A FIRST LOOK AT MEASUREMENT ERROR ON FIA PLOTS USING BLIND PLOTS IN THE PACIFIC NORTHWEST

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ABSTRACT.—Measurement error in the Forest Inventory and Analysis work of the Pacific Northwest Station was estimated with a recently implemented blind plot measurement protocol. A small subset of plots was revisited by a crew having limited knowledge of the first crew's measurements. This preliminary analysis of the first 18 months' blind plot data indicates that ranges of variation can be quite large. When blind plot results were summarized to facilitate comparisons with established tolerance standards, we found that diameters at breast height for trees > 20 inches d.b.h., heights for trees < 60 feet tall, and counts of down wood pieces did not meet standards in over 10 percent of cases. However, azimuths for condition class boundaries, diameters for trees ≤ 20 inches d.b.h., heights for trees ≥ 60 feet tall, and understory vegetation cover estimates by life form were within tolerance limits at least 90 percent of the time.

Forest Inventory and Analysis (FIA) timber resource bulletins are typically accompanied by estimates of standard errors based on the underlying sampling design. Efforts to quantify and account for error due to measurement variation are underway. FIA programs nationally employ systems of Quality Assurance/Quality Control (QA/QC or simply QA) under which trained personnel revisit plots and determine whether crew data are within measurement tolerances (commonly referred to as Management Quality Objectives, or MQOs). The blind plots used in this study differ from standard QC checks, typically performed for feedback, training, or certification of accomplishment of contract standards, in that regular production field crews were employed at both visits, rather than a QA crew. This captures variation between two relatively independent measurements collected in a normal manner at the same field location.

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METHODS

Blind Plot Field Protocol

The FIA program at the Pacific Northwest Research Station instituted blind plots during the 2000 field season. However, protocols have evolved somewhat since then to achieve more unbiased and complete estimates of measurement error (table 1). Because PNW is transitioning from several regionally and temporally inconsistent inventory designs to a new, nationally adopted design, this analysis incorporates data collected on four plot layouts. These designs all consist of a base point from which other points were established in various directions. Each point marks the center of a circular subplot where data on trees larger than 5 inches diameter at breast height (d.b.h.) were collected. Western (3 points in 2000, 10 blind plots) and eastern Washington (4 points in 2001, 15 blind plots) use 55.8- and 32.8-foot maximum radii for variable-radius tree sampling, with understory vegetation collected on 6.8- and 16.4-foot subplots, respectively. Plots in the annual inventories in Oregon (2000, 10 blind plots; 2001, 3 blind plots) and California (2001, 8 blind plots) use the nationally adopted design of 24-foot fixed-radius points for tree sampling and understory vegetation (although Oregon 2000 used a 6.8-foot understory vegetation plot). Annular plots designed to more reliably determine the presence of large trees (the definition of large tree varies depending on the inventory) extend 58.9 feet from subplot center (Forest Inventory and Analysis program,

Table 1.—*Changes in blind plot protocols over the first 2 years of their implementation at PNW FIA*

	2000	2001
Blind plots chosen by	field crew supervisors, based on access and ease of plot.	field crew supervisors, based on access to plot, and whether there is a condition class change or not.
Second crew receives	plot packet with all previous crews' information, including the information from the first visit of this year.	all old information from the plot, plus directions to the new plot from the first visit this year. No mapping information or data should be seen.
Second crew measures	d.b.h.s either at the old nail or where the crew felt was appropriate.	d.b.h.s at nail on subplots 1 & 2, where the crew felt was correct on subplots 3 & 4.
	coarse down wood transect placed either where first crew's was or where the second crew felt it was appropriate.	coarse and fine down wood transects along bearing the second crew felt was correct.
Second crew estimates	understory vegetation.	understory vegetation.
	Site tree data not taken.	Site tree data collected.
	New plotcard not written up.	New plotcard written up, mapping performed.

2000a, 2000b, 2001a, 2001b). The following data were collected at all visited points.

Condition class: condition classes are defined by differences in status of one of six mapping variables (reserved status, forest type, owner group, stand size, regeneration status, and tree density). Boundaries between condition classes are recorded for all sizes of subplots as azimuths and distances to subplot edges from subplot center.

Tree measurements: 1) d.b.h.: stem diameter at 4.5 feet above the ground on the uphill side of the tree. Recorded in tenths of inches using a metal d.b.h. tape; 2) height: length of main bole from ground to tip of leader, recorded to the nearest foot using a laser or clinometer.

Understory vegetation: cover of shrubs, forbs, and grasses is visually estimated as a percent of area of a circular microplot/subplot—defined by a radius of 6.8, 16.4, or 24 feet, depending on the inventory. Total cover of all understory life forms (ignoring overlap) is also recorded.

Down wood: by annual inventory 2001 definitions, down wood is dead woody material on the forest floor greater than 0.01 inches in diameter. Fine down wood 0.01 to 0.9 inches in diameter is measured on one 10-foot transect per point, pieces 1.0 to 2.9 inches in diameter are recorded on a 20-foot transect, and coarse pieces ≥ 3 inches in diameter and ≥ 3 feet long are tallied on two 58.9-foot transects per point. All decay classes are included. Snags are considered coarse dead wood if they lean at an angle greater than 45 degrees from the vertical. Tally rules for 2000 inventories included only pieces > 5 inches across and 3.3 feet long, not supported by their root system, on three 55.8-foot transects per point. Decay classes 1 to 4 were recorded. Fine down wood was not assessed in 2000 inventories.

Analysis Protocol

Condition class: distance and azimuth data collected as part of plot mapping were used to determine the proportion of area of each subplot in each condition class. Estimates by the two field crews for each subplot were paired and difference in condition areas calculated.

Tree measurements: for tree analyses, trees over 5 inches d.b.h. were paired by tag number so differences between d.b.h. and height measurements could be obtained. In the interest of time, all trees not readily matched (e.g., due to labeling errors or use of generic '999' tree numbers) were excluded. Because some blind crews measured diameter at what they deemed to be breast height, while others measured diameter at the existing d.b.h. nail, it was not possible to determine which method was used for each tree, and no distinction was made in the analysis.

Understory vegetation: differences between estimates of understory vegetation cover were analyzed at the subplot level after excluding all subplots where both crews recorded 0 percent cover. Although these records are legitimate, we considered their inclusion likely to overstate the degree of agreement between crews. Because a number of periodic and annual inventory protocols were implemented over the last 2 years, understory vegetation data were collected on three different sizes of plots. In most cases this was assumed not to greatly affect the magnitude of differences between crew estimates, although some exceptions are noted below.

Down wood: for this analysis we assumed changing protocols would not affect the amount of measurement variation, so a unified database was constructed. To reduce potential design effects, differences were calculated in terms of number of pieces per 100 feet of transect. Plots where neither crew recorded woody debris were dropped, following logic analogous to the case for understory vegetation. Fine down wood, which was collected only in 2001, was also expressed as pieces per 100 feet of transect.

Several related questions of interest were briefly explored. To determine whether measurement variation increased with magnitude of the characteristic being measured, measurements of d.b.h., height, and understory vegetation cover were divided into classes and compared. We also explored whether height differences varied with measurement method. Three combinations are possible: both crews measured with laser or clinometer, both crews estimated, or one measured and the other estimated. Additional questions of interest for understory vegetation were whether magnitude of difference between estimates increased with plot size and whether measurements taken from the initial visit were consistently lower or higher than those from the blind visit. Tests for significant differences between categories used non-parametric statistical methods due to skewed distributions and numerous outlying observations. All results reported as significant had one-sided p-values less than 0.05 by the Wilcoxon rank-sum test, unless otherwise noted.

RESULTS

Although every attribute had a few cases of extreme differences between crews, on average most differences were quite small (table 2). Close to half of the d.b.h. measurements and coarse down wood counts had no differences, and roughly a quarter of the understory vegetation measurements were identical between crews. Condition boundary azimuths, height measurements, and fine down wood counts showed less agreement, but median differences were not extreme, except possibly in the case of fine down wood.

Using the average of the two crews' measurements as the true value (e.g., of d.b.h. for each tree), MQOs were met at least 90 percent of the time for condition boundary azimuths, diameters on trees under 20 inches d.b.h., heights on trees 60 feet or taller, and cover for all understory vegetation cover categories (table 3). However, counts of small and large fine down wood were more often outside of tolerance limits than within them. If one crew's measurement was selected as the "true" value, then the only category where MQOs were met at least 90 percent of the time is percent cover of grass. MQOs for diameters on trees greater than 40 inches d.b.h., for heights of trees less than 60 feet tall, and for counts of all down wood were then not met in more than 50 percent of cases.

Did d.b.h. measurement error increase with tree diameter? Evidence is convincing that it did (fig. 1). Median differences in tenths of inches for trees 5 to 20, 20.1 to 40, and 40.1 to 60 inches d.b.h. were 1, 1, and 4, respectively. All differences were significant (significant differences between medians of one-tenth inch occur because the test used is not based directly on the measured values, but on the ranks of values). However, if difference is expressed as percent of d.b.h. (estimated as the average of the two diameters at breast height), there is no evidence that trees in the smallest two classes had different median measurement errors, but median measurement error for trees 40.1 to 60 inches d.b.h. was significantly greater than for either lower class.

Did height measurement error increase with height? The answer depends on the measurement used. Dividing the tree data set into four height classes of 0 to 40 (n = 185), 40.1 to 80

Table 2.—*Summary of values and differences obtained from 39 blind plots sampled in Washington, Oregon, and California during the 2000 and 2001 field seasons*

Measurement	Number in sample	Range of measurements[a]	Range of differences	Median of differences	Mean	Percent of differences that are 0
Condition Class Boundaries (degrees)						
azimuths	64 azimuths	N/A	0 - 102	5	10	11
Trees						
d.b.h. (in.)	778 trees	5 - 54.2	0 - 20.1	0.1	0.2	45
height (ft)	778 trees	101 - 96	0 - 96	3	5	13
Understory Vegetation Cover (as percent area of understory vegetation plot)						
total	149 subplots[b]	1 - 99	0 - 75	6	12	20
shrub	135 subplots	1 - 99	0 - 50	5	8	24
forb	121 subplots	1 - 88	0 - 45	4	7	24
grass	108 subplots	1 - 68	0 - 50	2	6	27
Number of Pieces of Down Wood (by plot)						
coarse[c]	28 plots	1 - 7	0 - 3	1	1	43
fine[d]	11 plots					
	small (0.01-0.25 in.)	9 - 1,071	8 - 1,108	50	157	0
	medium (0.25-0.9 in.)	8 - 94	0 - 70	10	21	9
	large (1.0-2.9 in.)	4 - 39	1 - 31	5	9	0

[a] Values averaged between crews.
[b] Number of subplots varies because only those subplots where both crews recorded vegetation for a category were included.
[c] Expressed as pieces per 100 feet of transect to reduce impact of design-based differences (see methods section for more detail).
[d] Expressed as pieces per 100 feet for easier comparison to coarse down wood.

(n = 324), 80.1 to 120 (n = 210), and 120+ (n = 59) feet, median height differences increased with height—from 2 to 2 to 4 to 7 feet, respectively. If difference is expressed as percent of tree height (estimated as the average of the two heights), then trees under 40 and over 120 feet tall had the largest differences (median about 6 percent), while trees between 41 and 120 feet tall had between 4 and 5 percent median difference. The magnitudes of the differences vary depending on how the trees are classified into categories, but several different classifications produced identical patterns.

Were height measurement differences greater where tree heights were estimated? Not too surprisingly, yes. Median difference in measurement height (feet) increased from 2 where both crews measured, to 5 where only one measured, to 6 where both crews estimated (fig. 2). Differences between both measured vs. one measured and both measured vs. both estimated were significant.

Did differences between life form level understory vegetation cover estimates increase with the amount of cover in the life form? Figure 3 suggests, and rank-sum tests confirm, that variation between crews was generally highest when percent cover of a life form fell between 40 and 60 percent and the vegetation decreased as cover moved towards 0 or 100.

Did understory vegetation cover estimate differences increase with vegetation plot size? These data give no evidence of plot-size-influenced differences for total cover or cover of shrub species. Median differences for forb cover estimated on 6.8-foot radius plots were greater than for forb cover on both 16.4- and 24- foot radius plots. However, grass cover estimation seems more variable on 16.4-foot radius plots than on other plot sizes (fig. 4).

Table 3.—*MQOs for the year 2001 shown with the percent of measurements not meeting these standards*

Measurement	MQO	Percent not meeting MQO	
Condition Class			
boundaries	+/- 10 degrees at plot boundary	10[a]	(31)[b]
area	none given	26	(39)[c]
Trees (by tree)			
d.b.h.[d]	+/- 0.1 in. for 5 to 20 in. d.b.h.	7	(23)
	+/- 0.2 in. for 20.1 to 40 in. d.b.h.	13	(26)
	+/- 0.3 in. for 40.1 to 60 in. d.b.h.	45	(55)
height	+/- 5% of true for <60 feet tall	28	(51)
	+/- 10% of true for ≥60 feet tall	4	(15)
Understory Vegetation (by subplot)			
cover percent	total cover +/-20 percent	7[e]	(19)
	life form cover +/- 1 class[f]		
	shrubs	~3	(13)
	forbs	~3	(15)
	grasses	~1	(6)
Number of Pieces of Down Wood (by plot)			
coarse down wood	+/- 2 pieces or +/- 5 percent of pieces	46	(64)
fine down wood			
small (0.01-.24 in.)	+/- 20 percent for 0 to 50 pieces	55	(55)
	+/- 25 percent for 51 to 100 pieces		
	+/- 50 percent for 100+ pieces		
medium (0.25-0.9 in.)	+/- 20 percent of pieces	45	(55)
large (1.0-2.9 in.)	+/- 20 percent of pieces	55	(82)

[a] Includes all condition class boundaries, regardless of size, on the same plot.
[b] Amounts in parentheses are the percent of measurements that would not meet MQOs if one crew's answer was deemed the "true" value. In cases where MQOs changed at set levels, average values between crews were used to determine which tolerance standard applied, but the full difference was used to gauge error.
[c] Of those 23 subplots where there was a condition class break involving condition class 1, 10 had a difference in the area assigned to condition class 1 that was ≥ 20 percent of the area of the subplot, using full differences.
[d] Different from the numbers reported in the poster because several trees were initially included in error.
[e] Vegetation cover percent and condition class data were reported as full differences between crew estimates for the poster. This was done because asymmetry of the tolerance classes (see next note) was thought to pose a problem. However, further analysis showed that it makes little difference for the data used here.
[f] Vegetation cover tolerance classes are 1-5, 6-10, 11-20, 21-40, 41-60, 61-80, 81-100 percent. Crews actually collect cover data to the nearest 5 (sometimes 1) percent.

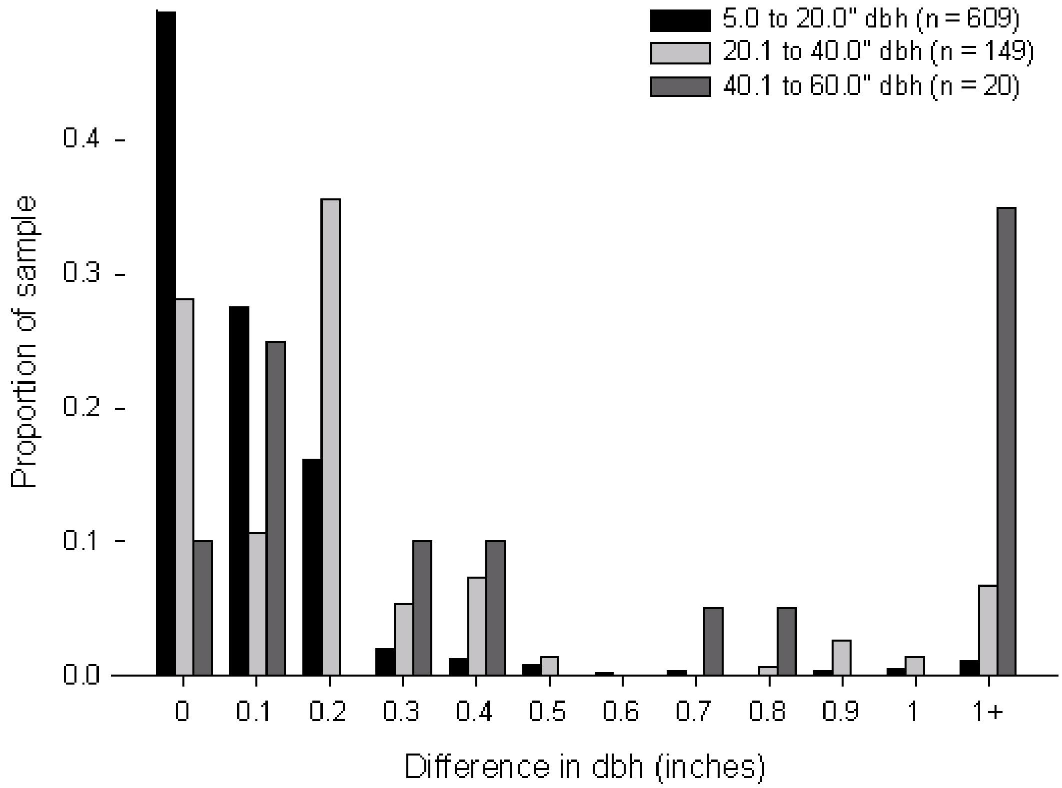

Figure 1.—*Distribution of d.b.h. differences between crews, by d.b.h. class. Difference categories (in inches) are 0, from >0 to exactly 0.1, from >0.1 to exactly 0.2, and so on. The 1+ category represents differences ranging from >1.0 up to 20.1 inches.*

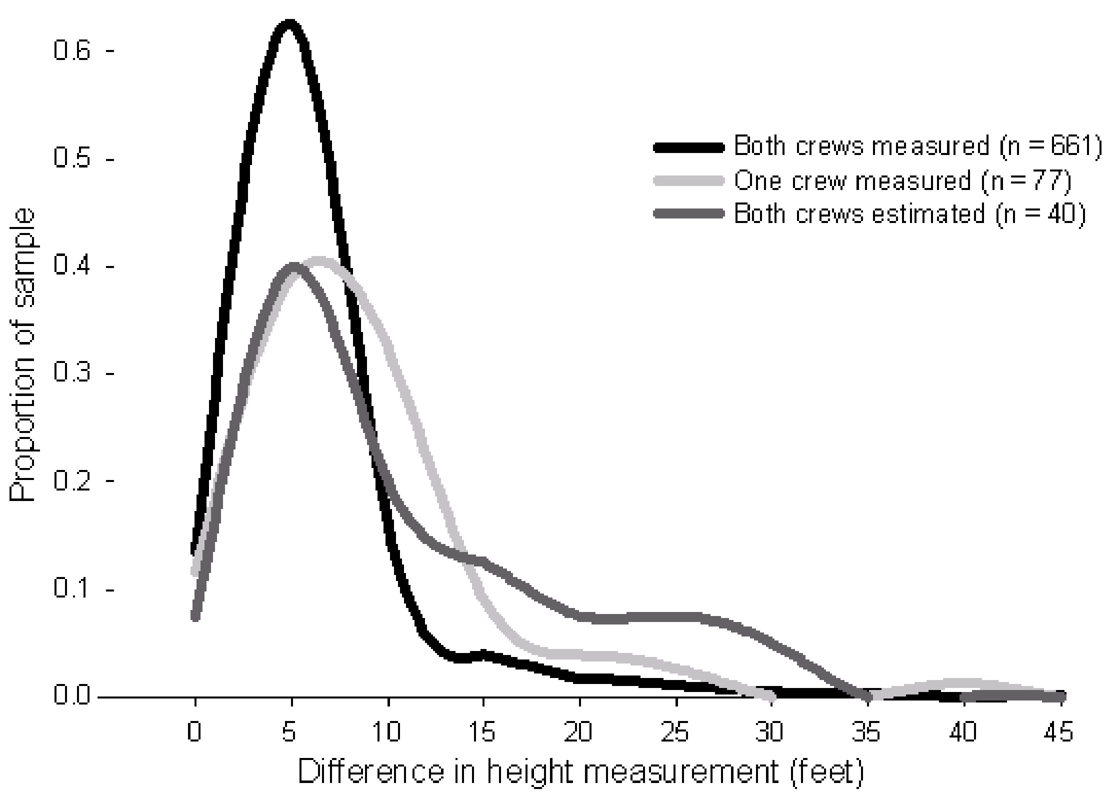

Figure 2.—*Distribution of height differences between crews, separated by measurement technique.*

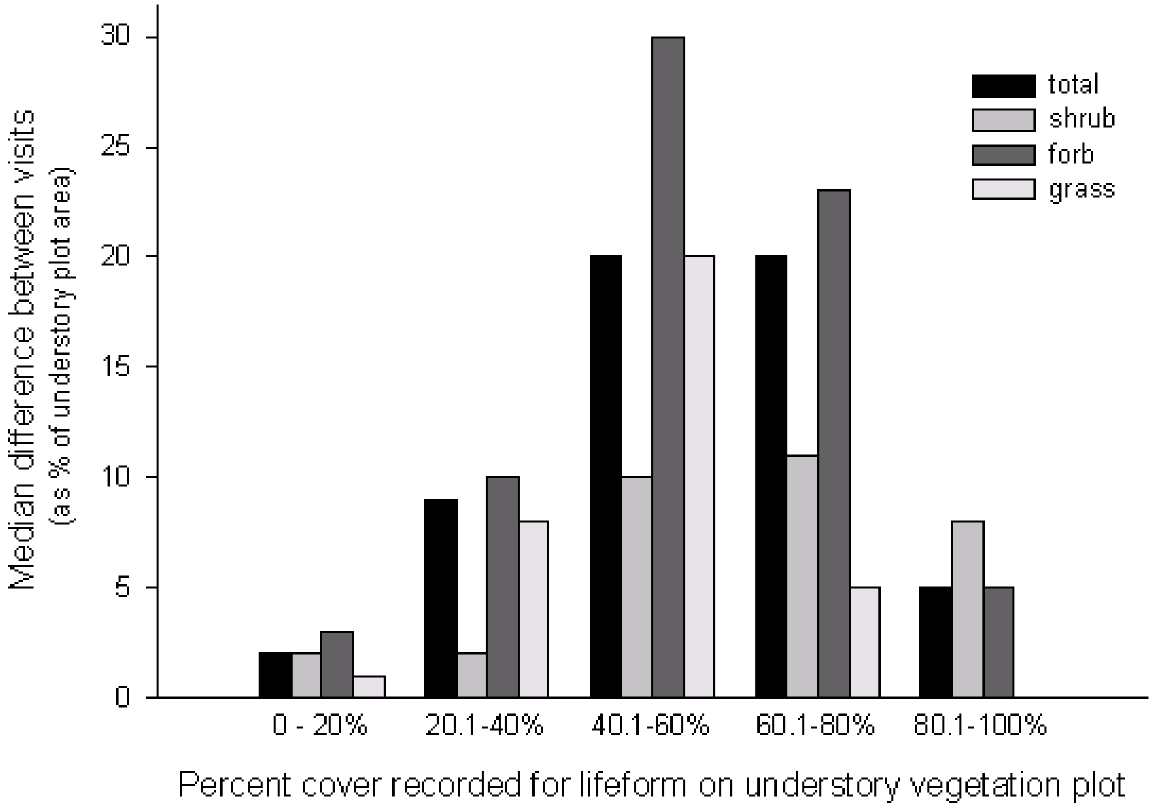

Figure 3.—*Median differences between crew cover estimates for total vegetation and for life form.*

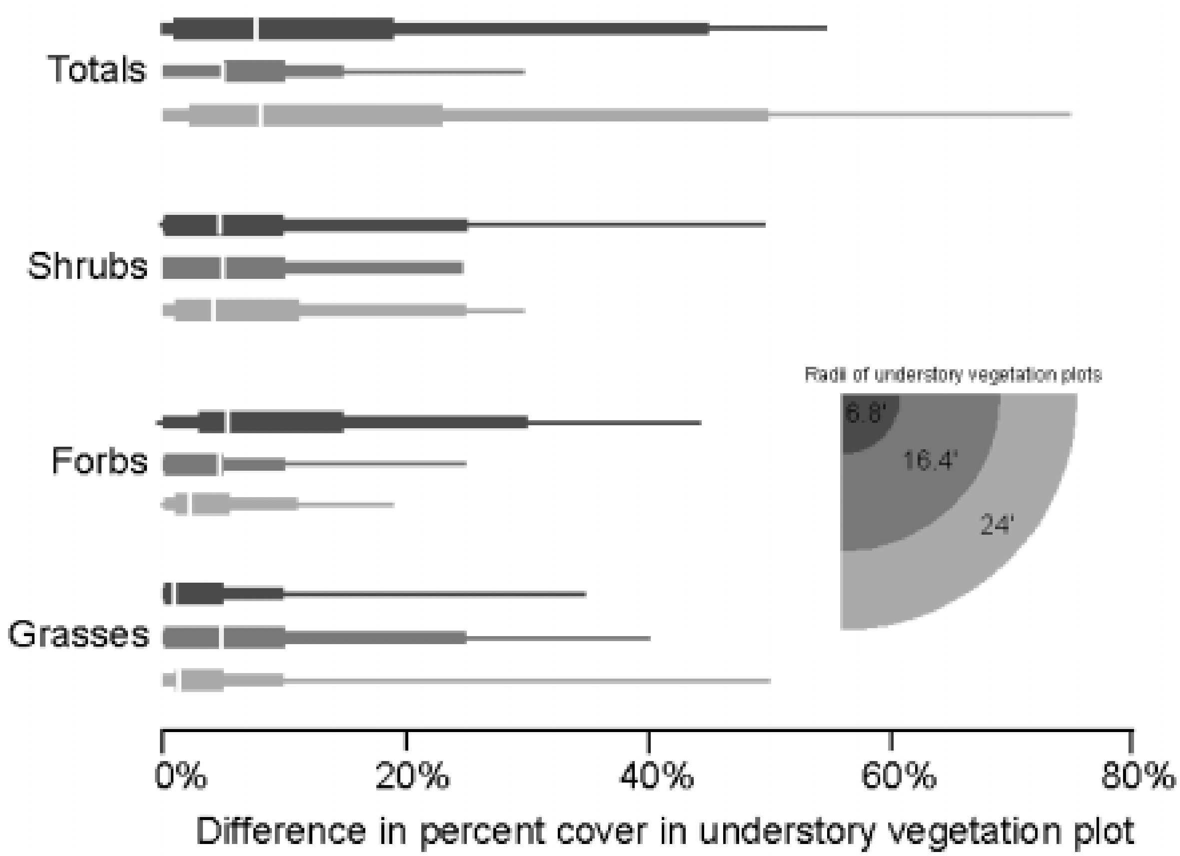

Figure 4.—*Box plots of differences in understory vegetation cover estimates, by understory vegetation plot size. Thickest bar indicates inter-quartile range (the middle 50 percent of the differences), next-thickest shows extent of observations within 1.5 inter-quartile ranges from the box, and thinnest extends to cover all outliers. White line is the median difference.*

Did one visit consistently produce higher understory cover estimates than the other? It appears that the first crews produced significantly higher estimates of cover for total understory vegetation, shrubs, and forbs; the second crews seem to have produced higher estimates of cover for grass (from Wilcoxon signed-rank tests). Exploratory analysis to determine if this could be related to number of days between visits or the season of the visits produced no significant results.

DISCUSSION

Computing differences between crew measurements is simple; comparing these differences to established MQOs is less so. Often tolerances are expressed as percentages of true values. When crew measurements are not identical, how can we identify or calculate the "true" value? Sometimes, permitted variation changes abruptly at some threshold. If the two crews' measurements fall on opposite sides of that threshold, how can the correct tolerance be selected? There are few alternatives to defining the average of all paired measurements as our best estimate of the "true" value. Unfortunately, this is a maximally optimistic approach to error reporting because it minimizes differences between crew estimates and "truth." It is thus likely that the number of plots/subplots/trees not meeting tolerances has been underestimated. Note that we have no basis for assuming that a QA crew's measurements would fall directly between two production crews' values. Analysis of several years' stored data from QA plots may not help resolve this issue, since cold checks (where the QA crew inspects the plot without the original crew) have not been performed on blind plots, and cold check data were not always preserved as distinct data sets. Quality Assurance data by itself cannot be used to estimate measurement error since such checks were carried out by QA staff with the crew's data in hand with little consistent protocol (i.e., not all attributes were checked and inspection was, in some instances, cursory). This likely produced greater agreement with production field crew results.

The nature of blind plots, in that regular crews conduct the second visit, is problematic as a basis for systematically assessing MQO achievement. While these data will likely prove useful in establishing how much measurement error can be expected for different plot attributes, which could, in turn, inform future revision and tuning of MQOs, MQO achievement would be better measured by stringent cold checks. This would require the adoption of standard procedures and the training of all QA crews in measurement techniques that would produce measurements for every attribute that are as accurate and precise as possible.

Ranges of variation for most measurements were quite large. Many of the most extreme differences are almost certainly due to data entry error, yet they were not excluded from this analysis because it is unlikely that they would be detected during the data loading process.

As expected, condition class area assessment poses a problem for crews (Wilson and others 1999). Boundaries along roads are mapped with fair agreement, but the answer to the question, "when is a road its own condition class?" is not clearcut. Similarly, demarcations between vegetated condition classes are rarely obvious. Condition class area variability is further complicated by hazardous or inaccessible conditions not acknowledged by every crew. The number of subplots with condition class boundaries in this sample was small (24 out of 152 where at least one crew mapped a boundary). Better comparisons of variation between different types of condition changes can be made as additional blind plots are added to the database. Analysis of variation in mapping is further complicated when crews recognize different numbers of conditions on a subplot.

We expected d.b.h. measurement variability to increase with diameter, but not to the extent observed here (fig. 1). Of the 20 trees in the 40.1- to 60.0-inch class, the 7 with the largest differences were from a single plot. Inspection of d.b.h. measurement type codes revealed that they were almost all trees where non-standard measurement techniques (estimation or the half-diameter method) were used by at least one crew. As our sample of large tree blind measures increases, we will be better able to determine how common differences of this magnitude are.

Tree height error also varied unexpectedly. One might assume, and the more relaxed MQO on trees over 60 feet indicates, that the taller the tree, the more difficult it would be to measure accurately. This relaxed tolerance for tall trees accounts in part for more tall-tree heights being within the MQOs. Measurement difference in feet appeared to increase non-linearly with tree height. Therefore, when differences are expressed as percentages of (averaged) tree height (as specified in the MQOs), trees of medium height (between 50 and 150 feet tall) had smaller differences than those under or above that range. This does not explain why 28 percent of trees less than 60 feet tall did not meet their MQO, however. Perhaps crews simply take more care with tall trees. More short trees may be growing in dense plantations where cruisers cannot get too far away lest they lose sight of the top or bole, or are hindered by vegetation and slash, and so end up taking measurements too close to trees, or where laser range finders used to measure height may more frequently sense the wrong tree. It may be that measurement instruments are used in a way where they will always produce a +/-2 foot difference, which is a negligible percent of a tall tree, but a larger portion of a shorter one. Measurement error is greatest for tree heights that were estimated (fig. 2), but both height classes have almost the same percent of trees that were estimated.

Previous studies (Sykes and others 1983) indicate that understory vegetation cover estimate differences are greatest in the middle ranges of cover, as was the case in this study for all understory life forms (fig. 3). We also expected to see an increase in estimate variability with increased plot size, but as Sykes and others observed (1983), this was not borne out by analysis (fig. 4). That may not rule out some effect of plot size; it could be masked by other factors influencing cover estimation, such as amount and height of vegetation present, slope, or season. Then again, it may be that size of the vegetation plot is not as important a factor as size of the crew. It was pointed out that the inventory using 16.4-foot radius plots had a small number of people assigned to it, who may have worked in closer proximity, traded crew partners more frequently, and so may have kept inter-crew estimation variability low. Differences hypothesized due to different plot sizes may be so small compared to individual estimators' ranges of variation that they are impossible to detect through blind plots.

For this sample of plots, the first crew consistently recorded higher percentages of forbs, totals, and possibly shrubs. Where visits were only a few days apart, an obvious explanation for the discrepancy is trampling. For plots with more time between visits, seasonal effects could come into play. This might not always act to decrease the second crew's estimate, however. Some visits were separated by more than 80 days. Depending on time of the first visit and phenology of the species present, seasonal influences could increase, decrease, or have no effect upon the life form cover analyzed here.

Figure 5 demonstrates that the larger pieces of down wood had smaller count differences, although magnitude of errors was too great to see that trend reflected in the MQOs (table 3). Tolerance standards for small fines become increasingly lenient with abundance (table 3), yet the sometimes large inconsistencies (up to several hundred pieces difference per 10

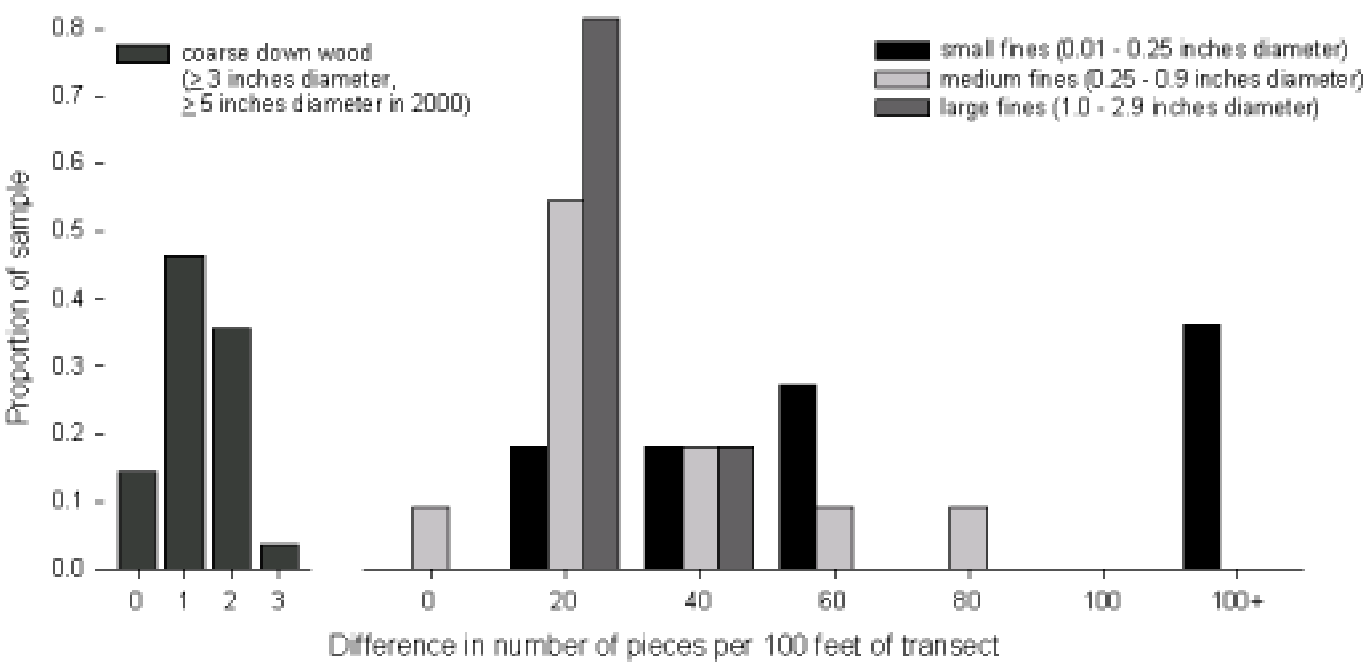

Figure 5.—*Differences in counts of coarse down wood (left) and the three categories of fines (right) converted to number of pieces per 100 feet of transect for easier comparison.*

feet for small fines) rendered even generous tolerances unattainable. This was the first year fines data were collected, so there may have been confusion with and inconsistent application of protocols. However, fine pieces are often numerous, hard to see, and easily moved, and therefore are difficult to count accurately. Note that for all fines data used here, blind plot protocol called for the transect to be placed where the second crew considered correct, so in some instances the same area might not be sampled. Obviously it is much easier to count larger pieces, yet even counts of coarse down wood are not entirely repeatable (again, transects may have followed slightly different azimuths).

This initial analysis represents a first step toward quantifying measurement error of various variables collected by PNW FIA crews. As more blind plots are completed, these estimates will be refined (15 plots per season are expected to be completed in each State—Oregon, Washington, and California). With more plots we should also be able to expand analyses in several directions. One such effort involves determining what effect measurement error might have on the reported standard error estimates. Examination of the effect on totals reporting should give some indication of whether these measurement variations are acceptable. From the preliminary results presented here, it is apparent that some measurements are quite inconsistent between crews. Large diameters at breast height, heights under 60 feet, and all down wood measurements are especially variable. There are three basic solutions to this: retraining crews with particular emphasis on attributes with high variability, revising measurement tolerances to make them more realistic, and redesigning measurement protocols.

Another question of interest is whether there are biases in field crew measurements. Of course, this requires knowledge of true values of measured attributes, a challenging bit of knowledge to obtain, so we may never reach a definitive answer.

Are the blind plots representative of the plot population as a whole? Perhaps that will not matter, since determination of measurement variation is the goal; crews could inventory areas that aren't plots at all and still produce estimates of measurement error. However, because we intend to extrapolate the results to all plots, if the sample used here was non-representative in some way that affected measurements, it could lead to inaccuracies in our predictions of measurement error. Future analyses will determine whether these plots reflect the plot population in terms of slope, distance from roads, density of understory vegetation, number of trees, range of tree ages and sizes, number of condition classes, proportion of private to public owners, and so on.

Since blind plots provide a repeat of all measures, in the future we will be able to extend this study to compare ranges of variation for every variable collected. This includes tree age, growth, damage, and crown measurements; site index; understory vegetation species counts and identification; ground cover transects; and fuel loading. This information, combined with calculations of sampling error, will be critical in assisting current and potential clients evaluate the fitness of FIA data for their intended uses.

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