An Alternative to the Kraft Crown Classification System

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Abstract. *Traditional Crown Class assignments can be difficult in the field because definitions of individual classes are confounded by ambiguous references to the position of 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 the field. Replacing traditional crown class with the two proposed alternative variables yields more specific information about each tree, which is potentially useful for modeling and other applications.*

Traditional Crown Class

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. The crown-class coding scheme historically used by the USDA Forest Service Forest Inventory and Analysis (FIA) program is based on the Kraft system. Except for the addition of the open-grown category, the definitions currently in use by FIA were originally sanctioned by the Society of American Foresters in 1917:

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, trees whose 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 **Co-dominant.** 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, co-dominant trees have small-sized crowns and are crowded on the sides.

4 **Intermediate.** Trees that are shorter than dominants and co-dominants, but their crowns extend into the canopy of dominant and co-dominant 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.

Alternative Crown Classification

Nicholas et al. (1991) observed poor repeatability with traditional crown classification, especially when applied to trees in uneven-aged stands. The USDA Forest Service Forest Health Monitoring (FHM) program encountered similar problems, which led to an investigation of alternative methods. Surmising that poor repeatability was caused by ambiguities between canopy position and light exposure in the traditional definitions, the two main elements of crown class were divided into separate variables—crown position and crown light exposure. Starting in 1998, FHM field crews used the following rules (USDA Forest Service 2002) to assign crown-position and crown-exposure values.

Crown position. First, an overstory canopy zone is identified, which encompasses the crown lengths of trees in the primary overstory (figure 1). 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 (< 50% canopy cover). Most trees in this stand are not competing with each other for light.

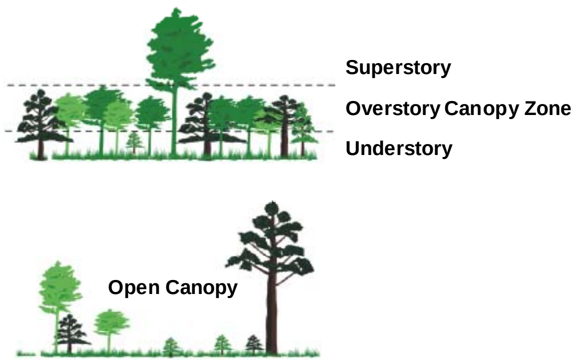

Figure 1. Crown position classification

Crown 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 are 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 percent of the tree length on that side must have live foliage exposed to direct light.

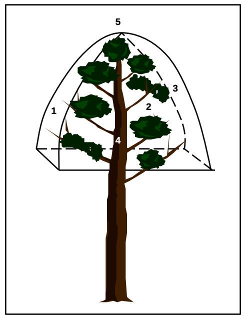

Figure 2. Crown light exposure classification

Repeatability of Traditional and Alternative Methods

When the FIA and FHM programs merged in 2000 the combined program decided to implement both classification systems until it could be demonstrated that only one was necessary. The implementation of both affords an opportunity for direct comparison of the two systems.

FIA's specified measurement quality objectives for the three crown classification variables are:

Crown class: exact match,

Crown position: exact match, and

Crown light exposure: exact match if crown light exposure is 0, otherwise + 1 class.

Quality-assurance (QA) crews continuously field-check measurements by production crews to determine the percentage of measurements within the desired measurement quality objective (WMQO). FIA's target WMQO for each of these three variables is 85 percent.

Based on QA data gathered in 2000, 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 percent WMQO, respectively). The 95-percent 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. Crown position and crown light exposure, but not crown class attained the 85 percent target WMQO.

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[a,b] (Percent)
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)

[a] Measurement Quality Objectives (MQO):
Crown position: exact match,
Crown light exposure: exact match if exposure = 0, otherwise + 1 class,
Crown class: exact match.

[b] 95 - percent confidence interval for WMQO in parentheses.

Translation Algorithm

The alternative classification system was designed to permit translation to the traditional system. FIA production-crew data from 2000 were used to develop a translation algorithm. A matrix generated from 17,889 sample trees was used to establish the frequency distribution of position/exposure assignments by crown-class assignments. 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 = (3/0,4/0) then crown class = 5.

The algorithm does not yield an estimate for crown class 1 (open grown) because there was almost no correlation between the assignment of this code between production crews and QA crews in the QA dataset. Poor repeatability for crown class 1 was attributed to an implied knowledge of past growing conditions, which is rarely available to field crews. Table 1 shows that the algorithm translates crown position and crown light exposure into crown class with 73-75 percent accuracy (based on comparisons of QA crew and production-crew algorithm values with their own field calls). When 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 percent, respectively), indicating that the algorithm assigns crown class with the same degree of accuracy as ocular estimates by field crews.

Potential Value of Alternative Classification

Because the translation algorithm yields results that are only equivalent to field-assigned crown class, it is reasonable to question the advantage of the alternative system, which requires two variables instead of one. For one potential application, growth modeling, 1998-1999 FHM growth data afforded some opportunity to examine whether the new variables add utility. Two series of stepwise linear regressions 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.

Results from the regression solutions are provided in table 2. 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. 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 alternative crown variables out-perform crown class alone in 32 out of 41 models. Partial r-squares from solution 2, which is 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.

Table 2. Partial r-squares[a] 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[b])			Stepwise solution 2 (Crown class fixed in the model[c])			
			Partial r-squares[d]		Model	Partial r-squares[d]			Model
	Species	n	Crown exposure	Crown position[e]	r-square	Crown class[f]	Crown exposure	Crown position[e]	r-square
Balsam fir	(Abies balsamea)	317	.017	.107	.124	.102	ns	ns	.102
Grand fir	(Abies grandis)	45	ns	.219	.219	.227	ns	ns	.227
Red maple	(Acer rubrum)	788	.081	ns	.081	.044	.038	ns	.082
Sugar maple	(Acer saccharum)	416	.022	ns	.022	.026	ns	ns	.026
Red alder	(Alnus rubra)	42	ns	.115	.115	.022	ns	.109	.131
Yellow birch	(Betula alleghaniensis)	133	ns	.083	.083	.079	ns	ns	.079
Sweet birch	(Betula lenta)	79	.054	ns	.054	.069	ns	ns	.069
Paper birch	(Betula papyrifera)	227	.072	ns	.072	.028	.046	ns	.075
Pt.-Orford cedar	(Chamaecyparis lawsoniana)	58	.085	ns	.085	.033	ns	ns	.033
Dogwood	(Cornus florida)	32	.340	ns	.340	.278	ns	ns	.278
American beech	(Fagus grandifolia)	229	.020	ns	.020	.020	ns	ns	.020
White ash	(Fraxinus americana)	84	.146	ns	.146	.083	.066	ns	.150
Black ash	(Fraxinus nigra)	67	.147	ns	.147	.037	.113	.058	.207
Sweetgum	(Liquidambar styraciflua)	213	.246	ns	.246	.144	.105	ns	.249
Yellow poplar	(Liriodendron tulipifera)	170	.127	ns	.127	.070	.058	ns	.128
Blackgum	(Nyssa sylvatica)	110	ns	.156	.156	.137	ns	ns	.137
E. Hophornbeam	(Ostrya virginiana)	45	ns	.367	.367	.346	ns	ns	.346
Sourwood	(Oxydendrum arboreum)	51	.115	ns	.115	.108	ns	ns	.108
Engelmann spruce	(Picea engelmanni)	161	.067	ns	.067	.104	ns	.026	.131
Black spruce	(Picea mariana)	70	.195	ns	.195	.071	.125	ns	.196
Red spruce	(Picea rubens)	146	.118	ns	.118	.067	.052	ns	.119
Lodgepole pine	(Pinus contorta)	362	.054	.012	.066	.040	.021	ns	.061
Ponderosa pine	(Pinus ponderosa)	171	.131	ns	.131	.098	.042	ns	.140
Red pine	(Pinus resinosa)	200	.150	ns	.150	.037	.114	ns	.151
E. white pine	(Pinus strobus)	217	.097	ns	.097	.042	.056	ns	.097
Loblolly pine	(Pinus taeda)	959	.126	.012	.138	.058	.079	ns	.137
Virginia pine	(Pinus virginiana)	98	.141	ns	.141	.041	.102	ns	.143
Quaking aspen	(Populus tremuloides)	367	.031	.019	.050	.019	.016	.025	.060
Black cherry	(Prunus serotina)	137	ns	ns	ns	.033	ns	ns	.033
Douglas fir	(Pseudotsuga menziesii)	444	.100	ns	.100	.038	.062	.022	.122
Bur oak	(Qercus macrocarpa)	37	.108	ns	.108	.089	ns	ns	.089
White oak	(Quercus alba)	119	.060	ns	.060	.126	ns	ns	.126
Water oak	(Quercus nigra)	107	ns	.189	.189	.172	ns	ns	.172
N. red oak	(Quercus rubra)	197	.104	.020	.124	.109	.020	ns	.130
Black oak	(Quercus velutina)	62	.300	ns	.300	.139	.158	.060	.357
Sassafras	(Sassafrass albidum)	31	ns	ns	ns	.131	ns	ns	.131
N. white cedar	(Thuja occidentalis)	90	.045	ns	.045	.038	ns	ns	.038
Basswood	(Tilia Americana)	37	ns	.107	.107	.131	ns	ns	.131
W. hemlock	(Tsuga heterophylla)	118	.086	ns	.086	.067	ns	ns	.067
Mountain hemlock	(Tsuga mertensiana)	35	ns	ns	ns	.026	.132	ns	.157
American elm	(Ulmus americana)	31	ns	.132	.132	.124	ns	ns	.124

[a] 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.

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

[c] 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.

[d] ns indicates the variable was not significant at the .05 level.

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

[f] Crown class was computed by algorithm from crown light exposure and crown position.

Conclusions

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, rendering them potentially useful for modeling and other research applications. More data are necessary to evaluate the potential advantages of the alternate system, but preliminary analyses indicate that the alternate variables are more highly correlated with growth than crown class. The cost of trading traditional crown class for the alternative procedure is one additional ocular estimate, which averages approximately 15 seconds per tree.

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