RECENT CHANGES IN THE ESTIMATION OF STANDING DEAD TREE BIOMASS AND CARBON STOCKS IN THE U.S. FOREST INVENTORY

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Abstract.—Until recently, standing dead tree biomass and carbon (C) has been estimated as a function of live tree growing stock volume in the U.S. Forest Service, Forest Inventory and Analysis (FIA) Program. Traditional estimates of standing dead tree biomass/C attributes were based on merchantability standards that did not reflect density reductions or structural loss due to decomposition common in standing dead trees. In 1999, the FIA program began consistent nationwide sampling of standing dead trees. That data may now be used to supplant previous approaches to standing dead biomass and C stock estimation. The objective of this study was to incorporate density reductions and structural loss adjustments into standing dead tree biomass/C estimation procedures and assess differences in estimates at multiple spatial scales. The results suggest that accounting for density reductions and structural loss in standing dead trees substantially decreases estimates of standing dead tree biomass and C at tree, plot, and regional scales. Incorporating density reductions and structural loss adjustments may improve the accuracy of standing dead tree biomass and C estimates in the U.S. forest inventory as well as the consistency with FIA field methods and documentation.

INTRODUCTION

Standing dead tree carbon (C) is part of the dead wood C pool recognized in the Land Use, Land Use Change, and Forestry (LULUCF) section of the U.S. National Greenhouse Gas Inventory produced annually by the U.S. Environmental Protection Agency. Forest ecosystem C estimates in the LULUCF are based on the national forest inventory conducted by the U.S. Forest Service, Forest Inventory and Analysis (FIA) Program. Until recently, standing live and dead tree (SDT) biomass and C estimates were calculated by FIA using the same procedures. It has been recognized that the density of dead wood generally decreases with each stage of biomass decay (Krankina and Harmon 1995, Sandstrom et al. 2005) and that structural losses (e.g., sloughing and breakage) occur throughout the decomposition process (Aakala et al. 2008, Cline et al. 1980, Raphael and Morrison 1987). This paper briefly describes the process of incorporating density reduction factors (DRFs) and structural loss adjustments (SLAs) into standing dead tree biomass and C estimates (for a complete description, see Domke et al. 2011). The study objectives were: 1) examine the distribution of SDTs across decay classes in the FIA database; 2) test the differences between unadjusted and adjusted standing dead tree biomass and C estimates (i.e., incorporation of DRFs and SLAs); and 3) suggest refinements of proposed SDT biomass and C estimation procedures and future research directions.

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METHODS

DRFs for SDTs were developed using standing and down dead wood samples categorized by decay class and divided into subsections where wood disks were cut from each end and volume and weight measurements (wet and dry) were taken to determine the density of wood and bark (Harmon et al. 2011).

DRFs were calculated as the ratio of the average current decayed density (current mass/volume) of the piece of dead wood to average undecayed (live tree mass/volume) density for each species and decay class (Table 1).

Preliminary SLAs for tops and branches and belowground biomass were estimated using qualitative descriptions from the FIA field guide (USDA Forest Service 2010) and other studies documenting structural loss by decay class and tree component (Cline et al. 1980, Krankina and Harmon 1995, Vanderwel et al. 2006). Preliminary SLAs for bark biomass were estimated from data collected as part of Harmon et al.'s (2011) study. Merchantable stem deductions due to rough, rotten, or missing cull were accounted for in the conversion from gross to sound volume (Woudenberg et al. 2010) so no additional SLAs—with the exception of bark biomass—were estimated for bole or stump components (Table 1).

Regional Case Study

The most abundant SDT species in the Lake States (Michigan, Minnesota, and Wisconsin) and Pacific Northwest (Oregon and Washington) were selected to compare differences in unadjusted and adjusted biomass and C stock estimates. While the two species selected (quaking aspen [*Populus tremuloides* Michx.] and Douglas-fir [*Psuedotsuga menziesii* (Mirb.) Franco], respectively) may not be representative of all species in their respective regions, they are both extremely common in the FIA database and provide a sound starting point for consideration.

Field data for each region and species were taken from the FIA database. All standing dead (SD) aspen and Douglas-fir trees with a diameter at breast height ≥ 12.7 cm were included in the analysis. A total of 9,369 SD aspen trees were sampled on 3,975 plots in the Lake States from 2005-2009, and 10,144 SD Douglas-fir trees were sampled on 2,825 plots in the Pacific Northwest from 2001-2009.

Mean differences in tree-level biomass estimates for the component ratio method (CRM), CRM+DRFs, and CRM+DRFs+SLAs were compared by diameter class for each tree species. Mean differences of tree level biomass estimates for each approach were not tested for statistical significance for two reasons. First, information was not available to estimate the uncertainty of the tree level biomass predictions. Second, differences between estimates for individual trees on the same plot were expected to be highly correlated. Techniques for accommodating these correlations, particularly with different numbers of trees per plot, are beyond the scope of this study.

Estimates of plot-level SDT biomass were calculated using the three approaches and compared for the two species and regions. The uncertainty of mean plot-level estimates can be attributed to two sources, the uncertainty of individual tree-level estimates and plot-to-plot sampling variability. The uncertainty of the tree-level estimates is generally regarded by national forest inventory programs as negligible relative to the sampling variability and, therefore, was ignored for these analyses. Mean differences in

Table 1.—Density reduction factors by species and preliminary SLA for each decay class by tree component for all tree species in the FIA database; table adapted from Domke et al. (2011)

	Density Reduction Factors		Structural Loss Adjustment Factors				
Decay Class	Quaking aspen	Douglas-fir	Top	Bark	Bole	Stump	Roots
1	0.970	0.892	1.00	0.92	1.00	1.00	1.00
2	0.750	0.831	0.50	0.66	1.00	1.00	0.95
3	0.540	0.591	0.20	0.39	1.00	1.00	0.80
4	0.613	0.433	0.10	0.21	1.00	1.00	0.65
5	0.613	0.433	0.00	0.00	1.00	1.00	0.50

plot-level estimates were calculated in three steps. First, the estimate for each tree was calculated using each approach. Second, plot level differences were calculated as the difference between the CRM estimate of the plot total and the CRM+DRFs and CRM+DRFs+SLAs estimates of the plot total. Mean plot-level differences were calculated as the mean over all plots of the previously calculated plot-level differences. A t-test was used to determine the statistical significance in the mean differences; in effect, the test was a paired t-test because it focused on mean differences rather than differences of means. The null hypotheses were that the mean differences between estimates of C stocks were not significantly different from zero ($\alpha = 0.01$).

RESULTS

The distributions of SD aspen and Douglas-fir trees tended toward a normal distribution centered around the third decay class (see Domke et al. 2011). Nearly 29 percent of SD aspen were missing branches and an additional 16 percent lacked top and branch biomass. For Douglas-fir stems in the Pacific Northwest, only 5 percent of sample trees had missing tops and branches and more than 73 percent of stems had at least some top, branch, and bark biomass present.

The difference in individual tree biomass estimates was compared by diameter class in Figure 1. Bole and stump biomass estimates were quite similar for the CRM+DRFs and CRM+DRFs+SLAs for both study species across diameter classes (differences were due to SLAs for bark biomass in each component), but substantially less than the CRM estimates. The CRM+DRFs+SLAs produced an almost uniform trend for top and branch biomass across diameter classes, while belowground biomass trends increased more or less consistently with the other two methods.

Mean plot-level differences in tree component biomass for the three estimation procedures were statistically significantly different for both species across the two regions. The CRM+DRFs and CRM+DRFs+SLAs decreased plot-level SD bole biomass estimates for aspen by 35 percent (65.8 kg) and 42 percent (78.1 kg), respectively across the Lake States (Table 2). In the Pacific Northwest, the CRM+DRFs reduced plot-level SD Douglas-fir bole biomass by 32 percent (595.0 kg) and the CRM+DRFs+SLAs reduced bole biomass by 36 percent (672.7 kg) (Table 2). For results on individual trees and regional population estimates, see Domke et al. (2011).

DISCUSSION

Forest inventories in the United States have transitioned from a timber focus toward a more holistic sampling of forest ecosystem attributes such as C stocks of standing dead trees. Likewise, the estimation procedures associated with the changing inventory need to be inclusive of tree attributes beyond those required by the forest products industry. Developing SDT biomass and C stock estimates within the construct of an inventory system traditionally designed to estimate growing stock volume requires: 1) the development of a SDT decay class system which is both qualitative for ease of use in the field and quantitative to account for structural loss by tree component and species; 2) the development of DRFs for SDT species in each decay class, with specific emphasis on advanced decay classes; and 3) the development of a flexible SDT estimation procedure which incorporates initial SLAs and DRFs and allows for continual refinement.

SDTs are an important part of the dead wood forest ecosystem C pool recognized by the international community. In an effort to improve the accuracy of biomass and C stock estimates that are used in various facets of the national forest inventory, preliminary DRFs and SLAs have been developed for SDTs. These adjustments reflect the current state of the science on SDT biomass/C estimation and result in significantly lower plot-level biomass estimates, and thus, substantial differences in regional SDT biomass and C stock estimates. The results from this study suggest that incorporation of the SDT adjustments will

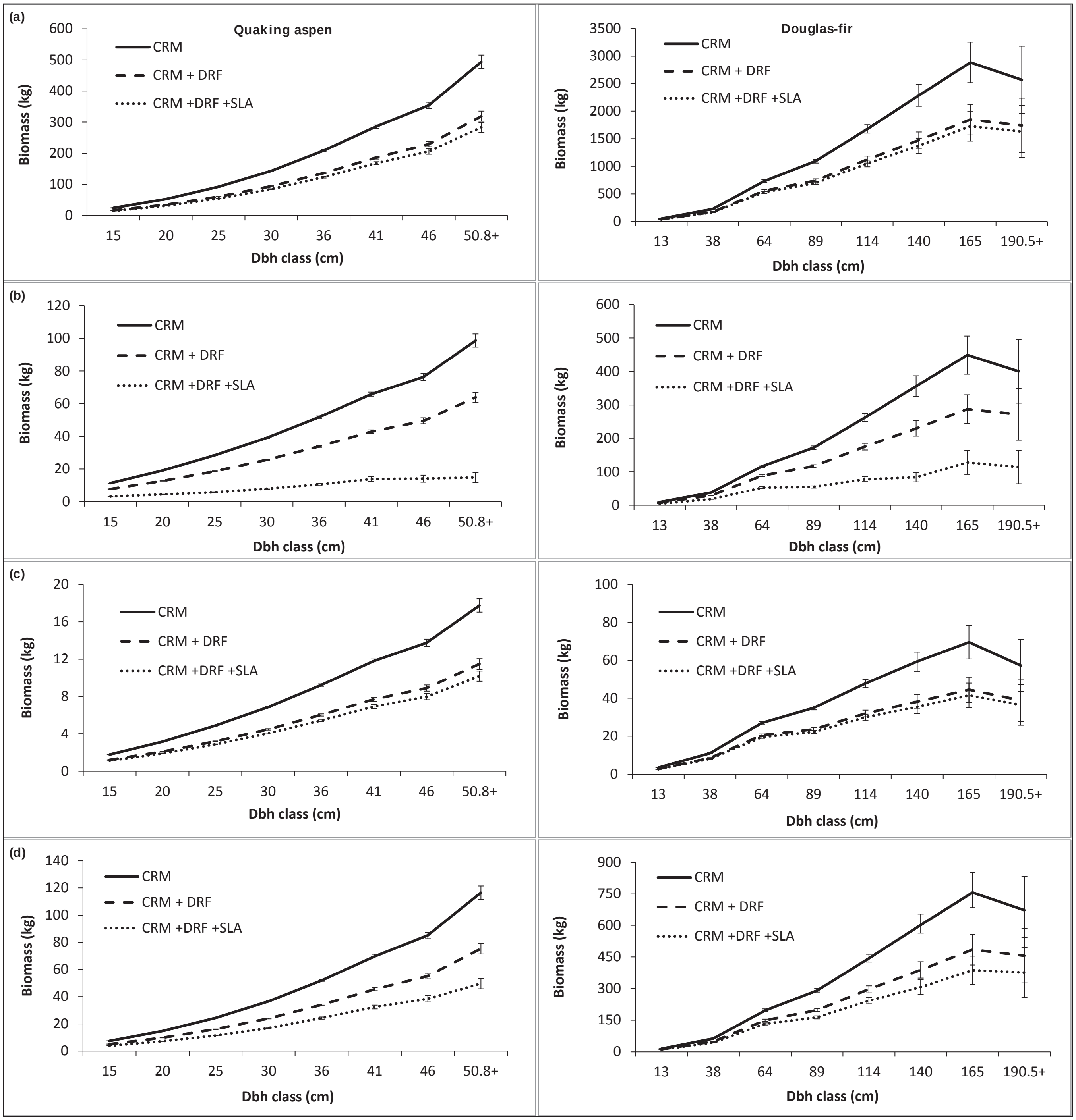

Figure 1.—Mean (with standard errors) SD biomass (oven-dry kg) by tree species (quaking aspen on left, Douglas-fir on right; note the y-axis scale differs by species), estimation method, and d.b.h. class for: a) bole, b) top and branches, c) stump, and d) belowground components; adapted from Domke et al. (2011).

Table 2.—Mean plot-level difference (d) in standing dead biomass (oven-dry kg) by tree component and estimation method (1 = CRM vs. CRM+DRF and 2 = CRM vs. CRM+DRF+SLA) for quaking aspen in the Lake States (2005-2009) and Douglas-fir in the Pacific Northwest (2001-2009); table adapted from Domke et al. (2011)

		Quaking aspen				Douglas-fir			
Component	Comparison	*t*	*df*	*p*	*d*	*t*	*df*	*p*	*d*
Top and branches	1	56.4	3966	<0.001	19.6	21.4	2823	<0.001	94.1
	2	56.8	3966	<0.001	45.1	21.2	2823	<0.001	203.1
Bole	1	48.1	3966	<0.001	65.8	21.2	2823	<0.001	595.0
	2	48.2	3966	<0.001	78.1	21.2	2823	<0.001	672.7
Stump	1	55.0	3966	<0.001	3.4	23.4	2823	<0.001	19.0
	2	55.2	3966	<0.001	4.0	23.5	2823	<0.001	21.5
Belowground	1	50.6	3966	<0.001	17.2	21.3	2823	<0.001	158.4
	2	49.9	3966	<0.001	26.6	21.2	2823	<0.001	216.5

substantially reduce estimates of dead wood biomass and C stocks across spatial-scales and tree species of the United States. While the preliminary estimates offer a sound starting point for SDT biomass and C estimation, more work is necessary to refine SLAs (perhaps by species and region) for each decay class used in national inventory field sampling.

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