THE ZERO INFLATION OF STANDING DEAD TREE CARBON STOCKS

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ABSTRACT

Given the importance of standing dead trees in numerous forest ecosystem attributes/processes such as carbon (C) stocks, the USDA Forest Service's Forest Inventory and Analysis (FIA) program began consistent nationwide sampling of standing dead trees in 1999. Modeled estimates of standing dead tree C stocks are currently used as the official C stock estimates for the National Greenhouse Gas Inventory (NGHGI). Given the enhanced rigor of empirical estimates of standing dead C stocks, it is paramount to assess the differences between empirical and modeled C stocks for standing dead trees. The goal of this study was to compare field- and model-based (Carbon Calculation Tool) estimates of plot-level (FIA plots) standing dead-tree C for the United States. The results suggest a strong divergence between the predictions of the model versus the field estimates. The model appears to have underestimated observed carbon stocks at the extremes (i.e., plots with very low and very high amounts of standing dead-tree biomass) and overestimated C stocks in between. Most notably, there was an enormous difference in the number of plots observed versus predicted to have little or no standing dead-tree mass, which field data suggest make up the bulk of the FIA plots. Some of this discrepancy may be caused by too many non-observations of dead trees at FIA plots (i.e., zero-inflated data) — a focal point for continuation of this line of research. The results of this study suggest that the current model-based estimates do not accurately reflect observations in the field.

INTRODUCTION

Because of the recognized role that forests play in the global carbon (C) cycle, in particular the mitigation of carbon dioxide emissions, the United Nations Framework Convention on Climate Change (UNFCCC) requires signatory countries to develop and report their national inventories of forest sources and sinks (Brown 2002). The official National Greenhouse Gas Inventory (NGHGI) of the U.S. bases its forest C stock and stock change estimates on a national forest inventory conducted by the U.S. Department of Agriculture's Forest Inventory and Analysis program (FIA). In the NGHGI, standing dead-tree C stocks are simulated for every FIA plot based on location and live-tree attributes (e.g., forest type) using a system of models embodied in the Carbon Calculation Tool (CCT). The CCT estimates standing dead-tree C stocks based on average ratios of dead/live biomass by region and forest type (Smith and others 2007). Due to the lack of a fully implemented field inventory of standing dead trees in the conterminous U.S. before 2010, a full comparison of simulated and field-based estimates has never been conducted. Given the potentially enhanced rigor of field-based estimates of standing dead C stocks, it is paramount to assess the differences between field- and model-based C stocks for standing dead trees. The goal of this study was to compare the frequency distributions of field- versus model-based estimates of aboveground standing dead-tree C stocks from FIA plots that could be used in the NGHGI.

METHODS

Data for this study came entirely from the FIA program's plot network, which is the foundation for the NGHGI. The FIA program is the primary source for information about the extent, condition, status, and trends of forest resources in the United States (Smith and others 2009). FIA applies a nationally consistent sampling protocol using a quasi-systematic design covering all ownerships in the entire nation (national sample intensity is one plot per 2,428 ha) (Bechtold and Patterson 2005). Land area is stratified using aerial photography or classified satellite imagery to increase the precision of estimates using stratified estimation. Remotely sensed data may also be used to determine if plot locations have forest land cover; forest land is defined as area at least 10 percent stocked with tree species, at least 0.4 ha in size, and at least 36.6 m wide (Bechtold and Patterson 2005). FIA inventory plots established in forested conditions consist of four, 7.2-m fixed-radius subplots spaced 36.6 m apart in a triangular arrangement with one subplot in the center (USDA 2007). All trees (standing live and dead) with a diameter at breast height of at least 12.7 cm are inventoried on forested subplots. All subplots within the same forest condition (e.g., forest type or stand age) were combined for areal estimates of tree attributes at the hectare level (study plot).

All inventory data are managed in a publicly available FIA database. Field data for this study were taken entirely from the FIA database, using the most recent annual inventory in the conterminous 48 states for a total of 127,996 unique observations. One exception is Wyoming where

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a periodic inventory was conducted in 1999 using the national plot design, ensuring compatibility with all other state inventories. The associated field data are available for download at the following site: http://fiatools.fs.fed.us (FIA Datamart). Annual inventories for each state were first initiated between 2000 and 2003 and run through 2008 (except for Wyoming), so sample intensities may vary by state.

Using all available FIA plot-level data, sampled between 1999 and 2008 (using periodic inventories that sampled standing dead; e.g., Wyoming), the aboveground standing dead-tree C stocks were determined by using FIA's regional volume equations (Woodall and others In Press) to determine sound cubic foot volume, which was then converted to dry biomass using the Component Ratio Method (Heath and others 2009) and the specific gravity value of each species (Miles and Smith 2009, Woudenberg and others 2011). Total biomass was converted to C by assuming that 50 percent of dry biomass is C. To account for the decay reduction of standing dead trees by decay class, a decay reduction factor was created for standing dead trees based on the weighted mean decay reduction factor by decay class for the U.S., using national mean decay reduction factors for coarse woody debris decay classes (Harmon and others 2008). More accurate species and decay-class specific decay reduction factors are currently under development. Individual study plots were considered individual, unique forest conditions (e.g., stand age) on each FIA plot with a field-based estimate of the plot's aboveground standing dead-tree C stock. A corresponding plot-level simulated aboveground standing dead tree C stock was determined for each study plot using CCT and as currently used in the NGHGI (Smith and others 2007).

RESULTS AND DISCUSSION

Field estimates of total standing dead-tree C suggest that a large number of FIA plots across the U.S. have little or no standing dead-tree C and that there is an exponential decline in the number of plots observed with increasing standing dead-tree C up until the 10+ Mg/ha class, where an increase was observed (Fig. 1). The results also suggest a strong divergence between the predictions of the modeled- versus field-based estimates. The model appears to underestimate observed C stocks at the extremes (i.e., plots with very low and very high amounts of standing dead-tree biomass) and overestimated C stocks in between (Fig. 1). Perhaps most importantly, there was an enormous difference in the number of plots observed versus predicted to have little or no standing dead-tree mass, which field data suggest make up the bulk of the FIA plots. Almost two thirds of all plot observations had less than 1 Mg/ha of standing dead-tree C, while the NGHGI model estimated only 15 percent of the plots having less than 1 Mg/ha of standing dead-tree C. Additionally, one quarter of all plot observations had no standing dead tree C whatsoever. So it is possible that some of the discrepancy between model and field estimates in areas with very low C stocks may be caused by too many non-observations of dead-trees at FIA plots (i.e., zero-inflated data). Most forest inventory plots had very little standing dead-tree C (< 1 Mg/ha), while the NGHGI model predicts at least an appreciable amount of standing dead-tree C at every plot as long as there is live-tree biomass present. The CCT model estimates standing dead-tree C based on some fraction of live-tree C, so every forest inventory plot with at least some live-tree C will be assigned a corresponding ratio of dead-tree C. This ratio estimator may be biased, a prevalent attribute of ratio estimators. A bias would be expected if the mean dead-tree mass was non-zero when the mean live-tree mass was zero or if the relationship is non-linear. Most FIA plots had very little standing dead-tree C, while less than 10 percent had greater than 10 Mg/ha. Because most forests across the U.S. are not overstocked (Woodall and others 2006), we would expect most forests to have very little density-induced tree mortality resulting in standing dead-tree C. On a minority of FIA plots, standing dead-tree C stocks may be exceeding 10 Mg/ha due to stochastic disturbances (e.g., insect mortality or fire) or overstocked conditions (i.e., density induced mortality).

CONCLUSIONS

The frequency distribution of standing dead-tree C stocks in the U.S. appears to show little or no standing dead-tree C in the majority of locations (FIA plots) with a decreasing frequency of plots with greater C and with a minority of locations having very large stocks (> 10 Mg/ha). It is possible that current field-based methods overestimate the number of locations with little or no standing dead-tree carbon, because of too many non-observations of dead-trees at FIA plots; this should be a focal point for continuation of this line of research. Otherwise, it is clear that the current model-based estimates used for the NGHGI do not accurately reflect observations of standing dead tree C stocks in the field.

LITERATURE CITED

Bechtold, W.A.; Patterson, P.L. eds. 2005. Forest Inventory and Analysis National Sample Design and Estimation Procedures. Gen. Tech. Report. SRS-GTR-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Brown, S. 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution. 116: 363-372.

Harmon, M.E.; Woodall, C.W.; Fasth, B.; Sexton, J. 2008. Woody detritus density and density reduction factors for tree species in the United States: a synthesis. Gen. Tech . Rep. 29. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 65 p.

Heath, L.S.; Hansen, M.; Smith, J.E. [and others]. 2009. Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach. In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest Inventory and Analysis (FIA) symposium 2008; 2008 October 21-23; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p 1-26.

Miles, P.D.; Smith, W.B. 2009. Specific gravity and other properties of wood and bark for 156 tree species found in North America. Res. Note NRS-38. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 35 p.

Smith, J.E.; Heath, L.S.; Nichols, M.C. 2007. U.S. forest carbon calculation tool: forest-land carbon stocks and net annual stock change. Revised. Gen. Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p. [DVD-ROM].

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-GTR-78. Washington, DC: U.S. Department of Agriculture, Forest Service. 336 p.

U.S. Department of Agriculture Forest Service. 2007. Forest Inventory and Analysis national core field guide, Volume I: Field, data collection procedures for phase 2 plots, version 4.0. Washington, DC: U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis. http://www.fia.fs.fed.us/library/ (accessed December 2010).

Woodall, C.W.; Heath, L.S.; Domke, G. [and others]. In Press. Methods and equations for estimating volume, biomass, and carbon for forest trees in the U.S.'s national inventory, 2010. Gen. Tech. Rep. NRS-GTR-xx. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. xx p.

Woodall, C.W.; Perry, C.H.; Miles, P.D. 2006. Relative density of forests in the United States. Forest Ecology and Management. 226: 368-372.

Woudenberg, S.W.; Conkling, B.L.; O'Connell, B.M. [and others]. 2011. The Forest Inventory and Analysis Database: database description and users manual version 4.0 for Phase 2. Gen. Tech. Rep. RMRS-GTR-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

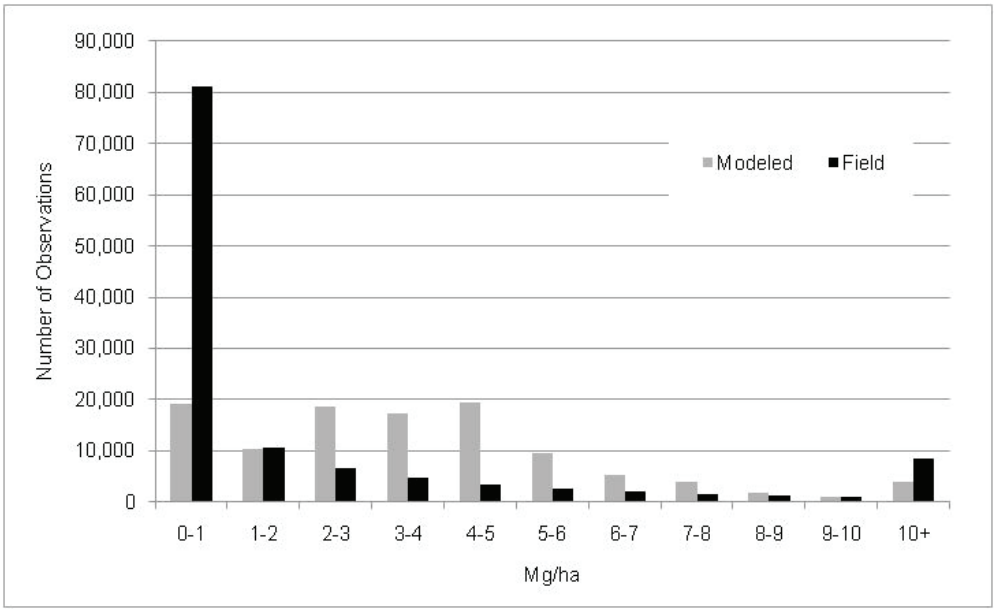

Figure 1—Frequency distribution of forest inventory plot-level standing dead C stocks (Mg/ha) estimated by field measurements and models, U.S., 1999—2008.