Improving Coarse Woody Debris Measurements: A Taper-Based Technique

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Abstract.—Coarse woody debris (CWD) are dead and down trees of a certain minimum size that are an important forest ecosystem component (e.g., wildlife habitat, carbon stocks, and fuels). Accurately measuring the dimensions of CWD is important for ensuring the quality of CWD estimates and hence for accurately assessing forest ecosystem attributes. To improve the quality of CWD diameter and length measurements, two quality control methods were used to estimate field-applicable taper thresholds to reduce measurement errors. Results indicated that both the taper outlier and taper model methods may be used to set thresholds for detection of egregious CWD dimension measurement errors. The taper outlier method determines the thresholds using three times the interquartile range of taper and a new metric of relative size. The taper model approach predicts large-end diameter based on small-end diameter and length. Both methods may be broadly applied to CWD pieces, regardless of decay, size, and species. Overall, incorporation of CWD taper attributes into field data recorders may allow "on the fly" assessment of possible measurement errors in the field.

National Inventory of Coarse Woody Debris

As defined by the U.S. Department of Agriculture Forest Service's Forest Inventory and Analysis (FIA) program, coarse woody debris (CWD) are down logs with a transect diameter ≥ 3 in and a length ≥ 3 ft (Woodall and Williams 2005). CWD are sampled during the third phase of FIA's multiscale inventory sampling design (USDA Forest Service 2004, Woodall and Williams 2005). CWD are sampled on transects radiating from each FIA subplot center. Each subplot has three transects 24 ft in length. Information collected for every CWD piece intersected by the transects are transect diameter, length, small-end diameter, large-end diameter, decay class, species, and presence of cavities. Transect diameter is the diameter of a down woody piece at the point of intersection with a sampling transect. Decay class is a subjective determination of the amount of decay present in an individual log. Decay class 1 is the least decayed (freshly fallen log), while decay class 5 is an extremely decayed log (cubicle rot pile). The species of each fallen log is identified through determination of species-specific bark, branching, bud, and wood composition attributes (excluding decay class 5 CWD pieces).

To date, the FIA program provides the only nationwide, pseudosystematic sampling of CWD resources. Forest fire, carbon, and wildlife sciences all depend on quality CWD data to provide information for numerous investigations and assessments (Woodall and Williams 2005). Therefore, ensuring the quality of CWD measurements is critical for ensuring the national credibility of FIA's down woody materials inventory.

CWD Measurement Errors

Accurate measurement of the dimensions of CWD pieces is essential for quality estimates of CWD weight/volume. Because CWD are measured in tandem with other field measurements, field crews sometimes inadvertently confuse the differing measurement precisions required of standing live and down dead trees. The diameters of standing live trees are measured to the nearest tenth of an inch, while the diameters of down dead trees are measured to the nearest inch. Additionally, field crews may record an additional digit for heights (e.g., turning

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18-ft CWD pieces into 180-ft oddities). Although this error is very rare, its occurrence can lead to extreme errors in plot-level estimates of CWD attributes. Using hypothetical data for one subplot (table 1), the differences in uncorrected and corrected CWD piece measurements can result in plot-level estimates nearly 50 times larger than the corrected estimate. Overall, rather obvious measurement errors on a relatively small proportion of FIA inventory plots may be skewing population estimates across the United States when left uncorrected.

Table 1.—*Coarse woody debris uncorrected and corrected data for one hypothetical FIA subplot.*

Type	CWD piece	Small-end diameter (in)	Large-end diameter (in)	Length (ft)
Uncorrected	1	3	40	10
	2	4	6	140
	3	30	70	34
Corrected	1	3	4	10
	2	4	6	14
	3	3	7	34

CWD = coarse woody debris; FIA = Forest Inventory and Analysis.

A Taper Solution?

The most desirable methodology for reducing field measurement errors is to prevent them at the source: field inventory crews. Crews enter data into Portable Data Recorders (PDRs) that often check for ranges in tree diameter at breast height, species, and length, among numerous other variables. If a simple metric of a CWD piece's dimensions could be used to ascertain acceptable CWD measurements, then this metric could be rapidly implemented into field crew PDRs. Taper is one metric of tree spatial dimensions that might be applied to CWD pieces. Taper is defined as change in a tree's diameter over a defined length (inches/foot). For this study, the taper of CWD pieces will be defined as

$$Taper_{cwd}=(D_L-D_S)/L \quad (1)$$

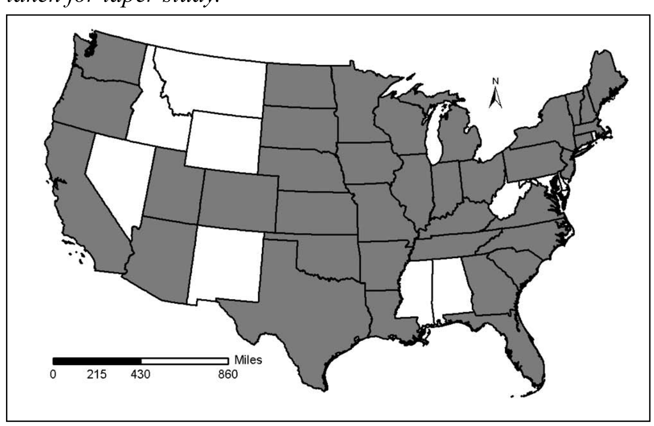
where:
D_L = the large-end diameter (in).
D_S = the small-end diameter (in.).
L = the total length (ft).

Using the taper of an individual CWD piece as one metric of its spatial dimensions is attractive for application for CWD data quality control. First, taper incorporates all three dimensional measurements of CWD pieces, so if even one of the dimension measurements is in error it will be reflected in taper. Second, a well-established base of knowledge on the taper of standing trees may be used to develop new CWD taper equations (Martin 1981). Finally, a single metric of taper may be easily programmed into PDRs, allowing for rapid field application. Therefore, the objectives of this study are (1) to estimate mean taper of CWD pieces by classes of transect diameter, species, and decay class, (2) to determine a methodology for using CWD taper outliers to identify CWD measurement errors, (3) to use a taper model (small diameter = f[large diameter, length]) to identify CWD measurement errors, and (4) to recommend a methodology for reducing CWD measurement errors based on study results.

Data/Analysis

The study data set consisted of individual CWD piece measurements sampled by the FIA program across the Nation from 2001 to 2004 (fig. 1). The information for every CWD piece included transect diameter, small-end diameter, large-end diameter, length, decay class, and species. The study data set had 20,018 observations and 190 individual tree species.

Figure 1.—*States (filled in) in which CWD measurements were taken for taper study.*



CWD = coarse woody debris.

Mean taper and standard errors were determined for CWD pieces by classes of transect diameter, decay class, and species. CWD taper outliers were determined by estimating the Interquartile Range (IQR) of CWD tapers and multiplying the IQR times three. Observations not within ± three times IQR of the median value were considered outliers. To investigate the effect of abnormally long CWD pieces, a metric of Relative Size (RS) was estimated by dividing length by large-end diameter. RS outliers were examined using the same outlier methodology (IQR times three) as with taper. Finally, a taper model was used to examine taper:

$$E\left(D_s\right) = \beta_0 + \beta_1 L + \beta_2 D_1 + \beta_3 DC_1 + \beta_4 DC_2 + \beta_5 DC_3 + \mu \quad (2)$$

$$\varepsilon \sim N\left(0, \delta_1 L \times D_l^{\delta_2}\right) \quad (3)$$

where:
E(.) = the statistical expectation.
D_s = the small-end diameter.
L = the total length.
D_l = the large-end diameter.
DC_i = decay class indicator variables.
β_i = parameters to be estimated.
ε = the random errors term.

Taper Outliers

Mean tapers (in/ft) increased with increasing transect diameter and with increasing states of CWD decay, but varied with no discernible pattern by species group (table 2). When we examine the distribution of taper by transect diameter class, taper appears to be constrained by the small-end diameter of CWD pieces (fig. 2). Most observations had taper below 1 in/ft; however, there were numerous outliers with tapers approaching 12 in/ft. CWD pieces with a small-end diameter of 30 in had an exceedingly large number of taper outliers. Because field crews measure standing trees to the nearest tenth of an inch and CWD pieces to the nearest inch, 3 in is the most common small-end diameter measurement for CWD pieces and is probably accidentally entered as 30 in into field PDRs. Based on interpretation of means, taper appears to be most dependent on the transect diameter of the CWD piece and thus should be an integral variable for taper outlier identification.

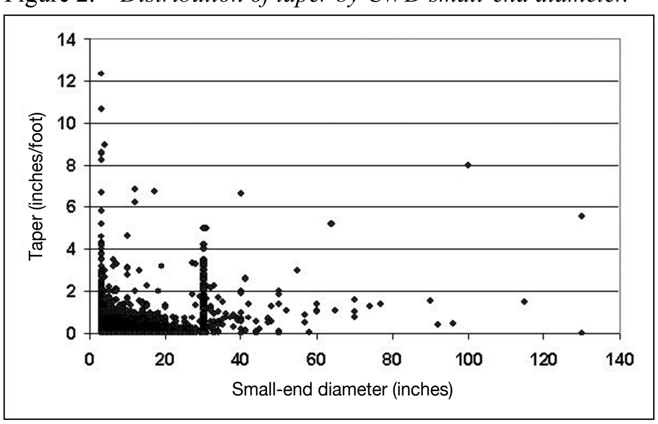
The percentile distribution of CWD tapers was determined and used to define an interval beyond which a taper observation would be considered an outlier +/- three times IQR (table 3). The median taper for all observations was 0.14 in/ft with 99 percent of taper observations below 1.33 in/ft. The IQR was estimated to be 0.155 in/ft, creating an acceptable taper interval of 0.000 to 0.6073. Unfortunately, this interval did not include pieces that taper too little such as a CWD piece with a small-end diameter of 5 in, a large-end diameter of 7 in, and a total

Table 2.—*Mean and associated standard errors for CWD taper by transect diameter class, decay class, and species groups.*

Variables	Classes	Mean taper (in/ft)	Standard error
Transect diameter (inches)	3.0–7.9	0.170	0.002
	8.0–12.9	0.236	0.004
	13.0–17.9	0.311	0.016
	18.0 +	0.760	0.045
Decay class	1	0.197	0.011
	2	0.191	0.004
	3	0.205	0.004
	4	0.224	0.005
Species groups	Spruce/fir/cedar	0.187	0.005
	Pines	0.217	0.005
	Maples	0.211	0.010
	Birches	0.171	0.010
	Hickories	0.242	0.049
	Oaks	0.256	0.010

CWD = coarse woody debris.

Figure 2.—*Distribution of taper by CWD small-end diameter.*



CWD = coarse woody debris.

Table 3.—*Order statistics for CWD taper and relative size.*

Percentiles	Taper	Relative size
100 (Maximum)	12.333	56.000
99	1.333	9.333
95	0.513	6.000
90	0.375	5.000
75 (Quartile 3)	0.238	3.667
50 (Median)	0.143	2.359
25 (Quartile 1)	0.083	1.400
10	0.000	0.833
5	0.000	0.600
1	0.000	0.300
0 (Minimum)	0.000	0.023
IQR (Q3-Q1)	0.155	2.267

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length of 150 ft. Another CWD dimensional metric, RS, may be used to help indicate suspect CWD dimensional measurements. Trees with relatively long lengths should have corresponding increases in large-end diameters. For instance, a length of 80 ft and a large-end diameter of 4 in appear questionable because most trees do not have 80 ft of length between a 4-in large-end diameter and the top of the tree (or end of branch). Thus, large RS values would indicate a suspect relationship between large-end diameters and lengths. The percentile distributions of RS for all study observations were determined, once again using three times IQR to define an outlier interval (table 3). The median RS was 2.359 ft/in with 99 percent of observations below 9.333. The IQR for RS was estimated to be 2.267 ft/in, creating an acceptable RS interval of 0 to 9.159 ft/in. Based on the study dataset, the taper and RS intervals "flagged" 5 percent of observations as being possible outliers.

Model-Based Approach

The taper model (eq. 2) had an r-squared of 0.69 with a root mean squared error of 2.07. The linear model was fitted using CWD decay classes as indicator variables due to differences in taper attributable to the decay of CWD pieces. In an operational sense, the taper model predicts small-end diameter given a set of field measurements (large-end diameter, length, and decay class). Also, the model error variance (eq. 3) is based on large-end diameter and length with the standard error as the square root of the variance. The small-end diameter prediction +/- two times the standard error allows for creation of an interval over which the small-end diameter measurement is likely to be valid. The model parameters for equation (2) were estimated to be β_0 =1.5928, β_1 = -0.05229, β_2 = 0.5323, β_3 = -0.1578, β_4 = -0.1128, and β_5 = -0.0702. Estimates of parameters for equation (3) were δ_1 = 0.000913 and δ_2 = 2.4191. Given these parameter estimates and the defined interval (+/- two times standard error), the taper model would have excluded 7.1 percent of the study data set observations.

Field Recommendations

Currently, range checks are used with numerous field variables (e.g., permissible codes for tree species) to maintain the quality of field measurements. Differences in precision required for standing tree and down, dead tree measurements exacerbate measurement errors in the field. These errors may be reduced by implementing simple data checks programmed into PDRs. The taper outlier and model methods both possess attributes attractive for field implementation. Both approaches can be easily programmed into PDRs. In addition, they both may be used to "flag" a small number of field measurements (between 5 and 7 percent of field measurements as demonstrated in this study). There is a balance between the quality of measurements and the efficiency of the sample protocols used to acquire CWD measurements. The key is to pick a method that increases the quality of measurements while not impacting measurement efficiency or complexity. Given these prerequisites, the outlier method may be deemed superior to the model method given its simplicity and ability to easily adjust the interval (3, 3.5, or 4 times IQR). Despite its complexity, however, the adjustable variable interval of the model method (1.5, 2, or 2.5 times the standard error) might be advantageous in certain field applications. Whether the taper or model method is selected for field implementation, both offer efficient alternatives for increasing the quality of CWD dimensional measurements and both should be tried in field situations.

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