A Numerical Rating System for Crown Classes of Southern Hardwoods

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ABSTRACT: *A numerical rating system to delineate crown classes of southern hardwoods is described. The system is bused on four criteria: (1) amount of direct sunlight from above, (2) amount of direct sunlight from the sides, (3) crown balance, and (4) relative crown size. The total point value assigned places the tree within one of the four crown classes. The rating system can be used to train inexperienced hardwood foresters and should give experienced foresters a better grasp of those factors important in hardwood crown classijcation. Time required to evaluate a tree varies by tree, by stand conditions, and by observer, but experienced users of the system can easily rate most trees in 30–45 seconds. The rating system is particularly useful in situations where an individual tree appears to be borderline between two crown classes. For researchers, the system provides: (1) an expression of individual-tree crown characteristics, and (2) documentation of changes in crown position and condition. In two tests comparing the numerical rating system with the conventional crown classification system, use of the rating system consistently improved the ability of participants to correctly identify crown classes. Dominant and suppressed trees were the easiest to assess with the numerical rating system, whereas codominant and intermediate trees were the most difficult. Agreement between participants and experts in identification of crown classes increased with the level of the participants' forestry knowledge and experience. In one test, a group of participants attending a continuing-education hardwood shortcourse, but with little to moderate hardwood experience, correctly identified the crown class of 78% of the trees after only I hr of training. South. J. Appl. For. 25(4):154–158.*

Key Words: Crown class, crown classification, southern hardwoods.

Crown classes are categories into which a tree may be assigned based on its crown development and crown position relative to adjacent trees and the general forest canopy. Crown classes are used to predict future performance of a tree and are the basis for many silvicultural decisions. Definitions and descriptions of conventional crown classes are well established (Smith 1986). For most conifers in single-species stands, crown classes are easily recognized on the basis of the tree's position in the main canopy. However, conventional crown classes based on crown position alone do not adequately reflect the growth potential of hardwood trees in mixed-species stands (Guttenberg and Putnam 1951). In hardwoods, crown class must account for both position in the canopy and crown size and density relative to the tree's size and species.

Conventional crown classes based solely on a tree's position in the canopy are not particularly useful in even-aged, mixed-species stands, such as those found in most eastern hardwood forests. They are not good indicators of future performance of trees in these stands because most species differ in shade tolerance and pattern of growth. It is difficult to obtain reliable and repeatable estimates of a crown's position in the canopy, especially in multistrata, mixed-species stands (Nicholas et al. 199 1). Consequently, numerous tree classification systems that either modify or expand the conventional crown classification system have been developed. Some of these systems were designed for mixed-species stands, such as mixed conifers (Hanzlik 1924), upland hardwoods (Smith 1954), southern bottomland hardwoods (Putnam et al. 1960), and northern hardwoods (Meteer and Linjala 1973). Several other tree classification systems were developed for multi-aged, single-species stands of various western conifers (Dunning 1928, Taylor 1937, Homibrook 1939, Keen 1943). One system was also developed for even-aged, single-species stands in the Lake States (Gevorkiantz et al. 1943).

Several of these classification systems expanded conventional crown classes into detailed hierarchical systems

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composed of several crown classes and numerous subclasses. Others combined conventional crown class with assessments of other tree characteristics to form elaborate tree classification systems. For example, the system proposed by Putnam et al. (1960) and modified by Meadows (1996) was based on crown class, tree vigor, species, and potential product class and provided a basis for planning and implementing partial cuttings in southern hardwoods. Unfortunately, most of these tree classification systems contained complex, highly subjective descriptions of up to 16 classes and subclasses. The systems were difficult to use in the field and unsuitable for reliably assessing crown classes of trees in mixed-species stands. For these reasons, we developed a numerical rating system to delineate crown classes of southern hardwoods. The system is based on both position and condition of the crown and can easily be used for silvicultural, instructional, and research purposes. The system is intended to be used in even-aged stands, but might be applicable in uneven-aged stands as well.

Description of the Rating System

Our rating system provides an orderly procedure to make the subjective evaluation of crown classes more objective. Two factors are important in crown classification of hardwood trees: crown position in the canopy and crown condition. The amount of direct sunlight received by the crown is a measure of crown position in the canopy. Crown balance and crown size are measures of crown condition, which is largely the result of the amount of sunlight received by the tree in the past, but may also be due to disturbance, decline, or other factors. Therefore, four criteria are used in this rating system to evaluate these factors for each tree: (1) amount of direct sunlight from above, (2) amount of direct sunlight from the sides, (3) crown balance, and (4) relative crown size. Crown condition is a good indicator of the potential growth of the tree, whereas the amount of direct sunlight received by the tree is indicative of its capacity to achieve that growth potential. The exact relationship among crown condition, amount of sunlight received, and growth potential is species-specific. However, a tree with a poor crown will grow slowly regardless of the amount of sunlight received, but a tree with a good crown is likely to reach its growth potential if direct sunlight is increased.

Numerical ratings are assigned for each of the four criteria as follows:

1. **Direct Sunlight from Above (0-lo)-Values** of 0 to 10 are assigned depending on the percent of the crown surface, as viewed from above, that receives direct sunlight.
2. **Direct Sunlight from the Sides (O-10)** -Values of 0 to 10 are assigned depending on the percent of the crown's sides that receive direct sunlight from above the crowns of adjacent trees or from openings between the crowns of adjacent trees. Only the upper 50% of the crown length is used to evaluate this criterion.
3. **Crown Balance (l-4)-Perpendicular** axes that intersect at the center of the bole at the base of the crown are used to divide potential crown space into four quadrants. Values from 1 to 4 are then assigned depending on the number of quadrants occupied by a substantial portion of the crown (20% or more of the total crown volume). Each quadrant is evaluated individually regardless of the condition of the crown in other quadrants.
4. **Relative Crown Size** (l-4)-Total crown size, in terms of both lateral spread and density, is assessed in relation to the diameter (dbh) and species of the tree. Values of 1 to 4 are assigned depending on whether the size is judged to be *severely limiting* to growth (1 point); *limiting* to growth (2 points); *somewhat limiting* to growth (3 points); or *not limiting* to growth (4 points).

Point values for each criterion are then totaled and crown class is assigned according to the following categories:

Dominant	24-28 points
Codominant	17-23 points
Intermediate	10–16 points
Suppressed	2-9 points

These unequal class sizes appear to be arbitrary but were set by the authors after a period of trial-and-error, in which total point values for numerous trees were compared to the crown classes assigned by the authors for the same trees.

Field Use of the Rating System

It is easier to evaluate a tree's crown during the growing season when leaves are on the tree. However, a dense understory may block the observer's line of sight and make it difficult to see the crown of an overstory tree. On the other hand, while it is easier to see the crown during the dormant season when leaves are off the tree, it is also more difficult to assess crown density in the absence of foliage. We recommend that new users limit use of the rating system to the growing season. Experienced users can readily distinguish between living and dead limbs within the crown and can reliably assess crown characteristics even during the dormant season. If periodic re-evaluations are desired, they should always be made at the same time of year to avoid this potential seasonal variability.

Each tree should be examined carefully before assigning point values. The observer should walk around the tree and examine the crown and sunlight characteristics from several vantage points. Ideally, sunlight characteristics are best examined from several locations beneath the outer edges of the tree's crown, whereas crown characteristics are best examined from locations near the bole of the tree. However, a dense understory may force the observer to make his assessment from a less-than-ideal location. The observer should objectively and independently evaluate each of the four criteria and must resist the temptation to force the point values to fit a preconceived notion of the tree's crown class. Point values for all four criteria, as well as the crown class, should always be recorded for each tree. The time required to rate a tree varies with experience of the observer, characteristics of the tree, and stand conditions, particularly those that affect the ability of the observer to see the crown. Experienced users of the system can rate most trees in 30–45 seconds, but may need as much as 1-2 minutes to rate trees that are very difficult to see.

To evaluate direct sunlight from above and from the sides, estimate the percentage of the crown's surface area that receives direct sunlight and assign a point value based on a 0 to 10 scale (coinciding with a range of 0 to 100%). For example, if approximately 80% of the crown surface area, as viewed from above, receives direct sunlight, then assign a value of 8 points for direct sunlight from above. Only whole numbers should be given for each criterion. The 0 to 10 point scale for direct sunlight facilitates the use of percentages to estimate the amount of sunlight received by the tree. Frequently, only small areas on the crown surface receive direct sunlight. In this case, an individual "spot" of sunlight must be large enough to cover at least 10% of the crown surface area to be considered as *direct* sunlight, and thus be included along with other "spots" in the total estimate for direct sunlight.

To evaluate crown balance, use imaginary, perpendicular axes that intersect at the center of the bole at the base of the crown to divide the crown into four quadrants. One point is assigned for each quadrant that contains a substantial portion of the crown (approximately 20% or more of the total crown volume). Trees with a well-balancedcrown would be assigned a maximum of 4 points. Crown symmetry, not lateral spread of the crown, is the characteristic under consideration. A crown may be small in relation to dbh, but still may receive 4 points for crown balance as long as it is symmetrical. Conversely, a large crown may receive only 1 point for crown balance if the entire crown is located in only one quadrant. The observer should beware of the tendency to equate crown lateral spread with crown balance.

To evaluate relative crown size, the observer must assess both lateral spread and density. Total leaf area is actually the characteristic in question. Relative crown size should be rated in relation to the optimal crown size for a tree of that species and dbh. Does the crown, in terms of its total leaf area, limit the growth of the tree? And, if so, by how much does it limit growth? The observer must remember that the size of the crown should be proportional to dbh. He must also consider species in his assessment because some species inherently have larger crowns than others. Most hardwoods exhibit a decurrent crown form, in which the lateral branches grow nearly as fast or faster than the terminal leader, resulting in a broad, spreading crown. Most conifers, and a few hardwoods, have an excurrent crown form, in which the terminal leader grows faster than the lateral branches below it, producing a conical crown (Kramer and Kozlowski 1979). For trees of equal dbh, decurrent species such as oaks *(Quercus* spp.) normally have larger, more spreading crowns than excurrent species such as sweetgum *(Liquidumbar styraciflua* L.). In general, most trees assigned 4 points for relative crown size have long, wide, dense crowns with ample foliage to support satisfactory growth of the tree.

Test of the Rating System

We conducted two formal tests to evaluate the consistency of the numerical rating system. In the first test, we used 30 hardwood trees of various sizes and species in a 50- to 60-yr-old mixed hardwood stand on a minor bottomland site in east-central Mississippi. Species included in the test were mockernut hickory *(Curyu tomentosu* [Poir.] Nutt.), green ash *(Fruxinuspennsylvunicu* Marsh.), sweetgum, cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.), overcup oak (Q. *lyrutu* Walt.), swamp chestnut oak *(Q. michuuxii* Nutt.), water oak (Q. *nigru* L.), willow oak (Q. *phellos* L.), and American elm (*Ulmus americana* L.). We assigned point values and crown classes to each tree. Three groups of individuals participated in the first test: (1) 35 sophomore forestry students, (2) 44 senior forestry students, and (3) 6 forestry graduate students and professors with various degrees of experience in hardwood silviculture. A short lecture and demonstration was conducted to familiarize participants with field use of the rating system. Each participant identified the crown class of each tree using the conventional definitions based on crown position alone and then independently evaluated each tree using the numerical rating system. The second test was conducted on a set of 16 different trees (of the same species mix as before) in the same stand and was administered to a group of 40 participants in a continuing-education hardwood management shortcourse. Previous hardwood management experience of participants ranged from "none" to "some." This test was conducted in the same fashion as the first test, with each participant independently assigning conventional crown classes and then rating the trees after a short lecture and demonstration by the authors.

In each test, total point values for each participant within a group were compared to the point values assigned by the authors, on a tree-by-tree basis. Regression analysis was used to test the degree of agreement between the total point values (Y) of the participants within a group and the value assigned by the authors (X). Agreement between participants and authors existed if the plotted regression line for that particular group was not significantly different from the line $Y = X$. For Y to equal X, the regression coefficients b_0 and b_1 must not be significantly different from 0 and 1, respectively.

Only the regression equation for sophomore forestry students in the first test yielded b_0 and b_1 significantly different from 0 and 1, respectively (Table 1). Regression equations for the other two groups and for all participants in the first test combined, as well as for the shortcourse participants in the second test, were not significantly different from the equation Y = X. Apparently all participants, except those with little forestry knowledge and experience, learned to use the rating system with some degree of consistency after 1 hr of training. As the participants' level of forestry knowledge and experience increased, the variability in point values assigned by participants decreased. Consequently, foresters with some experience should require less training than those with little or no experience to become proficient with the rating system.

In every case, use of the numerical rating system resulted in higher percentages of agreement between participants and

Table 1. Results of regression analyses to test the degree of agreement between total point score for hardwood crown class of each tree by each participant within a group (Y) and total point score of the same tree assigned by the authors (X), using the model: $Y = b_0 + b_1X$.

Group	b_0	b_1	r^2	Root MSE
Test 1				
Sophomores	2.36*	0.86’	0.73	3.77
Seniors	1.37	0.98	0.80	3.45
Graduates/professors	1.20	0.95	0.86	2.72
All participants	1.76	0.93	0.77	3.58
Test 2				
Shortcourse participants	1 8	1.06	0.81	2.75

* Significantly different from 0 at the 0.05 level of probability.
† Significantly different from 1 at the 0.05 level of probability.

authors than did use of the conventional crown class system (Table 2). Improvement ranged from 6 to 16 percentage points and was relatively consistent across groups and among crown classes. In the first test, agreement with the authors increased from 58% using the conventional system to 67% using the numerical rating system. Among shortcourse participants in the second test, agreement increased from 71% to 78% as a result of using the rating system. The numerical rating system, as compared to the conventional crown class system, clearly increased the reliability of hardwood crown classification by participants with a wide range of forestry knowledge and experience.

Across both tests, the greatest percentage of agreement between authors and participants using the numerical rating system occurred in suppressed trees, followed by dominant, codominant, and intermediate trees, in descending order (Table 2). Trees in the intermediate crown class were the most difficult to assess and showed an agreement of only 46% across all participants in the first test and 68% among the shortcourse participants in the second test. Agreement was also somewhat low for codominant trees (63% and 74% in the first and second tests, respectively). The amount of time used to train participants apparently was insufficient to allow them to consistently distinguish these middle crown classes.

Percentage of agreement clearly increased with increasing knowledge and experience of the group (Table 2). Sophomore forestry students (the least experienced group) agreed with the authors 64% of the time, while forestry shortcourse participants (the most experienced group) agreed with the authors 78% of the time. After a short training period, users of this numerical rating system should be able to consistently identify hardwood crown classes 70–80% of the time. The level of proficiency should increase with continued use of the system. Although inexperienced users of the system may initially require up to 3-4 minutes to rate an individual tree, experienced users can rate most trees in 30-45 seconds.

Applications of the Rating System

The numerical rating system presented here can be used as a training tool to help inexperienced foresters consistently distinguish hardwood crown classes. It also gives experienced foresters a better grasp of those factors important in hardwood crown classification. The rating system emphasizes that crown condition is a critical factor in crown classification of hardwood trees. Our system, based on both crown position and crown condition, delineates crown classes more reliably than does the conventional system based on crown position alone. The rating system is easy to understand and simple to use. New users can consistently and reliably apply the system with proficiency after just a few days of field practice. Because the rating system is subjective, there will always be some variation among observers. However, variation among experienced users is small and of little practical importance.

Reliable and consistent identification of crown classes is an important task that affects many silvicultural decisions in everyday operations, such as timber cruising and marking. For example, the timber marker may use crown class to help decide which trees to cut and which trees to leave. These decisions must be made quickly but consistently from tree to tree. In everyday operations, the forester unfortunately does not have time to apply the numerical rating system to every tree. However, the forester familiar with this rating system understands the importance of crown condition as a determinant of crown class. She can quickly apply the concepts of the rating system and assign a crown class to the tree without actually assigning point values to each of the four criteria. In situations where a tree appears to be borderline between two crown classes, the forester should take the extra time required to apply the rating system, calculate a total point value, and assign the appropriate crown class to the tree.

Table 2. Percentages of hardwood crown classes, as assigned by participants using the conventional crown class system (CS) and using the numerical rating system (RS), that agreed with crown classes assigned by the authors, for each participant group and for each crown class.

	Crown class									
	Dominant		Codominant		Intermediate		Suppressed		All trees	
Group	CS	RS	CS	RS	CS	RS	CS	RS	CS	RS
Test 1										
Sophomores	57	63	52	62	39	50	64	75	55	64
Seniors	65	76	56	62	32	41	77	84	61	68
Graduates/professors	70	77	62	75	47	63	63	77	61	74
All participants	62	71	55	63	36	46	71	80	58	67
Test 2										
Shortcourse participants	80	86	67	74	59	68	86	94	71	78

For researchers, the rating system provides: (1) an expression of individual-tree crown characteristics, and (2) documentation of changes in crown position and condition. The system presents a less subjective, more precise, and more detailed picture of the tree than does the conventional system. Because it produces acontinuous numeric variable, the rating system eliminates the need for arbitrarily defined "subclasses," such as "low" codominant or "high" codominant, and for confusing intermediate classes, such as "intermediate/codominant," to indicate a borderline situation. The total point value assigned to a tree not only delineates its crown class, but also numerically identifies the relative placement of that tree within its crown class. If point values for all four criteria are recorded periodically, trends in tree vigor are more apparent than if crown class alone is recorded. For example, although a change of one or two points could be attributed to variation in assessment by the observer, a tree that is given significantly fewer points for direct sunlight at successive evaluations may be losing dominance, even though its crown class remains unchanged. This application is one of the most valuable uses of the rating system because it enables the researcher to detect this trend, whereas recording of crown class alone does not.

Although the rating system was developed for southern bottomland hardwoods, it may be applicable to other eastern hardwoods as well. Modifications and refinements to the system may be necessary as more is learned about hardwood growth traits and the factors affecting them. Species with different growth forms or ecological requirements may need different definitions or modified versions of the rating system. For example, crown balance and relative crown size may be more important for species with decurrent crown forms than for species with excurrent crown forms. Similarly, the amount of direct sunlight received by the crown may be more important for shade-intolerant species than for shade-tolerant species. The use of a weighting factor for each criterion for different species or species groups may be necessary to further refine the system.

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