Improving Estimates of Acceptable Growing Stock in Young Upland Oak Forests in the Missouri Ozarks

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ABSTRACT. *Estimates of regeneration or growing stock in young oak forests may be too high unless criteria are established that define explicitly acceptable growing stock. In young hardwood stands, crown class can be used to identify acceptable growing stock because it is related to the future growth and survival of reproduction. A method is presented for assigning crown class categories to hardwood stems based on their diameters (dbh). Young upland oak forests originating from clearcuts in the Missouri Ozarks were sampled to determine the relationship between dbh and crown class. Stands were 19 to 25 yr old. Threshold diameters* (TD) *separating one crown class category from another were determined using regression analyses.* TD *was not significantly affected by species group, and in some cases by aspect and slope position. Quadratic mean stand diameter (QMSD) was significantly related to* TD. *As QMSD increased so did* TD. *When QMSD equals 3 in., trees with dbh ≥ 3.9 in. are allocated to the codominant and dominant crown class category, and those ≥ 2.5 in. to the dominant, codominant, and intermediate category.* TD *can be used to assign a crown class category to individual trees, thereby improving estimations of acceptable growing stock. By this method, crown class can be used to define acceptable growing stock and evaluate stocking, yet it does not have to be measured in stand inventories. North. J. Appl. For. 15(1):28–32.*

In young oak stands in the Missouri Ozarks, high stem densities can give the illusion of adequate stocking, but as these stands develop through the dynamic stem exclusion stage (Oliver and Larson 1990), stocking of desirable crop trees may prove to be inadequate. Standards are needed for defining acceptable growing stock. These should include a list of desirable species and measures related to a tree's ability to acquire the growing space it needs to become a quality crop tree.

Estimates of acceptable growing stock can be improved by considering stocking in relation to crown class categories. Crown class is a useful measure of a tree's competitive status. It can be used to identify acceptable growing stock because it is related to the future growth and survival of young hardwoods (Marquis 1991, Ward and Stephens 1994). Crown class can be used to segregate a population of young hardwoods into acceptable or unacceptable categories. For example, the definition of acceptable growing stock may be limited to certain species and trees that occupy only codominant and dominant crown classes. Oak reproduction in the intermediate and overtopped crown classes may be considered as unacceptable growing stock because they have little chance of growing into the codominant or dominant classes (Ward and Stephens 1994). However, shade-tolerant trees (e.g., sugar maple) that are in the intermediate crown class may be considered acceptable reproduction because their growth and survival are higher than for midtolerant species such as the oaks, and hence, they have a greater likelihood of developing into crop trees.

Crown class is a subjective system used to categorize trees (e.g., dominant, codominant, intermediate, and overtopped) based on their relative crown position and the proportion of the tree's crown that receives direct sunlight (Smith et al. 1997). Marquis (1991) found that crown class was correlated with diameter (dbh), and strongly influenced diameter growth in young stands of black cherry, sugar maple, red maple, and

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American beech. Dominant trees had greater diameter growth than trees in the intermediate and overtopped crown classes. Similarly, Ward and Stephens (1994) reported that crown class and dbh were highly correlated in 25-yr-old northern red oak. They found that initial crown class influenced the movement of red oak into the dominant and codominant crown classes. For example, red oaks in the overtopped crown class at age 25 only had a 0.4% chance of becoming dominant or codominant by age 55, whereas 26% of the codominant oaks were able to move into the dominant crown class. Moreover, the initial crown class of young red oak was found to influence survival between the ages of 25 and 85. Virtually all of the initially overtopped and intermediate trees were dead by age 85, while about two-thirds of the dominant oaks survived. Lorimer (1981) also observed that mortality rate of red oak varied by crown class in New York.

This article integrates the concept of acceptable growing stock with observed or predicted tree diameter by relating crown class to dbh. We hypothesized that dbh could be used to classify trees into crown class categories. Classification of trees into one of two crown class categories (e.g., codominant and dominant, or not) can be used to identify stems that are likely to grow into desirable crop trees and to partition stand diameter distributions into acceptable and unacceptable growing stock. Ultimately, crown class can be related to dbh, which is a more objective and precise measurement in field inventories. In addition, dbh can be used to quantify important stand attributes such as basal area and stocking by diameter classes. Foresters can use this information with standards defining acceptable growing stock to evaluate stand stocking.

Methods

Hardwood stems were sampled in ten even-aged stands that originated from clearcutting on the Salem Ranger District, Mark Twain National Forest in the Missouri Ozarks. These stands had been undisturbed since clearcutting. The stands were comprised primarily of white oak (23%), black oak (11%), hickories (15%), blackgum (10%), and flowering dogwood (17%). Other species included scarlet oak, post oak, blackjack oak, sassafras, and red maple. The study stands ranged in age from 19 to 25 yr. For all the stands sampled, quadratic mean stand diameter was 3.2 ± 0.6 in., basal area averaged 84.6 ± 17.6 ft^2/ac, and there were 1,607 ± 522 trees/ac.

Data were collected from eighty-nine 0.05 ac circular plots representing a wide range of slope positions and aspects. On each plot, aspect and slope position were determined. Aspects were classified into one of three categories based on azimuth according to Sander et al. (1984). Plots occupying azimuths from 0 to 90° (northeast quadrants) were classified as "cool," those from 180 to 270° (southwest quadrants) as "hot," and the remaining quadrants (southeast and northwest) were classed as "neutral." The range of slope positions from ridgetop to toe slope was divided into three equal classes (i.e., upper, middle, and lower) based on degrees from horizontal. Crown class, dbh, and species were recorded for each living tree, regardless of its reproductive origin (i.e., seedling sprout, stump sprout, etc.). Stems in sprout clumps were treated as individual trees if the fork was below dbh. Quadratic mean stand diameter (QMSD) was calculated for each plot based upon the sample trees.

Crown class was determined according to Smith et al. (1997), where:

D = Dominant trees that have well developed crowns rising above the general level of the crown cover, and receiving direct sun from above and partly from the sides.

C = Codominant trees that have medium-sized crowns forming the general level of the crown cover, and receiving direct sun from above and relatively little from the sides.

I = Intermediate trees that have small crowns extending into the crown cover formed by the D and C trees, and receiving little direct sun from above and none from the sides.

O = Overtopped trees that have crowns entirely below the general level of the crown cover, and receiving no direct sun from either above or from the sides.

The relationship between crown class and threshold dbh can be illustrated by a 2 × 2 contingency table (Table 1). In Table 1, *TD* represents the threshold dbh that distinguishes membership in one or the other of the two crown class categories that define the acceptability of growing stock. To facilitate identifying *TD*, each observed tree in each plot was placed into one of the four cells of the contingency table, depending on its dbh, observed crown class, and subjectively chosen value of *TD*. For each of many iterations, *TD* was gradually incremented over the range of tree diameters observed in the stands. For any one value of *TD*, the numbers of trees in cells 1 and 4 represent correctly classified individuals. The percentage of correct classifications was determined by summing the number of trees in cells 1 and 4 and dividing by the total number of sample trees. The value of *TD* producing the largest percentage of correct classifications was considered the *observed TD* for that plot.

Regression methods were then used to predict the *TD* in relation to plot QMSD, species group, slope position, and aspect. Two models were developed to classify trees into (1) either $D + C$ or $I + O$ crown class categories, or (2) either $D + C + I$ or O crown class categories. Approximately half of the data ($N = 45$ plots) were randomly selected and used to develop models for predicting *TD* that define crown class categories based on stand and site characteristics. The remaining data ($N = 44$ plots) were used to validate the model

Table 1. A contingency table for defining threshold dbh *(TD)* that identifies the break between crown class categories. In this example, trees are being separated into the $D + C$ and $I + O$ crown class categories.

	Crown class category	
Diameter	$I + O$	$D + C$
Dbh < *TD*	1	2
Dbh ≥ *TD*	3	4

Table 2. Comparison of stand characteristics between the data used to develop regression models and those used to validate the model. Values given are the mean ± one standard deviation.

Data set	Quadratic mean stand diameter (in.)	Basal area (ft^2/ac)	Trees/ac
Model development ($N = 45$ plots)	3.2 ± 0.6	82.0 ± 16.0	1,562.7 ± 499.5
Model validation ($N = 44$ plots)	3.2 ± 0.6	87.1 ± 19.0	1,652.3 ± 546.3

by comparison of model predictions with observed crown class values (Vanclay 1994). These two subsets of the data were very similar in species composition and stand characteristics (Table 2).

Both linear and nonlinear (e.g., power and exponential functions) regression models were considered in defining the relationship between TD and a set of stand and site variables. The categorical variables aspect, slope position and species group (i.e., oak vs. nonoak, and *Leucobalanus* vs. *Erythrobalanus*) were dummy coded (Pedhazur 1982). Various transformations of the independent variables such as square root and logarithmic were tested, although a plot of TD and QMSD suggested a linear relationship. Regression residuals were analyzed to test for homogeneity of variance and the need for additional independent variables such as interactions among other variables. In all models, the distribution of residuals indicated that there was homogeneity of variance and that interactions of independent variables were not influencing the response of the dependent variable, *TD*. Models were evaluated based on the overall F-statistic, coefficient of determination (R^2), significance of individual predictor variables, and plots of the estimated and observed *TD* by QMSD, aspect and slope position. Stepwise regression (SAS Institute Inc. 1988) also was used to select from among the alternative models. The best models were used to predict crown class category from plot QMSD, aspect and slope position using the *independent* data subset. Comparison of predicted and observed crown class category was used to select the best-fit, final model.

Results and Discussion

The *TD* used to allocate young hardwoods into crown class categories based on their dbh was most consistently and significantly related to QMSD in all regression models tested ($P < 0.0001$). The variable *species group* was not significantly related to TD in any of the models. This suggests that crown differentiation in young hardwoods (i.e., 19 to 25 yr old) developing in Missouri Ozark clearcuts was not statistically related to the species composition in the stand. Although the tree crown canopy was closed and crown differentiation was occurring in all the stands sampled, there has not been enough time for differences in competitive abilities among the species to cause a strong segregation of stems by species into the various crown classes.

When *TD* was used to separate the $D + C$ crown class category from the $I + O$, plot QMSD was the only significant factor. Trends in *TD* were not statistically related to aspect or slope position among the plots used to develop the regression models. Of the various models tested, this "best" model was selected using stepwise regression methods:

$$TD = 2.2079 + 0.5499 * \text{QMSD} \quad (1)$$

where *TD* defines the threshold dbh that most consistently separates $D + C$ trees from $I + O$ trees ($P < 0.0002$, $R^2 = 0.28$) (Figure 1).

Based on this model, *TD* equals 3.9 in. when QMSD is 3 in. Upland oak stands in the Missouri Ozarks approach a QMSD of 3 in. when they are about 20 yr old (Dey 1991). When QMSD is 3 in., trees with a dbh equal to or greater than 3.9 in. would be classified as $D + C$, and those with smaller diameters as $I + O$ based on the model in (1).

To test the usefulness of the *TD* model in correctly identifying crown classes, trees were used from an independent sample of 44 plots with QMSDs between 2.15 and 4.4 in. A total of 3,635 trees were classified using the model in (1). Plot QMSD was input into model (1) to determine *TD*, which was subsequently used to classify each individual tree on a plot based on its dbh. Comparison of predicted and observed crown class categories revealed that most of the trees (92.2%) were correctly classified on all 44 plots. The model did slightly better in predicting crown class category for *I* and *O* trees than for *D* and *C* trees (Table 3). The addition of aspect and slope position to the model in (1) improved the R^2 to 0.41, but it did not improve the model's ability to predict crown class category (92.9% of the trees were correctly classified using this model). When aspect and slope position were

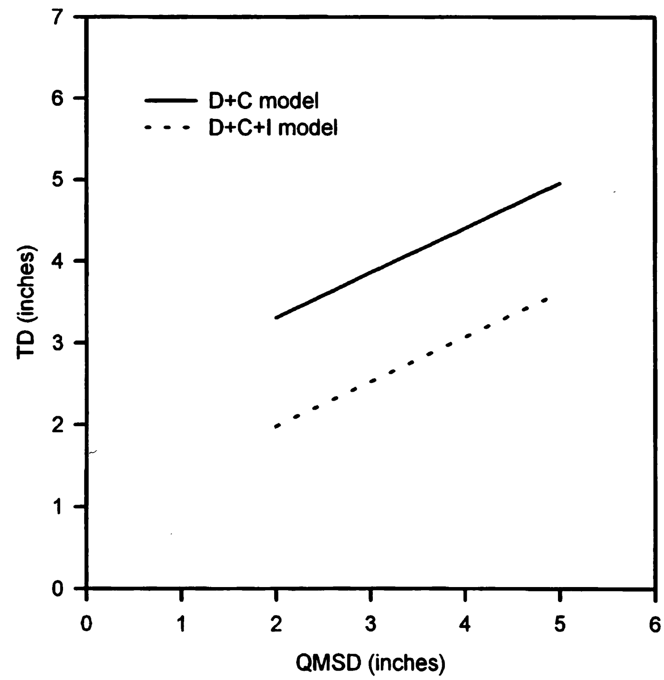

Figure 1. Relation between quadratic mean stand diameter (QMSD) and threshold dbh *(TD)* of trees in $D + C$ (solid line), and $D + C + I$ (dotted line) crown class categories.

Table 3. Validation of the *D* + *C* model (1). Results are presented as the percentage (number) of correctly classified trees by the observed crown class category.

Observed crown class category	Correctly classified	Incorrectly classified
$D+C$	84.3 (621)	15.7 (116)
$I+O$	94.2 (2,731)	5.8 (167)
Total	92.2 (3,352)	7.8 (283)

considered with QMSD in predicting *TD*, their parameter estimates were not significant ($P > 0.05$), although the overall model was significant ($P < 0.0007$).

Models were also developed to classify trees into the $D + C + I$, or O crown class categories. Quadratic mean stand diameter was the single best predictor of *TD*, and the following model was selected to classify trees into crown class categories:

$$TD = 0.8881 + 0.5457 * \text{QMSD} \quad (2)$$

where *TD* defines the threshold dbh that separates trees in the O crown class category from all others ($P<0.0001$, $R^2=0.55$) (Figure 1). For example, when QMSD is 3 in., trees with a dbh less than 2.5 in. would be classified as O and those with larger diameters as $D + C + I$.

The model in (2) was used to predict crown class category using the independent data set (44 plots, 3,635 trees). Comparison of predicted and observed crown class categories showed that the model correctly classified 88.7% of all the trees. The model performed equally well in predicting crown class category for trees in either the $D + C + I$ or O observed crown class categories (Table 4). Regression of QMSD, aspect and slope position on *TD* was selected by stepwise procedures as the best model ($P < 0.0001$, $R^2 = 0.64$). Although aspect and slope position were significantly correlated to *TD*, their inclusion in the model with QMSD did not improve the ability of the model to predict crown class category (89.1% of the trees were correctly classified using this model). Therefore, the model in (2) was chosen as the best model for defining the *TD* that separates trees in the O crown class category from those in the $D + C + I$.

The *TD* used to classify trees into specified crown class categories increases as QMSD increases (Figure 1). Marquis (1991) reported that the dbh separating one crown class from another is not a constant but varies with age and species. His observations support the relationship in Figure 1, in part, because QMSD is related to stand age. However, in this study, significant differences were not found among species groups with respect to dbh and crown class.

Table 4. Validation of the *D* + *C* + *I* model (2). Results are presented as the percentage (number) of correctly classified trees by the observed crown class category.

Observed crown class category	Correctly classified	Incorrectly classified
$D+C+I$	86.8 (1,164)	13.2 (177)
O	89.9 (2,061)	10.2 (233)
Total	88.7 (3,225)	11.3 (410)

Application

Foresters conducting surveys of young hardwood stands can use the crown class–dbh relationship to improve their assessment of stand stocking. Crown class has been shown to be a good criterion for defining acceptable growing stock. Oaks in the $D + C$ crown class category are most likely to survive and become desirable crop trees. Estimates of acceptable growing stock are improved by considering crown class. However, crown class is a more subjective and less precise observation than are measurements such as tree height and diameter. The models presented here permit the use of crown class in acceptable growing stock definitions without requiring direct observation of it in the field. Trees sampled in any inventory can be assigned a crown class category based upon a measure of their dbh and the calculated *TD*. This method allows for the consideration of crown class without increasing the cost or time required to inventory the stand.

The importance of defining acceptable growing stock when evaluating the adequacy of stocking is demonstrated by the following example. ACORn (Dey et. al. 1996) was used to project stand development 21 yr after clearcutting a 70-yr-old upland oak forest (site index 70, base age 50 for black oak) based on a preharvest inventory of the overstory and of the advance reproduction. When all species were considered acceptable growing stock regardless of crown class category, ACORn estimated that there would be 1,764 trees/ac and 89% stocking at stand age 21. About 80% of the stems and 44% of the stocking occurred in the 1 to 3 in. diameter classes (Figure 2). Species such as flowering dogwood, sassafras, and blackgum accounted for about 31% of the stocking. If,

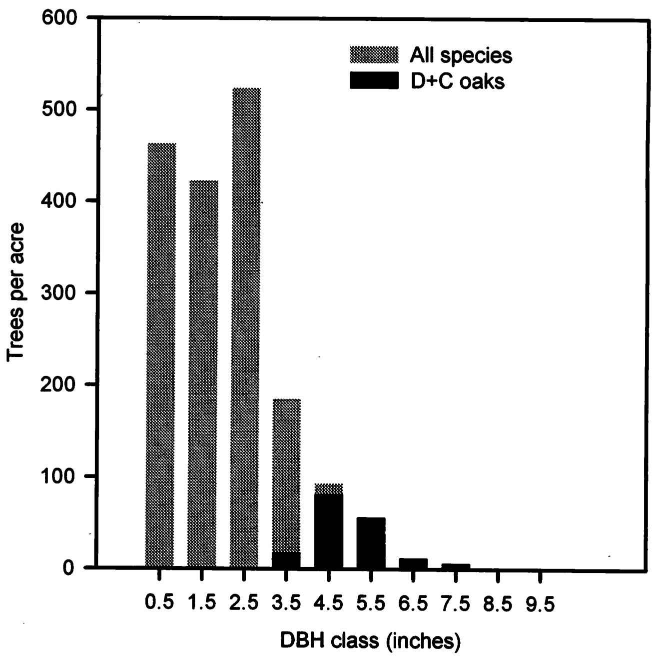

Figure 2. Predicted diameter distributions 21 yr after clearcutting a 70-yr-old upland oak forest in the Missouri Ozarks (site index 70, base age 50 for black oak). The ACORn regeneration model (Dey et al. 1996) was used to make the predictions based on a preharvest inventory of the overstory and of the advance reproduction. Diameter distributions are presented for all species regardless of crown class (gray bars) and for oaks in the *D* + *C* crown class category (black bars).

however, only oaks in the $D + C$ crown class category were considered acceptable growing stock, then ACORn estimated that there would be 174 stems/ac and 28.6% stocking of desirable stems based on the TD computed using model (1) (Figure 2). This represented a marginally acceptable level of desirable stocking according to Sander et al. (1984). When acceptable growing stock was defined as oaks in the $D + C + I$ crown class category, it was estimated that there would be about 350 stems/ac and 41% stocking of desirable stems based on the *TD* from model (2). High densities of less desirable species, or desirable species with small diameters may give the false perception that stocking is adequate in the early years following harvesting. Many of the small diameter oaks may not survive to maturity, and the survivors will likely be relegated to the *I* and *O* crown classes as the stand develops.

Diameter distributions, whether based on actual inventories or computer simulations, are insufficient by themselves to determine the adequacy of stocking. Additional information is needed to determine the proportion of stems that is acceptable growing stock. Tree species is one factor that affects the desirability of stocking. Crown class can also be used to define acceptable growing stock because it is a measure of a tree's competitive status and influences the survival and growth of reproduction.

Crown class is highly correlated with diameter, especially for young hardwoods. This relationship exists for a variety of species including maples, oaks, hickories, beech, and black cherry. Classification of hardwoods into specified crown class categories can be accomplished using dbh in Missouri Ozark upland forests.

The *TD* that separates one crown class category from another increases with increasing QMSD. When QMSD equals 3 in., which corresponds to a stand age of approximately 20 yr, trees with a dbh equal to or greater than 3.9 in. are placed in the $D + C$ crown class category. For oaks, this represents acceptable growing stock because oaks in the *I* and *O* crown classes are unlikely to survive or to grow into the *D* and *C* classes. If, however, stems in the $D + C + I$ crown class category are considered desirable, then tree dbh must equal or exceed 2.5 in., when QMSD is 3 in., for trees to be acceptable growing stock. If trees in all crown classes are desirable, then the entire diameter distribution defines acceptable growing stock.

TD, which defines the boundary of crown class categories, can be used to partition diameter distributions into specific crown class categories. Crown classes may be grouped by species in such a manner that they represent acceptable and unacceptable growing stock. Thus, the models presented in this paper can be used by foresters to better quantify and evaluate acceptable growing stock.

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