The Relationship of Diameter at Breast Height and Crown Diameter for Four Species Groups in Hardin County, Tennessee

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ABSTRACT. *A set of simple linear regression models for predicting diameter at breast height (dbh) from crown diameter and a set of similar models for predicting crown diameter from dbh were developed for four species groups in Hardin County, TN. Data were obtained from 557 trees measured during the 1989 USDA Southern Forest Experiment Station survey of the forests of Tennessee, with supplemental aerial photographic observations. Estimates of individual tree crown diameter were obtained from ground measurements and from measurements made on 9 × 9 in. color aerial photographs (with nominal scale of 1:4,800) taken during the fall color season. In practice, users of aerial photographs can estimate dbh by measuring crown diameter, converting it to feet using the photo scale, and applying the appropriate equation. Similarly, crown diameter can be estimated from a ground measurement of dbh. This procedure may be useful in reducing the time required for field measurements. It may also be used to calculate crown diameters for datasets that include dbh but no direct measurement of crown attributes. South. J. Appl. For. 19(4):177–181.*

Foresters have used aerial photographs to obtain information about forest stand characteristics for many years. However, the use of remotely sensed data, in many instances, has been limited to providing descriptions of land cover in the form of maps and summary statistics. Aerial photographs have been used primarily to segregate forest stands, to classify them according to forest type, height, density, and site, and to compile the areas of the various units (Spurr 1948). Almost 4 decades later, the concept of estimating quantitative forest stand characteristics from aerial photographs had not yet reached its fullest potential (Smith 1986).

Diameter at breast height (dbh) is a tree characteristic that is included in many forest inventories because it is an easily measured variable that is related to the amount of growing space occupied by a tree and it is often used to determine the volume of the tree. The estimation of dbh from photographically-measured variables is of great interest to foresters. This is because the major cost components of a forest inventory derive mainly from the expense and difficulty of establishing and measuring sample plots on the ground. The cost of ground work is particularly acute for inventories in remote areas (Aldred and Hall 1975).

A simple linear regression model for predicting dbh from tree crown measurement for southern pines was developed in an early study (Minor 1951). Bonnor (1964) investigated the relationship between dbh and the product of crown width and height of lodgepole pine (*Pinus contorta*) and concluded that it was unaffected by stand density. Additional studies of the dbh/crown width relationship were made for a number of conifer species (Bonnor 1968). A study of crown width and dbh for well-stocked, uneven-aged stands of upland oaks (*Quercus* spp.) and hickories (*Carya* spp.) in southern Illinois indicated that the relationship was independent of site, crown class, and species (Minkler and Gingrich 1970). Later work reported a coefficient of determination of 0.80 between dbh and crown diameter for 900 ponderosa pine (*Pinus ponderosa*) trees in northern Arizona (Hitchcock 1974). The relationships of bole diameters and crown widths of seven bottomland hardwood species in Mississippi were determined using simple linear regression, and it was shown that the inclusion of tree height did not improve prediction of crown width (Francis 1986). A comparison of dbh and crown area for trees in a mixed boreal forest region concluded that

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regression models with a low number of independent variables may deserve more attention than has been suggested in the literature (Hall et al. 1989).

Crown diameter is an important variable for wildlife habitat suitability index models (Hays et al. 1981, Sousa 1987). However, the ground measurement of crown diameter is a time-consuming process and often is not included as a component of inventories that emphasize timber volumes. The ability to predict crown diameter from dbh provides an efficient method of obtaining an estimate of crown diameter. This is especially true if the dataset did not include a direct measurement of crown diameter.

Forest inventory methods based on aerial photos and photogrammetric methods can be developed if the mathematical relationship between dbh and crown diameter has been established. This is because direct measurement ofdbh is not possible and crown diameter is often used as a substitute. Conventional forest inventory procedures using aerial photographs have tallied visible crowns using circular fixed-area sample plots (Husch et al. 1982). Another approach for estimating the density of forest stands involves the derivation of a technique for obtaining stand density from aerial photographs based on the principles of selection with probability proportional to size. This is accomplished by the development and use of an aerial-photo angle-gauge that is used in a procedure very similar to the ground point-sampling technique (Gering and May 199 1, Gering 1992).

The objective of this study was to determine the simple linear relationship between dbh and crown diameter for trees in natural forest stands located in Hardin County, Tennessee. Two models are possible:

$$DBH = a + b(CROWN) \quad (1)$$

$$CROWN = a + b(DBH) \quad (2)$$

DBH was a direct measurement taken during the ground-based inventory. Ground-measured and photo-derived crown diameters *(CROWN)* were used in separate analyses. Crown measurements were used as independent variables in (1) and dependent variables in (2).

Methods and Data

The USDA Forest Service conducted the 1989 Survey of Tennessee, with data collected in the fall of 1988 using the standard Forest Inventory and Analysis (FIA) procedure. Supplemental information was collected on 557 trees located on and adjacent to the 46 study plots in Hardin County. These 557 trees were live with dbh greater than 5.0 in. They were in the dominant or codominant crown class and either in the sawtimber or pole product class. Predominant tree species included oaks (*Quercus* spp.), hickories (*Carya* spp.), sweetgum (*Liquidambar styraciflua*), yellow poplar (*Liriodendron tulipifera*), loblolly pine (*Pinus taeda*), and shortleaf pine (P. *echinata*). Less numerous tree species included maple (*Acer* spp.), ash (*Fraxinus* spp.), and elm (*Ulmus* spp.). The additional data collected included an estimate of the ground-measured crown diameter for each tree obtained by taking the arithmetic mean of the horizontal crown diameter measured on the north-south axis and again on the east-west axis. This was accomplished using a cloth tape held at a point visually located under the edge of the crown of the tree being measured. The edge of the crown was defined as the perimeter of the crown that was visible and identifiable from the ground directly below. If any axis coincided with single, long branches, the crown width was determined to be located at the average edge along that axis. While this procedure of projecting the perimeter of the crown vertically to the ground with diameter measurements being made on this projection does presume a regular or circular tree crown, it has been used extensively and can be replicated (Minor 1951, Hays et al. 1981, Husch et al. 1982).

As part of this study, aerial photographs of Hardin County were flown during September 1988. The FIA field crews used color 9 x 9 in. prints (with an overall nominal scale of 1:4,800) to establish ground inventory plots near thecenterof each photograph. The nominal scale for each photograph was determined for the location of these plots. It is important to note that the major portion of the study area is located in the southern coastal plain of Tennessee, with the northeast quarter of the area located in the western Highland Rim. While terrain does display changes in topographic elevation, the relative difference is minor. Thus, displacement of objects on the photographs due to relief was minimal. On truly vertical photographs, the center of the photograph would be identified as both the principal point and the nadir. This results in minimal radial displacement of the objects under study.

Trees which had been measured as part of the ground inventory supplemental dataset were randomly selected and individually identified on the photos whiie in the field. Crown diameter, based on photo measurements, for each of these 121 trees in the subset was later estimated using a 7×-power monoscopic comparator, which provided magnification of the tree under study. A reticle was inserted into the comparator so actual measurements of crown diameter could be made. The reticle illustrated a series of circular diameters, increasing in size from 0.6mm to 2.5mm at an increment of 0.1 mm. Crowns were compared to these circles and a corresponding diameter was selected. Crown diameter was then converted to feet using the nominal scale for that particular photo. Avery (1978) noted that tree crowns (as observed on aerial photographs) are rarely circular, but because individual limbs are often invisible on photos, they usually appear roughly circular or elliptical. He concluded that most interpreters can determine crown diameter with reasonable precision.

Results and Discussion

The complete dataset provided information for the development of simple linear models between dbh and ground-measured crown diameter. The subsample dataset allowed for the development of the similar relationship between dbh and photo-measured crown diameter. Statistical tests were conducted to determine if one simple linear equation sufficed for the relationship between dbh and crown diameter for all trees or if a separate equation would bc necessary for each of several species groups. These analyses were conducted separately for the ground-measured crowns and photo-measured crowns. The initial tests indicated that the assumptions associated with the method of least squares were satisfied. However, while trees were selected on a random basis, all were taken from the dominant or codominant crown classes; this was required if they were to be identified and measured on the aerial photographs.

F-tests to compare the regression parameters were significant at the 5% level. indicating that separate equations were required for hardwoods and softwoods. Additional F-tests (significant at the 5% level) indicated that the hardwood group should be further divided into two groups, the oaks/hickorics and gum/yellow poplar. The data were sorted by species composition groups due to the differences in the relationship ofdbh and crown diameter. While it was necessary to separate oaks and hickories from gums and yellow poplars, it was also desirable to retain a general group for all hardwood trees. Though the photographic coverage for this project was obtained during the beginning of the fall color season and tree identification was relatively easy, it is sometimes difficult to identify the specieson an aerial photograph, particularly if photographic coverage was obtained during the summer. Also, there are tree species included in the general hardwood group which do not occur frequently enough to allow creation of additional groups such as was done with the oaks/hickories and gum/yellow poplar. Therefore, the complete dataset and the subsample dataset were each sorted into four categories or groups based on species composition. Sample size, means, and ranges of dbh and crown diameter for the four species groups are summarized in Table I.

The selection of one variable as the independent variable and the other as the dependent variable is based on the intended use of the model. For determining dbh from either photo-measured or ground-measured tree crowns, Model I would be used. Model 2 **would** be used when estimating crown diameter from dbh measurements. The linear regression coefficients, sample size, coefficient of determination, and root mean square error for Model I are summarized in Table 2. Similar results for Model 2 are summarized in Table 3.

A representative scatter plot showing dbh and ground-measured crown diameter for the 448 hardwood trees and the fitted regression line using theestimates for Model I is shown in Figure I. The plotted points indicate a linear trend within the range of the data. The coefficient of determination, r^2, was 0.801 for the fit of these data. When the dataset was sorted into the two hardwood species groups, it appeared that Model I provided a better fit for the gum/yellow poplar (r^2 = 0.935) than for the oaks/hickories (r^2 = 0.853). However, sorting by species groups did reduce the number of observations used during the specific regression analysis, particularly the gun/yellow poplar group. Both the oaks/hickories and gum/yellow poplar subsets indicated a better fit to the model than the general hardwood category, indicating variation was increased due to the presence of other tree species.

A similar situation exists for Model 1 when used with photo-measured crown diameter for the hardwood, oaks/hickories, and gum/yellow poplar groups. A second representative scatter plot showing dbh and photo-measured crown diameter for the 97 hardwood trees and the fitted regression line using the estimates for Model I is shown in Figure 2. The plotted points again give an indication of a linear trend within the range of the data. The value for r^2 was 0.708 for this fit of the model. Sorting the dataset by species groups resulted in an r^2 of 0.678 for the oaks/hickories and an r^2 of 0.85 1 for gum/yellow poplar.

DBH and ground-measured crown diameter for the loblolly/shortleaf group had an r^2 of 0.644 when fitted to Model I and did not demonstrate as strong a relationship as did the fit for each of the three hardwood groups. Determining the actual edge ofthc tree crown during the ground inventory may have been more consistent for the hardwood trees exhibiting decurrent branching characteristics and fall colors than for the pines. Also, the pines may have had more frequent occurrence of single, long branches resulting in a greater number of approximate estimations of crown diameter. The opposite result appears to be the case for photo-measured crown diameters with this group using Model 1, with an r^2 = 0.935. While the number of observations in this subset is relatively small. there appears to be an indication that those trees which exhibit an excurrent branching pattern, the pines and gums, were easier to identify and measure on the photos. Also, individual limbs are often invisible on aerial photos (Table 2). Similar trends are observed for the fitting of Model

Table 1. Sample size, means and ranges of diameter at breast height (dbh) and average crown diameter for two methods of measuring crown diameter and four species groups in Hardin County, TN.

		dbh		Crown diameter	
Species group	n	mean	range	mean	range
Crown measured on ground		(in)		(ft)	
All hardwoods	448	13 59	5 o-37 2	28 10	8 O-72 0
Oaks/hickories	179	13 31	5 o-33 3	28 72	8 O-72 0
Gum/yellow poplar	24	14 50	5 5-36 7	27 81	120-685
Loblolly/shortleaf	109	8 38	5 1-17 2	14 73	7 5-30 0
Crown measured on photo					
All hardwoods	97	17 73	5 2-36 7	32 68	9 4-56 0
Oaks/hickories	39	17 99	6 6–33 3	34 26	11 8-56 5
Gum/yellow poplar	11	1506	5 5–36 7	28 76	134-560
Loblolly/shortleaf	24	9 15	5 1–17 2	16 04	9 3–26 8

Table 2. Linear regression[1] coefficients, sample size, coefficient of determination, and root mean square error for regression to predict diameter at breast height in inches from crown diameter in feet for two methods of measuring crown diameter and four species groups in Hardin County, TN.

Species group	a	b	n	r^2	root mse
Crown measured on ground					
All hardwoods	1 6961	0 4233	448	0 801	2.7370
Oaks/hickories	1 5050	04108	179	0 853	2 2846
Gum/yellow poplar	-0 6978	0.5463	24	0 935	2 1890
Loblolly/shortleaf	1 6254	0.4586	109	0 644	15215
Crown measured on photo					
All hardwoods	2 0820	0 4636	97	0.708	3 6879
Oaks/hickories	2.2440	0 4597	39	0.678	3 6405
Gum/yellow poplar	-2 9026	0 6246	11	0 851	4 0609
Loblolly/shortleaf	0 6733	0 5287	24	0.752	1.6182

[1] *DBH* = a + *b(CROWN)*, where CROWN is crown diameter measured in feet, *DBH* is diameter at breast height measured in inches

2 which predicts crown diameter from dbh. The results of the regression analyses indicate that the relationship between dbh and crown diameter is fairly strong, with r^2 values ranging from 0.644 to 0.935 (Table 3).

One important cautionary note must be made, however. Crown diameter measurements obtained from aerial photographs are not directly comparable with similar measurements made on the ground. Only that portion of the crown which is visible from directly above will be measured on the photographs; branches obscured by other trees will not be seen. Therefore, aerial measurements of crown diameter will generally be less than measurements of the same trees made on the ground (Spurr 1948). This is demonstrated in the results of this study but does not present a problem because ground-measured crown diameters and photo-measured crown diameters were independently fit to the models. It would be inappropriate to use the models developed for ground-measured crown diameters with data obtained from aerial photographs.

Conclusions

The purpose of this study was to determine the simple linear relationship between diameter at breast height and crown diameter for trees in natural stands located in Hardin County, Tennessee. Dbh is a direct measurement that can be made efficiently during ground inventories with a high degree of precision and accuracy. However, dbh is not a measurement that can be made on aerial photographs. A simple linear model that predicts dbh from crown diameters measured on aerial photos can provide an indirect method of estimation. Predicted dbh can then be used to determine values for the basal area and volume of individual trees. Summing these individual values would then provide an estimation of stand basal area and volume.

The direct measurement of crown diameter in ground inventories is a time-consuming process and is often omitted from many forest inventories. If such is the case, a forester needing this information would either be required to re-inventory the tract of land or use a model which predicts crown diameter from dbh. The predicted values of crown diameter can then be used as input for wildlife suitability index models and other analyses that use crown characteristics.

The equations developed in this study provide a means for predicting either dbh or crown diameter, depending on the data and the model used. Scatter plots of the data exhibit a linear relationship within the range of the data. Summary statistics of the regression analyses indicate that the models express the relationships reasonably well. While the actual estimates of the regression parameters are valid only for the region of Tennessee near Hardin County, the results support previous studies which investigated the relationship between dbh and crown diameter for other species and geographic locations.

Table 3. Linear regression[1] coefficients, sample size, coefficient of determination, and root mean square error for regression to predict crown diameter in feet from diameter at breast height in inches for two methods of measuring crown diameter and four species groups in Hardin County, TN.

Species group	a	b	n	r^2	root mse
Crown measured on ground					
All hardwoods	2 3977	1 8909	448	0 801	5 7845
Oaks/hickories	1.0887	2 0769	179	0 853	5 1367
Gum/yellow poplar	2 9924	17122	24	0 935	3 8753
Loblolly/shortleaf	2.9660	1 4038	109	0 644	2 6620
Crown imeasured on photo					
All hardwoods	6 3733	1 5266	97	0 70%	6 6922
Oaks/hickories	7 7031	1 4758	39	0 67%	6 5227
Gum/yellow poplar	8 2411	1 3624	11	0 851	5 9975
Loblolly/shortleaf	3 0198	1 4225	24	0 7.52	2 6544

[1] *CROWN = a + b (DBH)*, where *CROWN* is crown diameter measured in feet, *DBH* is diameter at breast height measured in inches

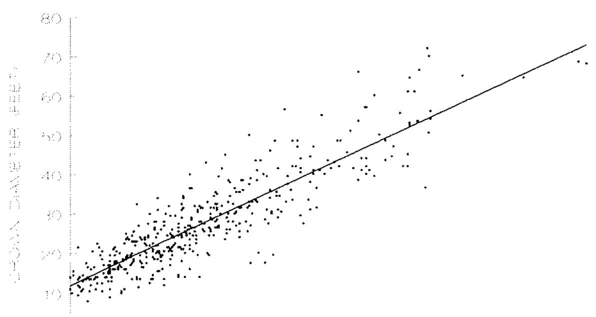

Figure 1. Relationship between diameter at breast height *(DBH)* and ground-measured crown diameter *(CROWN)* for 448 hardwood trees located in Hardin County, TN. The regression line represents the fit of the data to the model: *DBH = a + b(CROWN)*.

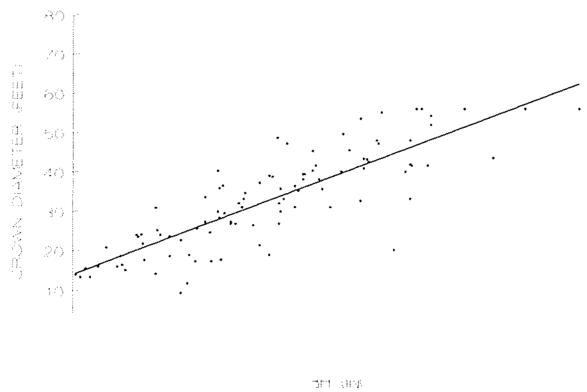

Figure 2. Relationship between diameter at breast height (DBH) and photo-measured crown diameter (CROWN) for97 hardwood trees located in Hardin County, TN. The regression line represents the fit of the data to the model: *DBH = a + b(CROWN)*.

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