ASSESSING THE UNCERTAINTY OF FOREST CARBON ESTIMATES USING THE FVS FAMILY OF DIAMETER INCREMENT EQUATIONS

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Abstract.—Serving as a carbon (C) accounting tool, the Forest Vegetation Simulator (FVS) is widely used by forest managers and researchers to forecast future forest C stocks. Assessments of the uncertainty that FVS equations provide in terms of their ability to accurately project forest biomass and C would seemingly differ, depending on the region and scale of interest to the user. This analysis used permanent sample plot data obtained from the annual Forest Inventory and Analysis (FIA) Program database to assess the performance of the diameter at breast height (d.b.h.) increment function in the Northeast and Lake States variants of FVS. Up to three measurements of FIA plots were recorded, representing more than 10 years of observed growth. Total aboveground biomass and C were estimated using the FIA's component ratio method, which served as a field-based measure of forest biomass/C. After initial FIA measurements were forecasted with the species-specific d.b.h. increment equation from the appropriate FVS variant, biomass/C was calculated and compared with the field-based measure. Results found that d.b.h. increment was generally underpredicted across both regions, which resulted in deviations when comparing model- and field-based predictions of biomass. Generally, a 10 percent error in predicting d.b.h resulted in a 25 percent error in predicting total aboveground biomass and C. Assessing the amount of uncertainty as predictions from FVS are used by managers and researchers will continue to provide information for those attempting to quantify the intricate processes of forest C dynamics.

INTRODUCTION

Growth models like the Forest Vegetation Simulator (FVS) provide predictions for individual trees, but forest managers typically make decisions at the stand level. Because error begins to compound as one scales from the individual tree to the plot and stand, quantifying the uncertainty associated with this scaling would have a direct impact on stand-level estimates. For example, some argue that a 10 percent bias in measuring diameter at breast height (d.b.h.) can result in a 25 percent error in predicted basal area (BA) (Gertner and Dzialowy 1984). BA is a relatively straightforward calculation, but for measures such as aboveground biomass and C, computations are much more complex. This complexity can be seen in the component ratio method (CRM) administered by FIA, which estimates total aboveground C for individual trees (Woodall et al. 2011).

FVS is a distance-independent growth model that projects future forest conditions, composition, and stand structure. A key determinant of future forest stocks in FVS lies in its diameter increment (Δdbh) function. Similarly, national biomass equations (Jenkins et al. 2003, 2004) rely heavily on d.b.h., and d.b.h. is widely used in the CRM to calculate aboveground C (Woodall et al. 2011). Increasingly, FVS is being used to estimate forest C into the future, yet little is known about the uncertainty of forest C estimates that might arise from a potential bias inherent in the Δdbh equation used. The goal

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here was to use Forest Inventory and Analysis (FIA) remeasurement data from the Northeast and Lake States to quantify the uncertainty of plot-level C stocks using different implementations of d.b.h. increment equations in FVS.

METHODS

FIA Data

Tree and plot records were obtained from the U.S. Forest Service's FIA Program. Many of these inventory plots were remeasured but some were not. Data were obtained from the online FIA database at http://apps.fs.fed.us/fiadb-downloads/datamart.html (accessed November 11, 2011). Compiled data spanned eight ecoregions. Plots began measurement in 1998.

Diameter Increment in FVS

Diameter increment is estimated differently in the Lake States (FVS-LS) and Northeastern (FVS-NE) variants of FVS. Key differences in the Δdbh equations used in the two regions are (1) diameter increment is predicted in FVS-LS, whereas BA increment is predicted in FVS-NE and then converted to diameter, (2) in the competition modifier, tree crown ratio, species maximum and plot BA, and quadratic mean d.b.h. are used in FVS-LS, whereas BA is used in larger trees in FVS-NE, and (3) an adjustment factor is added to Δdbh predictions in FVS-LS.

FVS-LS

The Δdbh for trees ≥5.0 inches in FVS-LS is predicted using a potential-modifier approach and adjustment factor. First, potential diameter growth is estimated using tree d.b.h., crown ratio, and species site index (Hahn and Leary 1979). Second, a competition modifier is estimated using tree d.b.h., maximum species BA, plot BA, and quadratic mean d.b.h. (Holdaway 1984). Predicted annual Δdbh is assumed to be the product of the potential and modifier components and is then corrected to the cycle length. Lastly, an adjustment factor is predicted based on tree d.b.h. and d.b.h. squared, and is added to Δdbh Equation coefficients for the three components of Δdbh are provided for 28 species groups (Dixon and Keyser 2008a).

FVS-NE

The Δdbh for trees ≥5.0 inches in FVS-NE is also estimated using the potential-modifier approach (Teck and Hilt 1991). First, potential BA growth is estimated using tree d.b.h. and species site index. Second, a growth modifier is estimated using the BA in larger trees. Lastly, predicted annual BA growth is estimated by multiplying the potential and modifier components. Basal area growth is added to current tree BA and converted to a tree diameter. Equation coefficients are provided for 28 species groups (Dixon and Keyser 2008b).

Analyses

This analysis was limited to all trees with d.b.h. ≥5.0 inches because (1) it is the threshold for measurement trees on FIA Phase 2 plots, and (2) it is the threshold for the large-tree Δdbh equations within FVS. Increments for d.b.h. were standardized to a 5-year interval for each tree that survived a remeasurement period, given that most FIA plots were remeasured on a 5-year time step. So, Δdbh_5 represents 5-year d.b.h. increment.

Volume, biomass, and C were estimated for each initial measurement on each individual tree using the CRM (Woodall et al. 2011). Predictions were made separately for growing stock and cull trees. Summaries of these variables were made for each FIA plot. Plot-level summaries were calculated using the predicted Δdbh_5 from FVS, representing a "predicted" plot condition. Plot-level summaries were then calculated using actual FIA measured d.b.h., representing the "observed" value. Only surviving trees in Y2 measured in Y1 were used, and FIA plots with no observed treatment (e.g., silviculture or harvesting) since the last measurement were used. Percent accuracy within 15 percent and bias were computed for each FIA plot and summarized by ecoregion.

RESULTS AND DISCUSSION

Lake States

Mean Δdbh_5 bias (observed-predicted) provided by FVS-LS was as low as 0.01 inch/5 years for the trees in the Laurentian mixed forest ecoregion and as high as 0.25 inch/5 years for trees in the prairie parkland ecoregion. This slight underprediction of Δdbh_5 differs somewhat from Pokharel and Froese's finding (2008) of a general overprediction of the FVS-LS model for trees in Michigan. The differences could arise because Pokharel and Froese (2008) employed data from FIA inventory cycles in the 1980s and early 1990s, whereas this analysis employed data from the annual inventory design beginning around 2000. Similarly, 5-year increments were used here, whereas 10-year increments were used by Pokharel and Froese (2008). The degree that biomass/C predictions are influenced by a Δdbh equation for a specific species of interest is a subject for further investigation.

Northeast

Underprediction of 5-year diameter increment was similarly observed using FVS-NE. Mean Δdbh_5 bias provided by FVS-NE was as low as 0.05 inch/5 years for the trees in the outer coastal plain mixed forest ecoregion and as high as 0.40 inch/5 years for trees in the eastern broadleaf (continental) ecoregion. A more substantial underprediction was generally observed for those ecoregions with fewer FIA plots located on the fringes of the northeastern geographic range (e.g., Western Allegheny plateau).

Uncertainty in Plot-level Carbon

Adding the predicted Δdbh_5 to initial d.b.h. and scaling to the plot level, FVS predicted basal area, volume, and biomass/C well for some ecoregions in the Northeast (e.g., Laurentian mixed forest and eastern broadleaf [oceanic]) and Lake States (Laurentian mixed forest) (Table 1). For Northeast plots, percent accuracies were generally similar for the three variables. For the Lake States, however, percent accuracies decreased as one scaled from basal area to volume and biomass. This result for FVS-LS as opposed to FVS-NE likely arises because of the adjustment factors used and the differing volume equations employed in the two regions.

Generally, a 10 percent error in predicting d.b.h. resulted in a 25 percent error in predicting total aboveground biomass and C (Fig. 1). Although the CRM uses a myriad of calculations to arrive at aboveground biomass and C, initial results do not seem to show that errors in individual tree predictions lead to larger uncertainties of forest C when compared to plot-level basal area predictions.

Table 1.—Ecoregions examined, number of FIA plots, and evaluation statistics for basal area, volume, and biomass/carbon

Ecoregion	Code	Plots (n)	Mean Δdbh_5 Bias (inches)	Percent Accuracy (±15%) Basal Area	Volume	Biomass/C
Northeast						
Laurentian mixed forest	212	3,212	0.09	91	90	91
Eastern broadleaf (oceanic)	221	2,262	0.14	64	64	64
Eastern broadleaf (continental)	222	262	0.40	38	38	39
Western Allegheny plateau	223	12	0.19	17	25	25
Adirondack-New England mixed forest	232	115	0.19	12	14	14
Central Appalachian broadleaf forest	M211	2,329	0.09	96	96	96
Outer coastal plain mixed forest	M221	1,062	0.05	61	61	61
Lake States						
Laurentian mixed forest	212	2,376	0.01	97	64	61
Eastern broadleaf (continental)	222	581	0.20	92	43	41
Prairie parkland	251	10	0.25	90	50	50

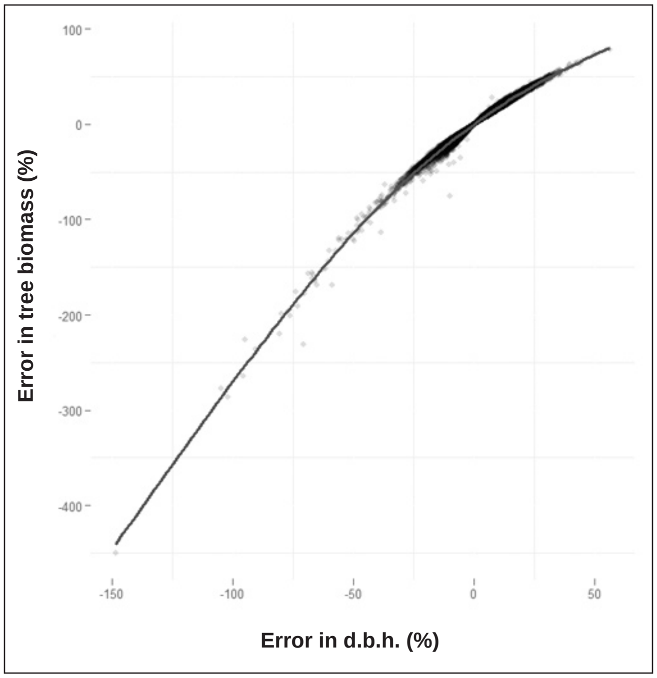

Figure 1.— Percent error in predicting 5-year diameter increment with associated uncertainty in predicting tree biomass using the FIA component ratio method.

CONCLUSIONS

Using FIA data from the northeastern U.S. and Lake States, this analysis found that the current implementation of FVS underpredicted tree diameter increment throughout the two regions. Previous work in the Lake States (Pokharel and Froese 2008) and ongoing work in the Northeast suggest that recalibrating the diameter increment functions in FVS may not prove effective, suggesting new Δd.b.h. models be engineered. As managers will continue to rely on C accounting tools like FVS to project future forest C stocks, assessing the level of uncertainty as these models scale output to upper level hierarchies will help provide more information for those seeking improved methodologies for quantifying forest C dynamics.

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