Predicting Tree Groundline Diameter from Crown Measurements Made on 35-mm Aerial Photography

Gary F. Hagan
Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907
James L. Smith
School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

ABSTRACT: Linear regression models to predict diameter at groundline in two loblolly pine (*Pinus taeda* L.) plantations from 35-mm aerial photo tree measurements were constructed and evaluated. Two one-acre plots were established in Virginia piedmont plantations with differing densities and aerial photos of the plots were acquired. Photo measurements of total tree height, crown width, and crown area, and transformations of these variables were tested to develop prediction relationships. The natural log of crown area indicated a linear relationship with diameter at groundline, and this simple linear model was chosen as the prediction function for both plots. A validation procedure with independent data indicated approximately 70 percent of the predictions were in error by one one-inch diameter groundline class or less.

INTRODUCTION

THE INCREASING COST and sophistication of forest thinning operations has created a need for better ways to plan and monitor them. Often, however, the information needed to plan a harvest is not collected in a traditional forest inventory. For instance, the advent of the feller-buncher has resulted in a need for information on stem diameter at groundline (DGL). Feller-bunchers have limited shear and accumulator capacities, and, thus, to plan a mechanized selective thinning, groundline diameter distribution data is required.

The need for a rapid and economical method for obtaining information on groundline diameters prompted a study on predicting DGL from aerial photography. The relationship between diameter at breast height (DBH) and the photo-measurable variable of crown diameter is well documented (Minor, 1951). A logical extension of this relationship is to predict DGL from measurements made on aerial photographs.

The objective of this research was to construct and evaluate linear regression models which predict stem diameter at groundline from measurements made on 35-mm aerial photographs of two loblolly pine (*Pinus taeda* L.) plantations in the Virginia piedmont. The uniqueness of this study arises not just from the prediction of a new tree characteristic from aerial photographic measurements, but also from the conditions specified in the study. First, only measurements made on aerial photographs were used as predictor variables. Many other researchers have either utilized ground collected values of photo-measurable variables as predictors of DBH (Bonnor, 1968), or have not made it clear what type of data was used (Minor, 1951). Second, a typical mixture of species found in these stands was included in the analysis, not just loblolly pine. These conditions more closely approximate operational situations than have many past attempts to predict DBH from aerial photography.

PAST WORK

Many studies have shown that DBH is directly correlated with crown diameter. The relationship approaches a straight line but is generally slightly curvilinear or sigmoid in shape (Spurr, 1960). The estimation of DBH solely from crown diameter frequently produces standard deviations about the regression line of 2 inches (Spurr, 1960). Earlier, Minor (1951), working with loblolly pine, established a simple linear regression estimation model for DBH from crown diameter with a coefficient of determination of 0.76. He found that trees could be classified into 2- or 3-inch diameter classes from 1:20,000 scale aerial photos.

Later researchers discovered that the relationship between DBH and crown width was not strong enough to provide reliable estimates of DBH. Aldred and Sayn-Wittgenstein (1972) concluded that tree height is the best variable for estimates of diameter and volume. Using Arizona ponderosa pine (*Pinus ponderosa* Laws.), Minor (1960) found height multiplied by crown width had the best correlation with

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 5, May 1986, pp. 687–690.

0099-1112/86/5205-687$02.25/0

DBH. Research with red pine (*Pinus resinosa* Ait.) produced a DBH prediction model based on total crown width, total tree height, and the product of these two variables. This equation accounted for 91.5 percent of the variation of the data and had a standard deviation about the regression line of 1.24 inches (Bonnor, 1964). Bonnor's height and crown measurements were field, not photo, measurements.

The great irregularities in the shape of tree crowns were found to cause difficulty in measuring and defining crown width, radius, or diameter on aerial photographs and also in the field (Kippen and Sayn-Wittgenstein, 1964). Sayn-Wittgenstein and Aldred (1967) report crown diameters were measured with a standard deviation of 2 feet with 1:1,200 scale 70-mm photographs. Crown area, defined as the area occupied by the projection of the crown onto a horizontal plane, was more reliably measured and was estimated as quickly and more consistently than crown width (Aldred and Sayn-Wittgenstein, 1972). Crown area was never less significant than crown width as an independent variable to estimate diameter or volume. A dot grid was found to be effective for measuring crown area. A grid with approximately 17 dots per tree crown, providing that the grid density does not exceed 10,000 dots per square inch, gives the necessary precision and minimizes counting errors by the interpreter (Aldred and Sayn-Wittgenstein, 1972).

DATA

A one-acre plot, 104.4 feet by 417.6 feet, was established in each of two loblolly pine plantations located in the piedmont of Virginia. On each plot, the location (x,y coordinates), species, and crown class of each tree greater than 3 inches at DBH was recorded. Diameter at groundline was measured with a diameter tape one inch above ground level. Crown width, at the widest point as determined visually, was measured with a 100-foot tape. The basic characteristics of the two plots are presented in Table 1.

Aerial photography of the two plots was acquired using a Canon AT-1 35-mm single lens reflex camera equipped with a 50-mm lens and Kodacolor ASA 100 print film. The photography was taken in October during the Autumn color change, which facilitated the identification of hardwood stems. Several photo identifiable targets were placed at known locations in each of the two plots. The planned scale of the negatives was 1:3,000, which resulted in a nominal aircraft altitude of 492 feet above the ground. Image cropping was minimized by enlarging to a 4 by 6-inch print format. The resulting print scales were 1:570 for plot 1 and 1:640 for plot 2. The exact scale of each print was determined by first determining the scale of the negatives. The photo distance between ground control points was measured on the negatives and compared to the ground distance between the known points. Following the enlargement process, an enlargement factor for each print was calculated by comparing the distance between the ground markers measured on the prints to the same distance measured on the negatives. The individual enlargement factors were then multiplied by the negative scales to find the 4 by 6-inch print scales.

TABLE 1. SUMMARY OF THE CHARACTERISTICS OF THE TWO PLOTS ESTABLISHED IN LOBLOLLY PINE PLANTATIONS IN THE VIRGINIA PIEDMONT.

Variable	Plot 1	Plot 2
Stems per acre		
Loblolly pine	388 (97%)	510 (73%)
Virginia pine	9 (2%)	98 (14%)
Mixed hardwoods	4 (1%)	94 (13%)
Total	401 (100%)	702 (100%)
Total Basal Area (sq ft)	127	125
Planting spacing (ft)	10×8	8×8
Age (years)	17	18
Site Index (feet, base age 25)	60	60
Average DGL (in.)	9.7	7.6
Average DBH (in.)	7.6	5.5

METHODS

The first step in the process of constructing and testing a photo based DGL prediction equation was to pair a subsample of trees in each plot to their image on the aerial photography. A map of stem locations and photo identifiable targets was compared to each photo to identify the ground-measured stem corresponding to each crown image present on the photos. A random sample of 125 trees was then taken in each plot. Seventy-five trees were used to construct the prediction function for each plot, with the remaining sample trees used as a validation data set. Only conifers, loblolly pine and Virginia pine (*Pinus virginiana* Mill.), were selected as sample trees because hardwood stems are generally not cut in a thinning. The selected trees spanned the range of groundline diameters and crown classes, although not all crown and diameter classes were equally represented.

Photo measurements of sample trees characteristics were then made to use as predictor variables. On the photo image of a selected tree, total height, crown width, and crown area were measured. Individual tree heights were measured using a Sokkisha parallax bar under an Old Delft Scanning Stereoscope. Crown diameter, at the widest point, was measured with a 0.1 mm graduated scale under monoscopic 7× magnification. Crown area was estimated with a fine dot grid while viewing each crown monoscopically with a 7× magnifier. The criteria proposed by Aldred and Sayn-Wittgenstein (1972) were used to select the grid density. On plot 1, a grid with 484 dots per square inch was utilized. An average of 19 dots were counted on each tree crown. On plot 2, which had smaller trees and smaller scale photography than plot 1, a 1,156 dots per square inch dot grid was used to estimate crown area. This resulted in an average dot count per crown of 18.

Traditional linear regression techniques were used to estimate the relationship between DGL and several photo-measured tree characteristics for each plot. Standard model selection procedures were employed to determine which independent variables produced the best prediction function. Combinations of crown area, crown diameter, tree height, and transformations of these variables were plotted against DGL to determine the forms of the various relationships. A model was selected for each plot on the basis of R^2, standard error about the regression line, average absolute value of the residuals, and the model bias as judged by examining plots of the residuals.

Because the predominant use of these regression functions would be for forecasting DGL, it was necessary to test their predictive power on the independent validation data sets. The raw average, the average absolute value, and the standard deviation of the independent residuals were computed for each plot to estimate the accuracy and precision of the DGL predictions. The residuals were examined to ascertain whether any trends in accuracy and precision were present in the data.

RESULTS AND DISCUSSION

SELECTED REGRESSION MODELS

Although many more complicated models were tested in this study, the model selection procedure resulted in the following simple prediction models being chosen for the two plots:

Plot 1.

$$\text{DGL} = -4.10 + 3.17 * \ln(\text{CA})$$
$$R^2 = 0.52$$
$$Sy.x = 1.33 \text{ in.}$$
$$C.\ V. = 13.7\%$$

Plot 2.

$$\text{DGL} = -0.902 + 2.48 * \ln(\text{CA})$$
$$R^2 = 0.51$$
$$Sy.x = 1.52 \text{ in.}$$
$$C.\ V. = 19.3\%$$

where DGL = diameter groundling (in.),
CA = photo-measured crown area (sq ft), and
ln = base e logarithm.

The initial plotting of the independent variables indicated that a strong, nonlinear relationship existed between crown area and DGL. The logarithmic transformation was necessary to produce a linear relationship. The negative intercepts are likely caused by a small sampling from the smaller diameter classes. Crown area consistently produced prediction functions with better precision and accuracy than did any form of the variable crown width. Total tree height contributed little to the quality of the regressions, contradicting earlier research that predicted DBH from aerial photographs (Spurr, 1960). This contradiction, however, can be explained by noting that many past studies used ground measured values to construct prediction equations of this type. The imprecision of height measurements on aerial photos is well documented (Needham and Smith, 1984), which seemingly reduces its ability to contribute to DGL predictions made strictly from photo-measurements.

The results of this study differed from the earlier works on the precision of DBH estimation. The coefficients of determination for the photo-based DGL models were less than most reported for DBH for several reasons. First, diameter at groundline tends to be more variable than DBH, thereby reducing the precision of prediction models. Second, many previous researchers utilized more precise ground measurements as predictor variables. Finally, the trees used to construct the equations were selected randomly, representing all crown classes, and trees were not selected on the basis of visibility from the air. All these factors together reduce the quality and precision of the prediction models, but these conditions resulted in models which resemble operational conditions more closely.

Residual plots indicated that both prediction models were unbiased. However, a difference in precision for the two equations was present, with the model for plot 1 superior to that for plot 2. Over 80 percent of the trees from plot 1 used to build the regression had predicted DGL values which were in error by one one-inch diameter class or less. That same statistic drops to approximately 66 percent for plot 2. This lower precision can be attributed to the greater species diversity and higher stocking levels present in plot 2. Higher stand density translates into smaller, more closely spaced, and overlapping tree crowns which could have adversely affected the ability of the interpreter to accurately and precisely estimate crown area.

VALIDATION PROCEDURE

A validation procedure utilizing the independent random sample of 50 trees from each plot tested the quality of the DGL predictions with the selected models (Table 2). For both models, approximately 70 percent of the DGL predictions were in error by one one-inch DGL class or less. The validation

TABLE 2. RESULTS OF TESTS OF THE DIAMETER GROUNDLINE PREDICTION MODELS ON INDEPENDENT DATA SETS

	Plot 1	Plot 2
Dgl Predictions	Relative Frequencies (%)	
Correct DGL class	32	24
± 1 DGL class	40	46
± 2 DGL classes	24	18
± 3 DGL classes	4	12
Average error in DGL prediction	−0.06 in.	−0.59 in.
Average absolute value of the errors in DGL prediction	1.0 in.	1.2 in.

TABLE 3. PREDICTED VALUES FOR THE TWO DGL PREDICTION MODELS ACROSS A RANGE OF CROWN AREA

Crown Area (sq ft)	Predicted DGL Plot 1 (in.)	Predicted DGL Plot 2 (in.)
10	3.2	4.8
30	6.7	7.5
50	8.3	8.8
70	9.4	9.6
90	10.2	10.3
110	10.8	10.8
130	11.3	11.2
150	11.8	11.5

procedure confirmed that the model derived for plot 2 was inferior to the model for plot 1. The average residual values are -0.06 in. on plot 1 and -0.59 in. on plot 2. The plot 2 equation shows more of a trend toward overprediction. A chi-squared test for accuracy developed by Freese (1960) was applied to both models. With $\alpha = 0.01$, 68 percent of the predictions would be in error by no more than 1 inch in plot 1, while the estimated percentage within 1 inch falls to 58 percent for plot 2.

COMPARISON OF THE TWO MODELS

The similarities of the two prediction models were also examined. Table 3 presents the predicted DGL values over a range of crown area. More than 90 percent of all the sample trees in the two data sets were contained in this range of crown area. Excluding the smallest values of crown area, the predicted DGL values are very similar for the two models. Therefore, the two regression lines were tested for equality of intercepts and slopes. Using all the sample points (construction and validation), the regressions were refit separately for each plot and again with the data from the two plots combined into one data set. The results of the test indicated that there was no significant difference between the two fitted regression lines (F value $= 2.31$, p value $= 0.11$); i.e., the error sums of squares of the prediction equations were not significantly reduced by treating the two plots as separate populations. Using all the sample trees from both plots, the DGL prediction equation becomes

$$\begin{aligned} \text{DGL} &= -1.73 + 2.63 * \ln(\text{CA}) \\ R^2 &= 0.61 \\ Sy.x &= 1.41 \text{ in.} \\ C.\ V. &= 15.9\% \end{aligned}$$

CONCLUSION

The results of this study are not intended for use as a general DGL prediction model across the range of ages, sites, and conditions in which loblolly pine is found. A much larger sample would be needed to derive such a model. This study did, however, show that diameter at groundline could be rapidly and easily estimated solely from measurements made on aerial photography with accuracies and precisions acceptable for some applications. The resulting DGL prediction models were used for planning and simulating a selective mechanized thinning between access corridors. For this use, DGL predictions within a one-inch class for 60 percent of the trees are sufficient. Although less precision and accuracy was obtained in this study than in earlier works, the random selection of trees and exclusive use of photo measurements for model development closely approximate conditions that would be encountered with field applications. The simple prediction models require only crown area measurements. This can be accomplished quickly with only monoscopic magnification, eliminating the need for time-consuming stereoscopic viewing and measurements.

The 35-mm photographic format offers a timely and inexpensive means to provide information for predicting the DGL distribution in a pine plantation, thus enabling an efficient selective mechanized thinning to be planned.

REFERENCES

Aldred, A.H., and L. Sayn-Wittgenstein, 1972. *Tree Diameters and Volumes from Large Scale Aerial Photographs*. Forest Management Institute Information Report FMR-X-40. Canadian Forestry Service. 39 p.

Bonnor, G.M., 1964. A Tree Volume Table for Red Pine by Crown Width and Height. *For. Chronicle* 40(3): 339–346.

———, 1968. Stem Diameter Estimates from Crown Width and Tree Height. *Commonwealth For. Rev.* 47(1): 8–13.

Freese, F., 1960. Testing Accuracy. *For. Sci.* 6(2): 139–145.

Kippen, F.W., and L. Sayn-Wittgenstein, 1964. *Tree Measurements on Large Scale, Vertical 70mm Air Photographs*. Canadian Dept. For. Pub. 1053. 15 p.

Minor, C.O., 1951. Stem-Crown Diameter Relations in Southern Pine. *J. For.* 49(7): 490–493.

———, 1960. *Estimating Tree Diameters of Arizona Ponderosa Pine from Aerial Photographs*. USDA For. Serv. Rocky Mt. For. and Range Exper. Sta. Res. Note No. 46. 8 p.

Needham, T., and J.L. Smith, 1984. An Evaluation of the use of 35mm Aerial Photography for Determining the Height of Trees in Loblolly Pine Plantations. *Proc. of 50th ASP-ACSM Meeting*, Wash. D.C. pp. 222–230.

Sayn-Wittgenstein, L., and A.H. Aldred, 1967. Tree Volumes from Large Scale Photos. *Photo. Eng.* 33(1): 69–73.

Spurr, S.H., 1960. *Photogrammetry and Photo-Interpretation*. 2nd ed. Ronald Press, N.Y. 472 p.

(Received 7 August 1985; accepted 31 October 1985; revised 22 January 1986)