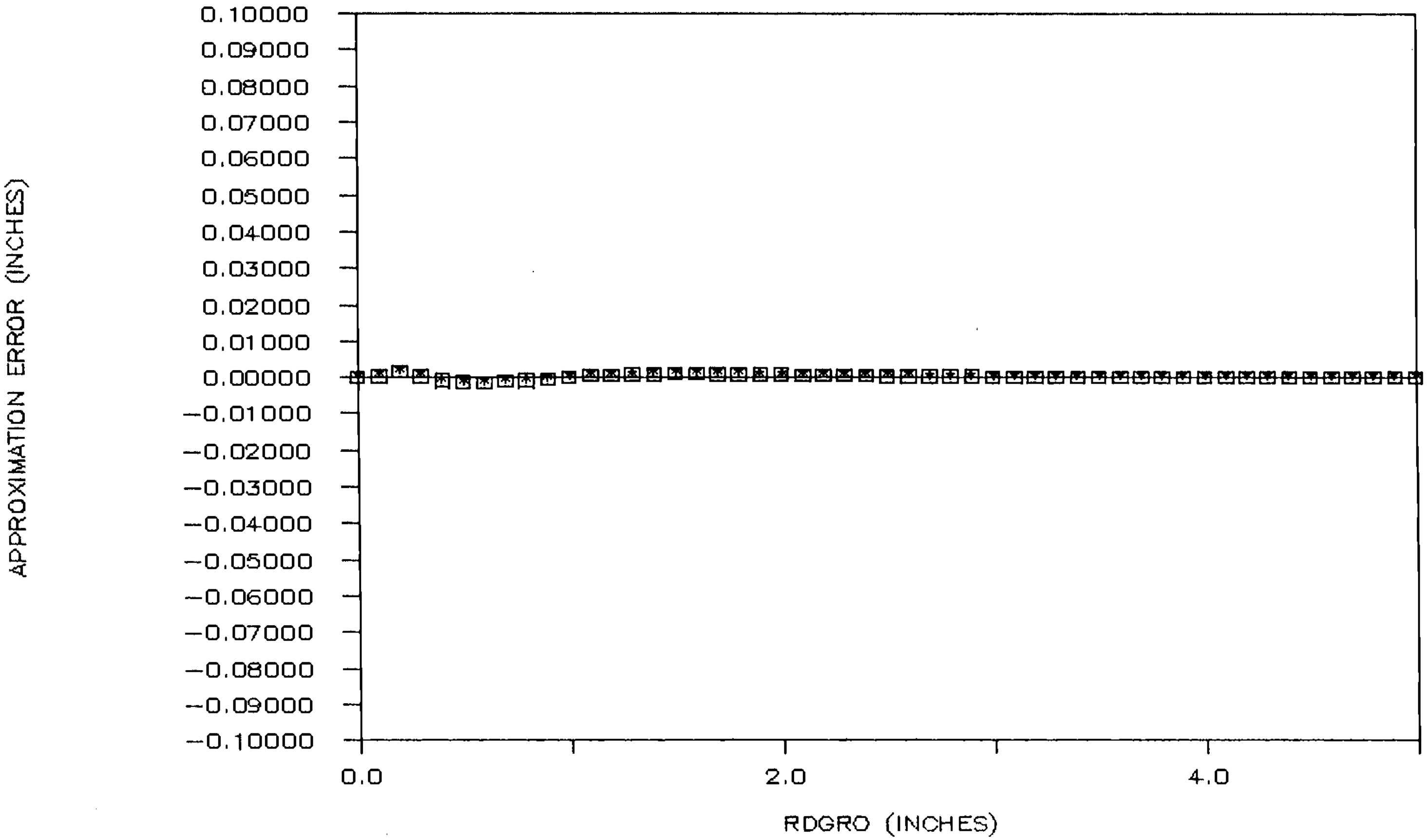

Figure I.3: Errors resulting from approximating the inverse of equation (2) by equation (3) plotted over growth rate values (RDGRO) used to develop equation (3).

DISCUSSION

Results of the analysis by paired t-test indicate that increment borings provide a means of obtaining unbiased estimates of the average diameter-growth in the stand as determined from repeated measurements with a diameter-tape. However, for individual trees in the stand, there appears to be a statistically significant trend to overestimate actual diameter-growth in slow growing trees and to underestimate it in fast growing trees. For example, in equation (2), for RDGRO of zero, BDGRO overestimates by 0.2 inches, and, for a RDGRO of three inches, BDGRO underestimates by 0.1 inches.

Whether this trend is of practical significance will depend upon the use and the reliability desired by the particular user. For making stand-table projections, perhaps errors of these magnitudes may not be of practical importance. For developing single-tree growth-and-yield models, a trend such as observed in this study may significantly distort the diameter growth equation(s), and validation of single-tree growth and yield models would be more difficult if the modeling data set were collected by one procedure and the validation data set were collected by the other.

The trend found in this study could be caused by missing, or missed, annual rings in trees with low growth rates and by pseudo annual rings in trees with higher growth rates. Therefore, the presence or magnitude of this trend possibly could differ from species to species, depending upon the likelihood of the species having missing or pseudo rings. Because all of the plots at Black Rock and Burnt Woods are middle aged, this trend possibly could differ by age for the same species.

The proposition that the trend observed in this study could have been caused by a misspecification of equation (1) was rejected because the measured IDGRO often exceeded the measured RDGRO for trees with low RDGRO rates and this finding cannot be explained by errors in estimating bark thickness.

Finally, increment cores were measured in the field by experienced inventory crews and under close supervision. Use of laboratory equipment and procedures such as those described by Monserud (1984) and Biging and Wensel (1984) conceivably may reduce or eliminate the trend found in this study.

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SECTION II

A SIMULATION STUDY ASSESSING THE EFFECT UPON GROWTH MODEL PREDICTIONS OF USING ALTERNATIVE PLOT DESIGNS TO MEASURE PREDICTOR VARIABLES

ABSTRACT

The effect upon growth-model predictions of using alternative-sample-plot designs to measure predictor variables was examined. Five forest stands were generated through computer simulation, based on field data (covering a range of stand conditions) and random spatial distributions. Two variable-radius-plot designs and four fixed-radius circular plots were used to sample simultaneously the generated stands. Sample data then were used to simulate diameter-growth and gross-basal-area-growth-rate predictions in both a single-tree/distance-independent growth and yield model and a whole-stand/diameter-free growth model. In comparing the models' growth predictions, the plot design used to develop the model was the standard against which alternative plot design were evaluated.

Both fixed-radius and variable-radius plots provide, with varying degree of precision, unbiased estimates of stand-level predictor variables. For both models, the average gross-basal-area-growth-rate predictions from 50 samples of each alternative design were not significantly different from the standard design. However, large differences in individual predictions may occur as a result of using a different plot design. The magnitude of these differences depend on the stand size and density.

INTRODUCTION

Growth-and-yield models provide predictions of future stand development and are used to evaluate different sivicultural prescriptions and management alternatives. The development of a tree depends upon its size and vigor, its relative position in the stand, and characteristics of the stand such as its density and site quality. Therefore, all single-tree and all whole-stand growth-and-yield models (Munro 1974) use stand-level information such as basal area, number of trees per acre and crown competition factor (Krajicek et al. 1961) as predictor variables in their growth-rate equations (Curtis et al. 1981, Wykoff et al. 1982, Holdaway 1984, Ritiche and Hann 1985, Wensel et al. 1987, Dolph 1988, Hann and Larsen 1990). In addition, indicators of the relative position of the tree in the stand, such as stand basal area in trees larger than the subject tree and crown competition factor in larger trees, also have been used as predictor variables in single-tree growth models (Wykoff et al. 1982, Ritiche and Hann 1985, Dolph 1988, Hann and Larsen 1990) .

In practice, the stand's population parameters, such as basal area per acre, are rarely known and, as a result, they are estimated from a sampling design. If variability in the size of trees and/or distribution of trees exists in a stand, then the sample estimates also differ from place to place in the stand. Furthermore, application of two plot designs at the same point in the stand usually result in different estimates of the stand's attributes, even if both designs are themselves unbiased estimators of these attributes. Therefore, the ability of the model to predict the development of a stand depends upon the sampling design used to measure the predictor variables in the model. Thus, sampling and modeling can be highly interrelated.

If one plot design is used to collect data to develop an equation and another design is used to apply the equation, the result may be to introduce stochastic predictor variables into the equation. From econometrics, it is well established that introducing variability into a predictor variable can produce biased estimates of the dependent variable (Kmenta 1971). Stage (1977) argued that one advantage of using inventory data to develop growth-and-yield models was that the predictor variables used to develop the model are automatically measured by the same methods that will be used to apply the model, therefore possible problems with biased predictions are avoided.

Although there have been a number of forestry studies concerning the effect of sample design and size on the precision of sample estimates, little work in forestry has been conducted on the effect of using alternative plot designs upon the accuracy and precision of predictions from equations or models. As examples of the former, empirical studies comparing systematic, stratified and simple random sampling have been conducted (Payandeh 1970a). Smith and Burkhart (1984) studied the effect of sample design and stratification scheme on yield estimates from simulated pine plantations. Their conclusions that greater precision can be obtained by either increasing sample size or by stratification were in general agreement with sampling theory (Cochran 1977). The effect of spatial distribution of the elements in a population on the relative performance of sampling designs was pointed out by Palley and O'Regan (1961). Payandeh (1970b) also incorporated the effect of spatial distribution in his evaluation of systematic and stratified sampling from computer generated stands.

Concerning plot design, both Vuokila (1965) and Smith (1975) found that decreasing fixed-area plot size resulted in increasing the variability in the estimates of stand attributes. Curtis (1983) suggested that highly variable estimates of stand parameters could bias estimates of regression parameters in growth equations. Jaakkola (1967) found that estimates of stand basal area varied between two plot designs centered at the same point in the stand, and that these basal-area differences also caused the parameter estimates for a simple growth-model to differ (though the difference was not statistically significant).

The objective of this study was to assess the effect upon growth-rate predictions of using six different sample plot designs to measure the predictor variables in both a single-tree and a whole-stand growth and yield models. The two growth models used were the southwest Oregon version of ORGANON (Hester et al. 1989), a single-tree/distance-independent (Munro, 1974) model, and the coastal Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) simulator, DFSIM (Curtis et al.; 1981), a whole-stand model. In assessing these effects, the design that came closest to the design used to develop the growth model was considered the standard against which the five alternative designs were evaluated.

METHODS

Computer simulation has often been used to examine sampling issues (e.g., Palley and O'Regan 1961, Payandeh 1970b and Smith and Burkhart 1984) because it allows quick and efficient sampling of a wide array of stand conditions with a large number of replications. The main disadvantage of using computer generated stands has been that they may not be an exact representation of the forest stands to be sampled (Newnham and Maloley 1970).

The main concern in this study was to compare the relative performance of different plot designs when sampling the same forest stand conditions. Therefore, I believe that producing an exact replication of a forest stand would be less critical in this type of relative comparison than it would be in a study examining the adequacy of a sampling design to characterize stand conditions. As a result, computer-simulation techniques were used to conduct the analysis.

To create a forest stand on a computer requires the following steps: (1) the spatial pattern of the stand must be determined (i.e., the coordinates of each tree in the stand must be determined), (2) a list of trees and their physical attributes (such as diameter at breast height, total height and crown ratio) must be generated, and (3) the trees must be assigned to the coordinates

(Sukwong et al. 1971). Fortran programs were developed for this analysis. The first program was used to create the desired spatial patterns. The second program generates and assigns a tree list to the points in the spatial distribution; it then samples the generated stands. A reliable and tested random number generator is an essential component of a computer simulation-program. The one chosen for this analysis was previously tested by Scharge (1979).

Generation of Spatial Patterns

The first stage in the simulation of the stands was to generate their spatial patterns. A distribution free approach similar to the one presented by Newnham (1968) and Newnham and Maloley (1970) was used to generate the spatial patterns. The program can produce a wide range of uniform, random and clumped (aggregated) patterns for populations of specified area and density. Only random patterns were used in this analysis for the following reasons:

1. All stands to be simulated were of natural origin therefore the uniform pattern was not appropriate.
2. To generate a clumped pattern required more information than did the random pattern. This information concerned the location pattern of

clump centers and the degree of aggregation of trees in a clump. Such information was lacking for the stands to be simulated.

3. This study was designed to explore for possible problems, and their magnitudes, caused by the use of alternative plot designs. The objective was not to definitively describe these effects for all possible stand spatial patterns and structures.

In the program, random patterns were generated by use of random numbers from a uniform (0,1) distribution. The random numbers were multiplied by the stand-area dimensions to determine the X and Y coordinates for each point. Because each point is to be occupied by a tree with physical dimensions, a minimum nearest-neighbor distance was imposed such that no two points (trees) may be closer than the specified minimum distance. Because of this restriction, the patterns generated were not random in the strict statistical sense. The minimum nearest-neighbor distances used in generating the stands ranged from 2.0 to 4.0 feet depending on the stand density and diameter distribution. An example of the random patterns used is shown in figure II.1.

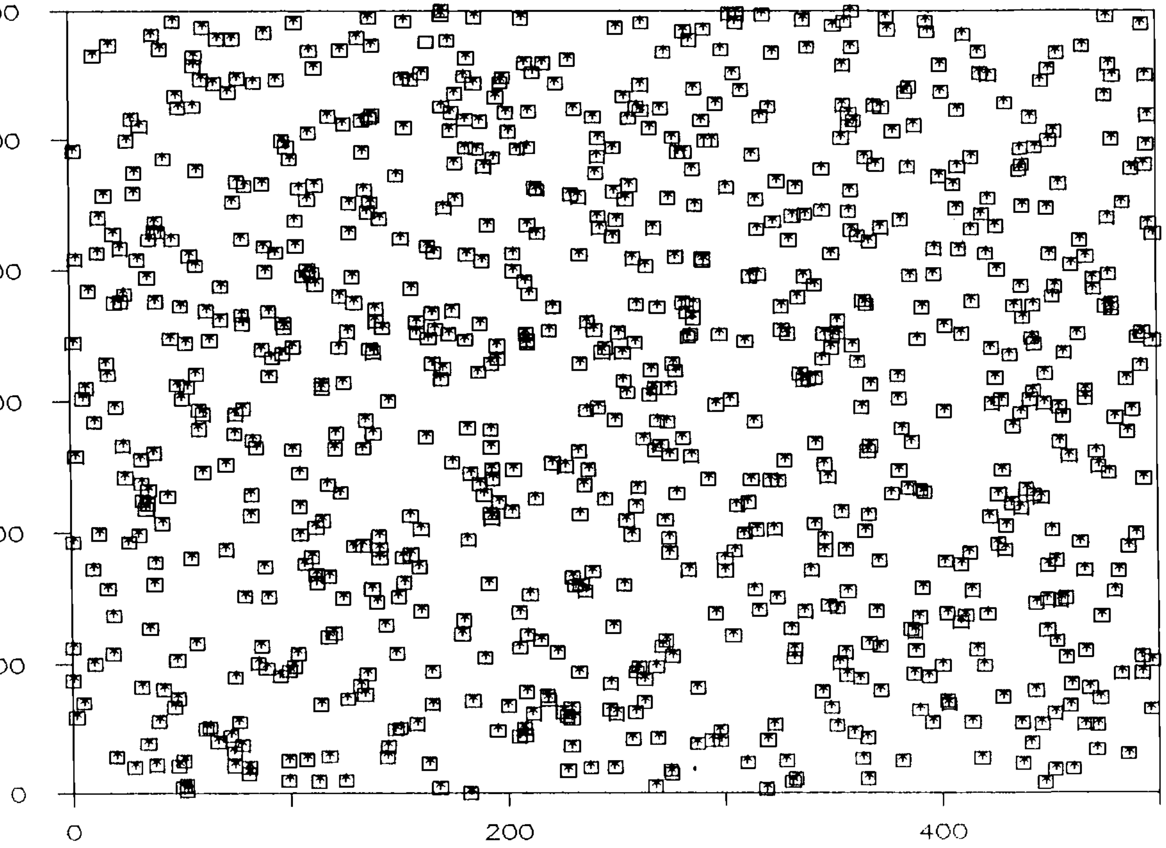

Figure II.1: An example of the random patterns used in generating the stands in this study. In this example, the random spatial pattern is composed of 500 points plotted in an area 600 units by 500 units.

Generating and Assigning Tree Variables

The second stage in the stand simulation was the generation and assignment of the individual tree characteristics to the coordinates. Rather than generating tree lists in the fashion of Sukwong et al. (1971) or Daniels et al. (1979), actual tree lists were selected from the 391 plots measured in the early 1980's from the mixed conifer stands of southwest Oregon. These plots were part of the Forestry Intensified Research (FIR) growth-and-yield project and were used to develop the southwest Oregon version of ORGANON (hereafter called SW-ORGANON).

Plot data from five Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)stands covering a range of ages, densities and site qualities were used to simulate the stands in this analysis. The study was restricted to stands with at least 80 percent of their basal area in Douglas-fir in order to use DFSIM. Measurements of each tree used in this study included diameter at breast height (DBH), total height (HT), crown length (CL) and a species code. A summary of the plot data is given in table II.1.

To assign a tree to a set of coordinates, it was assumed that a linear relationship existed between the DBH of a tree and the area it occupied (Newnham and

Maloley 1970). The area occupied by each point in the spatial distribution (a polygon area) was constructed by joining the bisectors of the lines connecting each point with it's immediate neighbors. For borderline trees, the points were replicated outside the area boundaries to eliminate edge effect in calculating the area of occupancy. This was done by "mirroring" the spatial pattern (i.e. the inside left edge was replicated outside the right boundary and the inside right edge was replicated outside the left boundary, etc.). The algorithm used to calculate the area of the polygon was that described by Brown (1965) and used by Newnham and Maloley (1970). The expansion factor of each tree was used to expand the actual per-acre-plot-data to eight acres.

Table II.1 : Summary of the data used to generate the Douglas-fir stands in this study.

Stand	Total Age	Trees Per Acre	BA Per Acre	----- DBH ----- Mean	Standard Deviation	Site Index*
1	77	189.0	233.2	13.9	15.0	91.4
2	65	126.8	185.1	15.7	16.4	109.9
3	44	305.3	224.2	10.9	11.6	101.8
4	20	465.5	68.4	4.4	5.2	109.4
5	24	1058.5	40.2	1.8	2.6	61.8

* Hann and Scrivani (1987) site index for Douglas-fir.

Sampling the Simulated Stands

Six plot designs were used in this study to sample the generated stands. Two of these were clusters of subplots and four were fixed-area plot designs.

The first cluster design consisted of 10 sample points spaced 150 feet apart with a variable radius subplot and two circular nested fixed-area subplots centered at each sample point (Figure II.2). The smaller of the two fixed-area subplots had a radius of 7.78 feet and was used to sample trees 4.0 inches or less in diameter, whereas the larger fixed-area subplot had a radius of 15.56 feet and provided data on trees 4.1 to 8.0 inches in diameter. The variable-radius subplot had a BAF of 20 and was used to sample trees larger than 8.0 inches in diameter. This design was used to collect the data for the development of SW-ORGANON and is termed here the SWO design.

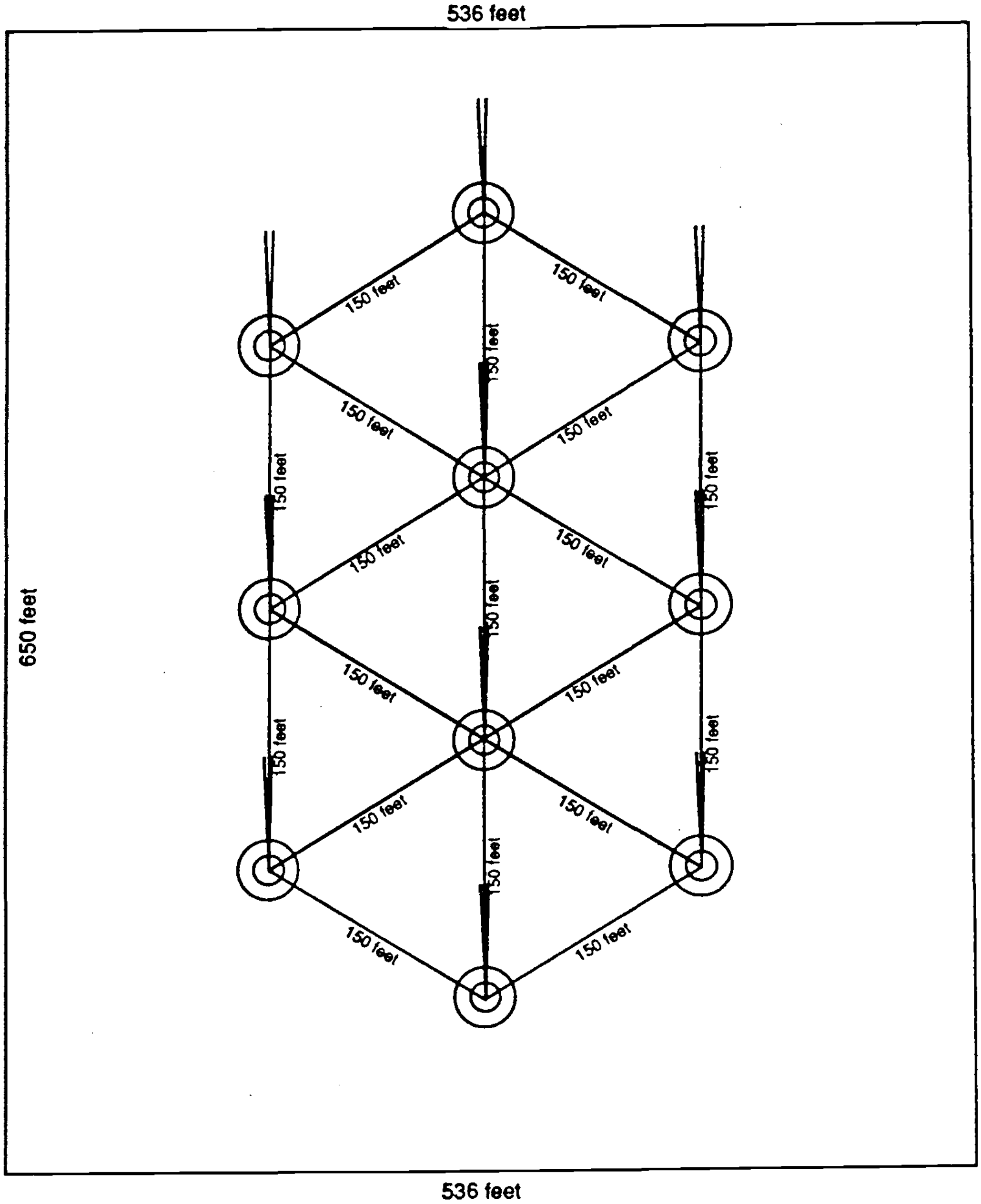

Figure II.2: The SWO design in an 8.0 acre area.

As a contrast to the SWO design, a second cluster design was created based upon one used by the Bureau of Land Management (BLM) in southwest Oregon. The BLM design consists of a cluster of five sample-points spaced 65 feet apart with a variable-radius subplot and a single circular fixed-area subplot centered at each sample point. The fixed-area subplot has a radius of 11.11 feet and provides sample data on trees 7.0 inches in DBH or smaller . The variable-radius subplot uses a BAF of 30 and is used to sample trees greater than 7.0 inches in DBH.

For this study, the BLM design was modified by use of a 6.35-foot radius subplot for trees 4.0 inches or smaller in DBH. The variable-radius subplot of 30 BAF then was used for all trees with a DBH over 4.0 inches. These modifications were made to standardize the upper DBH limit of the fixed-area subplot on this design (designated hereafter as CLU) to the upper limit on the smallest subplot of the SWO design. The CLU design is shown in Figure II.3 where it has been overlaid on the SWO design.

The four fixed area plots used in this study were all circular and were 1.0, 0.5, 0.2 and 0.1 acre in area. These plots are shown in figure II.4 relative to the SWO design.

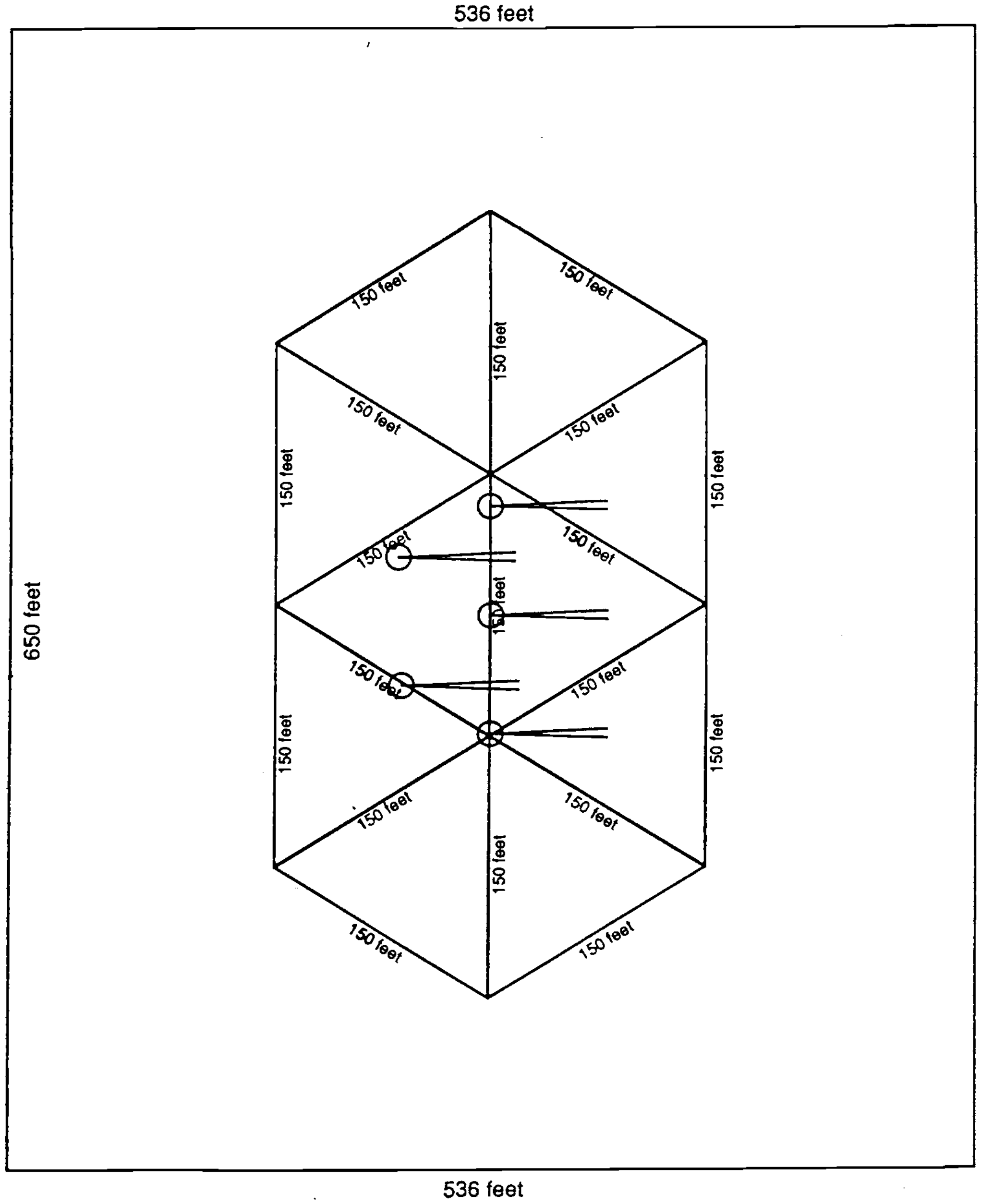

Figure II.3: The CLU design relative to the SWO design in an 8.0 acre area.

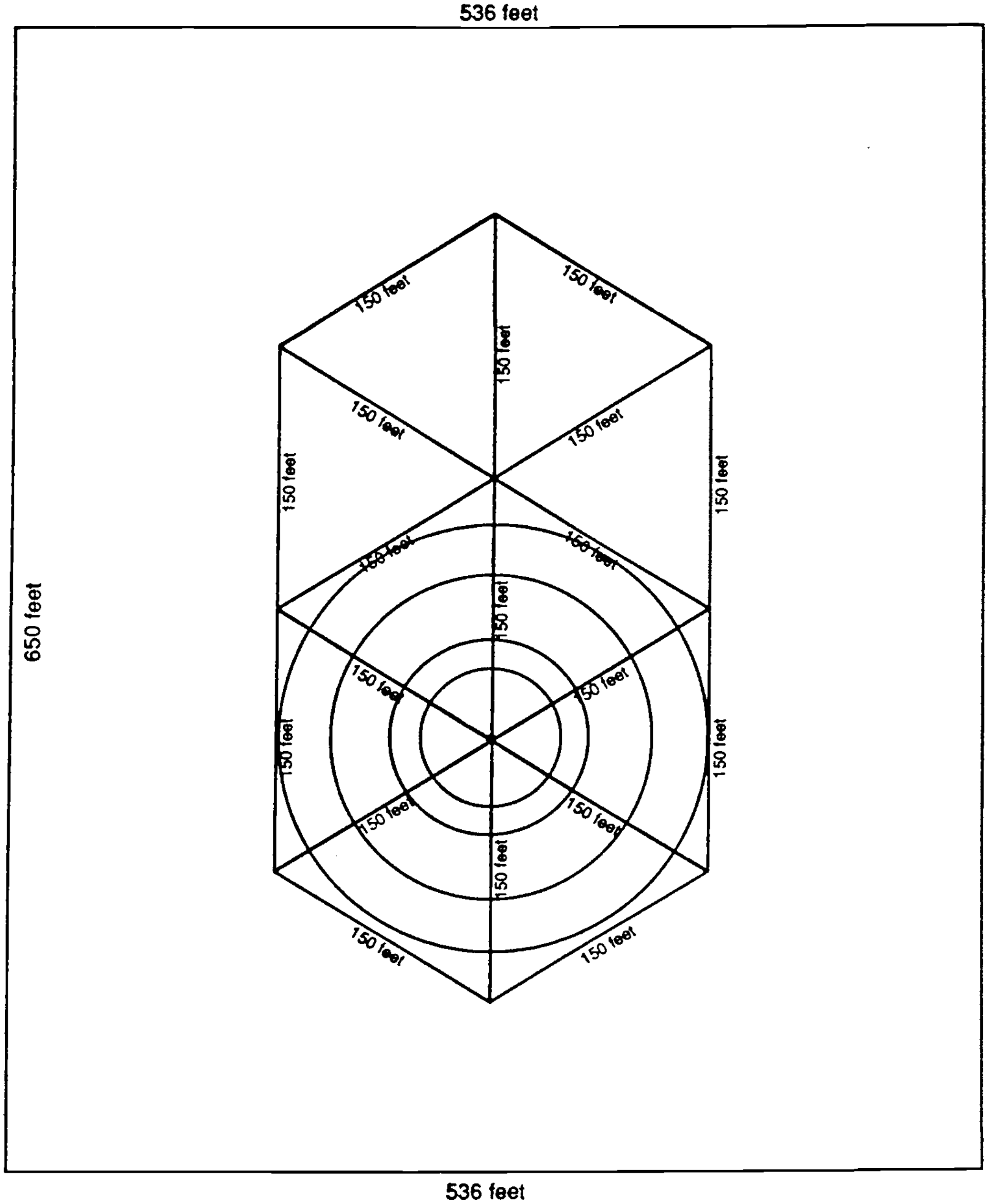

Figure II.4: The four circular fixed area plots relative to the SWO design in an 8.0 acre area.

Instead of generating a large forest stand in the computer's memory and randomly locating a number of sample points within that stand, an eight acre piece of the stand was generated around a sample point , using the stand's tree data and a random spatial distribution. All plot designs were centered around this sample point. The eight acre piece was of sufficient size (650 by 536 feet) to incorporate all plot designs and to eliminate bias due to edge effect. For each of the five stands, the process of generating a randomly distributed piece of eight acres was repeated 50 times, by use of a different random pattern each time. This resulted in 50 samples from each of the six plot designs. This process is equivalent to randomly locating 50 sample points in a large area covered by the same stand structure.

A sample size of 50 was considered adequate by examining the standard errors of the basal area per acre estimates from the SWO design in stand 1 for different sample sizes (Figure II.5). Beyond 30, increasing sample sizes produced only small gains in reduced standard errors. Therefore, it was believed that a sample size of 50 should be adequate for most stand conditions.

The information recorded for each sampled tree was diameter at breast height, total height and crown ratio. Further computations provided estimates of stand basal area per acre in trees larger than the subject tree, number of trees per acre and stand basal area per acre.

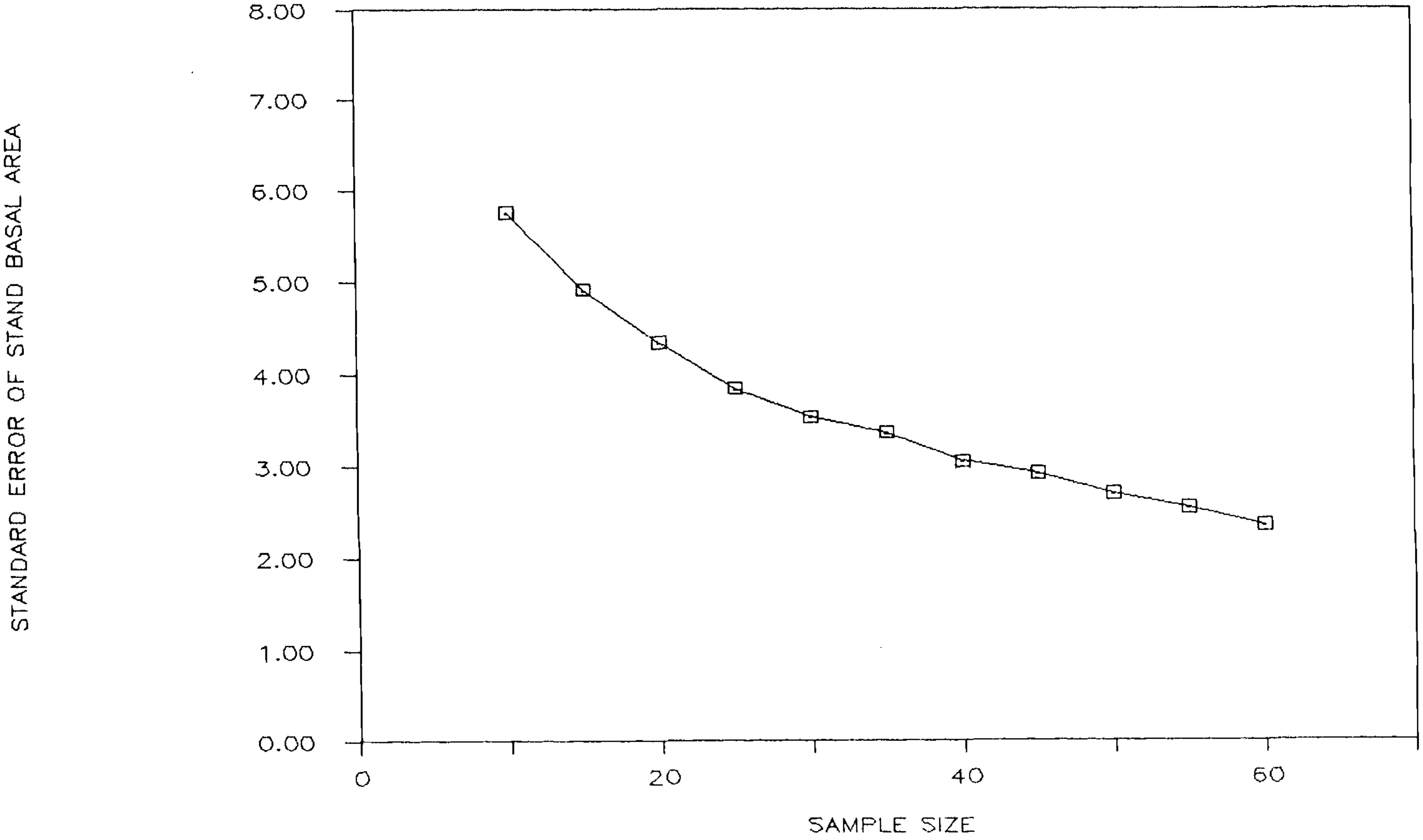

Figure II.5: Standard error of stand (1) basal area (ft.^{2})estimates over sample size.

Growth Predictions

Predictions of the stand gross-basal-area-growth rate from both SW-ORGANON and DFSIM were used to evaluate the effect of alternative plot designs because computation of gross-basal-area-growth rate was relatively straight-forward in both models. For SW-ORGANON, predicted gross basal area growth rate for the stand was determined by:

$$BAGO = K\sum_{i=1}^{n}\{[(DBH_i+DGRO_i)^2-(DBH_i)^2][EXP_i]\}$$

Where,

BAGO = Five-year gross basal area growth for the stand predicted from SW-ORGANON

K = 0.005454154

$DGRO_i$ = Five-year diameter growth for the ith sample tree

EXP_i = The expansion factor for the ith tree

n = Number of sample trees

The diameter-growth equation model in SW-ORGANON was developed by Hann and Larsen (1990) and is of the form:

$$DGRO = f(DBH, CR, SI, BAL, BA)$$

Where:

CR = Crown ratio.

= CL/HT

SI = Hann and Scrivani (1987) Douglas-fir site index for the stand.

BAL = Basal area per acre in trees with DBH's larger than the subject tree.

BA = Stand basal area per acre.

A detailed description of this equation and its parameter estimates were given by Hann and Larsen (1990).

The DFSIM gross-basal-area-growth model for unthinned and unfertilized stands is of the form:

1. For stands with a quadratic mean diameter below 5.55 inches,

$$BAGD = f(A,S)$$

Where:

BAGD = One year gross-basal-area-growth rate for the stand predicted from DFSIM

A = Stand age at breast height

S = King's (1966) site index

2. For stands with a quadratic mean diameter 5.55 inches or larger,

$$BAGD = f(A, S, BA, TPA)$$

The growth model and associated parameters were given by Curtis et al. (1981).

These procedures were used to predict both BAGO and BAGD for each plot design's 50 samples in all five stands. Unfortunately, the quadratic mean diameter of stand 5 was only 2.7 inches and therefore the first equation of BAGD was used. Because this equation does not incorporate a density measure, BAGD was identical for all plot designs. Therefore, the DFSIM predictions for stand 5 were not included in the analysis.

Data Analysis

The relative precision for estimates of BA, TPA, BAGO, BAGD was assessed using the following analyses:

1. Sample estimates of BA and TPA from the six plot designs were compared to the actual stand values by use of a _t_-test.
2. The relative precision of the BA and TPA estimates from the six plot designs was evaluated on the basis of their standard errors.
3. As a test for bias, the paired _t_-test was used to compare the BAGO predictions using the alternative plot designs (CLU and the four fixed area plots) to predictions using the SWO design.
4. The paired _t_-test was also used to compare the BAGD predictions using the alternative plot designs (SWO, CLU, 1.0-, 0.5- and 0.1-acre plots) to predictions using the 0.2-acre plot design.
5. The precision of the BAGO predictions between the alternative plot designs and the standard SWO design was evaluated by use of Freese's (1960) and Gregoire and Reynolds (1988) procedures.
6. The precision of the BAGD predictions between the alternative plot designs and the standard SWO design was also evaluated by use of Freese's (1960) and Gregoire and Reynolds (1988) procedures.

The SWO design was chosen as the standard for the SW-ORGANON projections because it was used to collect the data for the model development. The DFSIM growth model was based on data collected on fixed-area plots that ranged from 0.1 to 1.0 acres in size. Therefore, a plot size of 0.2 acres was chosen as the standard method of sampling for DFSIM against which the other plot designs were evaluated.

Freese (1960) suggested that the standard chi-square test of a hypothesized variance could be used to test the precision of a technique or a method of estimation against an standard method. If D_1, D_2 ....D_n is a random sample of the differences between the standard and the alternative method or model, then the precision requirement depends on a specified acceptable error (E) and a probability statement such that

$$\Pr[|D| \leq E] \geq 1-\alpha.$$

Freese's formulation of the test expresses this requirement in terms of a hypothesized variance bound, that is

$$\mathrm{Var}(D) \leq E^2/X^2_{(1-\alpha)}(1). \qquad (1)$$

Where $X^2_{(1-\alpha)}(1)$ is the chi-square with 1 degree of freedom corresponding to $(1-\alpha)$ probability .

Reynolds (1984) discussed the assumptions underlying Freese's (1960) procedure. He pointed out that the translation of the error requirement into a variance bound assumes the distribution of D is normal and that the expectation of D is zero. The test statistic

$$\sum_{i=1}^{n} D^2{}_i/\mathrm{Var}(D) = \sum_{i=1}^{n} D^2{}_i * X^2{}_{(1-\alpha)}(1)/E^2$$

is used to test the hypothesis in (1). This statistic has a chi-square distribution with n degrees of freedom under the null hypothesis. The hypothesis would be rejected at a given level of significance if the test statistic is in the upper tail of the $X^2(n)$ distribution.

Reynolds (1984) suggested a more conservative formulation of the hypothesis in which the alternative method or model is judged acceptable only if there is strong evidence against the hypothesis

$$\mathrm{Var}(D) \geq E^2/X^2{}_{(1-\alpha)}(1) \qquad (2).$$

This hypothesis is rejected if the test statistic is in the lower tail (determined by the level of significance used) of the chi-square distribution with n degrees of freedom.

Following Rennie and Wiant (1978), Reynolds (1984) used the hypothesis form in (1) above to solve for the critical error LE:

$$LE = [\sum_{i=1}^{n} D^2{}_i * X^2{}_{(1-\alpha)}(1)/X^2{}_{(1-\alpha')}(n)]^{0.5}$$

the smallest value of E, at the α' significance level, that will lead to the acceptance of the hypothesis.

Similarly the critical error UE:

$$UE = [\sum_{i=1}^{n} D^2{}_i * X^2{}_{(1-\alpha)}(1)/X^2{}_{(\alpha')}(n)]^{0.5}$$

from the hypothesis in (2) is the smallest value of E that leads to the rejection of hypothesis at the α' level of significance.

Gregoire and Reynolds (1988) showed that these hypotheses actually concerns the (1-α) quantile of the distribution of the absolute differences $|D|$. A point estimate of this quantile (a point below which (1-α)100% of the absolute errors will lie) is

$$ME = [(\sum_{i=1}^{n} D^2{}_i/n) * X^2{}_{(1-\alpha)}(1)]^{0.5}.$$

The critical errors LE and UE derived by Reynolds (1984) can be interpreted as a lower and upper bounds of the (1-α) quantile of the distribution of $|D|$.

The comparisons in (5) and (6) above are presented in terms of the point estimates and confidence intervals of the (1-α) quantile of the distribution of the percent differences in growth predictions between the standard and the alternative plot designs being compared. The differences were computed for each of the 50 sample points in each of the five stands.

RESULTS

A comparison of actual and estimated values of BA and TPA by stand and plot design is given in table II.2. All plot designs provide, with varying degree of precision, unbiased mean estimates of BA and TPA in all stands. In the younger stands (4 and 5) with quadratic mean diameters of 5.2 and 2.7 inches, respectively, the cluster designs (SWO and CLU) gave the lowest precision in estimating TPA, although their precision in estimating BA is comparable to that of the fixed-area plots. Because the clusters are composed of variable-radius subplots, trees on these designs are selected with probability proportional to their basal area, whereas, in fixed-area-plot sampling, trees are selected with probability proportional to frequency.

The lower precision of the BA estimates using the CLU design compared to the SWO design, especially in the young stands, could be attributed to the larger BAF and the single, smaller fixed-area subplot used in the CLU design. For the four fixed-area plots, gain in precision due to increasing plot size, from 0.5 to 1.0 acre for example, agrees with the theoretically expected gain due to an increase in the area sampled. In stands whose trees are randomly distributed, the use of a one-acre plot should give precision similar to that from two

0.5-acre plots or ten 0.1-acre plots, etc.

Table II.2. Mean stand basal area (BA) and number of trees per acre (TPA) estimates, their standard errors (S.E.), by plot design, and the p-value of comparing these estimates to the actual stand values.

	Actual			Estimated					
Stand Number	BA ft^2	TPA	Plot Design	BA $ft.^2$			TPA		
				Mean	S.E.	p-value	Mean	S.E.	p-value
1	233.2	189.0	SWO	231.6	2.70	0.5539	191.4	2.60	0.3605
			CLU	228.6	4.94	0.3554	178.8	3.93	0.0126
			1.0 ACRE	237.3	3.41	0.2363	189.3	1.68	0.8595
			0.5 ACRE	235.3	5.20	0.6909	188.8	2.15	0.9263
			0.2 ACRE	237.1	7.21	0.5923	194.3	2.99	0.0829
			0.1 ACRE	235.1	10.52	0.8586	189.8	4.84	0.8696
2	185.1	126.9	SWO	184.1	2.63	0.7004	126.8	2.31	0.9722
			CLU	188.3	4.73	0.5047	124.9	3.98	0.6214
			1.0 ACRE	185.5	2.44	0.8775	127.7	1.37	0.5525
			0.5 ACRE	188.4	3.58	0.3642	129.2	1.85	0.2172
			0.2 ACRE	187.9	5.30	0.6026	127.3	3.38	0.9018
			0.1 ACRE	185.1	7.25	0.9984	120.0	4.43	0.1276
3	224.2	305.3	SWO	226.0	2.75	0.5155	315.5	3.55	0.0058
			CLU	229.0	4.49	0.2898	307.1	8.38	0.8267
			1.0 ACRE	230.3	2.35	0.0126	308.3	2.36	0.2031
			0.5 ACRE	227.9	3.40	0.2810	303.5	3.62	0.6334
			0.2 ACRE	224.9	5.61	0.9018	299.9	5.84	0.3642
			0.1 ACRE	219.7	6.55	0.4953	294.6	7.67	0.1708
4	68.4	465.5	SWO	69.1	1.29	0.5793	466.9	10.07	0.8900
			CLU	68.6	2.58	0.9326	452.9	14.80	0.3994
			1.0 ACRE	69.2	0.55	0.1426	463.1	1.81	0.1929
			0.5 ACRE	69.4	0.85	0.2395	462.6	2.17	0.1864
			0.2 ACRE	67.2	1.25	0.3498	456.5	3.48	0.0129
			0.1 ACRE	66.8	1.70	0.3620	456.2	4.93	0.0660
5	40.2	1058.5	SWO	39.5	0.78	0.3467	1062.8	17.79	0.8113
			CLU	36.7	2.02	0.0863	1039.0	36.31	0.5985
			1.0 ACRE	40.1	0.99	0.8881	1064.7	4.58	0.1832
			0.5 ACRE	39.7	1.37	0.6982	1068.4	6.72	0.1479
			0.2 ACRE	39.2	1.94	0.5944	1056.2	9.95	0.8191
			0.1 ACRE	38.7	2.76	0.5848	1052.4	13.71	0.6619

Differences in the BAGO predictions between the standard SWO design and the alternative designs (CLU, 1.0-, 0.5-, 0.2-and 0.1-acre plots) are summarized in table II.3. For example, the first set of values in Table II.3 shows the mean difference in the BAGO predictions between the CLU design and the SWO design, the standard error of the mean difference and the significance level of testing the hypothesis that the mean difference is equal to zero. Also given are the 0.95 quantile of the absolute differences in percent terms (ME%) and the lower (LE%) and upper (UE%) 95% confidence bounds of the quantile. The interpretation of these "critical errors" in table II.3 is that 95% of the BAGO predictions using the alternative plot design were within ± ME% of the BAGO predictions using the standard SWO design and that LE% and UE% are the 95% confidence bounds (based on 50 samples) of the quantile estimated by ME%.

The levels of significance (p-values) in table II.3 indicate that on the average the BAGO predictions using any of the alternative plot designs are unbiased. However, the magnitude of the differences in percent terms, as indicated by the values of (ME%) in table II.3 vary for the different alternative plot designs considered and is also affected by the stand structure. The smallest percent differences were in stand 3, ranging

Table II.3. Summary statistics of the differences in the ORGANON 5-year gross-basal-area-growth-rate (sq.ft.) predictions, comparing the alternative plot designs to the standard SWO-ORGANON design.

Plot	Stand	Differences			Critical Errors*		
Design	Number	Mean	S.E.	p-value	ME%	LE%	UE%
CLU	1	0.342	0.160	0.0372	15.8	13.4	19.2
	2	-0.073	0.206	0.7242	21.9	18.3	27.3
	3	0.014	0.181	0.9376	11.6	9.7	14.4
	4	0.678	1.249	0.5897	43.1	36.0	53.6
	5	0.572	0.960	0.5540	71.2	59.5	88.5
1.0 ACRE	1	0.070	0.124	0.5743	12.0	10.2	14.6
	2	-0.049	0.133	0.7089	14.0	11.7	17.4
	3	0.017	0.135	0.9032	8.8	7.4	11.0
	4	0.035	0.621	0.9559	23.0	19.2	28.6
	5	-0.489	0.384	0.2079	32.2	26.9	40.1
0.5 ACRE	1	0.083	0.156	0.5951	14.8	12.5	18.0
	2	-0.163	0.164	0.3242	17.5	14.7	21.8
	3	0.191	0.162	0.2426	10.6	8.9	13.1
	4	0.078	0.621	0.9008	22.9	19.2	28.5
	5	-0.443	0.401	0.2752	33.0	27.6	41.0
0.2 ACRE	1	0.010	0.240	0.9671	22.9	19.4	27.8
	2	-0.062	0.222	0.7829	23.5	19.6	29.2
	3	0.385	0.201	0.0616	13.2	11.0	16.4
	4	0.865	0.728	0.2409	25.9	21.6	32.2
	5	-0.218	0.395	0.5840	30.6	25.5	38.0
0.1 ACRE	1	0.626	0.336	0.0673	32.6	27.6	39.7
	2	0.301	0.309	0.3349	32.8	27.4	40.8
	3	0.572	0.286	0.0512	18.8	15.7	23.4
	4	1.012	0.835	0.2317	29.3	24.5	36.5
	5	-0.090	0.487	0.8536	36.8	30.8	45.8

* Critical errors at the $\alpha=0.05$ probability level using Gregoire and Reynolds (1988) procedure.

from ± 8.8% when using the 1.0 acre plot to ± 18.8% for the 0.1 acre plot. Stand 3 is the average stand in terms of age, site quality and stocking. The magnitude of the percent differences resulting from using the CLU design (compared to the SWO design) in the older stands (1, 2 and 3), were comparable to those obtained using the large fixed-area plots. However, differences of a much greater magnitude resulted when using the CLU design in the younger stands (± 43.1% for stand 4 and ± 71.2% for stand 5).

Similarly, the statistics for the differences in the BAGD predictions are presented in table II.4, where growth predictions using the SWO, CLU, 1.0-, 0.5- and 0.1-acre plots were compared to the BAGD predictions using the 0.2-acre plot. Again, the mean of the BAGD predictions from any of the alternative plots is unbiased. The 0.95 quantile of the distribution of the differences and it's 95% confidence interval were given by the "critical errors" in table II.4.

When the other fixed-area plots were used, the percent differences in the BAGD predictions for all four stands were within ± 13% of the BAGD predictions using the 0.2-acre plot as a standard (table II.4). Differences of a similar magnitude also were obtained when the SWO and the CLU designs were used in the older stands (1, 2 and 3) as shown in table II.4. However, in

Table II.4. Summary statistics of the differences in the DFSIM one year gross-basal-area-growth-rate (sq. ft.) predictions, comparing the alternative plot designs to standard fifth acre fixed area plot.

Plot	Stand	Differences			Critical Errors*		
Design	Number	Mean	S.E.	p-value	ME%	LE%	UE%
SWO	1	0.006	0.028	0.8323	11.5	9.6	14.2
	2	0.011	0.031	0.7115	11.9	9.9	14.8
	3	-0.020	0.052	0.7047	15.5	12.9	19.3
	4	-0.097	0.092	0.2989	25.9	21.6	32.1
CLU	1	0.019	0.030	0.5239	12.2	10.2	15.2
	2	-0.008	0.034	0.8143	13.5	11.3	16.8
	3	-0.042	0.054	0.4408	15.9	13.3	19.8
	4	-0.023	0.146	0.8770	43.5	36.3	54.1
1.0 ACRE	1	-0.018	0.025	0.4760	10.2	8.5	12.7
	2	0.003	0.029	0.9135	11.4	9.5	14.2
	3	-0.060	0.041	0.1525	12.5	10.4	15.5
	4	-0.118	0.061	0.0604	12.9	10.8	16.0
0.5 ACRE	1	-0.004	0.022	0.8738	8.8	7.4	10.9
	2	-0.010	0.026	0.7077	10.4	8.7	12.9
	3	-0.037	0.033	0.2634	9.9	8.3	12.3
	4	-0.123	0.046	0.0099	10.4	8.7	12.9
0.1 ACRE	1	0.027	0.032	0.4146	12.9	10.8	16.1
	2	0.033	0.028	0.2424	11.6	9.7	14.4
	3	0.053	0.042	0.2190	12.7	10.6	15.8
	4	0.036	0.062	0.5717	13.4	11.2	16.6

* Critical errors at the $\alpha=0.05$ probability level using Gregoire and Reynolds (1988) procedure.

stand (4) the percent difference for the two cluster designs were within ± 26% and ± 43%, respectively, of the BAGD predictions using the 0.2-acre plot.

The percent differences (ME%) in BAGO predictions (relative to the SWO design) and BAGD predictions (relative to the 0.2 acre plot) are plotted over BA in figure II.6 for alternative plot designs of CLU and 1.0 acre. This graph illustrates the effect of the stand density (expressed in terms of BA) on the differences in growth predictions resulting from changing the plot size or design. The percent differences in predictions from both models using the CLU design were the largest of all designs in the young stands with small basal areas per acre. In general, the 1.0-acre plot had the smallest differences in predictions for both models. For all fixed-area plots, percent differences (ME%) in the BAGD predictions were smaller in magnitude and seem not to be so much affected by changing BA as were the percent differences in the BAGO predictions. In addition, the percent differences of BAGD were approximately the same for all alternative fixed-area plots (table II.4), whereas the percent differences of BAGO increased as plot size decreased (table II.3).

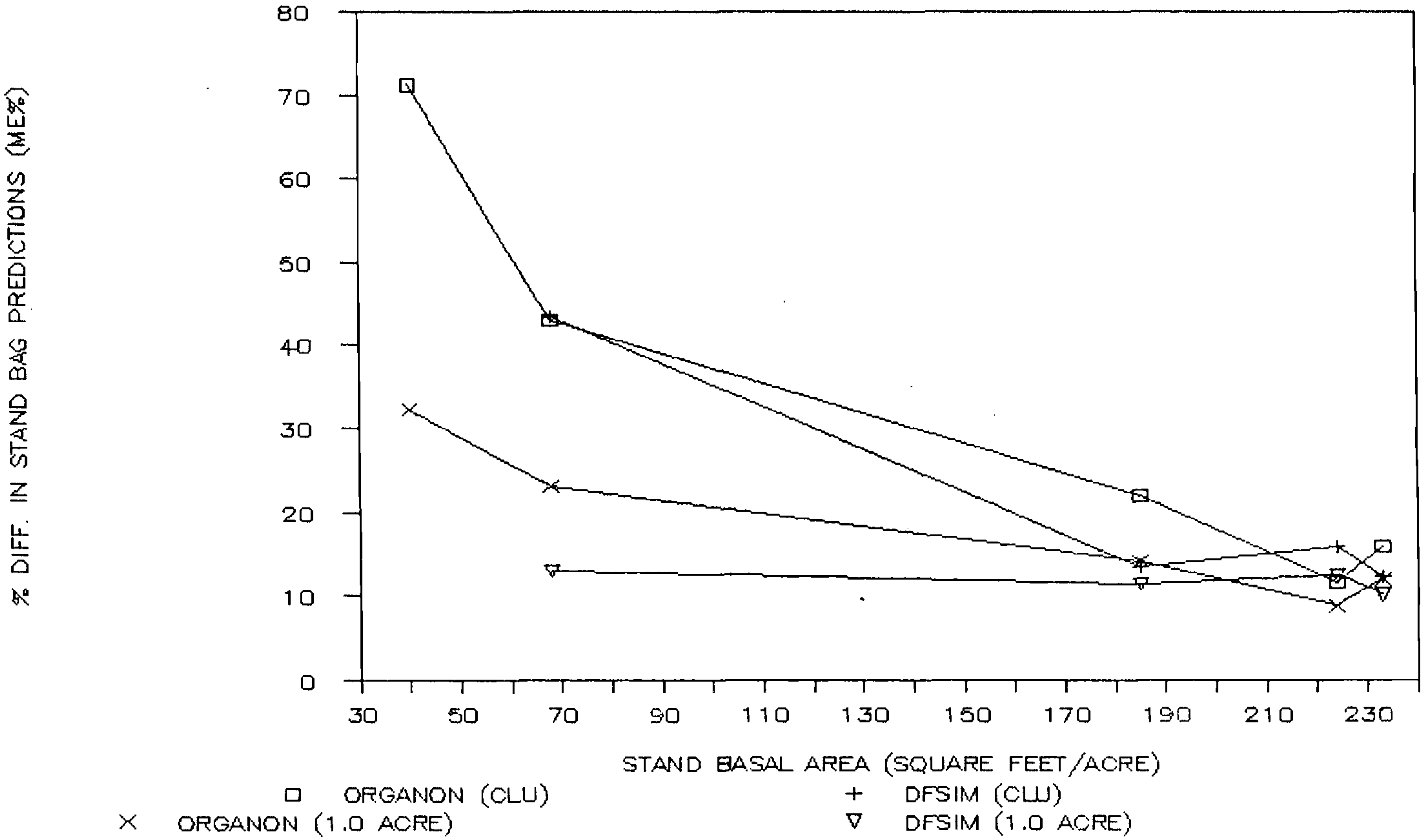

Figure II.6: Percent differences (ME%) in SW-ORGANON and DFSIM gross basal area growth predictions between two alternative plot designs (CLU and 1.0 acre plot) and each model's standard plot design plotted over stand basal area.

DISCUSSION

For the SW-ORGANON model, differences in predicting BAGO are caused by differences in predicting five-year diameter-growth rate. These diameter-growth-rate differences, in turn, are a direct result of the variability in estimating BA and BAL. For Douglas-fir, BAL has a stronger effect upon individual tree diameter-growth-rate than does BA (Hann and Larsen 1990). To examine the effect that changes in estimates of these independent variables could have upon diameter-growth-rate predictions, differences in SW-ORGANON five-year diameter-growth-rate predictions were plotted over differences in BA and BAL. A strong linear relationship was found in the plots of differences in diameter-growth-rate over BAL. Figure II.7 is an example of such a plot. No trends were observed in the plots over BA. For Douglas-fir, therefore, differences in predicting BAGO were mostly related to differences in estimating BAL.

An attempt was made to correct for the bias in estimating BAL by developing an equation to predict the differences in BAL estimates that result from changing plot design as a function of the relative size of the tree. Simple linear regression was used to model the relative differences in BAL estimates as a function of

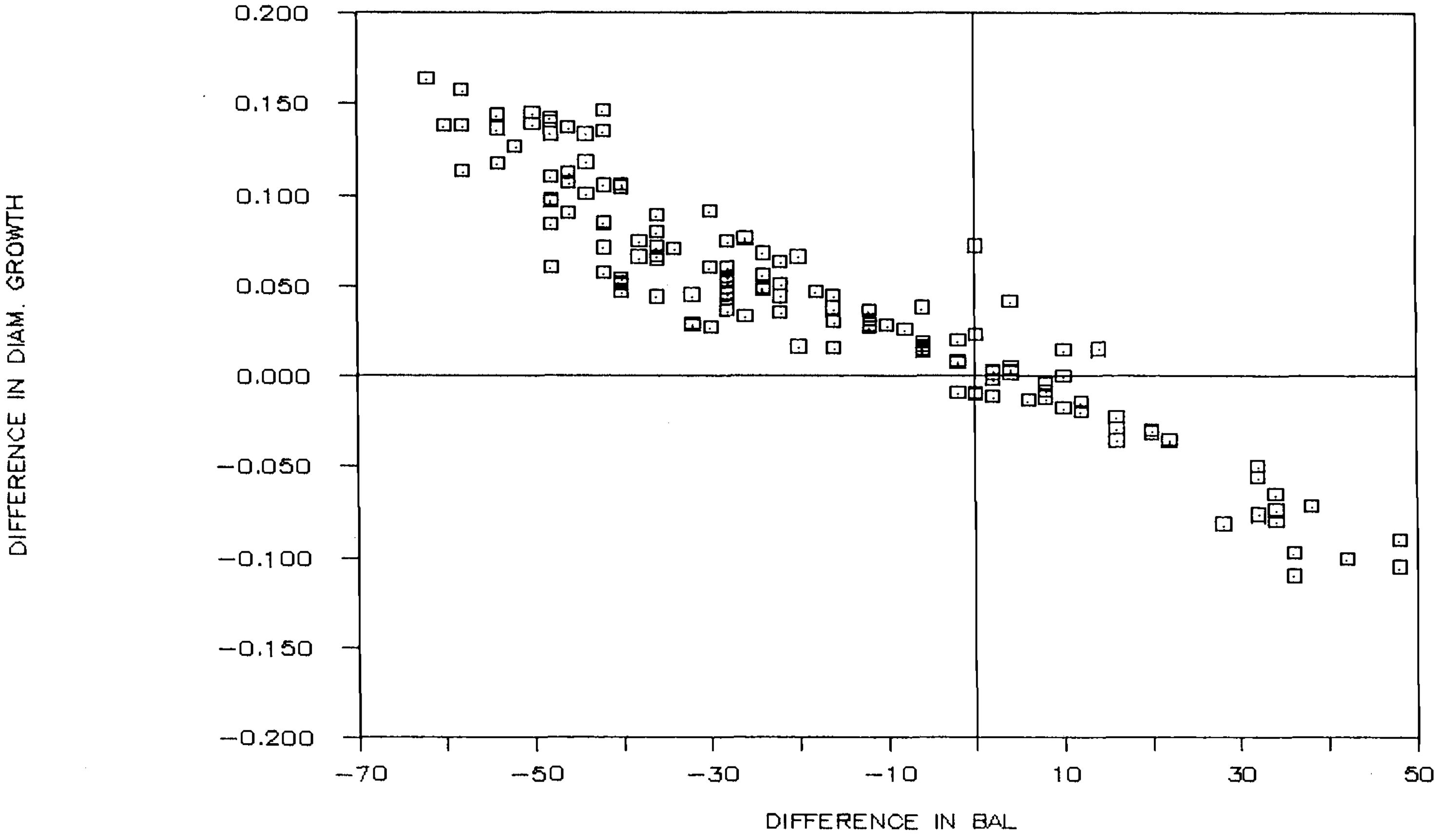

Figure II.7: Differences in SW-ORGANON tree diameter growth predictions between CLU and SWO designs plotted over differences in the two designs estimates of basal area in trees larger than the subject tree (BAL) for stand 1.

the relative size of the tree (tree diameter divided by maximum diameter in the stand). Unfortunately, the results of the regression analysis indicated that less than 4% of the variation in the relative differences in BAL could be explained by the relative size of the tree.

For DFSIM, BAGD predictions depend upon BA and TPA estimates. Plots of differences in BAGD predictions over differences in BA estimates resulted in a strong linear relationship, indicating that differences in the BAGD predictions were mostly related to the differences in BA estimates using alternative plot designs. This relationship is illustrated in figure II.8 using the CLU design as an alternative to the 0.2-acre plot in stand 1.

The two major forestry applications that use predictions from growth-and-yield models are: (1) to evaluate different management and silvicultural prescription options for a particular stand, and (2) to plan harvest scheduling and determine the allowable cut for a forest. In the first application, the results of this study indicate that using a plot design different from the original design of the model could distort the decisions concerning the treatment of the stand. For projections by use of a single plot or cluster in a stand (the usual practice), it may not be know if the difference in prediction using an alternative design is ± UE%, zero percent or something in between.

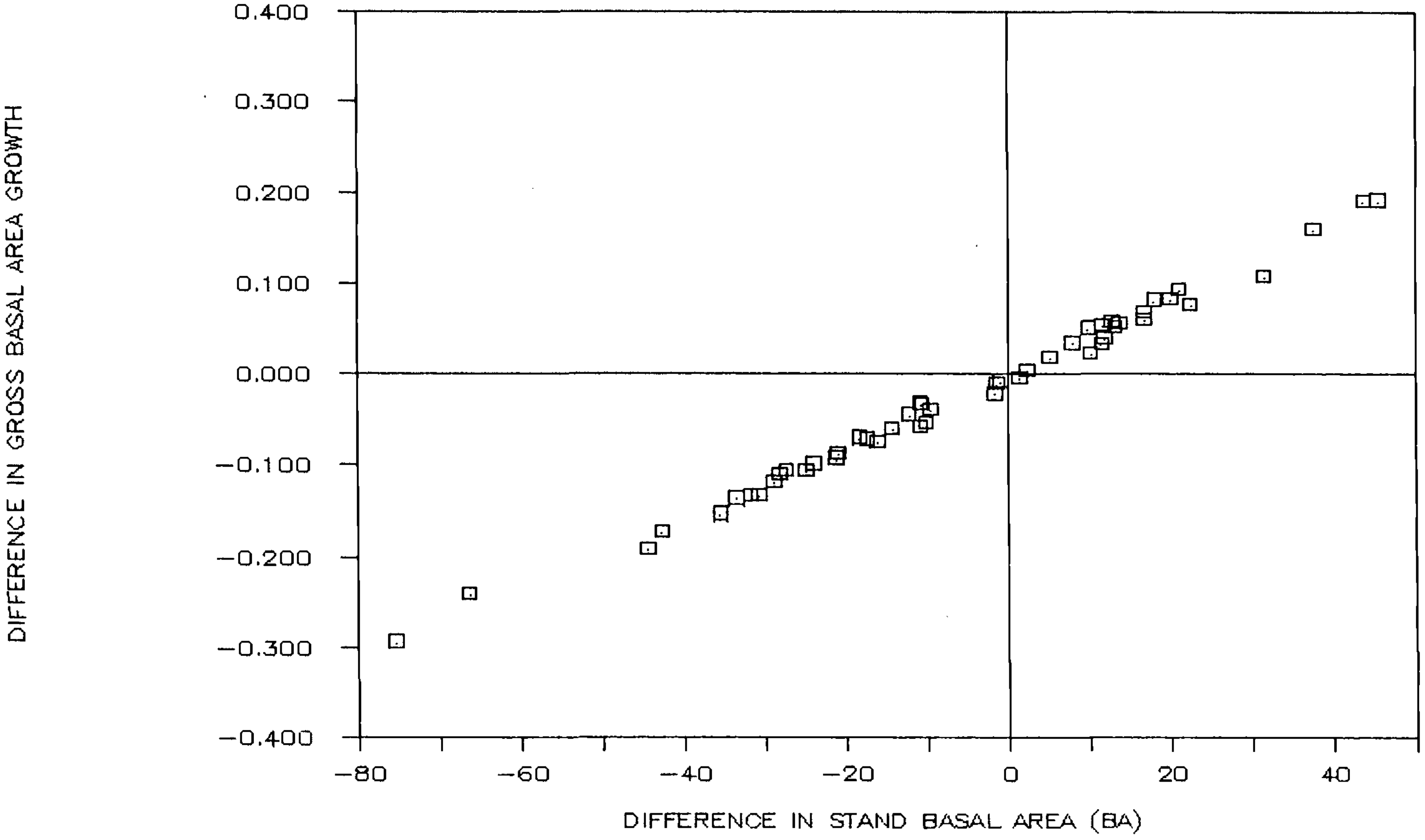

Figure II.8: Differences in DFSIM gross stand basal area growth predictions between CLU design and the 0.2 acre plot plotted over differences in the two designs estimates of stand basal area (BA) for stand 1.

In the second application, the general practice has been to stratify the stands in a forest by age, species, productivity,land use or other classes and then to measure a number of sample plots in each stratum. In this case estimating the mean growth in a stratum by predicting each plot separately and then averaging the predictions could help to minimize problems associated with a plot design that differs from the design used to develop the model. This would be particularly true if the stratification was successful at grouping similar stands. The number of plots that should be measured in each stratum depends upon the form of the alternative plot design, the particular growth model to be used, the attributes of the stratum, and the precision desired. As an illustration, the number of CLU plots needed for the average of the BAGO predictions to be within ± 10% of the average obtained using the standard SWO design, 95 times in a 100, were estimated for each stand using the variance estimates from table II.3. The resulting sample sizes are given in table II.5.

In addition to their potential impact upon making stand and forest-management decisions, changes in in plot design also could complicate the process of validating a growth-and-yield model. If the plot design used to collect the validation data differs from the original plot design used to collect the modeling data, then

Table II.5. ORGANON mean 5-year gross-basal-area-growth using the standard SWO design and the number of CLU plots needed to estimate growth within ± 10% of the SWO predictions.

Stand	SWO mean BAG ft.^{2}/5 years	Number of CLU plots needed
1	15.8	3
2	13.2	5
3	21.3	2
4	40.9	19
5	18.3	56

differences in individual plot predictions would be affected both by the difference in the designs and by possible bias and/or imprecision in predicting the attributes of the validation data by the model. Although the averaging of predictions across all validation plots should help to minimize the effect of using an alternative plot design upon bias, the effect of using an alternative plot design upon the precision of predicting the validation data set is not so easily removed. Therefore, tests for model bias in predicting the validation data set will probably accept the null hypothesis of no difference more often than they should because the variance of the differences in prediction is increased by the differences in plot design.

Finally, it should be emphasized that the results of this study depend upon the assumed random spatial pattern of the coordinates used to generate the stands. In severely clumped stands, the effect of using alternative plot designs upon growth-model predictions possibly could be even greater.

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SUMMARY AND CONCLUSIONS

In the first part of this study, the objective was to examine possible trends in Douglas-fir diameter-growth estimated from increment cores as compared with that obtained from repeated measurements of tree diameter over time. Growth data were collected from permanent plots located in two Douglas-fir study areas in the central Coastal Range of Oregon. Diameter growth was measured for a six-year period (1979-1985). The results indicated that diameter growth measured from two increment cores taken opposite to each other provide an unbiased estimate of the stand average diameter-growth as determined from repeated measurements. However, a statistically significant trend was found in the differences in individual tree diameter-growth between the two methods. Measurements from increment cores were found to overestimate actual diameter-growth in slow growing trees and underestimate it for fast growing trees. A nonlinear model was used to characterize these differences. The significance of the observed trend and the use of the calibration model to correct the bias in increment cores measurements were discussed.

The objective of the second part of the study was to investigate the effect of changing plot design in sampling for predictor variables upon growth-models predictions. Data from five Douglas-fir stands in the mixed conifer zone of Southwest Oregon, representing a range of site quality, stand age and density, were used to generate the stands in this study. Random patterns were used to characterize the spatial distribution of the stands. Six plot designs, including both variable-radius and fixed-radius plots, and two growth models were examined. The two growth models used were the Southwest Oregon growth-and-yield model (ORGANON), a single-tree/distance-independent model, and the Coast Douglas-fir simulator (DFSIM), a whole-stand model. The different plot designs were examined with respect to the precision with which they estimate the predictor variables used in the two models. Gross-basal-area-growth predictions from both models were used to evaluate alternative plot designs relative to the model standard design.

The following conclusions were drawn from the results of the study :

As would be expected, both fixed-radius and variable-radius plots provide, with varying degree of precision, unbiased estimates of stand basal area and number of trees per acre.

For Douglas-fir, variables used in individual tree growth-and-yield models that reflect the relative position of the tree in the stand, such as stand basal area in trees larger than the subject tree (BAL), proved to be more sensitive to changes in plot size and design than stand variables such as stand basal area (BA).

For fixed-area plots, changes in plot size had more effect on growth predictions from the SW-ORGANON model than they did using the DFSIM model. However, differences of greater magnitudes could result in the model growth-predictions using a cluster design that incorporate a variable-radius plot.

The effects of changing plot design upon growth predictions, depend on the stand size and density.

Validation of a growth model using a plot design different than the one used to collect the modeling data may be difficult. Differences that may incorrectly be attributed to the model behavior could actually be affected by the change in the sample plot design.

The results of this study depend on the random nature of the spatial distributions used in generating the stands. In severely clumped (aggregated) stands the effect upon models growth-predictions could possibly be even greater.

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