Crown Radius and Diameter at Breast Height Relationships for Six Bottomland Hardwood Species

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Abstract

The relationship between a tree's crown radius and diameter at breast height (DBH) has a variety of uses including forest competition studies, tree crown densities, spacing and stocking relationships, wildlife habitat suitability models, and tree volume estimations. Estimating DBH from mean crown radius (MCR) is of interest to natural resource managers because MCR can be estimated from high resolution digital imagery using remote sensing techniques. DBH is a common tree dimensional characteristic that is used to quantify tree and stand structure. This research presents MCR/DBH and DBH/MCR relationships for boxelder (*Acer negundo* L.), sweet pecan (*Carya illinoensis* (Wang) K. Koch), sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.), Nuttall oak (*Quercus nuttallii* Palmer), and American elm (*Ulmus americana* L.). The linear model, $y = a + b * x$, provided the best model fit with adjusted r^2 values of 0.567 to 0.855 for the 6 species. Crown radius can be determined from digital imagery and then used to predict DBH.

Introduction

A tree's crown is defined as that part of a tree bearing live branches and foliage (Helms, 1998). Photosynthesis occurs in leaves and the products from photosynthesis, that is photosynthates, are translocated through the crown's branches from the leaves to the remainder of the tree. Concurrently, water and mineral nutrients absorbed by the roots are translocated through the trunk to branches and leaves. A tree's crown therefore represents the above-ground spatial requirements needed for a tree to survive, grow, and reproduce (Kramer and Kozlowski, 1979).

The shape of a tree's crown is influenced by 2 broad factors: genetics and physical environment (Zimmerman and Brown, 1971; Daniel et al., 1979). Specific tree species tend to have characteristic crown shapes, especially when growing in an open environment. These shapes are then modified by the physical environment including competition between tree crowns through physical abrasion from wind events. Crown shape therefore represents the physical space a tree utilizes for growth as modified by the physical environment.

While a tree's crown represents its potential for growth and development, crown measurements are difficult to obtain (Bechtold et al., 2002). A more easily measured tree variable, such as diameter at breast height (DBH, 1.4 m above the ground), is often used as a surrogate for a tree's crown dimensions. Tree crown dimensions, especially the horizontal dimension, radius or diameter, are well correlated with a tree's DBH. The mean crown radius MCR (or crown diameter)/DBH relationship is particularly useful for determining crown competition factors (Krajicek et al., 1961; Vezina, 1962; 1963; Strub et al., 1975), stand density and stocking relationships (Dawkins, 1963; Roberts and Ross, 1965; Minckler and Gingrich, 1970; Goelz, 1996), and tree growth (Zeide, 1986; Cole and Lorimer, 1994). Likewise, the DBH/tree crown radius (or diameter) relationship is useful for determining tree and stand volumes from aerial photographs (Minor, 1951; Bonnor, 1968; Gering and May, 1995). Volume determination is especially important with recent advances in remote-sensing technology that allow for rapid crown radius or crown diameter measurement, conversion to DBH, then determination of tree volume. Inventory costs are greatly reduced compared to conventional tree DBH measurements in the forest. The objectives of this study were to develop MCR/DBH and DBH/MCR relationships for selected bottomland hardwood species.

Materials and Methods

Location.–The study site was located on Pittman Island in Issaquena County, MS (32°55′ N latitude, 91°09′W longitude) within the unprotected lands along the Mississippi River (batture lands). The site is characterized by ridge and swale topography due to channel migration of the Mississippi River (Mitsch and Gosselink, 1986). Soils vary but are primarily composed of Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts), Sharkey clay (very fine, smectitic, thermic Chromic Epiaquerts), Bowdre silty clay (clayey over loamy, smectitic, thermic Fluvaquentic

Hapludolls), and Robinsonville very fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Udifluvents). The climate is characterized as humid and warm. The monthly average high temperature is 28°C in July and the monthly average low temperature is 6°C in January. Precipitation averages 142 cm per year with the greatest monthly average in March (15.7 cm) and the lowest monthly average in August (6.8 cm) (Rolling Fork, MS weather station located about 25 km north of Pittman Island; source http://www.msstate.edu/dept/GeoSciences/climate). Periodic summer droughts occur in the region. Past management activities in the forest included a partial harvest in 1979-1980 and infrequent light harvests before 1969.

Measurements.–Six bottomland hardwood species were selected based on their commonality in forests of the Mississippi River batture. These species are boxelder (*Acer negundo* L.), sweet pecan (*Carya illinoensis* (Wang) K. Koch), sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.), Nuttall oak (*Quercus nuttallii* Palmer), and American elm (*Ulmus americana* L.). Trees from each species were selected from control plots of a larger study of the effects of reproduction methods on flora and fauna common in the batture (Lockhart et al., 1996). Trees were selected from a variety of DBH classes to represent a range of diameters and crown widths (see Table 1 for descriptive statistics for each species). Each tree was measured for DBH (cm) and ocularly assessed for crown radius (m) in eight directions from the main bole–every 45° beginning with magnetic north–to the vertically projected edge of the crown. Crown classes, a reflection of a tree's relative competitive status (Smith et al., 1997), were assessed for each tree. Each tree was assigned a crown class of dominant, codominant, intermediate, or overtopped.

Analyses.–Crown radii for each tree were summed and MCR determined. MCR/DBH ratios (MCR divided by DBH) were calculated and compared to an independent data set collected from the Delta Experimental Forest located near Stoneville, MS (about 60 km north of Pittman Island). A description of data collection methods for this independent data set is found in Francis (1986). MCR/DBH ratios were compared within species between the two data sets using t-tests in PC-SAS (SAS, 1986). Comparisons between species were done with a one-way analysis-of-variance. Significant differences were noted at $p \leq 0.05$. Regression models using DBH as the independent variable and MCR as the dependent variable were evaluated using Table Curve version 5.01. Likewise, models were also evaluated using MCR as the independent variable and DBH as the dependent variable. Table Curve evaluates more than 8,000 model forms ranging from simple linear to complex non-linear models.

Results and Discussion

DBH/MCR Ratios.–The DBH/MCR ratio is a measure of the efficiency of a tree to accumulate DBH per unit of crown area. The higher the ratio, the more efficient a tree (or species) is at accumulating DBH. Comparing all trees in the study, green ash was found to be the most efficient species at accumulating DBH and American elm the least efficient (Table 2). For example, for each meter of crown radius in green ash, 13.9 cm of DBH was accumulated, whereas only 7.9 cm of DBH was accumulated in American elm. No differences occurred among the remaining species. When overtopped trees were removed from the data set leaving only trees that received a minimum of direct sunlight at the top of the crown, green ash was still the most efficient species at accumulating DBH and American elm was still the least efficient (Table 2). Boxelder was also more efficient than sweet pecan, sugarberry, and Nuttall oak. Note though that a higher percentage of trees from shade-tolerant species (boxelder, sugarberry, and American elm) were crown classed as overtopped compared to moderately shade-intolerant species (sweet pecan, green ash, and Nuttall oak).

The DBH/MCR ratios for green ash and Nuttall oak in the present study were significantly greater than those found by Francis (1986) for the same species, P=0.0001 and 0.0001, respectively. Sugarberry and American elm had similar ratios between the two studies (P=0.0640 and 0.1432, respectively). Apparently, site conditions or stand history may influence the DBH/MCR ratio for a given species. The site studied by Francis (1986) was fairly homogeneous consisting of Sharkey clay. Further, Francis collected data only for trees in the dominant, codominant, and intermediate crown classes while the ratios in the present study included overtopped trees in addition to the other three crown classes. Data in the present study represent a wider range of diameter classes than Francis (1986; see Table 1). Furthermore, the forest in the present study was subject to periodic harvesting, favoring moderately shade-intolerant species such as green ash and Nuttall oak, whereas the stand in Francis (1986) was relatively undisturbed, which may have influenced the difference in the DBH/MCR ratios between the two studies.

MCR/DBH Regression Models.–Theoretically, the MCR/DBH relationship would be sigmoid for forest grown trees (Dawkins, 1963). Crown expansion would be slow relative to early DBH growth as trees are crowded in dense young stands. As trees begin to express dominance, DBH growth increases almost linearly as crown expansion increases. When the tree reaches maturity, crown expansion essentially ceases while DBH continues to increase as photosynthates acquired through photosynthesis are increasingly used for tree maintenance and support.

Dawkins (1963) further identified 6 general crown-diameter to bole-diameter (e.g., DBH) relationships in trees based on work from previous investigators. Three relationships were linear and differed in whether the y-intercept was zero, positive, or negative. The 3 other relationships were non-linear. One was sigmoid as described above while the other two were power functions with a positive or negative slope.

Results from the present study indicated that high coefficients of determination ($r^2 > 0.90$) were attainable for each species. Non-linear equations with multiple polynomials, up to 14 to 16 order polynomials, accurately described MCR/DBH relationships within species. But these equations are not robust since they are specific to this particular data set and probably not applicable to other MCR/DBH data sets of the same species. The linear equation (1) was selected as the best general relationship to describe the MCR/DBH relationship, indicating that crown radius increases with increasing DBH within the limits of our data set.

MCR = a + b * DBH where:

MCR = mean crown radius (m),

DBH = diameter at breast height (cm), and

a, b = coefficients determined from regression.

Linear equation 1

Results from linear regression for the 6 bottomland hardwood species are shown in Table 3. Coefficients of determination (r^2) ranged from 0.87 for sweet pecan to 0.56 for boxelder. These coefficients of determination are similar for 3 of the 4 species common between this study and Francis (1986). Coefficients of determination were 0.61, 0.82, and 0.86, for sugarberry, green ash, and Nuttall oak, respectively from Francis (1986). The one species with a considerable difference in the coefficient of determination is American elm–0.65 in the present study and 0.81 in Francis (1986). A likely explanation for this difference is the spreading, umbrella-like crown of overstory American elm. Francis (1986) measured only trees with a portion of their crown in the overstory (dominant, codominant, and intermediate crown classes) while our data also included trees in the overtopped crown class. Shade-tolerant species, such as American elm, that are in the overtopped crown class tend to have a large crown radius per unit DBH in an effort to capture more sunlight in the understory. The species with the lowest coefficients of determination (boxelder, American elm, and sugarberry) are all shade-tolerant species.

The linear MCR/DBH relationships with positive y-intercepts shown in Table 3 follow the Type 2 behavior described by Dawkins (1963). Dawkins (1963) stated that a possible depression in the relationship could occur at the upper end of the MCR/DBH relationship due to tree senility. Such a depression is possible with bottomland hardwood species, but none was found in the present study. The forest in which the crown radii and DBH data were collected was under management. As trees approach a large size, about 70 to 80 cm, they are harvested, thereby preventing them from reaching even larger sizes and making testing for a depression in the MCR/DBH relationship impossible.

DBH/MCR Regression Models.–Much interest exists in DBH/MCR relationships due to their utility in forest inventory using remote sensing techniques. Measurements of crown radius (or crown diameter) from aerial photographs or digital imagery can be converted to DBH at the individual tree level. Diameter at breast height can then be readily converted to volume. Use of remote sensing techniques for stand volume determination reduces inventory costs because the expense and difficulty of establishing and measuring sample plots on the ground is reduced or eliminated (Gering and May, 1995).

Results from linear regression using MCR as the independent variable and DBH as the dependent variable for the 6 bottomland hardwood species are in Table 4. Coefficients of determination (r^2) were the same as in Table 3 because the independent and dependent variables were only switched. The coefficients for sweet pecan, Nuttall oak, and green ash ($r^2 \geq 0.74$) were similar to Gering and May (1995) for upland hardwoods ($r^2=0.80$), oaks/hickories ($r^2 = 0.85$), and gum/yellow-poplar ($r^2=0.94$) species groups. Gering and May (1995) noted that caution should be exercised when using DBH/MCR relationships from remote sensing measurements. Crown diameter (or crown radius) measurements obtained from remote sensing measurements will generally be less than measurements of the same trees using ground-based measurements (Spurr, 1948). They stated that only that portion of the crown visible from directly above will be measured on imagery while branches obscured by others trees will not be seen. Gering and May (1995) further stated that it may be inappropriate to use DBH/MCR relationships developed from ground-measured crown variables with data obtained from remote sensing. Further work is needed to compare ground-measured and remote-sensing measured crowns in bottomland hardwood species.

In summary, linear equations were developed to predict MCR from DBH and DBH from MCR for 6 bottomland hardwood species in the batture along the Mississippi River. These equations can be useful in predicting crown radius from forest inventories for stocking guideline development, growth models, remote sensing/stand volume estimation, and wildlife suitability index models that use crown characteristics. Results were in general agreement with a previous study of crown radius and DBH relationships in bottomland hardwoods; although enough differences existed to warrant further study. Future research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes among the various bottomland hardwood species.

ACKNOWLEDGMENTS.–We thank the Arkansas Forest Resources Center and Anderson-Tully Company for their financial support in the development of the Pittman Island Project. We also thank Tom Dell, Steve Meadows, Ted Leininger, 2 anonymous reviewers, and the Assistant Editor for their constructive reviews of this manuscript.

Table 1. Basic statistics for tree dimensions for bottomland hardwood species for Pittman Island and the Delta Experimental Forest from Francis (1986).

Species	n	DBH (cm)			MCR(m)		
		average	range	stand. dev.	average	range	stand. dev.
Pittman Island							
boxelder	85	28.1	9.6–55.9	11.0	2.87	0.74–4.76	0.92
sweet pecan	106	35.5	11.0–85.6	19.2	3.60	0.85–8.87	1.95
sugarberry	111	26.7	9.7-61.5	11.8	2.82	0.97-6.08	1.04
green ash	85	44.5	10.3-89.5	20.4	3.38	0.29-7.50	1.48
Nuttall oak	92	50.9	10.3-97.0	20.3	4.87	1.56-9.67	1.79
American elm	89	29.6	8.9-61.0	13.9	3.67	1.22-6.49	1.16
Delta Experimental							
Forestsugarberry	75	38.2	19.1-69.3	11.3	4.24	2.45-5.89	0.84
green ash	75	39.0	14.2-72.4	14.9	4.55	1.98-8.78	1.52
Nuttall oak	75	47.6	17.3-89.7	18.8	6.33	2.55-11.12	2.26
American elm	75	39.0	19.1-69.3	12.9	4.66	2.19-8.19	1.33

Table 2. DBH/MCR ratios for 6 bottomland hardwood species on Pittman Island, Issaquena County, Mississippi.

Species	All trees			Dominant, Codominant, and Intermediate Crown Classes only		
	n	ratio	std. dev.	n	ratio	std. dev.
boxelder	85	10.2b[1]	4.1	47	12.3b	4.2
sweet pecan	106	10.1b	2.6	77	10.3c	2.2
sugarberry	111	9.5b	2.5	53	10.7c	2.1

Table 2. Continued

Species	All trees			Dominant, Codominant, and Intermediate Crown Classes only		
	n	ratio	std. dev.	n	ratio	std. dev.
green ash	85	13.9a	6.8	67	14.0a	3.5
Nuttall oak	92	10.4b	2.1	81	10.9c	1.6
American elm	89	7.9c	2.5	45	9.2d	1.8

[1]Ratios within a column followed by different letters are significantly different at $p \leq 0.05$.

Table 3. Linear regression coefficients[1], coefficient of determination, and mean square error for regression to predict MCR (m) from DBH (cm) for 6 bottomland hardwood species on Pittman Island, Issaquena County, MS.

Species	a	b	adjusted r^2	mean square error
boxelder	1.03881	0.06024	0.56	0.57914
sweet pecan	0.22824	0.09022	0.87	0.65957
sugarberry	0.83957	0.06901	0.67	0.54968
green ash	0.55786	0.05782	0.76	0.65359
Nuttall oak	0.71736	0.07655	0.84	0.68130
American elm	1.61597	0.06395	0.65	0.64182

[1] Regression coefficients are for the linear equation MCR = a + b * (DBH).

Table 4. Linear regression coefficients[1], coefficient of determination, and mean square error for regression to predict DBH (cm) from MCR (m) for 6 bottomland hardwood species on Pittman Island, Issaquena County, MS.

Species	a	b	adjusted r^2	mean square error
boxelder	2.32630	9.44191	0.56	7.25046
sweet pecan	2.22484	9.69720	0.87	6.83823
sugarberry	-0.15586	10.02871	0.69	6.62635
green ash	4.59360	12.62015	0.74	10.40775
Nuttall oak	0.25439	10.97732	0.84	8.15868
American elm	-6.47036	10.29775	0.65	8.14452

[1]Regression coefficients are for the linear equation DBH = a + b * (MCR).

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