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Cover photo: Logging truck with two deck trailer, Wayah Ranger District, Nantahala National Forest.

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Abstract

The 2001 Kentucky Forest Inventory and Analysis survey overestimated hardwood saw-log volume in tree grade 1. This occurred because 2001 field crews classified too many trees as grade 1 trees. Data collected by quality assurance crews were used to generate two types of adjustments, one based on the proportion of trees misclassified and the other on the proportion of saw-log volume misclassified. Measures of variability for the estimated proportions were based on a cluster sampling design. Both methods significantly reduced estimated saw-log volume in tree grade 1. We believe that the saw-log volume approach is superior to the tree approach, but that both approaches generate improved estimates of tree grade saw-log volumes. The standard errors of the adjustment proportions are given and can be used to calculate standard errors of the adjusted values.

Keywords: Cluster sampling, Forest Inventory and Analysis, quality assurance, saw-log, tree grade.

Introduction

The 2001 Kentucky Forest Inventory and Analysis (FIA) survey estimated hardwood saw-log volume and classified it into five tree grades (1 to 5). However, the 2001 FIA volume estimate for tree grade 1 for Kentucky was more than twice as large as that for 1988. This caused concern, and FIA believed that the 2001 field crews might have assigned too many trees to tree grade 1.

FIA evaluates its tree grade data by comparing it to that collected in check plots by quality assurance (QA) personnel. The QA field staff are experienced field crew members who are responsible for training and evaluating field production personnel. The QA personnel are considered to be experts in FIA data collection. The QA crew collects data in a random sample of the production plots within a few weeks of the production measurement. Some of these checks are blind; that is, the QA crew collects its data without knowledge of the production plot data. There are also cold checks; in these the QA crew reviews the initial data, records any inconsistencies with their own data, and then scores the field crew on accuracy.

The data from the FIA QA database confirmed that trees had been misclassified as grade 1 but contained only 30 observations for trees that were classified as grade 1—not enough observations to provide a good basis for an adjustment. Such a small sample leads to large standard errors of estimates, large confidence intervals, and poor precision. For instance, an estimate of the proportion of trees classified as tree grade 1 by the field crews but as tree grade 2 by the QA crews was 0.53. A 95 percent confidence interval for this estimate was 0.35 to 0.72, which was considered too wide for adjustment purposes.

It was considered desirable that the 95 percent confidence interval have a half width of no more than 0.10, which implies that 100 observations are required in each tree grade to get a good estimate of a proportion and ensure the 0.10 error bound. This sample size was computed under the worst-case scenario, that is when $p = 0.50$, so in most instances a somewhat lower number of observations may be taken to achieve the same precision. Although the binomial distribution was assumed here for simplicity when calculating the required sample size, a more appropriate method based on cluster sampling was used for subsequent calculations. This method will be explained later.

The FIA QA data included adequate numbers of observations for tree grades 2 and 3 but few for tree grades 4 and 5. However, this was not a concern because misclassification in tree grades 4 and 5 was of no practical consequence. Thus, the QA crews were sent to grade additional trees previously classified by the field crews as tree grade 1 to provide data that would be used to create the adjustment. Additional trees in the other four tree grades were graded also, where this was feasible. The QA crews had no knowledge of the initial field classifications of these additional trees.

Methods

The field and QA tree grade classifications for an individual hardwood tree can be compared only if both crews agree that the tree has diameter at breast height (d.b.h.) $\geq$ 11 inches and is a growing-stock tree (tree class 2).[1] Tree class is an initial measure of tree quality and indicates whether a tree has a log meeting certain size, soundness, and grade requirements. The trees that do not have a log meeting these requirements are classified as cull trees and are not graded.

[1] U.S. Department of Agriculture Forest Service. 2001. Forest Inventory and Analysis, Southern Research Station field guide, Volume 1: field data collection procedures for phase 2 plots. [Not paged]. Unpublished report. On file with: USDA Forest Service, Southern Research Station, Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919.

Trees that do have a log meeting the requirements are classified as growing-stock trees and are graded.

A summary of the field crews' and the QA crews' tree grade classifications for 445 hardwood trees distributed across Kentucky that were jointly classified as tree class 2 and had a d.b.h. of ≥ 11 inches is shown in the matrix below:

$$G = \begin{bmatrix} 36 & 28 & 14 & 5 & 2 \\ 5 & 85 & 16 & 10 & 1 \\ 0 & 7 & 163 & 23 & 5 \\ 1 & 3 & 3 & 17 & 2 \\ 1 & 3 & 3 & 4 & 8 \end{bmatrix}$$

where

G_{ij} = the number of trees that the field crews classified as tree grade *i* that should have received tree grade *j* according to the QA crews' data for row *i* = 1, 2, 3, 4, and 5 and column *j* = 1, 2, 3, 4, and 5

For instance, out of the 85 trees (36 + 28 + 14 + 5 + 2) that the field crews classified as tree grade 1, only 36 were similarly classified as tree grade 1 by the QA crews. This is an indication that the field crews may have been classifying too many trees as tree grade 1, and thus overestimating the increase in the total saw-log volume in tree grade 1 for the 2001 survey.

The matrix *G* is easier to interpret if it is converted to a probability matrix that reflects the proportions of the field crews' trees that are correctly and incorrectly classified based on the QA data. Let:

P^T_{ij} = the proportion of the field crews' tree grade *i* trees that should have been tree grade *j* according to the QA crews' data.

This yields a probability matrix based on trees as follows:

$$P^T = \begin{bmatrix} 0.42353 & 0.32941 & 0.16471 & 0.05882 & 0.02353 \\ 0.04274 & 0.72650 & 0.13675 & 0.08547 & 0.00855 \\ 0.00000 & 0.03535 & 0.82323 & 0.11616 & 0.02525 \\ 0.03846 & 0.11538 & 0.11538 & 0.65385 & 0.07692 \\ 0.05263 & 0.15789 & 0.15789 & 0.21053 & 0.42105 \end{bmatrix}$$

Note that the probabilities in each row sum to 1 because they are conditional on the field crews' tree grade classification. Obviously, P^T_{11} is the proportion of tree grade 1 trees that was classified correctly by the field crews. This is 0.42353 and indicates that only approximately 42 percent of the field crews' tree grade 1 trees were actually tree grade 1 and that about 58 percent of the field crews' tree grade 1 trees were classified incorrectly. This is much too large an error to be tolerated and a correction is needed.

To adjust for the misclassification, the matrix P^T could be used to assign the unadjusted saw-log volume in each tree grade obtained from the 2001 survey to an adjusted volume for each tree grade. Let the unadjusted saw-log volume in each of the five tree grades be defined by the vector

$$V_u = \begin{bmatrix} 12{,}236 \\ 16{,}319 \\ 22{,}022 \\ 3{,}937 \\ 3{,}079 \end{bmatrix}$$

These values are the actual results from the 2001 survey and are in millions of board feet. Then, an adjusted volume based on the comparison of the field to QA crews' data is defined as:

$$V^T_A = P^{T\prime} V_U \qquad (1)$$

where

$P^{T\prime}$ = the matrix obtained by transposing P^T

When the matrix and the uncorrected volume vector are multiplied together, we get a corrected volume vector that redistributes the uncorrected volume. The adjusted volume vector sums to the same total volume. In this method, it is assumed that the QA data classifies trees by tree grade correctly. However, it must be emphasized that this has not been validated in the field. Thus, the accuracy of the volume correction depends on the correctness of the QA classifications, which could only be assumed.

Although trees were classified by tree grade by the field crews and QA crews, a more appropriate adjustment method may be to determine the proportion of volume misclassified instead of the proportion of trees misclassified. The data provided volume on each saw-log. Let P^S_{ij} = the proportion of the volume of the field crews' tree grade *i* trees that should have been volume of tree grade *j* trees according to the QA crews' data.

Using computations similar to those used for the tree approach, we obtained the following saw-log probability matrix.

$$P^S = \begin{bmatrix} 0.49595 & 0.30127 & 0.13890 & 0.04426 & 0.01962 \\ 0.07892 & 0.64954 & 0.13905 & 0.12214 & 0.01034 \\ 0.00000 & 0.04932 & 0.81728 & 0.09680 & 0.03660 \\ 0.09569 & 0.17541 & 0.04046 & 0.65230 & 0.03614 \\ 0.13594 & 0.11704 & 0.07101 & 0.18299 & 0.49301 \end{bmatrix}$$

An adjusted volume based on the comparison of the field crews' to QA crews' data is defined as:

$$V_A^S = P^{S\prime} V_U \qquad (2)$$

where

$P^{S\prime}$ = the matrix obtained by transposing P^S

This P^S matrix based on saw-log volume exhibits trends similar to those found in the P^T matrix based on trees. The differences may reflect a relationship between tree size and the probability that field crews will classify trees correctly. For instance, consider those trees classified as grade 1 by both the field and QA crews. Forty-two percent are classified as grade 1 trees by both field and QA crews when the tree approach is employed, and 50 percent of the volume is classified correctly when the tree volume approach is taken. This suggests that larger trees may have a higher likelihood of being jointly classified as tree grade 1, which is reasonable because they are the best saw-log volume producing trees. In addition, since volume is to be adjusted, it's reasonable to use volume as a criterion in the matrix.

Another characteristic of the adjustment is the precision associated with the P^T and P^S matrices, which are not known quantities but are only estimated based on survey data. The variability of each element of these matrices is based on a sample of trees within a sample of plots, and hence calculation of the variance of each proportion cannot be based on the assumption of simple random sampling. Thus, variability is based on a cluster sampling design (Cochran 1977). For the tree approach, the estimated proportions shown in the matrix P^T are defined as:

$$\widehat{P_{ij}^T} = \frac{\sum_{k=1}^{n_i} a_{ijk}}{\sum_{k=1}^{n_i} m_{ik}} \qquad (3)$$

where

a_{ijk} = number of trees on plot *k* that are classified as tree grade *i* by the field crews and tree grade *j* by the QA crews
m_{ik} = total number of trees on plot *k* that are classified as tree grade *i* by the field crews
n_i = number of plots that had trees classified as tree grade *i* by the field crews

The typical sample variance of a proportion in cluster sampling is defined approximately (ignoring the finite population correction and the sampling variability of n_i) as:

$$\hat{V}\left(\widehat{P_{ij}^T}\right) = \frac{1}{n_i(\bar{m}_i)^2}\left(\frac{\sum_{k=1}^{n_i} a_{ijk}^2 - 2\widehat{P_{ij}^T}\sum_{k=1}^{n_i} a_{ijk} m_{ik} + \widehat{P_{ij}^T}^2 \sum_{k=1}^{n_i} m_{ik}^2}{n_i - 1}\right) \qquad (4)$$

where

$\bar{m}_i = \sum_{k=1}^{n_i} \frac{m_{ik}}{n_i}$, which is the average number of trees classified as tree grade *i* by the field crews on the n_i plots

The standard error is simply the square root of $\hat{V}\left(\widehat{P_{ij}^T}\right)$.

The saw-log volume approach utilizes a slightly different form for the estimators and is based on the ratio of means (Cochran 1977). The proportions shown in the matrix P^S are defined as:

$$\widehat{P_{ij}^S} = \frac{\sum_{k=1}^{n_i} y_{ijk}}{\sum_{k=1}^{n_i} x_{ik}} = \frac{\sum_{k=1}^{n_i} \frac{y_{ijk}}{n_i}}{\sum_{k=1}^{n_i} \frac{x_{ik}}{n_i}} = \frac{\bar{y}_{ij}}{\bar{x}_i} \qquad (5)$$

where

y_{ijk} = total saw-log volume of all trees on plot *k* that are classified as tree grade *i* by the field crews and tree grade *j* by the QA crews
x_{ik} = total saw-log volume of all trees classified as tree grade *i* by the field crews on plot *k*
n_i = number of plots that had trees classified as tree grade *i* by the field crews

The typical sample variance for the ratio of means is defined approximately (ignoring the finite population correction and the sampling variability of n_i) as:

$$\hat{V}\left(\widehat{P_{ij}^S}\right) = \frac{1}{n_i(n_i-1)(\bar{x}_i)^2}\left(\sum_{k=1}^{n_i} y_{ijk}^2 + \widehat{P_{ij}^S}^2 \sum_{k=1}^{n_i} x_{ik}^2 - 2\widehat{P_{ij}^S}\sum_{k=1}^{n_i} y_{ijk} x_{ik}\right) \qquad (6)$$

where

$\bar{x}_i = \sum_{k=1}^{n_i} \frac{x_{ik}}{n_i}$, the average total saw-log volume for all trees classified as tree grade *i* by the field crews on the n_i plots.

The standard error is simply the square root of $\hat{V}\left(\widehat{P_{ij}^S}\right)$.

Note that the equations for both estimated proportions are identical, except for the tree or saw-log proportion, as are those for the sample variances. This is easily verified by setting $a_{ijk} = y_{ijk}$ and $m_{ik} = x_{ik}$, when it is easy to see that equation (3) becomes equation (5) and equation (4) becomes equation (6).

Results

The adjusted volume based on the tree approach was obtained from equation (1) and results in

$$V_A^T = \begin{bmatrix} 6{,}193 \\ 17{,}606 \\ 23{,}317 \\ 7{,}895 \\ 2{,}583 \end{bmatrix}$$

In addition, using equation (4) and taking square roots, the standard errors of the proportions are:

$$SE(P^T) = \begin{bmatrix} 0.05939 & 0.04520 & 0.04404 & 0.03058 & 0.01654 \\ 0.02142 & 0.05530 & 0.03180 & 0.03170 & 0.00826 \\ 0.00000 & 0.01257 & 0.03265 & 0.02749 & 0.01320 \\ 0.03524 & 0.06708 & 0.06240 & 0.12975 & 0.05500 \\ 0.05208 & 0.09561 & 0.10205 & 0.07655 & 0.11788 \end{bmatrix}$$

The adjusted volume based on the saw-log approach was obtained from equation (2) and results in

$$V_A^S = \begin{bmatrix} 8{,}152 \\ 16{,}424 \\ 22{,}345 \\ 7{,}798 \\ 2{,}875 \end{bmatrix}$$

In addition, if we use equation (6) and take square roots, the standard errors of the proportions are:

$$SE(P^S) = \begin{bmatrix} 0.05563 & 0.04752 & 0.03842 & 0.02533 & 0.01447 \\ 0.04657 & 0.07504 & 0.03387 & 0.04498 & 0.00975 \\ 0.00000 & 0.01871 & 0.03564 & 0.02601 & 0.02152 \\ 0.08328 & 0.08202 & 0.02350 & 0.16528 & 0.02986 \\ 0.12177 & 0.07474 & 0.05259 & 0.07119 & 0.15328 \end{bmatrix}$$

Both V_A^T and V_A^S significantly reduced the saw-log volume in tree grade 1 from that in the original FIA 2001 inventory estimates in V_U . To compensate for this, both methods increased the saw-log volume most in tree grade 4. The standard error matrices reflect the variability in the proportion estimates for both approaches. They are useful in setting confidence intervals around the proportions and determining the errors. Recall that an approximate confidence interval is plus or minus two times the standard error. Thus, since most of the standard errors are 0.05 or less, the error bounds for most proportions are within $2(0.05) = 0.10$. This gives confidence that the adjustments are reasonably well behaved.

Conclusion

FIA QA data was used in developing an adjustment method to correct unusually high tree grade 1 saw-log volumes generated by the 2001 Kentucky survey. We believe that the saw-log volume approach is superior to the tree approach but that both approaches yield improved estimates of tree-grade saw-log volumes. The standard errors of the adjustment proportions are given and can be used to calculate standard errors of the adjusted values. These results depend on the assumption that the QA data is accurate and thus may contain an unknown amount of error.

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