Section 1: Tree Crown Indicator

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Introduction

Tree crown conditions provide valuable insight into the health of forest ecosystems. The U.S. Forest Service has been collecting tree crown data since 1990. Between 1990 and 1999, these data were obtained by the Forest Health Monitoring (FHM) program. In 2000, the FHM plot network and the Forest Inventory and Analysis (FIA) program merged, which resulted in crown data collection being undertaken by FIA. A national quality assurance (QA) program was implemented by FIA (USDA Forest Service 2004a) to continuously monitor the quality of inventory data collection. One aspect of this QA program entails independent remeasurement of a randomly selected subset of sample plots. These data are used to evaluate measurement repeatability by comparing the QA measurements to those obtained during the visit by the production plot crew.

The purpose of this study is to analyze measurement repeatability for the suite of crown condition variables collected by FIA to assess the health of tree crowns.

Methods

Field Data Collection

FIA phase 2 (P2) plots occur at an intensity of approximately 1 plot per 6,000 acres in a spatially distributed sampling grid across the United States (Bechtold and Patterson 2005). Crown condition data are obtained from FIA Phase 3 (P3) sample plots, which comprise one-sixteenth subset of FIA P2 sample plots. Thus, each P3 plot represents roughly 96,000 acres (Reams et al. 2005).

For all attributes measured on a sample plot, a repeatability criterion (measurement quality objective [MQO]) is specified in terms of a tolerance and compliance rate. The acceptable range of differences between independent measurements is defined by the tolerance. The expected proportion of differences that are within the tolerance is specified by the compliance rate (see the introductory text). The FIA P3 field guide (USDA Forest Service 2004b) provides in-depth descriptions of field data collection procedures and repeatability standards for crown indicator variables.

This assessment is based on data from trees measured on 147 FIA P3 plots that were randomly chosen for QA inspection between 2002 and 2004. The distribution of QA plots by region were as follows: SRS = 49; NE = 20; NC = 35; IW = 37; PNW = 6. There are two sets of data from these plots. The first set of observations was collected during the production inventory visits. The second set of data is from ‘blind check’ remeasurement of these same plots by an independent field crew within two weeks after the production inventory measurement. The measurement protocols were identical for both crews.

Matching Procedures

Due to the ‘blind check’ nature of the plot remeasurement, there was no guarantee that the same tree number was assigned by both crews to the same tree. There are a number of reasons this may occur, including missed trees and differences in sample inclusion determination. Thus, the trees measured by each crew need to be matched to compute valid measurement differences. To accomplish this, a data-matching algorithm was used to ensure that both measurements were observations of the same tree.

The matching algorithm employed weighted distance functions based on distance and azimuth from plot center and tree diameter at breast height (d.b.h.) to determine appropriate pairings of data from the independent measurements. Although species are assigned numeric codes, there is no intrinsic meaning in terms of differences, e.g., how ‘far away’ is an oak from a maple. As such, there was no clear method to quantify species differences and species was not used in tree matching. This process was designed to only match trees where the location and size attributes were within prespecified ranges of agreement. The remaining unmatched trees were individually evaluated and either added to the matched data or set aside as extra trees. This same procedure was employed by Pollard et al. (2006) to match trees on FIA P2 plots.

Analytical Techniques

The repeatability of the various crown indicator variables was assessed via the differences between observed values from production and QA crews. Differences were computed by subtracting the production inventory measurement from the QA measurement.

$$d_{ij} = x_{ij} - y_{ij}$$

where: d_{ij} = difference between QA crew and production crew for tree i, crown variable j
x_{ij} = observation from QA crew for tree i, crown variable j
y_{ij} = observation from production crew for tree i, crown variable j

The percentage of observations falling within the range of the specified tolerance level was determined:

$$p_j = \frac{\sum w_{ij}}{n_j}$$

where: p_j = estimated proportion of observations within tolerance t_j for crown variable j

t_j = specified tolerance level for crown variable j

$$w_{ij} = \begin{cases} 1 \text{ if } |d_{ij}| \leq t_j \\ 0 \text{ if } |d_{ij}| > t_j \end{cases}$$

n_j = number of observations for crown variable j

Exact binomial 95 percent confidence intervals for the percentage of the observations within tolerance also were computed (Balakrishnan and Nevzorov 2003). If we denote the number of observations within tolerance as $m_j = \sum w_{ij}$ and solve

$$0.025 = \sum_{m_{Uj}}^{n_j} \binom{n_j}{m_{Uj}} p_j^{m_{Uj}} (1 - p_j)^{n_j - m_{Uj}}$$

and

$$0.025 = \sum_{0}^{m_{Lj}} \binom{n_j}{m_{Lj}} p_j^{m_{Lj}} (1 - p_j)^{n_j - m_{Lj}}$$

for m_{Uj} and m_{Lj} respectively, then we can compute the upper (p_{Uj}) and lower (p_{Lj}) confidence limits for p_j as

$p_{Uj} = \frac{m_{Uj}}{n_j}$ and $p_{Lj} = \frac{m_{Lj}}{n_j}$, respectively.

These computations were performed using SAS® statistical software (SAS Institute, Inc. 2003).

The confidence intervals were applied to the calculated proportion of observations within tolerance for each variable. If the MQO compliance rate was within the interval, the measurement repeatability was assumed to have met the established standards. Other reported statistics that describe the distribution of measurement differences include mean difference and root mean squared difference (RMSE).

Results and Discussion

Uncompacted Crown Ratio

The length of the tree section between the live crown top and the live crown base defines the uncompacted crown length. To obtain uncompacted crown ratio, the uncompacted crown length is divided by the length from the base of the tree to the live crown top. Observations are recorded to the nearest 1-percent, with values ranging from 0 to 100.

Overall, independent measurements of uncompacted crown ratio were within the ±10 percent tolerance 79.1 percent of the time, which is below the 90 percent MQO compliance rate (Table 1.1). Regionally, the values ranged from 67.9 percent (NE) to 88.1 percent (NC). NC was the only region that met the target compliance rate (i.e., the confidence interval includes 90 percent). The magnitude of the mean difference suggests bias should be of little concern. RMSE values show that the average discrepancy between independent measurements ranged from roughly 10 percent to 15 percent. As shown in Tables 1.2 and 1.3, separating the data into hardwood and softwood groups indicated that repeatability was poorer for hardwood trees (76.7 percent) than softwood trees (81.9 percent). This result was not unexpected as the deliquescent crown form for many hardwoods makes it difficult to clearly establish the tree top and crown base. These results are comparable to the results reported by Pollard and Smith (1999, 2001). In their evaluation of QA data collected by the FHM Program in 1998 and 1999, repeatability was also poorer for hardwoods than for softwoods.

A more detailed analysis was conducted to determine if measurement repeatability problems may be related to crown ratio values. The uncompacted crown ratio data were thus grouped into 5 percent classes (based on the measurement recorded by the QA crew) and repeatability statistics were generated for each class (Table 1.4). For classes having reasonable sample sizes (≥20 trees), the repeatability was relatively consistent (70 to 80 percent), with perhaps the exception of the 90 percent and higher categories where repeatability increased notably. However, a trend is evident in the mean differences. For trees having low crown ratios, the QA measurement is, on average, smaller than the production inventory measurement. Conversely, there is a tendency for the QA measurement to be higher than the production inventory measurement for ratios above 55 percent. QA crews are more likely than production crews to assign extremely low and extremely high values. Further investigation is needed to ascertain the underlying cause(s) of this pattern.

Subsequent to the data used for this QA analysis, procedures were modified in 2006 for estimating uncompacted crown ratio for leaning and down trees and trees with dead tops. Uncompacted crown ratio was previously estimated based on tree height above the ground (not tree length). Currently, uncompacted crown ratio for all trees (leaning or not) is based on tree length. In addition, the denominator of the ratio has been redefined to include actual tree length (as defined by FIA), rather than the top of the live crown. Uncompacted crown ratio is thus expressed as a percentage of actual tree length. The result is that uncompacted crown ratio now includes dead tops (but not broken or missing tops). It is not yet apparent if or how these changes affect measurement repeatability.

Table 1.1—Repeatability statistics for tree crown attributes by FIA region.

Variable	Tolerance	MQO compliance rate	FIA region	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
Uncompacted crown ratio	±10%	90	SRS	75.3	71.8 - 78.6	2.6	14.9	648
			NE	67.9	63.9 - 71.8	1.9	15.4	558
			NC	88.1	85.5 - 90.4	-0.4	9.7	712
			IW	83.0	80.3 - 85.4	-0.8	10.1	881
			PNW	68.1	57.7 - 77.3	2.8	13.9	94
			ALL	79.1	77.6 - 80.6	0.7	12.5	2893
Crown light exposure	±1 class[a]	85	SRS	87.2	84.4 - 89.7	-0.1	0.9	648
			NE	83.5	80.2 - 86.5	-0.1	1.0	558
			NC	89.5	87.0 - 91.6	-0.1	0.8	712
			IW	84.4	81.9 - 86.8	-0.2	1.2	881
			PNW	92.6	85.3 - 97.0	0.2	0.8	94
			ALL	86.4	85.1 - 87.6	-0.1	1.0	2893
Crown position[b]	No tolerance	85	SRS	90.0	87.4 - 92.2	-	-	647
			NE	81.2	77.7 - 84.3	-	-	558
			NC	90.3	87.9 - 92.4	-	-	712
			IW	70.7	67.6 - 73.7	-	-	881
			PNW	77.7	67.9 - 85.6	-	-	94
			ALL	82.1	80.6 - 83.5	-	-	2892
Vigor class	No tolerance	90	SRS	80.0	72.8 - 86.0	-0.1	0.5	155
			NE	82.2	77.2 - 86.5	0.0	0.4	281
			NC	70.5	61.9 - 78.1	-0.2	0.6	132
			IW	63.0	52.3 - 72.9	0.3	0.7	92
			PNW	25.0	0.6 - 80.6	-0.8	0.9	4
			ALL	76.4	72.9 - 79.5	0.0	0.5	664
Crown density	±10%	90	SRS	78.9	75.0 - 82.4	1.0	11.7	493
			NE	60.7	54.6 - 66.6	-2.8	14.9	270
			NC	78.6	75.0 - 81.9	-0.5	11.0	579
			IW	67.8	64.4 - 71.1	0.0	13.4	789
			PNW	67.8	57.1 - 77.2	-3.1	13.0	90
			ALL	72.2	70.3 - 74.1	-0.4	12.6	2221
Crown dieback	±10%	90	SRS	97.4	95.5 - 98.6	-0.2	6.3	493
			NE	90.4	86.2 - 93.6	-1.2	8.5	270
			NC	96.9	95.1 - 98.1	0.0	7.4	579
			IW	95.9	94.3 - 97.2	0.9	7.6	789
			PNW	96.7	90.6 - 99.3	-0.9	6.7	90
			ALL	95.9	94.9 - 96.6	0.1	7.4	2221
Foliage transparency	±10%	90	SRS	86.6	83.3 - 89.5	-0.9	10.3	493
			NE	77.8	72.3 - 82.6	-1.6	15.1	270
			NC	94.8	92.7 - 96.5	-1.3	8.7	579
			IW	95.9	94.3 - 97.2	-0.1	7.2	789
			PNW	96.7	90.6 - 99.3	-1.4	7.9	90
			ALL	91.4	90.2 - 92.5	-0.8	9.6	2221

[a] ±1 class when exposure > 0; no tolerance when exposure = 0
[b] Mean difference and RMSE not reported for categorical variables

Table 1.2—Repeatability statistics for tree crown attributes from 1543 hardwood trees across the U.S.

Variable	Tolerance	MQO compliance rate	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
Uncompacted crown ratio	±10%	90	76.7	74.5 - 78.8	1.1	13.8	1543
Crown light exposure	±1 class[a]	85	87.4	85.7 - 89.0	-0.1	0.9	1543
Crown position[b]	No tolerance	85	86.3	84.5 - 88.0	-	-	1542
Vigor class	No tolerance	90	73.1	68.5 - 77.3	0.0	0.6	405
Crown density	±10%	90	75.8	73.1 - 78.2	0.1	12.1	1130
Crown dieback	±10%	90	94.1	92.5 - 95.4	0.0	9.0	1130
Foliage transparency	±10%	90	87.4	85.4 - 89.3	-1.2	11.6	1130

[a] ±1 class when exposure > 0; no tolerance when exposure = 0
[b] Mean difference and RMSE not reported for categorical variables

Table 1.3—Repeatability statistics for tree crown attributes from 1350 softwood trees across the U.S.

Variable	Tolerance	MQO compliance rate	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
Uncompacted crown ratio	±10%	90	81.9	79.7 - 83.9	0.2	10.8	1350
Crown light exposure	±1 class[a]	85	85.2	83.2 - 87.0	-0.1	1.1	1350
Crown position[b]	No tolerance	85	77.3	74.9 - 79.5	-	-	1350
Vigor class	No tolerance	90	81.5	76.2 - 86.0	0.0	0.5	259
Crown density	±10%	90	68.6	65.7 - 71.3	-0.9	13.2	1091
Crown dieback	±10%	90	97.7	96.6 - 98.5	0.2	5.1	1091
Foliage transparency	±10%	90	95.5	94.1 - 96.7	-0.4	7.0	1091

[a] ±1 class when exposure > 0; no tolerance when exposure = 0
[b] Mean difference and RMSE not reported for categorical variables

Table 1.4—Repeatability statistics for crown ratio measurements by crown ratio class.

QA crew observation[a]	Tolerance	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
0%	±10%	50.0	6.8 - 93.2	-10.3	14.2	4
5%	±10%	66.7	9.4 - 99.2	-25.0	46.3	3
10%	±10%	80.0	44.4 - 97.5	-11.7	22.4	10
15%	±10%	62.5	40.6 - 81.2	-9.7	20.7	24
20%	±10%	72.9	58.2 - 84.7	-6.4	14.2	48
25%	±10%	71.0	58.1 - 81.8	-4.7	14.6	62
30%	±10%	75.6	64.9 - 84.4	-5.0	14.4	82
35%	±10%	81.3	73.8 - 87.4	-1.2	12.0	139
40%	±10%	83.1	77.1 - 88.1	-1.5	10.8	195
45%	±10%	79.9	74.0 - 85.0	-2.5	10.5	219
50%	±10%	77.6	72.0 - 82.5	-1.5	12.8	263
55%	±10%	79.6	73.5 - 84.9	1.3	11.2	206
60%	±10%	74.0	67.7 - 79.6	2.0	13.1	223
65%	±10%	68.8	61.7 - 75.2	1.2	12.7	192
70%	±10%	71.9	64.4 - 78.5	3.2	11.9	167
75%	±10%	70.8	63.5 - 77.3	4.0	15.0	178
80%	±10%	76.4	69.0 - 82.8	2.6	14.3	157
85%	±10%	79.6	72.0 - 85.9	3.6	13.0	142
90%	±10%	87.4	81.7 - 91.9	3.5	12.1	183
95%	±10%	88.8	82.7 - 93.3	3.9	12.2	152
100%	±10%	95.1	91.6 - 97.4	2.3	7.6	244

[a] QA crew observations were grouped into 5-percent classes: 0% = 0%, 5% = 1-5%, 10% = 6-10%, …100% = 96-100%.

Crown Light Exposure

A measure of the amount of direct sunlight a tree receives is given by the crown light exposure variable. The measurement protocol requires the tree to be divided vertically into four equal sides. A count of the number of sides receiving direct light if the sun were directly above the tree is made. One is added to this count if the tree receives direct light from the top. The total is the value entered for crown light exposure, with acceptable values ranging from 0 to 5.

The repeatability assessment for crown light exposure measurements indicated 86.4 percent of the observations were within the tolerance (Table 1.1). The attained repeatability (86.4 percent) slightly exceeded the MQO compliance rate of 85 percent. Evaluations by FIA region showed a high level of consistency across regions and the confidence intervals for each region included the MQO value. The small values for mean difference indicate negligible bias, while RMSE were generally near 1 class. The results also were very consistent between hardwood and softwood species (Tables 1.2 and 1.3), suggesting that evaluation of crown light exposure is unaffected by tree crown characteristics and foliage type.

Crown Position

Crown position information is collected for each tree to indicate where an individual tree crown is located in relation to the overstory trees. Three codes are used in stands where the crowns are closed (i.e., ≥50 percent crown cover at the stand level). These codes denote superstory, overstory, and understory crown positions. An additional code is used for stands lacking crown closure (<50 percent crown cover). In this case, all trees in the stand are assigned a single code of open grown.

The comparison of matched crown position measurements showed exact agreement (tolerance level is 0) between independent measurements 82.1 percent of the time with a 95 percent confidence interval of 80.6 percent - 83.5 percent (Table 1.1). The desired compliance rate is 85 percent. There was a notable amount of regional variation, from 70.7 percent (IW) to 90.3 percent (NC). Based on the confidence intervals, the NE region was slightly out of compliance, but the IW region failed to achieve the MQO compliance rate by a substantial amount. Repeatability was somewhat less for softwood trees (77.3 percent) as compared to hardwood trees (86.3 percent) for all regions combined (Tables 1.2 and 1.3). This difference probably contributed to the low compliance rate in the IW since the region contains a high proportion of softwoods. The fact that repeatability for hardwood trees slightly exceeded the MQO compliance rate indicates that improved repeatability for softwoods is needed.

A confounding factor in the analysis of crown position repeatability was the conditional use of codes depending on whether the stand-level crown closure attained 50 percent or more. In situations where differences in determining whether crown closure has occurred, all of the crown position codes will differ between crews. Given that the tolerance is zero, this lowers the overall repeatability statistic. For these data, 210 trees on 17 plots were affected by differences in crown closure determination. Excluding these data from the analysis increased agreement between the independent crown position measurements to 88.5 percent, which exceeds the MQO compliance rate of 85 percent.

Additional analyses indicated that the crown closure differences primarily occurred in the IW region where there is a high level of forest/woodland interface. Of the 210 trees affected by crown closure differences, 193 occurred in the IW region. These 193 trees occurred over 14 conditions, where open crown conditions were observed nine times by the QA crew and five times by the production crew. Thus, there is a tendency for the QA crew to determine lack of crown closure more often than the production crew.

IW also had the lowest repeatability statistic (70.7 percent) for crown position among all regions (Table 1.1). Excluding the data where crown closure determinations differed resulted in an increase to 90.6 percent repeatability between crews in IW. Decreasing differences on degree of crown closure between crews, especially in the IW region, will increase the repeatability of crown position observations.

Crown Vigor Class

Tree saplings (1.0 inch ≤ d.b.h. ≤4.9 inches) are assigned a crown vigor class for the purpose of identifying very good or extremely poor crowns. The ratings are based on crown dieback, uncompacted crown ratio, and amount of missing or damaged foliage. Vigor is recorded in three classes: 1 = vigorous, 2 = moderate vigor, and 3 = poor vigor. Most saplings are in class 1.

The repeatability of crown vigor class measurements is evaluated with no tolerance for differences. Results of the analysis show the overall repeatability of 76.4 percent (95 percent confidence interval of 72.9 percent to 79.5 percent) did not attain the MQO compliance rate of 90 percent (Table 1.1). All regions failed to attain the desired compliance rate, although SRS and NE regions were fairly close with upper confidence limits near 86 percent. Statistics presented for the PNW region should be viewed with caution, as only four trees contributed to the analysis. Comparisons between hardwood and softwood species (Tables 1.2 and 1.3) show that agreement between measurements was better for softwoods (81.5 percent) than hardwoods (73.1 percent).

Repeatability of crown vigor measurements was also independently assessed for each of the three classes. The results shown in Table 1.5 clearly indicate that repeatability is poor when the QA crew observes crown vigor other than class 1. Analysis of the mean difference and RMSE values indicate that the poor repeatability for classes 2 and 3 are the result of the QA crew recording a higher vigor class (lower tree vigor) than the production inventory crew, on average.

Table 1.5—Repeatability statistics for crown vigor measurements by crown vigor class.

QA crew observation	Tolerance	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
1	No tolerance	83.5	79.9 - 86.7	-0.2	0.4	491
2	No tolerance	56.7	48.6 - 64.6	0.4	0.7	157
3	No tolerance	50.0	24.7 - 75.3	0.8	1.1	16

Crown Density

Crown density is a measure of how much light is blocked by the tree crown. The measurement protocol entails defining tree crown shape and using a reference card to determine the percentage of light being obscured. Observations are recorded in 5-percent classes, with a value of 0 for trees with no crown (i.e., epicormic branches only).

Overall, crown density repeatability was the lowest among all the crown indicator variables. Evaluated with a tolerance of ±10 percent, the attained repeatability for crown density was 72.2 percent with an associated 95 percent confidence interval of 70.3 to 74.1 percent (Table 1.1). This was an undesirable realization, as the MQO standard is 90 percent. Regional results ranged from 60.7 to 78.9 percent for the NE and SRS units, respectively. No individual regions achieved the MQO compliance rate. The mean differences show no practical bias. The average deviation between independent measurements (based on RMSE) ranged from approximately 11 to 15 percent. Consistency was higher for hardwood species than for softwood species (75.8 percent and 68.6 percent, respectively) (Tables 1.2 and 1.3).

Pollard and Smith (1999, 2001) also found that between-crew agreement was more consistent for hardwoods than softwoods and that both species groups were below the MQO standard of 90 percent. Repeatability has declined since 1999. Pollard and Smith (1999, 2001) observed 83 percent agreement for hardwoods in 1998 and 89 percent in 1999; and 75 percent for softwoods in 1998 and 86 percent in 1999.

Further analyses of crown density repeatability shows that the most consistent agreement between measurements occurred when observed values were 60 percent or less (Table 1.6). In this range, measurements are within ±10 percent of each other, on average, more than 70 percent of the time. Repeatability decreased with increasing crown density when crown densities became greater than 60 percent. A precipitous decline occurs beyond the 60 percent point, e.g. only one-third of the production crew measurements were within tolerance when the QA crew recorded a value of 80 percent. There were no matched observations within ±10 percent for crown density of 85 percent. No values were recorded by the QA crew above 85 percent. This poor repeatability is probably due in part to the rarity of trees with high crown density. Crown densities above 75 percent are rare for most species unless they are open-grown. FHM data from the South (1995-1999) had a maximum crown density of 85 percent. The QA data used by Pollard and Smith had a maximum density of 90 percent (1 tree). Caro et al. (1979) noted that rare events are less likely to have strong inter-observer agreement simply because observers do not assess these conditions frequently.

An interesting bias in crown density ratings was observed (Table 1.6). Generally, the difference between crews becomes larger as crown density moves away from the 45 to 50 percent range. For trees having low crown density, the QA measurement is, on average, smaller than the production inventory measurement. Conversely, there is a tendency for the QA measurement to be higher than the production inventory measurement for density ratings above 50 percent. The RMSE values depict a similar trend. This indicates that production crew values tend to gravitate toward the mean, which was also observed with the crown ratio data.

Table 1.6—Repeatability statistics for crown density measurements by crown density class.

QA crew observation[a]	Tolerance	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
0%	±10%	66.7	22.3 - 95.7	-17.5	27.6	6
5%	±10%	83.3	35.9 - 99.6	-5.8	11.4	6
10%	±10%	66.7	38.4 - 88.2	-9.0	16.3	15
15%	±10%	61.3	42.2 - 78.2	-9.7	17.0	31
20%	±10%	68.2	52.4 - 81.4	-10.1	16.8	44
25%	±10%	67.5	55.9 - 77.8	-7.0	13.5	77
30%	±10%	73.4	66.3 - 79.8	-5.2	12.1	177
35%	±10%	77.7	72.9 - 82.1	-2.6	11.1	337
40%	±10%	74.8	70.3 - 78.8	-2.7	11.7	420
45%	±10%	78.7	74.0 - 82.9	-0.2	10.7	343
50%	±10%	71.8	65.7 - 77.5	0.7	12.2	238
55%	±10%	70.9	64.0 - 77.1	3.6	11.8	199
60%	±10%	71.6	63.6 - 78.7	5.7	13.6	148
65%	±10%	57.3	46.4 - 67.7	8.2	15.4	89
70%	±10%	52.1	37.2 - 66.7	9.8	16.0	48
75%	±10%	38.5	20.2 - 59.4	16.7	21.2	26
80%	±10%	33.3	9.9 - 65.1	17.9	21.7	12
85%	±10%	0.0	0.0 - 52.2	26.0	27.0	5

[a] QA crew observations were grouped into 5-percent classes: 0% = 0%, 5% = 1-5%, 10% = 6-10%, …100% = 96-100%.
Note: There were no observations above 85% from the QA crews.

Crown Dieback

An estimate of the recent mortality of branches with fine twigs occurring in the upper and outer portions of the tree is provided by the crown dieback variable. Percent dieback is measured as a percentage of the total crown area. Observations are recorded in 5 percent classes, with a value of 0 for trees with no dieback.

Both these results and those reported by Pollard and Smith (1991, 2001) indicate that crown dieback is the most repeatable measurement within the crowns indicator suite. Overall repeatability was assessed at 95.9 percent with a tolerance of ±10 percent (Table 1.1). This exceeds the MQO compliance rate of 90 percent. All FIA regions met the MQO standard and RMSE values ranged from roughly 6 to 8 percent. As expected with a measurement exhibiting high levels of consistency, evaluations by hardwood and softwood species groups both exceeded the specified compliance rate. Softwood trees attained a statistic of nearly 98 percent, while hardwood trees were somewhat lower at 94.1 percent (Tables 1.2 and 1.3).

Most trees had little or no crown dieback. In the data used for this study, 95 percent of the trees had dieback of 10 percent or less according to the QA crew (Table 1.7). The small amount of dieback occurring on a large proportion of the trees resulted in high repeatability statistics. However, most classes between 15 to 40 percent did not attain the MQO standard. It is also in this range where sample sizes decreased substantially, suggesting that this may be a ‘threshold’ area where crews began to measure trees with amounts of dieback that were not commonly encountered. Minimal experience in measuring trees with these attributes could contribute to increased measurement variability. There were

Table 1.7—Repeatability statistics for crown dieback measurements by crown dieback class.

QA crew observation[a]	Tolerance	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
0%	±10%	98.1	97.2 - 98.7	-1.7	4.5	1357
5%	±10%	98.2	96.8 - 99.1	0.9	6.7	605
10%	±10%	100.0	97.6 - 100	4.5	6.9	150
15%	±10%	72.2	54.8 - 85.8	7.6	9.9	36
20%	±10%	39.1	19.7 - 61.5	5.7	15.1	23
25%	±10%	60.0	14.7 - 94.7	8.0	12.2	5
30%	±10%	22.2	2.8 - 60.0	18.9	22.5	9
35%	±10%	0.0	0.0 - 45.9	20.8	27.2	6
40%	±10%	40.0	5.3 - 85.3	23.0	27.7	5
45%	±10%	33.3	0.8 - 90.6	26.7	34.9	3
50%	±10%	50.0	6.8 - 93.2	-1.3	28.6	4
55%	±10%	100.0	2.5 - 100	0.0	0.0	1
60%	±10%	0.0	0.0 - 97.5	35.0	35.0	1
65%	±10%	50.0	1.3 - 98.7	27.5	38.9	2
70%	±10%	100.0	2.5 - 100	5.0	5.0	1
75%	±10%	33.3	0.8 - 90.6	23.3	30.8	3
80%	±10%	50.0	1.3 - 98.7	-7.0	13.9	2
85%	±10%	-	-	-	-	0
90%	±10%	50.0	6.8 - 93.2	10.0	18.4	4
95%	±10%	-	-	-	-	0
100%	±10%	50.0	6.8 - 93.2	49.5	70.0	4

[a] QA crew observations were grouped into 5-percent classes: 0% = 0%, 5% = 1-5%, 10% = 6-10%, …100% = 96-100%.

relatively few trees beyond 40 percent crown dieback, although wide confidence intervals caused by small sample sizes in this data range consistently included the MQO compliance rate of 90 percent. Mean differences between crews are generally positive, indicating that QA crews are more likely to assign higher dieback values than production crews, again indicating that production crews tend to gravitate toward the mean.

Foliage Transparency

Foliage transparency describes the amount of light coming through the live portion of the crown (i.e., where normal, damaged, or partly missing foliage occurs). Crown dieback and other dead branches are not included. Once the foliated area of the crown is determined, a reference card is used to estimate transparency in 5-percent classes, with a value of 99 percent for trees with no crown (i.e., epicormic branches only).

With a tolerance of ±10 percent between independent measurements, the repeatability of foliage transparency (91.4 percent) exceeded the MQO compliance rate of 90 percent; however, the regional analyses show that the SRS slightly missed the specified standard and the NE was substantially out of compliance (Table 1.1). As with the other variables, the mean differences were trivial. The RMSE values reflected the regional differences, with a minimum of 7.2 percent (IW) and a maximum of 15.1 percent (NE). There was a marked difference in repeatability between hardwood and softwood species. The measurements had 95.5 percent repeatability for softwoods, but only 87.4 percent agreement for hardwoods (Tables 1.2 and 1.3). Pollard and Smith (1999, 2001) also found a difference in repeatability between hardwood and softwood species, though not to the same extent. Repeatability was higher for softwoods than for hardwoods but only by 3 to 4 percent. The characteristics of hardwood crowns probably contribute to this discrepancy, as exclusion of light gaps between branches must be taken into account.

An analysis of repeatability by foliage transparency classes showed some trends that were similar to other crown indicator variables (Table 1.8). Most notably, the same bias was evident that was found for both crown ratio (Table 1.4) and crown density (Table 1.6), i.e., the mean differences indicated the QA measurement was smaller than the production crew for low values of foliage transparency and were higher than the production crew when foliage transparency was high. The transition from negative to positive mean differences occurred near the 20 percent level, which is in the region where most of the data were concentrated.

Another discerned trend was a drop in repeatability outside the 5-35 percent foliage transparency range. Again, this seems to coincide with a precipitous decline in sample size and a progression into amounts of foliage transparency that are not often observed.

Table 1.8—Repeatability statistics for crown foliage transparency measurements by foliage transparency class.

QA crew observation[a]	Tolerance	Percent within tolerance	95% CI	Mean difference (QA crew – production crew)	RMSE	Records
0%	±10%	10.0	0.3 - 44.5	-20.4	21.0	10
5%	±10%	80.0	28.4 - 99.5	-8.0	9.5	5
10%	±10%	92.1	88.4 - 94.8	-5.3	8.7	302
15%	±10%	96.6	95.1 - 97.8	-2.1	7.9	746
20%	±10%	95.3	93.4 - 96.7	-0.1	7.3	69
25%	±10%	87.3	82.8 - 91.0	1.0	10.7	276
30%	±10%	77.1	67.9 - 84.8	4.3	10.7	105
35%	±10%	61.4	45.5 - 75.6	5.5	15.2	44
40%	±10%	40.0	12.2 - 73.8	7.0	22.6	10
45%	±10%	25.0	3.2 - 65.1	13.1	19.3	8
50%	±10%	40.0	5.3 - 85.3	4.2	28.5	5
55%	±10%	33.3	0.8 - 90.6	20.0	21.6	3
60%	±10%	50.0	1.3 - 98.7	17.5	19.0	2
65%	±10%	-	-	-	-	0
70%	±10%	100.0	15.8 - 100	5.0	5.0	2
75%	±10%	50.0	1.3 - 98.7	25.0	35.4	2
80%	±10%	-	-	-	-	0
85%	±10%	-	-	-	-	0
90%	±10%	-	-	-	-	0
95%	±10%	0.0	0.0 - 97.5	80.0	80.0	1
100%	±10%	40.0	5.3 - 85.3	43.4	58.3	5

[a] QA crew observations were grouped into 5-percent classes: 0% = 0%, 5% = 1-5%, 10% = 6-10%, …100% = 96-100%.

Conclusions

Crown attributes that effectively meet the MQO compliance rate include crown light exposure, crown dieback, and foliage transparency. Current training methods and measurement protocols for these variables are producing acceptable levels of measurement repeatability.

Crown position was slightly below the MQO compliance rate when evaluated at the national level due to repeatability problems with the open-grown classification in the IW region. More training in this region, especially with respect to 50 percent crown closure, should help to achieve compliance both nationally and regionally.

The uncompacted crown ratio, vigor class, and crown density measurements did not attain the MQO compliance rate. Experts in field data collection of crown attributes should re-evaluate the standards for these variables to determine if they are realistic. If additional training cannot correct the problem, the MQO should be modified to be in accordance with observed repeatability statistics. If an MQO adjustment (compliance rate and/or tolerance) is implemented, the utility of each indicator needs to be re-evaluated with respect to the revised MQO. Additionally, analysts and researchers who utilize these data should assess whether the repeatability of the crown measurements is sufficient for their respective analyses.

Finally, measurement protocols for uncompacted crown ratio and crown density have changed since the data used in this analysis were collected. As data collected under these revised protocols becomes available, additional analyses are warranted. These protocol changes are expected to yield at least some improvement in measurement repeatability.