Crown Position and Light Exposure Classification-An Alternative to Field-Assigned Crown Class

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ABSTRACT: *Crown class, an ordinal tree-level mensuration attribute used extensively by foresters, is difficult to assign in the field because definitions of individual classes are confounded by ambiguous references to the position the tree in the canopy and amount of light received by its crown. When crown class is decomposed into its two elements-crown position and crown light exposure--field assignments are more repeatable, and crown class can be assigned by algorithm with the same degree of accuracy that it can be estimated in thefield. Replacing traditional crown class with the twoproposedalternative variables yields more specific information about each tree. Crown position and crown light exposure add information potentially useful for modeling and other applications. North. J. Appl. For. 20(4):154–160.*

Key Words: Tree crown class, crown position, crown light exposure.

The concept of crown class, a traditional mensuration variable used extensively in the field of forestry, was first introduced in nineteenth century Germany by Kraft (1884). The longstanding favor of crown class among foresters is attributed to its functionality as a measure of competitive stress on individual trees. As such, it has been utilized for a wide variety of applications. Crown class is used in thinning prescriptions designed to favor vigorous trees in superior competitive positions (Smithet al. 1997). It is required for the determination of site index, which is based on age-height relationships of dominant and codominant trees (Husch et al. 1982). The effects of crown class have been correlated with growth and productive capacity (Trimble 1969, Assmann 1970, Fairweather 1986); response to thinning (McMinn 1988); mortality, shade tolerance and species succession patterns (Ward and Stephens 1993); needle mass, crown shape, and leaf area distribution (Gilmore and Seymour 1997); sapwood thickness (Smith et al. 1966); variation in sap flow (Granier 1987); moisture stress (Wright and Berryman 1980); and tree value (Dobie and McBride 1964).

USDA Forest Service Forest Inventory and Analysis (FIA) crews assign crown class to all live trees on the basis of the following definitions [USDA Forest Service (a) 2002]:

1. *Open grown.* Trees with crowns that have received full light from above and from all sides throughout their lifespan, particularly during the early developmental period.

2. *Dominant.* Trees with crowns extending above the general level of the crown canopy and receiving full light from above and partly from the sides. These trees are taller than the average trees in the stand and their crowns are well developed, but they could be somewhat crowded on the sides. Also, the crowns have received full light from above and from all sides during early development and most of their life. Their crown form or shape appears to be free of influence from neighboring trees.

3. *Codominant.* Trees with crowns at the general level of the crown canopy. Crowns receive full light from above but little direct sunlight penetrates to their sides. Usually they have medium-sized crowns and are somewhat crowded from the sides. In stagnated stands, codominant trees have small-sized crowns and are crowded on the sides.

4. *Intermediate.* Trees that are shorter than dominants and codominants, but their crowns extend into the canopy of dominant and codominant trees. They receive little direct light from above and none from the sides. As a result, intermediates usually have small crowns and are very crowded from the sides.

5. *Overtopped.* Trees with crowns entirely below the general level of the crown canopy that receive no direct sunlight either from above or the sides.

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The crown-classification system implemented by FIA is based on the Kraft (1884) system, with definitions drawn from terminology originally sanctioned by the Society of American Foresters (SAF) (1917). The only departure from the original terminology is FIA's addition of a category for open-grown trees. Since 1917, the SAF also has added categories for open-grown trees (i.e., emergents and predominants) (Helms 1998), but the basic descriptions of dominant, codominant, intermediate, and overtopped trees remain unchanged.

The Kraft crown classification system was originally intended for application in pure stands or stands composed of species with identical height regimes (Smith et al. 1997). However, in practice it is commonly applied to uneven-aged stands of mixed species, and recent SAF terminology specifically extends the concept of crown class to uneven-aged stands (Helms 1998). All of the crown-class categories listed above are based on a mixture of conditions related to crown position and light exposure. While the combinations of crown position and light exposure within each crown-class category may be consistent for uniform stands with closed canopies, extension of the traditional system to uneven-aged stands creates ambiguities that are difficult to resolve. As a result, field crews often struggle over how much weight to assign to canopy position and how much weight to assign to light exposure in the determination of crown class. In many western forests, water is often more limiting to tree development than light, and the references to competition for light are irrelevant or difficult to interpret. Nicholas et al. (1991) observed extremely poor repeatability with traditional crown classification, especially in uneven-aged stands, and expressed the need for an alternate scheme solely defined by the amount of light available to trees in such stands.

In response to poor repeatability and training difficulties associated with the traditional procedure, the USDA Forest Service Forest Health Monitoring (FHM) program developed an alternative that divides the two main elements of crown class into two separate variables-crown position and crown light exposure [USDA Forest Service (b) 2002]. This article has three purposes:

1. Test the repeatability of the traditional and alternative field methods,

2. Determine if the alternative variables can be accurately translated into a measure of traditional crown class, and

3. Investigate whether separate measures of crown position and crown light exposure have potential to contribute added value beyond traditional crown class.

Methods

Alternative Field Method

The following procedures were used to assign crown-position and crown light exposure values in the field.

Crown Position

First, an overstory canopy zone is identified, which encompasses the crown lengths of trees in the primary overstory (Figure 1). Although identification of the overstory canopy zone requires some subjectivity, the intent is to provide rules that are more specific and repeatable than those associated with crown class. Once this zone is established, trees are rated with regard to their position in relation to its midpoint and upper bound:

1. *Superstory.* The live crown top is at least two times the height of the top of the overstory canopy zone. The tree is open grown because most of the crown is above the overstory canopy zone (pioneers, seed trees, whips, remnants from previous stands).

2. *Overstory.* The live crown top is above the middle of the overstory canopy zone.

3. *Understory.* The live crown top is at or below the middle of the overstory canopy zone.

4. *Open Canopy.* An overstory canopy zone is not evident because the tree crowns in this condition are not fully closed. Most of the trees in this stand are not competing with each other for light.

Code 1 is not valid for seedlings or saplings (trees less than 5.0 in. dbh). Codes 1-3 are used in stands where the tree crown canopy is closed (i.e., crown cover ≥50% based on an ocular estimate of field conditions and aerial photography). If the canopy is not closed, code 4 is assigned. When used, code 4

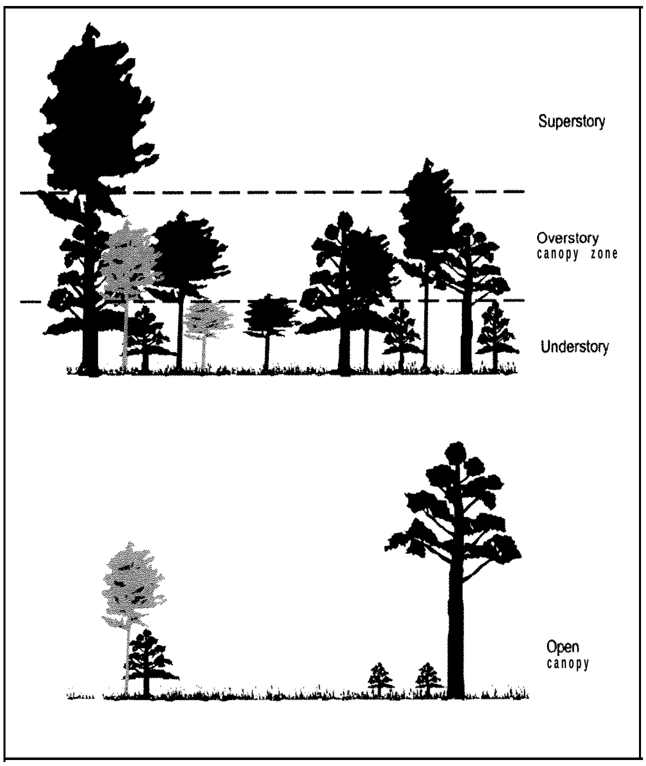

Figure 1. Crown position classification.

typically is allocated to all trees in the stand, even if some trees are grouped in small clumps. Code 4 is used for trees in stands where crown cover is less than 50% and trees in clumps less than 1 acre in size, when the overall forest is a patchwork of open areas and clumps of trees.

The superstory, overstory, and understory categories are equivalent to the A, B, and C canopy strata described by Oliver and Larson (1996). The overstory canopy zone (i.e., the B stratum) is used as a reference point to lend objectivity to the separation of superstory and understory trees from overstory trees. The open-canopy category was added to accommodate stands that do not exhibit any clear canopy stratification. Such stands are common in the arid regions of the western United States.

Crown Light Exposure

Tree crowns are divided vertically into four equal sides (or faces) (Figure 2). The number of sides that would receive direct light if the sun were directly above the tree is then counted; one is added if the tree receives any direct light from the top, for a possible total of five faces. In order for a side to be counted, more than 30% of the tree length on that side must have live foliage exposed to direct light. Thus, trees with live-crown ratios of 30% or less can have a maximum crown light exposure of one, and individual sides with live crown ratios of 30% or less are not counted. The 30% cutoff was adopted because it promotes repeatability, and because reductions in tree vigor have been associated with crown ratios below 30% (Smith et al. 1997). Crown light exposure codes are assigned as follows:

0 The tree receives no direct light because of heavy shading by trees, vines, or other vegetation.

1 The tree receives direct light from the top or one side.

2 The tree receives direct light from the top and one side (or two sides without the top).

3 The tree receives direct light from the top and two sides.

4 The tree receives direct light from the top and three sides.

5 The tree receives direct light from the top and four sides.

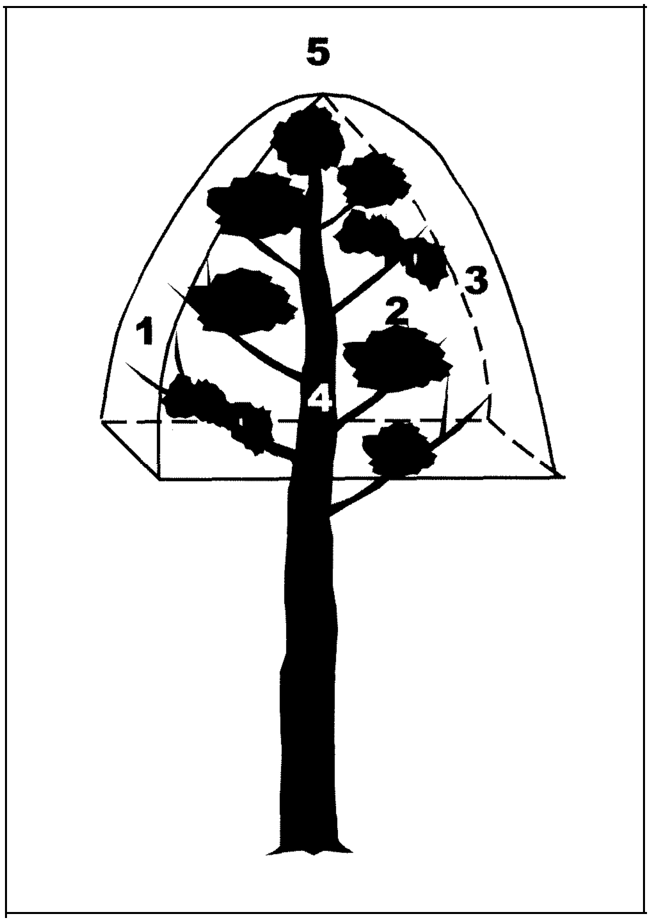

Figure 2. Crown light exposure classification.

Three Datasets

Three datasets were used to compare crown class with crown position and light exposure. All observations were made during the "leaf-on" growing season:

1. *2000 FIA Phase 3 Production Data.* Phase 3 plots are the subset of plots on the FIA sampling grid reserved for the primary purpose of measuring indicators of forest health. Sample intensity is approximately one plot per 96,000 acres. All three variables-crown class, crown position, and crown light exposure-were measured for each live tree sampled in 2000. This dataset includes 17,889 trees spanning 23 states across the United States.

2. **2000** *FIA Phase 3 Qualify-Assurance (QA) Data.* Regional trainers remeasured a subset of the Phase 3 plots measured in 2000 as part of FIA's QA program. The QA data were obtained from "blind checks," where QA crews visited plots shortly after production crews had completed them. QA crews independently remeasured these plots in the absence of production crews, and without consulting the production-crew data. Productioncrews were unaware that these plots would be checked when they collected the original data. The QA dataset used in this analysis consists of 783 remeasured trees from 18 states.

3. *1998-1999 FIA Phase 3 Growth Data.* Crown position and light exposure as described herein were initially implemented on Phase 3 plots in 1998. A subset of the 1998 plots was remeasured in 1999, yielding estimates of growth for the remeasured trees. Because there is some potential to use crown light exposure and position to model growth, this potential was investigated with 7,302 trees measured in both 1998 and 1999. The growth data were obtained from plots located in 25 states across the United States.

Data Measurement Quality Objectives

FIA strives to attain specific measurement quality objectives (MQOs), which are based on comparisons of production-crew data to QA crew data. MQOs for the three crown classification variables are:

- Crown class--exact match
- Crown position--exact match
- Crown light exposure-exact match if crown light exposure is 0; otherwise ±1 class.

WMQO is the percentage of estimates within the desired measurement quality objective. FIA's target WMQO for each of these three variables is 85% [USDA Forest Service (a) 2002; USDA Forest Service (b) 2002]. Upper and lower 95% confidence intervals for WMQO can be calculated with the normal approximation (Hollander and Wolfe 1973) as follows:

$$WMQO \pm 1.96\left(\frac{WMQO(100-WMQO)}{n}\right)^{0.5}$$

The 2000 FIA Phase 3 Production and QA datasets were used to test repeatability of field measurements, and todevelop a crown position/exposure to crown class translation algorithm.

Regression Models

The alternative field methodology produces three variables potentially useful for modeling and other special applications—crown class (computed by algorithm), crown position, and crown light exposure. Since crown class occasionally is used for growth modeling, the 1998-I 999 FIA growth dataset was used to model tree-level diameter growth as a function of crown class, crown light exposure, and crown position. Potential gains from the availability of crown position and crown exposure were evaluated by examining model r-squares and partial r-squares from stepwise linear regressions.

Results and Discussion

Repeatability of Traditional and Alternative Field Methods

Based on the 2000 QA data, comparisons of QA-crew field calls to production-crew field calls (Table 1) show that crown position and crown light exposure were more repeatable than crown class (83 and 85% vs. 69% WMQO, respectively). The 95% confidence interval for crown class does not overlap with the other two variables, indicating that crown class is significantly less repeatable than the individual crown position and crown light exposure variables. The target WMQO for these three variables (85%) was attained by crown position and crown light exposure, but not crown class.

Translation Algorithm

The 2000 production data were used to generate a matrix portraying the frequency distribution of field-crew position/exposure assignments by crown-class assignments (Table 2). Based largely on the cell in each row with the highest frequency, the following algorithm was derived to translate various combinations of crown position and crown light exposure codes into crown class codes:

if position/exposure combination = (1/0,1/1,1/2,1/3,1/4,1/5,2/5) then crown class = 2

if position/exposure combination = (2/1 ,2/2,2/3,2/4,4/2,4/3,4/4,4/5) then crown class = 3

if position/exposure combination = (2/0,3/1,3/2,3/3,3/4,3/5,4/1) then crown class = 4

if position/exposure combination = (310,410) then crown class = 5

Position/exposure combinations 1/0 and 2/5 were the only rows in Table 2 where the cell with the highest frequency was not used in the algorithm. Superstory trees receiving no light (position/exposurecombination l/O) becauseofvines, probably should be classified as dominant rather than overtopped, and overstory trees receiving full light on five faces (position/exposure combination 2/5) probably should be classified as dominant. A similar matrix was generated from the smaller QA dataset to check results obtained from the production crews. The 2000 QA data yielded frequency distributions very similar to those in Table 2, except QA crews assigned a dominant crown class to the majority of trees with position/exposure combination 2/5.

Table 1 shows that the algorithm translates crown position and crown light exposure into crown class with 73-75% accuracy (based on comparisons of QA crew and production crew algorithm values with their own field calls). When

Table 1. Percentage of observations within measurement quality objectives (WMQO), by crown variable, crew type, and data source, 2000 FIA Phase 3 data.

Crown variable, crew type, and data source	n	WMQO*,† (%)
Crown position		
QA crew field call vs. production crew field call	783	83 (80–85)
Crown light exposure		
QA crew field call vs. production crew field call	783	85 (82–87)
Crown class		
QA crew field call vs. production crew field call	783	69 (66–72)
QA crew field call vs. production crew algorithm	783	71 (68–74)
QA crew field call vs. QA crew algorithm	783	75 (72–78)
Production crew field call vs. production crew algorithm	17,889	73 (73–74)
QA crew algorithm vs. production crew algorithm	783	76 (74–79)

* Measurement Quality Objectives (MQO): Crown position: exact match, Crown light exposure: exact match if exposure = 0, otherwise ± 1 class. Crown class: exact match.

95% confidence interval for WMQO in parentheses.

Table 2. Frequency of assigned crown position/crown light exposure values by assigned crown class values, 2000 FIA Phase 3 production data.

Assigned crown position/crown light exposure combination		Assigned crown class: Open grown (1)	Dominant (2)	Codominant (3)	Intermediate (4)	Overtopped (5)
Superstory/0 faces	(1/0)	0	1	0	0	2
Superstory/1 face	(1/1)	0	4	2	0	1
Superstory/2 faces	(1/2)	0	1	1	0	0
Superstory/3 faces	(1/3)	0	5	2	0	0
Superstory/4 faces	(1/4)	0	12	2	0	0
Superstory/5 faces	(1/5)	7	41	0	0	0
Overstory/0 faces	(2/0)	0	0	174	456	210
Overstory/1 face	(2/1)	1	129	2,978	862	36
Overstory/2 faces	(2/2)	3	159	2,059	187	5
Overstory/3 faces	(2/3)	1	235	1,712	103	0
Overstory/4 faces	(2/4)	8	327	1,257	53	0
Overstory/5 faces	(2/5)	57	44.5	595	18	1
Understory/0 faces	(3/0)	0	0	18	460	2,277
Understory/1 face	(3/1)	2	2	64	688	237
Understory/2 faces	(3/2)	0	4	67	239	42
Understory/3 faces	(3/3)	3	1	73	177	9
Understory/4 faces	(3/4)	0	4	70	128	2
Understory/5 faces	(3/5)	10	17	70	113	7
Open canopy/O faces	(4/0)	9	0	3	3	9
Open canopy/l face	(4/1)	8	0	4	17	5
Open canopy/2 faces	(4/2)	15	0	15	14	0
Open canopy/3 faces	(4/3)	19	5	77	9	0
Open canopy/4 faces	(4/4)	29	29	188	19	0
Open canopy/5 faces	(4/5)	187	76	199	8	6

compared to QA crew field calls, production-crew estimates resulting from the algorithm are about the same as production-crew field calls (71 vs. 69%, respectively), indicating that the algorithm assigns crown class with the same degree of accuracy as ocular estimates by field crews.

The translation algorithm does not yield an estimate for crown class 1 (open grown). Crown class 1 differs from classes 2-5 in that it requires knowledge of past growing conditions, while the other classifications are based on current conditions. Field crews rarely have the required historical knowledge, and it is doubtful that open-grown trees as defined by FIA can be accurately identified. Of the 17,889 trees in the production dataset, only 2% were assigned crown class 1. Production crews assigned a crown class 1 to 1% of the trees in the QA dataset, yet no trees in the QA dataset were assigned crown class 1 by QA crews, demonstrating that crown class 1 is rare and difficult to classify consistently.

For crown classes 2-5, the classes most repeatable in the field were 3 and 5. Matches between QA-crew field calls and production-crew field calls for crown classes 2–5 were 5 1, 78, 56, and 71%, respectively. Results obtained by comparing QA-crew field calls to the production-crew values resulting from the algorithm were nearly identical, signifying the accuracy obtained with the algorithm equals the accuracy obtained in the field across the range of crown classes.

Potential Added Value of Crown Position and Crown Light Exposure

Because the translation algorithm, which is based on crown position and light exposure, yields results that are approximately equivalent to field-assigned crown class, it is reasonable to question the advantage gained by trading one existing field variable for two new ones. Ocular estimates of tree-crown variables usually require 10–20 seconds per tree, so the cost of substituting two variables for one is about 15 seconds per tree. This cost must be weighed against the additional information yielded by the proposed modification. For applications where nothing is required beyond a simple estimate of crown class, there is no reason to adopt protocols that require more work.

For research and monitoring applications, where individual variables often are used for multiple purposes, or the data have high potential for future value, the extra information may be worth the additional work. Splitting crown class into its two separate components yields more specific information about each tree, and has the potential to enhance the utility of a variable that has multiple applications in forest research. The field of remote sensing would almost certainly benefi t through higher correlations between field crown classification and canopy reflectance (Cooke 2002).

Because the alternative classification system has only been implemented since 1998, it was not possible, with the data at hand, to appraise the value added for most of the specific uses to which crown class has been or could be applied. For one potential application, growth modeling, the 1998-I 999growth data afforded some opportunity to examine whether the new variables add utility. Two series of stepwise linear regression solutions were designed to investigate whether or not crown position and crown light exposure increased the ability of linear models to predict tree growth beyond the use of crown class alone. For solution 1, mean annual tree-level basal-area growth was modeled as a function of crown position and crown light exposure, by species. Position and exposure were entered and retained only if these parameters were significant at the .05 level. For solution 2, growth was modeled as a function of all three crown variables. Crown class was fixed in the models first and retained. Position and exposure were then entered and retained if significant at the .05 level.

During model development, growth was evaluated in terms of diameter increment at breast height, as well as basal area increment at breast height. The latter produced better models, so tree-level basal area growth was selected as the dependent variable. Species with less than 30 observations were excluded from the growth analyses, as were species for which none of the

Table 3. Partial r-squares* resulting from the addition of crown class, crown exposure, and crown position to stepwise linear regressions of annual tree basal area growth, by species, without crown class in the model, and with crown class fixed in the model, 1998-1999 FIA Phase 3 data .

			Stepwise solution 1 (Crown class not in the model')			Stepwise solution 2 (Crown class fixed in the model")			
			Partial *r*-squares§			Partial *r*-squares§			
Species		*n*	Crown exposure	Crown position"	Model r-square	Crown class'	Crown exposure	Crown position'	Model r-square
Balsam fir	(*Abies balsamea*)	317	0.017	0.107	0.124	0.102	ns	ns	0.102
Grand fir	(*A. grandis*)	45	ns	0.219	0.219	0.227	ns	ns	0.227
Red maple	(*Acer rubrum*)	788	0.081	ns	0.081	0.044	0.038	ns	0.082
Sugar maple	(*A. saccharum*)	416	0.022	ns	0.022	0.026	ns	ns	0.026
Red alder	(*Alnus rubra*)	42	ns	0.115	0.115	0.022	ns	0.109	0.131
Yellow birch	(*Betula alleghaniensis*)	133	ns	0.083	0.083	0.079	ns	ns	0.079
Sweet birch	(*B. lenta*)	79	0.054	ns	0.054	0.069	ns	ns	0.069
Paper birch	(*B. papyrifera*)	227	0.072	ns	0.072	0.028	0.046	ns	0.075
Pt.-Orford cedar	(*Chamaecyparis lawsoniana*)	58	0.085	ns	0.085	0.033	ns	ns	0.033
Dogwood	(*Cornus florida*)	32	0.340	ns	0.340	0.278	ns	ns	0.278
American beech	(*Fagus grandifolia*)	229	0.020	ns	0.020	0.020	ns	ns	0.020
White ash	(*Fraxinus americana*)	84	0.146	ns	0.146	0.083	0.066	ns	0.150
Black ash	(*F. nigra*)	67	0.147	ns	0.147	0.037	0.113	0.058	0.207
Sweetgum	(*Liquidambar styraciflua*)	213	0.246	ns	0.246	0.144	0.105	ns	0.249
Yellow-poplar	(*Liriodendron tulipifera*)	170	0.127	ns	0.127	0.070	0.058	ns	0.128
Blackgum	(*Nyssa sylvatica*)	110	ns	0.156	0.156	0.137	ns	ns	0.137
E. hophorn-beam	(*Ostrya virginiana*)	45	ns	0.367	0.367	0.346	ns	ns	0.346
Sourwood	(*Oxydendrum arboreum*)	51	0.115	ns	0.115	0.108	ns	ns	0.108
Engehnann spruce	(*Picea engelmanni*)	161	0.067	ns	0.067	0.104	ns	0.026	0.131
Black spruce	(*P. mariana*)	70	0.195	ns	0.195	0.071	0.125	ns	0.196
Red spruce	(*P. rubens*)	146	0.118	ns	0.118	0.067	0.052	ns	0.119
Lodgepole pine	(*Pinus contorta*)	362	0.054	0.012	0.066	0.040	0.021	ns	0.061
Ponderosa pine	(*P. ponderosa*)	171	0.131	ns	0.131	0.098	0.042	ns	0.140
Red pine	(*P. resinosa*)	200	0.150	ns	0.150	0.037	0.114	ns	0.151
E. white pine	(*P. strobus*)	217	0.097	ns	0.097	0.042	0.056	ns	0.097
Loblolly pine	(*P. taeda*)	959	0.126	0.012	0.138	0.058	0.079	ns	0.137
Virginia pine	(*P. virginiana*)	98	0.141	ns	0.141	0.041	0.102	ns	0.143
Quaking aspen	(*Populus tremuloides*)	367	0.031	0.019	0.050	0.019	0.016	0.025	0.060
Black cherry	(*Prunus serotina*)	137	ns	ns	ns	0.033	ns	ns	0.033
Douglas fir	(*Pseudotsuga menziesii*)	444	0.100	ns	0.100	0.038	0.062	0.022	0.122
Bur oak	(*Quercus macrocarpa*)	37	0.108	ns	0.108	0.089	ns	ns	0.089
White oak	(*Q. alba*)	119	0.060	ns	0.060	0.126	ns	ns	0.126
Water oak	(*Q. nigra*)	107	ns	0.189	0.189	0.172	ns	ns	0.172
N. red oak	(*Q. rubra*)	197	0.104	0.020	0.124	0.109	0.020	ns	0.130
Black oak	(*Q. velutina*)	62	0.300	ns	0.300	0.139	0.158	0.060	0.357
Sassafras	(*Sassafrass albidum*)	31	ns	ns	ns	0.131	ns	ns	0.131
N. white cedar	(*Thuju occidentalis*)	90	0.045	ns	0.045	0.038	ns	ns	0.038
Basswood	(*Tilia Americana*)	37	ns	0.107	0.107	0.131	ns	ns	0.131
W. hemlock	(*Tsugu heterophyllu*)	118	0.086	ns	0.086	0.067	ns	ns	0.067
Mountain hemlock	(*T. mertensiana*)	35	ns	ns	ns	0.026	0.132	ns	0.157
American elm	(*Ulmus americana*)	31	ns	0.132	0.132	0.124	ns	ns	0.124

* The r-squares of independent variables are adjusted for variables that were entered first in the model. In solution 1, the variable with the highest r-square entered first. Crown class was entered first in solution 2, followed by the variable with the highest partial r-square.

† Model specification: growth = $b_0 + b_1$ (crown light exposure) + b_2 (crown position) where growth = tree-level basal-area increment per year.

†† Model specification: growth = $b_0 + b_1$(crown class) + b_2 (crown light exposure) + b_3 (crown position) where growth = tree-level basal- area increment per year.

§ ns indicates the variable was not significant at the 0.05 level.

Crown position was transformed to an ordinal variable by grouping code 4 (open canopy) with code 2 (overstory).

\# Crown class was computed by algorithm from crown light exposure and crown position.

three crown variables was statistically significant, resulting in a total of 41 species. The crown-position and light-exposure values used in the growth models were those at the beginning of the measurement interval in 1998. Crown class was not field assigned in 1998, but given that computed crown class is approximately equivalent to field-assigned crown class (based on results in Table I), crown-class values used in the models were those from the algorithm. Crown light exposure, which is ordinal, was entered into the models directly as recorded in the field. Crown position, a class variable (due to the open-canopy classification), was transformed into an ordinal variable for regression modeling purposes. This was achieved by combining the open-canopy class with the overstory class (i.e., crown position code 4 = 2). Trees in settings that are generally noncompetitive, but occasionally clumped, are growing in conditions most similar to overstory trees. Examination of model residuals did not reveal that any mathematical transformations of the independent variables were warranted.

Results from the regression solutions are provided in Table 3. Comparisons of the model r-squares from solution 1 to the partial r-squares of the crown-class variable in solution 2 show that the two new crown variables outperform crown class alone in 32 out of 41 models. Partial r-squares from solution 2 (a more conservative test of added value since crown position and light exposure have been adjusted for the effect of crown class) show that one or both of these variables contribute significantly to 21 of 41 models. Most of the improvement is attributed to the crown light exposure variable.

The results in Table 3 demonstrate that the new variables have potential utility for growth modeling, but the low *r*-squares associated with all of these models cannot be overlooked. Model r-squares from solution 2 ranged from .02 to .36, with an average of. 13 across all species. One possible explanation for the poor r-squares is the short 1 yr measurement interval of the growth variable. Data for growth periods longer than 1 yr were not available if growth was to be modeled as a function of crown condition at the beginning of the growth interval. However, it was possible to obtain a longer interval if growth were modeled as a function of crown condition at the terminal inventory, because the diameters of trees measured in 1998 (when the crown data were available) had been measured 1–4 yr in the past. This latter model would rarely be of practical utility, but it is useful for checking the correlation between growth and crown-classification variables to determine if the short measurement interval were responsible for low r-squares. When solution 2 of Table 3 was refit using past growth, with a mean measurement interval of 2.5 yr, the average r-square across the same 4 1 species was only 0.12 (as compared to 0.13 with the 1 yr growth interval). Thus, a longer growth interval did not improve the linear correlation between growth and crown condition. Factors that may add variability to growth for short intervals (e.g., dbh measurement error) are apparently counterbalanced by factors that may add variability to growth for longer measurement intervals (e.g., climatic factors and stand disturbances). Although the general linear correlation between crown-classification parameters and diameter growth appears rather weak (at least for these data), the additional variables still improved more than half of the models.

Conclusions

Traditional crown-class estimates do not attain the measurement quality objectives specified by FIA. Crown class can be replaced by two alternative variables that are each more repeatable—crown position and crown light exposure. An algorithm applied to the two alternate variables can estimate crown class with the same degree of accuracy as field-assigned crown class; so existing applications that require crown class are not jeopardized. The proposed alternate variables supply more specific information about each tree than crown class alone. They are therefore potentially useful for modeling and other research applications. The field cost of trading traditional crown class for the alternative procedure is one additional ocular crown estimate-about 15 seconds per tree.

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