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Title: Predicting Basal Area Growth in Young-Growth Douglas-fir Using Crown Competition Factor

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Dr. John F. Bell

A comparison between crown competition factor and basal area as to their ability to predict future basal area growth was conducted. It was shown that for a single age and site combination there was no real difference between the growth prediction ability of the two measures of stand density.

It was shown that acceptable estimates of Crown Competition Factor can be obtained by grouping trees into broad diameter classes.

Finally, it was shown that Crown Competition Factor and the average Competitive Stress Index for a stand are very highly correlated with each other.

Predicting Basal Area Growth in Young-Growth Douglas-fir Using Crown Competition Factor

by

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LIST OF COMMONLY USED ACRONYMS

Acronym	Meaning
BA	Basal area
BAG	Basal area growth
CCF	Crown Competition Factor
CSI	Competitive Stress Index
DBH	Diameter breast height
$\ell n(\ )$	Natural logarithmic transformation

ACKNOWLEDGMENTS

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PREDICTING BASAL AREA GROWTH IN YOUNG-GROWTH DOUGLAS-FIR USING CROWN COMPETITION FACTOR

INTRODUCTION

Growth prediction is an essential element in timber management decision making. By increasing the accuracy of stand growth estimation, foresters can more effectively determine harvest scheduling in order to maximize stand utilization. Stand growth is the result of the interaction of many variables such as stand age, site quality, and density. A certain degree of control over growth is obtained by the manipulation of stand density. It may not be possible to increase the absolute growth of a particular stand by altering its density, however it is possible to distribute that growth over a controlled number of stems. Different combinations of the physical characteristics of a particular forested area, such as soil, moisture, slope, temperature, and aspect result in different degrees of favorableness for tree growth. This combined effect is known as site quality. The result is that a particular area will produce the same amount of growth over a wide range of stand densities. Foresters can manipulate density within this broad range of maximum growth in order to produce trees of suitable size for their desired products (McArdle, 1961).

In the past such measures as basal area and number of stems have been used to quantify density. Neither of these deal directly with the problem of competition among trees. Recently, many different measures of inter-tree competition have been examined in an attempt to improve upon our ability to predict future growth (Alemdag, 1978).

The primary objective of this study was to evaluate the basal area growth prediction ability of Crown Competition Factor (CCF). Secondly, the sampling procedure for generating CCF data was examined for accuracy at different levels of density, and at different sampling intensities.

DATA COLLECTION

The Hoskin's levels-of-growing-stock study supplied the data base for my study. The Hoskin's plots are administered by Oregon State University's School of Forestry, as part of a cooperative effort with other state, federal, and industrial organizations. The study was begun in 1962 in an "effort aimed at providing the biological information necessary to develop reliable yield tables for managed stands. The participants adopted a study plan designed to examine (1) cumulative wood production, (2) tree size development, and (3) growth-growing stock ratios," Williamson and Staebler (1971).

The experimental design consists of eight treatments and a control, each with three replications. A total of 27,square one-fifth acre plots is included in the study, with the various treatments being assigned in a completely randomized fashion. The eight different treatments represent different thinning intensities designed to examine the three objectives mentioned earlier. The amount of basal area retained after thinning, for any particular treatment, is a predetermined percentage of the gross basal area increment of the control plots since the last thinning. These predetermined percentages are listed in Table 1. The even-numbered treatments were not analyzed because the predetermined percentage changed from one thinning to another. Thinning takes place whenever the average height growth of all the crop trees has increased by 10 feet since the last thinning. Thinnings have taken place in 1966, 1970, 1973, 1975, and 1979. The treatment plots all received a calibration thinning at the beginning of the study in 1963.

TABLE 1. PERCENT OF GROSS BASAL AREA INCREMENT RETAINED AS GROWING STOCK AFTER THINNING

Thinning	Treatment 1	3	5	7	9
First	10	30	50	70	100
Second	10	30	50	70	100
Third	10	30	50	70	100
Fourth	10	30	50	70	100
Fifth	10	30	50	70	100

The Hoskin's plots are located near Hoskins, Oregon, about 20 miles west of Corvallis. The plots are located on site II land, and the trees are all approximately 35 years old. This study area is located on the eastern slope of the Coast Range. and consists of naturally regenerated, even-aged Douglas-fir (*Pseudotsuga menziessii*).

In my study I examined data from treatments one, three, five, seven and the controls. Four yearly growth periods between 1974 and 1978 were studied. DBH measurements to the nearest one-tenth inch were available for all trees and all years between 1974 and 1978. No additional data collection was necessary to meet the objectives of my study. My analysis was performed on the Oregon State University Cyber Computer, with programs written in Fortran to manipulate the data.

LITERATURE REVIEW

Traditionally, density has been expressed in such terms as basal area, number of stems, or volume. However, none of these measures directly reflects the level of competition among trees in the stand.

Density and stocking are terms that indicate the level at which the productive capacity of a particular site is being utilized (Husch, 1972). Stocking is a qualitative term which indicates the comparison between the actual level of site utilization and that level of utilization associated with maximum growth under any given set of management constraints (Curtis, 1970). Depending upon management objectives, a stand may be referred to as being understocked, overstocked, or fully stocked (Gingrich, 1967). Stand density is a quantitative term that expresses the amount of site utilization on a per unit area basis. Terms mentioned earlier, such as the amount of basal area, or the number of stems are statements of stand density. The distinction between stocking and density is summarized by Curtis (1970) when he writes, "stocking is a comparison with current management objectives and stand density is almost any numerical quantity obtainable by measurement of the stand on an area basis."

The term competition refers to the demand placed upon the vital resources of the site by two or more organisms that rely upon these resources for growth and survival (Wilson, 1971). The more intense the competition, the greater the demand placed upon the site to supply adequate amounts of these vital resources, such as moisture, nutrients, and radiation. When competition becomes acute, the growth and survival of all individuals may be affected by a shortage of one or more of these resources (Whittaker, 1970). Competition among trees takes place both in the rooting zone and in the crown canopy, making the absolute level of competition difficult to determine. The relative level of competition reflects the interaction among trees for growing space. The growing space of a particular tree is that area in which it competes for site resources (Bella, 1971).

Measures of relative inter-tree competition have been developed in order to achieve a statement of stand density that more accurately describes the biological action taking place on the site. These measures of competition have been developed for the individual tree as well as the stand in general (Smith, 1977).

Individual Tree Measures of Competition

The level of competition experienced by a particular subject tree is dependent upon the number, location, and relative size of those neighboring competitor trees that are actively competing for the same resources. The amount of competition placed upon the subject tree by a competitor is assumed to be directly proportional to the size of the competitor and inversely proportional to the distance between the two trees.

Hegyi (1974) formulated an individual tree competition model stated in the following manner:

$$CIj = \sum_{i=1}^{n} \left(\frac{Di}{Dj}\right)\left(\frac{1}{Lij}\right)$$

Where:

CIj = the competition index for the j^{th} subject tree

Di = the DBH for the i^{th} competitor tree

Dj = the DBH for the j^{th} subject tree

Lij = the distance between the i^{th} competitor and the j^{th} subject tree

n = the number of competitors within the j^{th} subject tree's growing space area

It can be seen from this equation that the larger the relative size of the competitor tree, the larger its competitive influence will be upon the subject tree. Also, the inverse proportionality between competition and distance is apparent. The growing space area is calculated as a function of the maximum crown development for a subject tree of a particular size. The competition index calculated with equation (1) is a relative measure, and becomes meaningful only when compared to other values calculated similarly for other trees.

A similar measure of competition was developed by Quenet (1976). However, this index does not consider the relationship between competitor tree size and subject tree size.

Many of the more popular individual tree competition models concern themselves with the amount of influence zone overalp. The degree of competition affecting a particular tree is proportional to the amount of overlap of its growing space by the growing space of its neighbors. A tree's influence zone is equal to the growing space occupied by a tree of the same size growing in an open-grown condition. In other words, a tree's influence zone is defined as the growing space area that a tree occupies when unaffected by surrounding competition (Smith, 1977). Competition then occurs whenever the influence zones of two trees overlap. The size of a tree's area of influence is usually assumed to be proportional to the size of the tree. The relationship between tree diameter and open-grown crown width is often used to define the limits of a tree's influence zone (Arney, 1973; Bella, 1971; Staebler, 1951). Figure 1 shows the influence zone overlaps for a stand of three hypothetical trees.

The first competition index to use this influence zone overlap concept was developed by Staebler (1951):

$$CIj = \sum_{i=1}^{n} LOij \qquad (2)$$

Where:

CIj = the competition index for the j^{th} subject tree

LOij = the linear overlap of growing space circles between the i^{th} competitor and the j^{th} subject tree

n = the number of competitors within the j^{th} subject tree's growing space area

Bella (1971) formulated a competition index that reflects the assumption that larger trees will have a greater competitive influence upon their neighbors than will smaller trees. Bella assumes that a larger tree will more efficiently use the resources within its

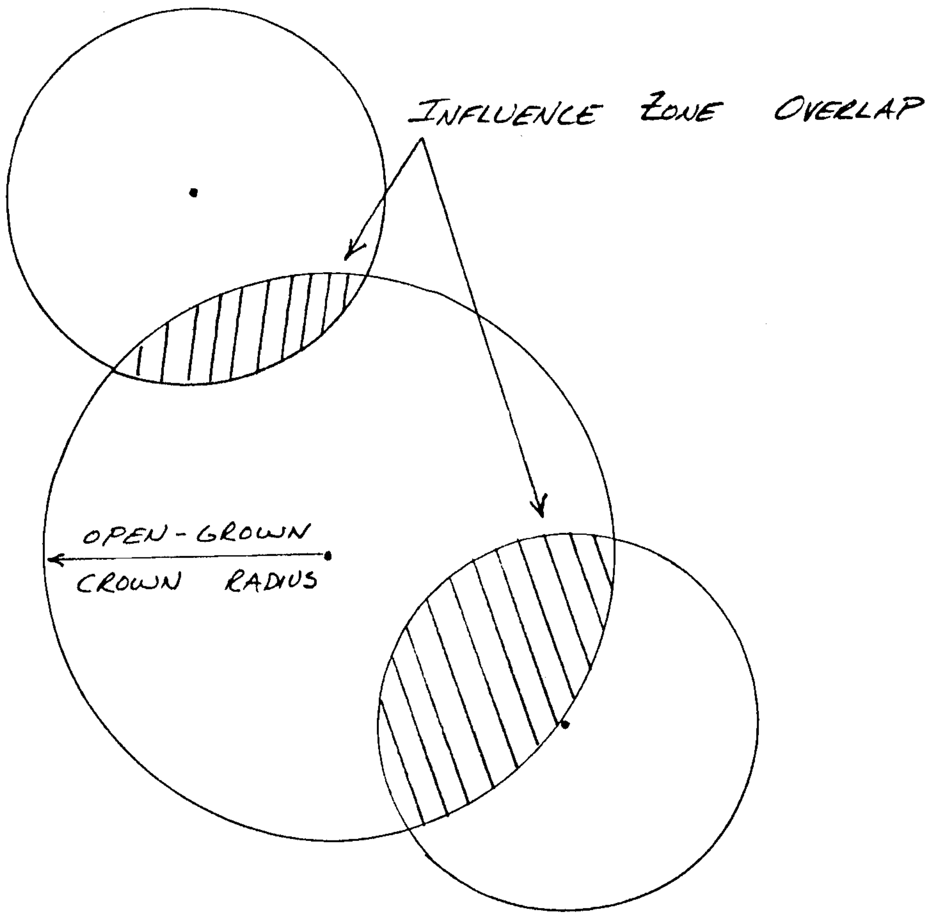

Figure 1. Influence zone overlaps for a stand of three hypothetical trees.

growing space than will smaller competitor trees in the same area.

$$CIj = \frac{\sum_{i=1}^{n} AOij}{Aj} \left(\frac{Di}{Dj}\right)^{a} \qquad (3)$$

Where:

CIj = the competition index for the j^{th} subject tree

AOij = the growing space area overlap of the i^{th} competitor with the j^{th} subject tree

Aj = the growing space area of the j^{th} subject tree

a = exponent

Di = the DBH for the i^{th} competitor tree

Dj = the DBH for the j^{th} subject tree

n = the number of competitors within the j^{th} subject tree's growing space area

The exponent allows for changes in the competition index caused by the tree size proportionality differences from species to species. In effect, the exponent causes the influence zone for a tree of a particular size to be increased or decreased.

Arney (1973) developed a competition index based upon the percent overlap of a subject tree's growing space by its competitors. He called this competition index Competitive Stress Index (CSI).

$$CSIj = \left(\frac{\sum_{i=1}^{n} AOij + Aj}{Aj}\right) * 100 \qquad (4)$$

Where:

CSIj = competitive stress index for the j^{th} subject tree

AOij - the growing space area overlap of the i^{th} competitor with the j^{th} subject tree

A_j = the growing space area of the j^{th} subject tree
n = the number of competitors within the j^{th} subject tree's growing space area

By computing the percent of growing space overlap, and using this as an index of relative competition, the need to consider tree size is eliminated.

The major problem created by using these individual tree indexes of competition is the need to know the relative positioning of all trees in the stand. This positioning can only be obtained through a costly, time-consuming process of stem mapping. In order for an index of competition to be useful in the development of growth prediction models, it must be computationally simple (Daniels, 1976).

Alemdag (1978) has shown that the diameter growth prediction ability of several of these competition indexes was quite low. In some cases the prediction ability was no better than that ovtained when using only diameter as a predictor variable. Alemdag goes on to conclude that even though the prediction ability of all the measures of competition was low, those that used larger influence zones gave better results. The phenomenon of root grafting will cause problems in the calculation of these individual tree indexes. By increasing the size of the influence zone, these problems will be reduced through averaging over a larger area according to speculation by Paine (personal communication, 1980). Alemdag's final conclusion was that the improvement in growth prediction was offset by the time and expense necessary in determining stem coordinates and calculating competition indexes.

Whole Stand Measures of Competition

Whole stand indexes of competition reflect the average density conditions existing within the stand. These are relative measures which reflect the average stand conditions in relationship to either a normal, fully stocked stand, or an open-grown stand situation (Smith, 1977). The three traditional measures of density mentioned earlier--basal area, number of stems, and volume--are all expressions of the average stand conditions, and are therefore considered whole stand measures of density (Husch, 1972). A normal, fully stocked stand is one in which the productive capacity of a particular site is being used to the maximum for a given management objective. An open-grown condition is one where the trees are allowed to grow without surrounding competition.

Reineke (1933) developed a whole stand index of competition that included the average stem size as well as the number of stems. His measure is called Stand Density Index (SDI):

$$SDI = \frac{No}{Ne} \tag{5}$$

Where:

No = the actual number of stems
Ne = the normal number of stems

The normal number of stems (Ne) is calculated using the following equation:

$$Ne = a\bar{D}^{b} \tag{6}$$

Where:

$\bar{D}$ = the DBH of the tree of average basal area

a,b = constants

Gingrich (1967) combined the number of stems with the basal area to derive a stocking percent chart for hardwoods. Although derived from measures of density, the chart is actually a qualitative expression of stocking.

Krajicck *et al.* (1961) developed Crown Competition Factor (CCF), which is a relationship between the actual stand conditions and those present in an open-grown situation. CCF compares the growing space available to the average tree in the stand to the maximum growing space that the tree could use if it were allowed to develop free from surrounding competition.

$$CCF = \frac{\sum_{i=1}^{N} Aj}{A} * 100 \tag{7}$$

Where:

Aj = the maximum open-grown crown area for the j^{th} tree in the stand

A = the area of the stand

N = the number of trees in the stand

The maximum open-grown crown area for a particular tree is equal to the area enclosed by the vertical projection of the open-grown crown of a tree of the same DBH. In other words, the maximum growing space that a tree can utilize is a function of its diameter (Paine, 1976). For young-growth Douglas-fir in the Willamette Valley, this function takes the following form:

$$MGSA_i = \Pi \left(\frac{CW_i}{2} \right)^2 \qquad (8)$$

Where:

$MGSA_i$ = maximum growing space area for a tree of diameter i
CW_i = open-grown crown width for a tree of diameter i

Also;

$$CW_i = b_0 + b_1 (DBH_i) + b_2 (DBH_i)^2 \qquad (9)$$

Where:

b_0, b_1, b_2 = regression coefficients

CCF has been shown to be independent of both stand age and site quality (Dahms, 1966). According to Spurr (1952), an ideal measure of density should be not only independent of site and age, but also simple to calculate and objective in nature. CCF meets these requirements.

It is true that whole stand indexes of competition reflect only average stand conditions. However, when working with large stands of trees, as is the case in production forestry, the time and money saved outweigh any losses incurred from merely recognizing these average conditions.

DATA ANALYSIS

Basal Area Growth Prediction

The data base for this study includes four treatments and a control, with three replications of each. Each treatment represents a different thinning regime. The amount of basal area retained after thinning is a function of the basal area growth response of the control plots (see Table 1). The four treatments represent the broad range of stocking usually associated with managed stands of young-growth Douglas-fir, while the control plots are characteristic of overstocked conditions that often prevail after natural regeneration. These overstocked control plots were eliminated from the analysis for several reasons. First, growth prediction and harvest scheduling are problems usually associated with managed stands, not overly dense unmanaged ones. Secondly, and most important, the control plots were ignored because of a lack of data for stocking levels between those plots that were thinned the lightest (treatment seven) and those plots that were not thinned at all (controls). Mortality was not a problem on the treatment plots, however it caused my calculations of basal area growth on the control plots to be erroneously low. The combination of these three factors made it impossible to fit meaningful regression equations to the data set when the control plots were included.

A regression analysis was performed for each of the yearly growth periods from 1975 through 1978. The amount of basal area growth (BAG) in square feet per one-fifth acre plot was used as the dependent variable. Independent variables, or predictor variables, included basal area (BA) in square feet per one-fifth acre, CCF, and several transformations and combinations of these two. Basal area and CCF values are those present at the beginning of each growth period. Age and site quality are significant variables in the prediction of future volume growth (McArdle, 1961), however the data base includes only one site and one age for all treatments, so the effects of these two variables upon BAG prediction is beyond the scope of this study. The different predictor variables tested for significance are listed in Table 2.

It was shown for growth year 1975 that the variable $\ell n(BA)$ was the best independent variable for predicting BAG. $\ell n(BA)$ produced a coefficient of determination (r^2) of 0.9173. This was significant at the .001 level. With $\ell n(BA)$ in the model, none of the other predictor variables could account for an additional significant amount of variation about the regression line at the .05 level. Figure 2 shows the correlation between $\ell n(BA)$ and BAG for growth year 1975.

When a model was tested using only $\ell n(CCF)$ as an independent variable, simplar results were observed; an $r^2 = 0.9138$ was generated. Likewise, with $\ell n(CCF)$ in the model, no other variables could account for a significant amount of the variation of the .05 level. Figure 3 shows the correlation between $\ell n(CCF)$ and BAG for 1975. The correlation between CCF and basal area was very high ($r = 0.9982$). This is because all of the data came from the same site and age

TABLE 2. INDEPENDENT VARIABLES TESTED IN REGRESSION ANALYSIS.

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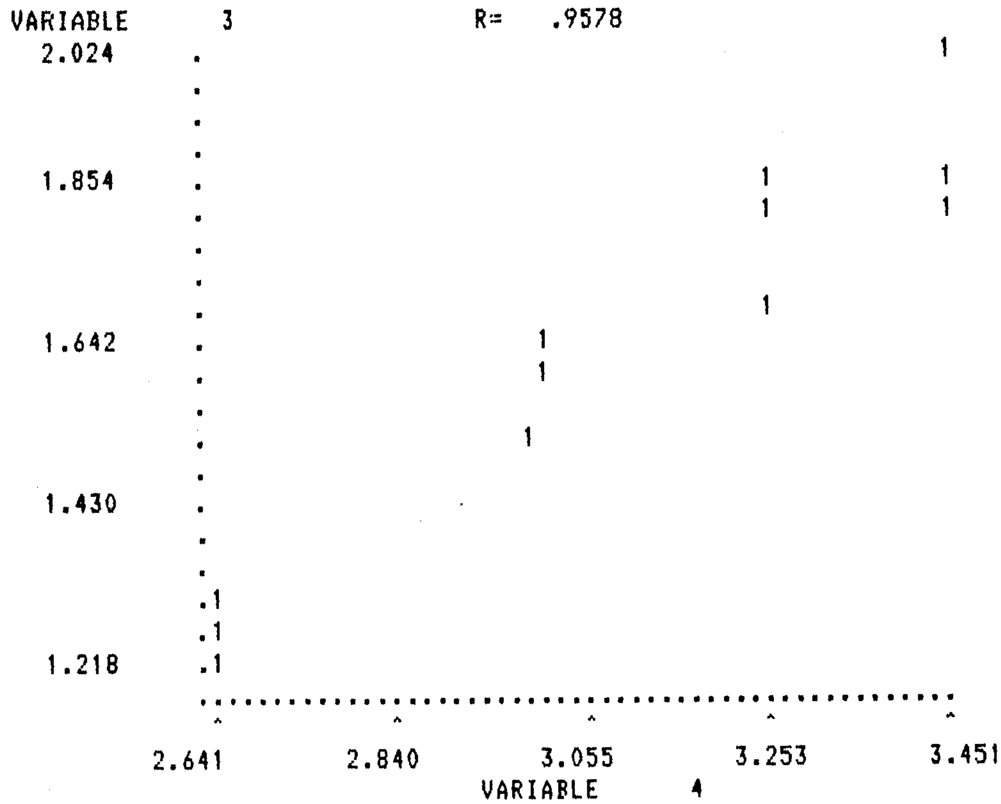
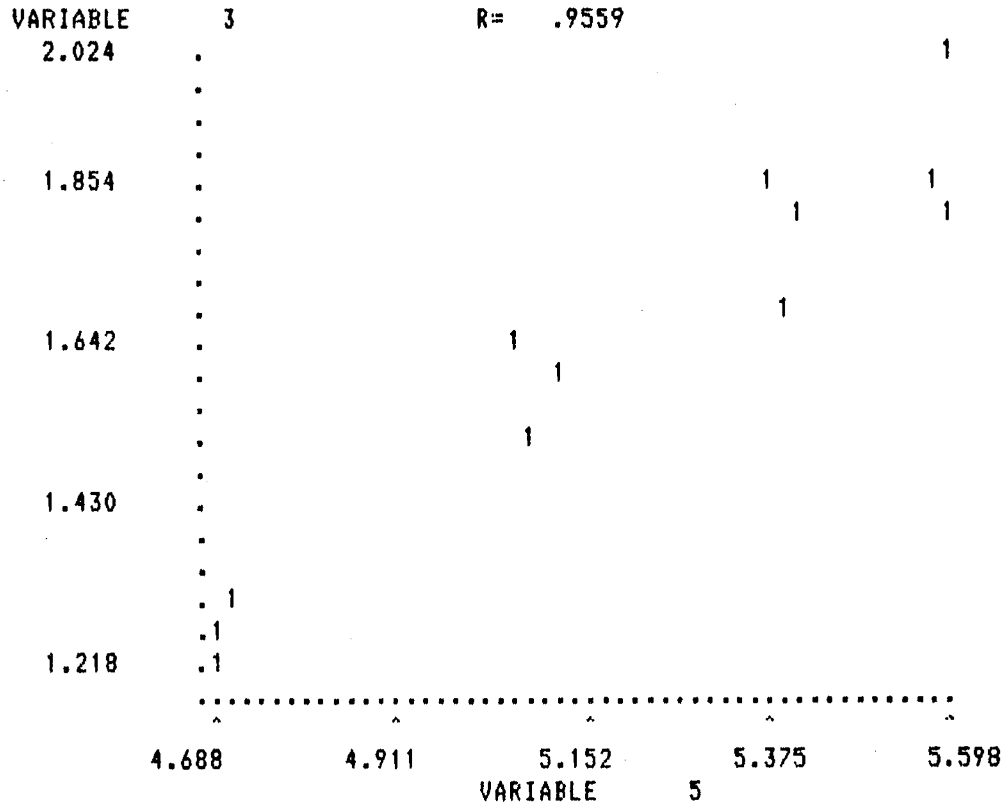
1. Basal Area (BA) (sq.ft./ $\frac{1}{5}$ acre)
2. CCF
3. ℓn(BA)
4. ℓn(CCF)
5. BA^2
6. CCF^2
7. (BA * CCF)
8. (ℓn(BA) * ℓn(CCF))



Variable 3 = BAG
Variable 4 = ℓn(BA)

Figure 2. Correlation between ℓn(BA) and Basal Area Growth (BAG) for growth year 1975.



Variable 3 = BAG
Variable 5 = ℓn(CCF)

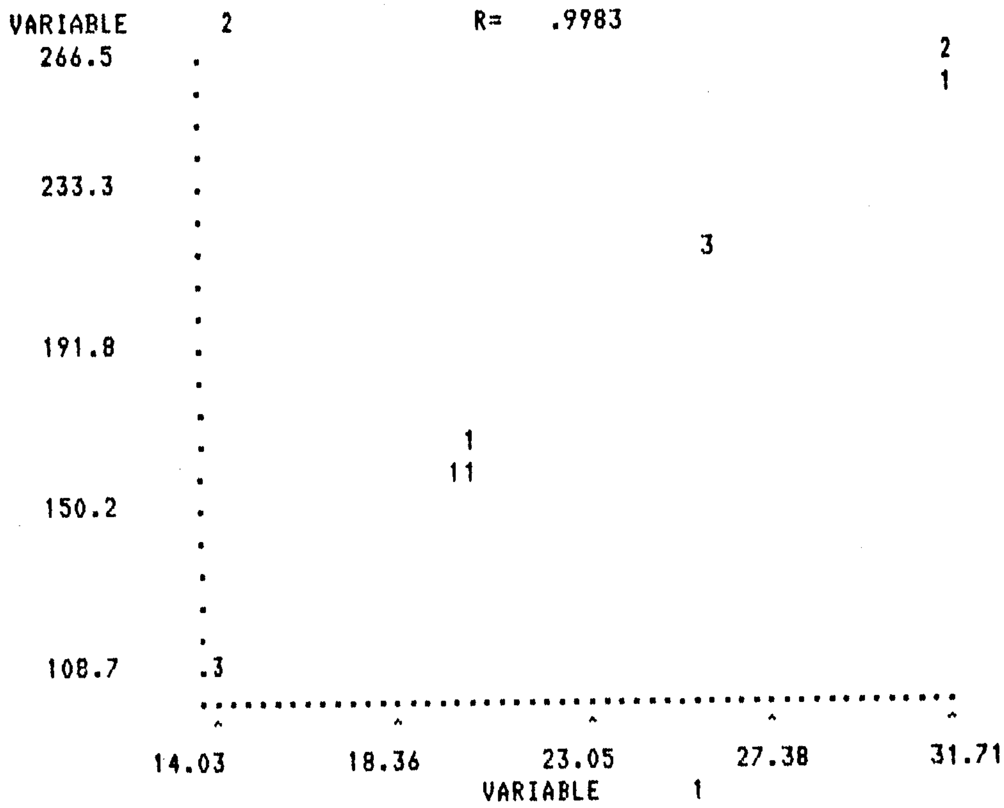
Figure 3. Correlation between ℓn(CCF) and Basal Area Growth (BAG) for growth year 1975.

combination. Figure 4 illustrates this correlation.

When BA was used to predict BAG, a significance level of .001 was again obtained; with $r^2 = 0.8855$. Once again no other variables could account for additional variation at the .05 level. A model using only CCF produced an $r^2 = 0.8799$. The cross-product variable $\ell n(BA) * \ell n(CCF)$ proved significant at the .05 level when added to the model containing CCF. Together, these two variables produced an $R^2 = 0.9261$. Correlations between BA and BAG, and between CCF and BAG, can be found in Figure 5 and Figure 6, respecitvely. A forward stepwise regression was performed and the results can be seen in Table 3.

It is clear that ℓn(BA) is the best predictor variable of those tested. The ℓn(CCF) is almost as good as ℓn(BA), which is logical because of the very high correlation between BA and CCF. The residuals for the model containing only ℓn(BA) are shown in Figure 7. The correlation of −0.2876 indicates a reasonably good fit. Even though it would not be significant at the .05 level, the addition of another independent variable with a negative coefficient would greatly reduce the residual correlation.

Growth year 1976 was very similar to 1975. Again, the best predictor variable was ℓn(BA), with ℓn(CCF) producing results almost as good. With only ℓn(BA) in the model, an $r^2 = .8264$ was produced. No other variables were significant at the .05 level with ℓn(BA) in the model. The model containing only ℓn(CCF) produced a slightly lower coefficient of determination ($r^2 = .8197$). Figure 8 shows the

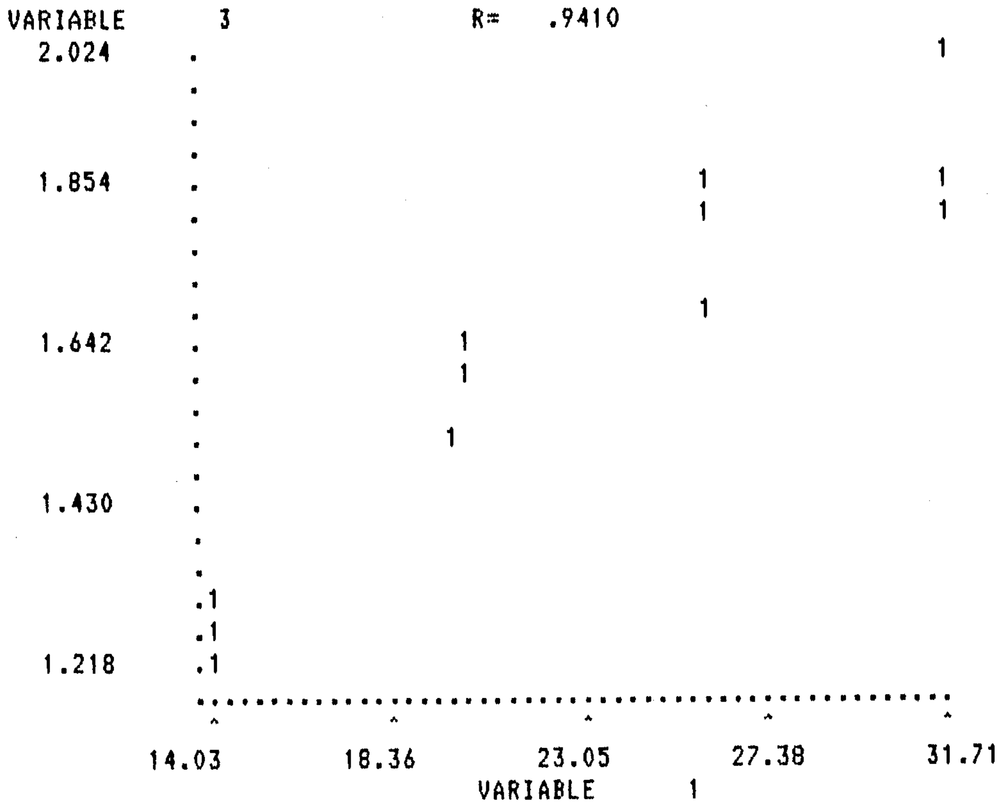


Variable 1 = BA
Variable 2 = CCF

Figure 4. Correlation between CCF and basal area for growth year 1975.

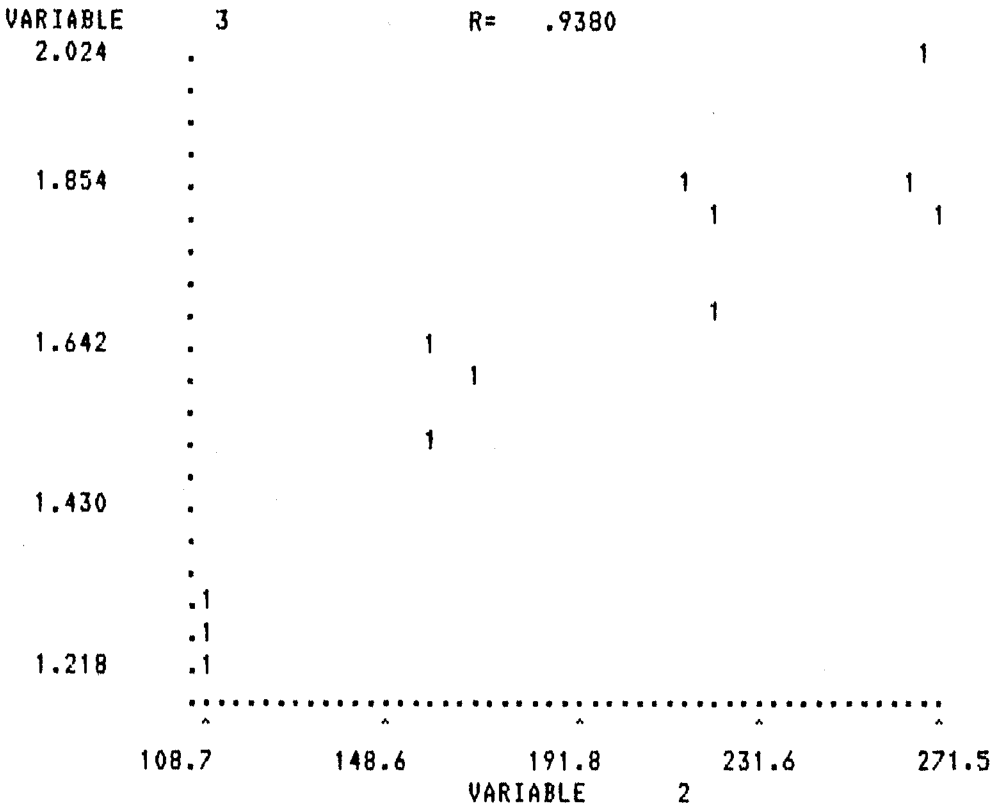
TABLE 3. RESULTS OF FORWARD STEPWISE REGRESSION FOR GROWTH YEAR 1975

Entering variable	Accum. R^2	Level of significance
1. $\ell n(BA)$	.9173	.001
2. CCF^2	.9257	N.S.
3. BA * CCF	.9263	"
4. $\ell n(CCF)$	.9277	"
5. CCF	.9278	"
6. BA	.9341	"
7. $\ell n(BA)$ * n(CCF)	.9347	"
8. BA^2	.9380	"



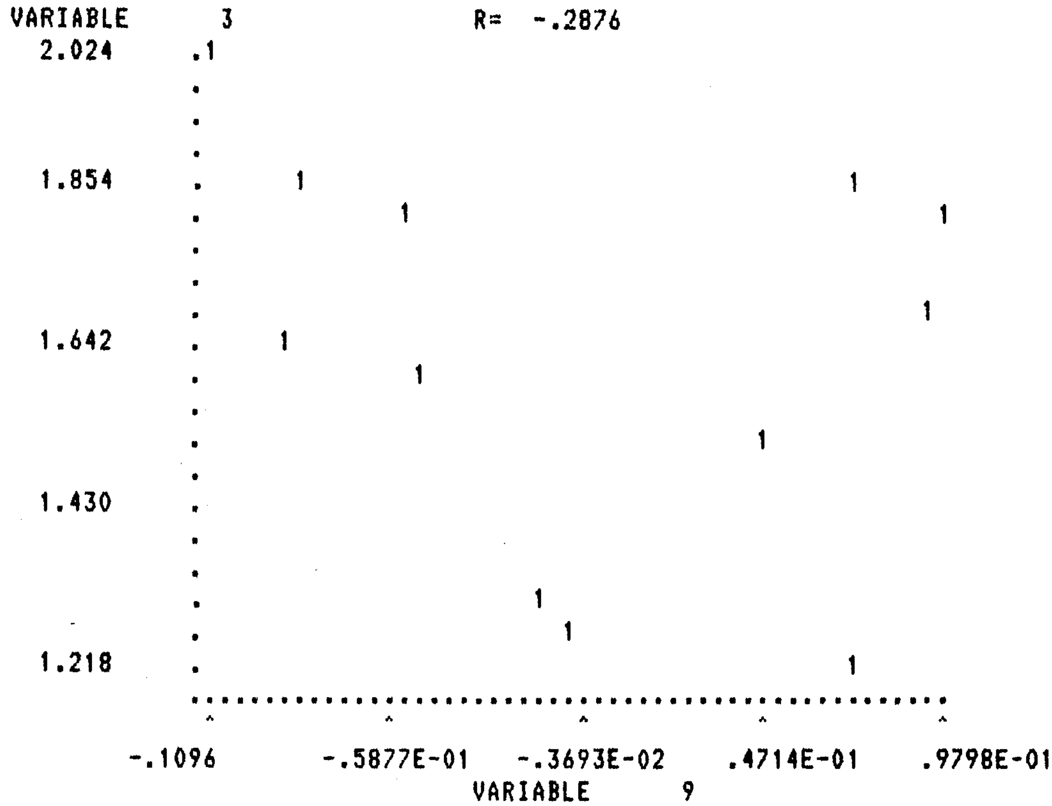
Variable 1 = BA
Variable ~~2~~ 3 = BAG

Figure 5. Correlation between basal area and Basal Area Growth (BAG) for growth year 1975.



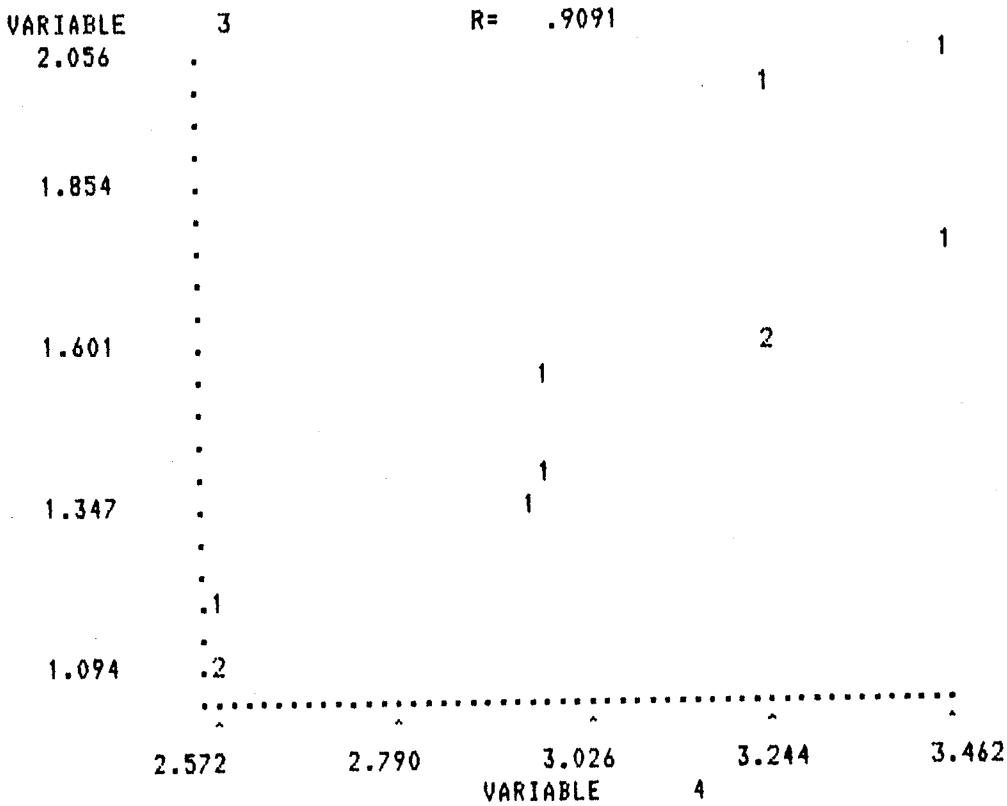
Variable 2 = CCF
Variable 3 = BAG

Figure 6. Correlation between CCF and Basal Area Growth (BAG) for growth year 1975.



Variable 3 = BAG
Variable 9 = Residuals

Figure 7. Correlation between residuals and Basal Area Growth for growth year 1975. The residuals are produced from the model using $\ell n(BA)$ as the only independent variable.



Variable 3 = BAG
Variable 4 = ℓn(BA)

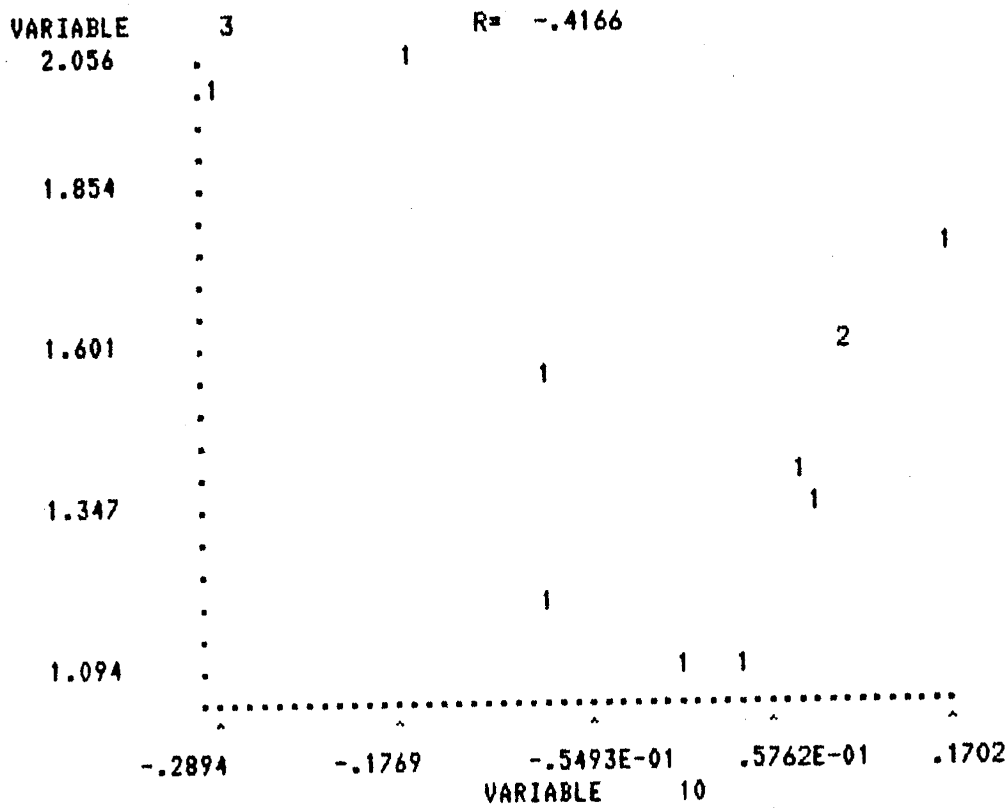
Figure 8. Correlation between ℓn(BA) and Basal Area Growth (BAG) for growth year 1976.

correlation between $\ell n(BA)$ and BAG. Since the correlation is not as good for 1976 as it was for 1975 using $\ell n(BA)$, the correlation of the residuals is higher ($r = -0.4166$). The residuals are shown in Figure 9. The results of a forward stepwise regression are shown in Table 4.

Growth year 1977 showed $\ell n(CCF)$ to be the single best independent variable in predicting BAG. However, $\ell n(BA)$ explains an additional amount of variation at the .05 level. The model with only $\ell n(CCF)$ produces an $r^2 = 0.7367$ while the model containing both $\ell n(CCF)$ and $\ell n(BA)$ has an $R^2 = 0.8379$. Results of the stepwise regression are shown in Table 5.

Growth year 1978 again showed $\ell n(CCF)$ to be the single best predictor variable with an $r^2 = 0.7143$. With $\ell n(CCF)$ in the model, no other variables could enter at the .05 level. The variable $\ell n(BA)$ was the second best single independent variable with $r^2 = 0.6988$. The stepwise regression results are summarized in Table 6.

When the data for all growth periods were combined, the results were consistent with those obtained for the individual growth years. This indicates that the changes from one growth year to another have little effect on the relative basal area growth prediction ability of those independent variables tested. One difference that did show up was that the best model had two variables, both of which were significant at the .001 level. The variable $\ell n(CCF)$ was the single best predictor of BAG. However, the interaction term $\ell n(BA) * \ell n(CCF)$ also enters this model and explains an additional amount of variation about the regression line at the .001 level.



Variable 3 = BAG
Variable 10 = Residuals

Figure 9. Correlation between residuals and Basal Area Growth for growth year 1976. The residuals are produced from the model using ℓn(BA) as the only independent variable.

TABLE 4. RESULTS OF FORWARD STEPWISE REGRESSION FOR GROWTH YEAR 1976.

Entering variable	Accum. R^2	Level of Significance
1. $\ell n(BA)$	.8264	.001
2. $\ell n(CCF)$	.8278	N.S.
3. $\ell n(BA) * \ell n(CCF)$	.8283	"
4. BA * CCF	.8360	"
5. CCF	.8372	"
6. BA^2	.9458	"
7. BA	.9495	"
8. CCF^2	.9765	"

TABLE 5. RESULTS OF FORWARD STEPWISE REGRESSION FOR GROWTH YEAR 1977.

Entering variable	Accum. R^2	Level of significance
1. $\ell n(CCF)$	.7367	.001
2. $\ell n(BA)$	.8379	.05
3. BA^2	.8427	N.S.
4. $\ell n(BA) * \ell n(CCF)$	.8708	"
5. BA * CCF	.8731	"
6. CCF^2	.9277	"
7. CCF	.9321	"
8. BA	.9475	"

TABLE 6. RESULTS OF FORWARD STEPWISE REGRESSION FOR GROWTH YEAR 1978.

Entering variable	Accum. R^2	Level of Significance
1. $\ell n(CCF)$	.7143	.001
2. BA^2	.7483	N.S.
3. BA	.7489	"
4. CCF	.7504	"
5. BA * CCF	.7529	"
6. CCF^2	.9432	"
7. $\ell n(BA)$	.9448	"
8. $\ell n(BA) * \ell n(CCF)$	.9677	"

Together these two variables produce an $R^2 = 0.8053$. By itself $\ell n(CCF)$ exhibits an $r^2 = 0.7656$. When a model was fit using only $\ell n(BA)$, the resulting r^2 was 0.7221. The variable $\ell n(CCF)$ would explain an additional amount of variation at the .001 level. Together these two predictors show an $R^2 = 0.7993$. Table 7 shows the results of the stepwise process.

This study indicates that for a given site and age combination, there is not any real difference between the basal area growth prediction ability of basal area and CCF. However, since CCF is independent of site and age, and basal area is not, then it should give more reliable results when used to predict growth over a wide range of site and age combinations.

Sampling for Crown Competition Factor

In order to calculate CCF you must know the number and size of all stems in the stand. Variable plot sampling techniques can be used to generate a stand table from sample points (Dilworth, 1978). At each sample point the "in" trees are recorded by diameter and a stand table can then be produced. The problem is one of determining how accurately the tree diameters must be recorded in order to obtain results consistent with the true CCF value for the stand. Computer programs were written to group all trees into diameter classes at varying ranges, and the resulting CCF estimates were then calculated and compared to the actual values for each of the treatments. The actual CCF values were obtained using every tree's true diameter

TABLE 7. RESULTS OF FORWARD STEPWISE REGRESSION FOR ALL GROWTH YEARS COMBINED

	Entering variable	Accum. R^2	Level of significance
1.	$\ell n(CCF)$	.7657	.001
2.	$\ell n(BA) * \ell n(CCF)$	.8053	.001
3.	BA^2	.8063	N.S.
4.	$\ell n(BA)$	.8197	"
5.	BA * CCF	.8201	"
6.	CCF^2	.8223	"
7.	CCF	.8225	"
8.	BA	.8244	"

as it was recorded to the nearest one-tenth inch. CCF estimates were then obtained by grouping all trees into diameter classes varying in size from two inches to eight inches. By grouping trees into eight-diameter classes, it amounted to calling all trees either small (8") or large (16") because of the limited range of diameters associated with this data set. The results of these different CCF estimations are shown in Table 8. When all treatments are grouped together, estimates of CCF are within ± 1 percent of the actual values using diameter classes of two inches, four inches, and six inches. The eight-inch diameter class estimates show a mean percentage error of 5.81 percent. The limited range of diameters within the data set may account for the large percentage errors received when using eight-inch diameter classes. This is evident in the dramatically over-estimated values for CCF obtained on the control plots (treatment nine). If a larger range of diameters was present, the percentage differences between the eight-inch diameter class estimates and the actual CCF values would probably average out better than they have here.

Even though this is just one isolated situation, the results are interesting. They show that a forester can estimate the diameter of the "in" trees at each sample point and still obtain quite accurate CCF figures. There appears to be no need to take accurate diameter measurements, when a quick estimate will product results capable of meeting the objectives of most studies where CCF values are necessary.

TABLE 8. COMPARISON BETWEEN ACTUAL CCF AND ESTIMATED CCF.

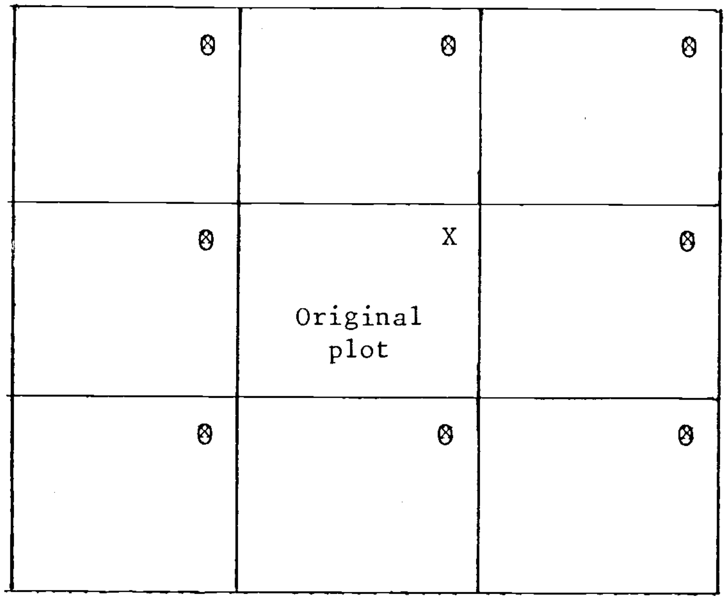
	TRT #1		TRT #3		TRT #5		TRT #7		TRT #9		ALL TRTs	
2"	0.32	2.32	1.08	1.41	0.74	1.18	0.18	1.74	0.07	1.57	0.38	1.72
4"	0.26	2.39	0.58	3.41	0.79	1.64	0.94	2.67	1.05	1.78	0.01	2.53
6"	0.41	4.34	3.15	4.17	0.19	3.15	0.17	1.89	5.99	1.91	0.56	4.38
8"	5.17	4.24	1.27	8.01	2.01	4.28	0.94	5.00	19.64	7.37	5.81	9.22
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD

$\overline{X}$ = the mean percentage difference between the actual CCF and the estimated CCF.

SD = the standard deviation of the percentage differences between the actual CCF and the estimated CCF.

Competitive Stress Index as a Whole Stand Measure of Density

Competitive Stress Index (CSI) was developed by Arney (1973) as an individual tree index of competition. Arney states that when the CSI values for all trees in a stand are averaged, the result is the same as the CCF value for that stand. Computer programs were written to calculate the average CSI for all plots in treatments one, three, five, and seven. In order to calculate the CSI for trees near the edge of the plots a buffer was created around the plots. This buffer concept is shown in Figure 10. This buffer amounts to directly including the competition from trees surrounding the plot into the CSI value of the plot itself. CCF includes this surrounding competition only indirectly because of its effect on the size of those trees near the plot edges. For this reason the average CSI values and the CCF values for the same plots were not the same. The average CSI values were consistently larger than the corresponding CCF figures. However, the correlation between the two proved to be very nearly perfect ($r = .997$). In other words, even though the numbers generated by these two indexes are different, they are practically the same.



X Location of tree on edge of plot.

⊗ Location of same tree in buffer plots.

Figure 10. Method of producing plot buffer for CSI calculations using a mirroring technique.

CONCLUSIONS

This study shows that for a given age and site combination, CCF and basal area will produce equally good predictions of basal area growth. However, since CCF has been shown to be independent of site and age, this indicates that it is a superior measure of density, and a better overall predictor of basal area growth. When using variable plot techniques to generate a CCF sample, tree counts and diameters are required to produce the necessary stand table in order to estimate CCF. In doing this an estimate of basal area is also obtained from the tree counts and the basal area factor used in sampling. In other words, an estimate of basal area is always obtained when a sampling process for CCF is undertaken. Therefore, CCF estimates can be produced merely by recording the diameters of the "in" trees at each sample point. Since the diameters of the sample trees need only be estimated to the nearest few inches, easily within the ability of trained forestry personnel, CCF data may be collected in addition to standard basal area data with virtually no additional time or expense.

BIBLIOGRAPHY

Alemdag, I. S. 1978. Evaluation of some competition indexes for the prediction of diameter increment in planted white spruce. Canadian Forestry Service. Ottawa, Ontario. Information Report FMR-X-108, 39pp.

Arney, J. D. 1973. Tables for quantifying competitive stress on individual trees. Pacific Forest Research Centre. Canadian Forestry Service. Victoria, British Columbia. Information Report BC-X-78, 30pp.

Bell, J. F., and A. Berg. 1972. Levels-of-growing-stock cooperative study on Douglas-fir. Report No. 2. The Hoskins study, 1973-1970. U.S.D.A. Forest Serv. Res. Paper PNW-130, 19pp., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Bella, I. E. 1971. A new competition model for individual trees. For. Sci. 17(3):364-372.

Brown, G. S. 1965. Point density in stems per acre. New Zealand Forest Res. Note 38. 11pp.

Cochran, W. G. 1963. Sampling Techniques. John Wiley and Sons, Inc., New York. 413pp.

Curtis, R. O. 1970. Stand density measures: an interpretation. For. Sci. 16(4):403-414.

Dahms, W. G. 1966. Relationships of lodgepole pine volume increment to Crown Competition Factor, basal area, and site index. For. Sci. 12(1):74-82.

Daniels, R. F. 1976. Simple competition indices and their correlation with annual loblolly pine tree growth. For. Sci. 22:454-456.

Dilworth, J. R. 1977. Log Scaling and Timber Cruising. O.S.U. Book Stores, Inc., Corvallis, Oregon. 462pp.

Gingrich, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the central states. For. Sci. 13:38-53.

Hegyi, F. 1974. A simulation model for managing jack pine stands. In: Growth models for tree and stand simulation. (J. Fries, Ed.) Royal College of Forestry, Research Notes No. 30, Stockholm, pp. 74-90.

Husch, B., C. I. Miller, and T. W. Beers. 1972. Forest Mensuration. Ronald Press Company, New York. 410pp.

Krajicek, J. E., K. A. Brinkman, and S. F. Gingrich. 1961. Crown competition--a measure of stand density. For. Sci. 7(1):35-42.

McArdle, R. E., W. H. Meyer, and D. Bruce. 1961. The Yield of Douglas-fir in the Pacific Northwest. U.S.D.A. Technical Bulletin No. 201.

Neter, J., and W. Wasserman. 1974. Applied Linear Statistical Models. Richard D. Irwin, Inc., Homewood, Illinois. 832pp.

Paine, D. P., and J. D. Arney. 1976. Crown competition factors for Douglas-fir (manuscript in process).

Reineke, L. H. 1933. Perfecting a stand density index for even-aged forests. J. Agr. Res. 46(7):627-638.

Smith, S. H. 1977. Evaluation of competitive stress index as a measure of stand density for young-growth Douglas-fir. M.S. thesis, Oregon State University. 188pp.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. The Iowa State University Press, Ames, Iowa. 593pp.

Spurr, S. H. 1962. A measure of point density. For. Sci. 8:85-96.

Staebler, G. R. 1951. Growth and spacing in an even-aged stand of Douglas-fir. Unpubl. M.F. thesis, University of Michigan, Ann Arbor.

Whittaker, R. 1970. Communities and Ecosystems. The Macmillan Company, New York. 158pp.

Williamson, R., and G. Staebler. 1971. Levels-of-growing-stock Cooperative Study on Douglas-fir; Report #1--Description of Study and Existing Study Areas. U.S.D.A. Forest Service Research Paper PNW-111. Portland, Oregon.