VERIFICATION OF THE JENKINS AND FIA SAPLING BIOMASS EQUATIONS FOR HARDWOOD SPECIES IN MAINE

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Abstract.—In 2009, the Forest Inventory and Analysis Program (FIA) updated its biomass estimation protocols by switching to the component ratio method to estimate biomass of medium and large trees. Additionally, FIA switched from using regional equations to the current FIA aboveground sapling biomass equations that predict woody sapling (2.5 to 12.4 cm d.b.h.) biomass using the Jenkins et al. (2003) equations (Forest Science 49 (1): 12-35) and then multiplying predictions by species-specific adjustment factors. The new equations have not been verified for saplings in Maine where sapling-dominated stands make up nearly 24 percent of the forest land. We verified the FIA sapling equations and Jenkins et al. (2003) equations for naturally regenerated hardwood species from an experiment in eastern Maine. Results demonstrate the FIA sapling equations underestimated observed aboveground woody biomass by between 15 and 37 percent. Our results suggest that the current species-specific sapling adjustment factors were inadequate for the trees in this study, and we propose a new set of adjustment factors based on the observed data.

INTRODUCTION

In 2009, the Forest Inventory and Analysis (FIA) Program updated its protocols for estimating biomass across the United States by switching to the component ratio method (CRM). The CRM was designed to provide consistent national-level biomass estimates similar to the current FIA volume estimates. In particular, the CRM uses specific gravity conversions to estimate bole wood and bark biomass and component proportions from Jenkins et al. (2003) equations to estimate biomass of tops and roots (Heath et al. 2009, Woudenberg et al. 2011). FIA also switched from using regional equations to predict sapling (i.e., trees between 2.5 and 12.4 cm diameter at breast height [d.b.h]) biomass to the current FIA aboveground sapling biomass equations (Heath et al. 2009). The new sapling equations predict oven-dry woody biomass (stem, stump, and woody crown) of saplings using the estimates from Jenkins et al. (2003), and then multiplying the estimate by a species-specific adjustment factor to ensure a smooth transition into estimates obtained for larger size classes of trees. The species-specific adjustment factors are the ratio of estimated biomass by the CRM and predictions by the Jenkins et al. (2003) equations for all 12.5 cm d.b.h. trees of a particular species.

Although the FIA sapling equations conform to biomass estimation techniques of larger trees, the switch to the new equations resulted in a decrease of sapling biomass in Maine by 34 percent between 2003 and 2010, even while corresponding stem densities increased by 11 percent during that time period (McWilliams et al. 2005, USDA FS 2012). The likely reason for the drastic reduction in sapling biomass in the region was the shift to the FIA sapling equations because the species-specific adjustment factors range between 0.7 and 0.8 for the common species in

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Maine. Unfortunately, biomass predictions using the FIA sapling equations have not been well verified in Maine where nearly 24 percent of the 7 million hectare forested area is dominated by sapling-size stands.

In this investigation, we verified the Jenkins et al. (2003) and FIA sapling equations for biomass estimation of hardwood saplings common in Maine, including red maple (*Acer rubrum* L.), paper birch (*Betula papyrifera* Marsh.), gray birch (*Betula populifolia* Marsh.), bigtooth aspen (*Populus grandidentata* Michx.), and trembling aspen (*Populus tremuloides* Michx.) from an experiment in eastern Maine.

METHODS

Experimental Design and Sampling

As part of a larger study, saplings of red maple, paper birch, gray birch, bigtooth aspen, and trembling aspen were destructively sampled in summer 2011 from a controlled experiment installed in a post-clearcut stand dominated by early successional hardwood species on the Penobscot Experimental Forest in eastern Maine. The experimental design is a 3 x 3 +1 factorial of silvicultural intensity (thinning, thinning plus enrichment planting, and intensive plantations) and species compositional objectives (hardwood, mixedwood, and conifer), plus an untreated control. A full description of the experiment can be found in Nelson et al. (2012, In press). Sample tree d.b.h. ranged from 2.7 to 12.0 cm and oven-dry woody biomass ranged from 0.88 to 48.25 kg (Table 1). Trees were cut at the root collar and dried at 65 °C for a minimum of 2 weeks (foliage and branches) or 6 weeks (bole) to constant mass. Foliage and branches were weighed separately to the nearest 10 mg, while boles were weighed to the nearest 10 g.

Analytical Approach

Oven-dry woody (branch, bole, and stump) biomass estimates of the Jenkins et al. (2003) and FIA sapling equations were compared to the observed data for the sample trees. Paper birch and gray birch were combined due to low sample sizes and because both the Jenkins et al. (2003) equation and sapling adjustment factor were the same for both species. Root mean square error (RMSE), bias (observed–predicted), and the minimum negligible difference (MDND) equivalence test (Radtke and Robinson 2006), where the null hypothesis is that the observed and predicted values are not equal (Robinson and Froese 2004), were used to assess model accuracy and precision.

RESULTS

The FIA sapling equations substantially underestimated aboveground woody biomass for all of the hardwood species in the investigation (Fig. 1). The predicted means were between 15.0 percent for paper birch and gray birch combined to 36.6 percent for trembling aspen lower than the observed means. RMSE of the FIA sapling predictions ranged from 1.0 kg for red maple to 6.7 kg for trembling aspen, and bias ranged from 0.8 kg for red maple to 3.7 kg for trembling aspen (Table 2). Because the predicted

Table 1.—Descriptive statistics of destructively sampled trees used to verify the Jenkins et al. (2003) and FIA sapling equations. The number of individuals (n), and median values and ranges of d.b.h. (cm) and woody biomass (branches and bole) in kg are shown.

Species	n	D.b.h. Median (cm)	D.b.h. Range (cm)	Woody Biomass Median (kg)	Woody Biomass Range (kg)
Red maple	6	3.4	2.7 - 6.0	2.75	1.19 - 8.10
Birch species	5	5.2	3.2 - 8.4	7.03	2.20 - 23.40
Bigtooth aspen	13	6.5	2.7 - 9.5	7.85	0.97 - 19.10
Trembling aspen	15	5.2	2.6 - 12.0	4.78	0.88 - 48.25

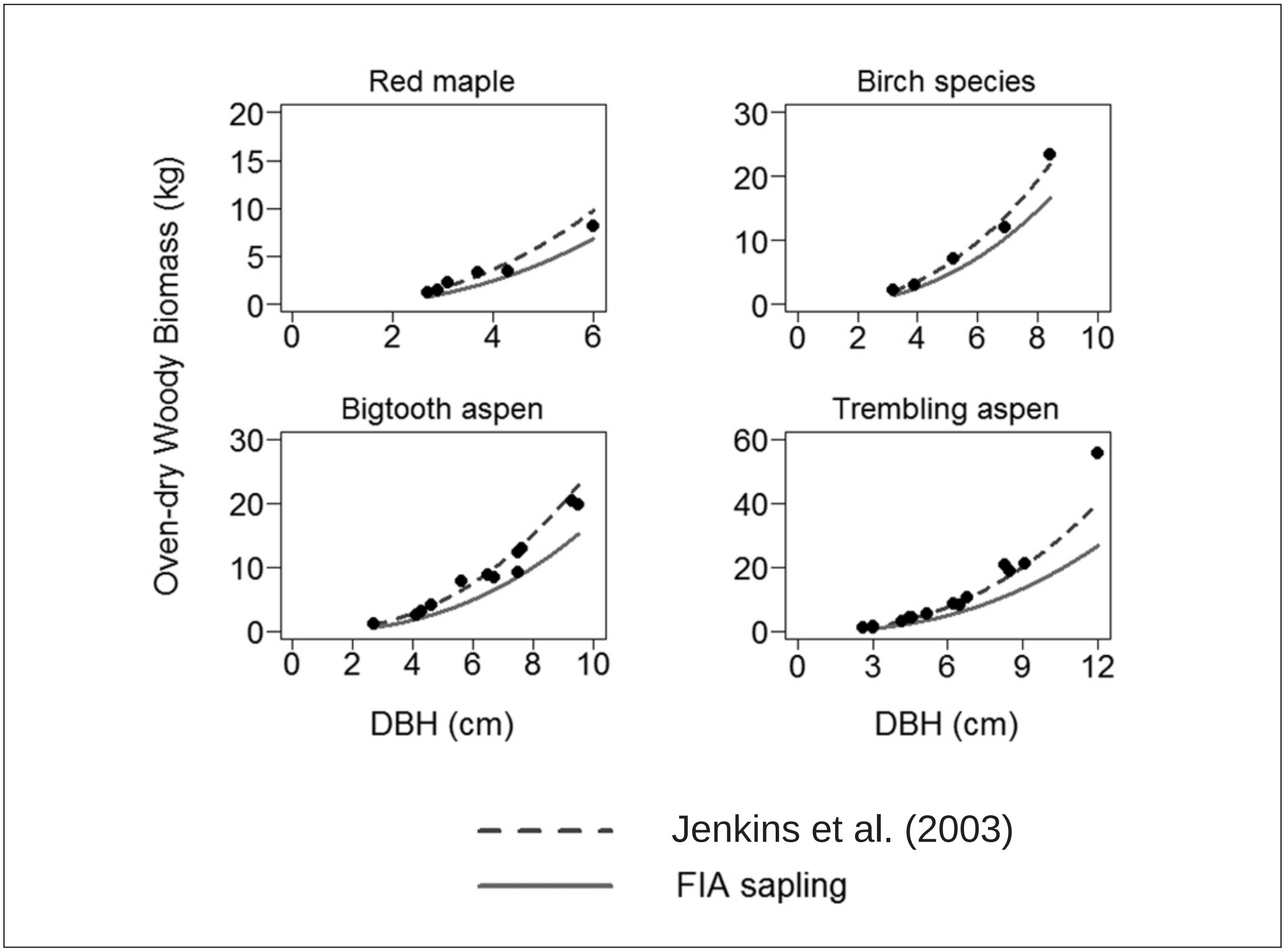

Figure 1.—Oven-dry woody biomass (kg) versus d.b.h. (cm) for the five naturally regenerated hardwood species (paper birch and gray birch combined). The solid circles represent the observed data, the dotted line represents estimates by the Jenkins et al. (2003) equations, and the solid line represents estimates by the FIA sapling equations.

Table 2.—Root mean square error (RMSE), bias (observed-predicted), prediction relative to observed (PRO), minimum detectable negligible difference (MDND), and equivalence test results for the Jenkins et al. (2003) equations (Jenkins) and FIA sapling equations (FIA Sapling)

	RMSE (kg)	Bias (kg)	Observed Mean (kg)	Predicted Mean (kg)	PRO (%)	MDND (%)	Null Hypothesis
Red maple							
Jenkins	0.88	0.57	3.28	3.65	11.31	31.89	reject
FIA Sapling	0.99	0.82	3.28	2.46	-25.13	14.00	not reject
Birch species							
Jenkins	1.33	0.86	5.66	6.52	15.16	38.16	reject
FIA Sapling	1.11	0.85	5.66	4.81	-14.98	1.19	not reject
Bigtooth aspen							
Jenkins	2.15	1.51	8.12	9.51	17.02	26.83	reject
FIA Sapling	2.42	1.89	8.12	6.23	-23.25	14.54	not reject
Trembling aspen							
Jenkins	2.41	1.21	10.18	9.83	-3.41	7.31	reject
FIA Sapling	6.71	3.72	10.18	6.45	-36.57	11.88	not reject

relative to observed values were all larger than the MDND for the FIA sapling equations, the null hypothesis of the equivalence test was not rejected. This suggested that the predicted mean was outside the range of the observed mean ± MDND and there was not enough evidence to reject that the two means were different.

Comparatively, the predicted means of the red maple, birch species, and bigtooth aspen Jenkins et al. (2003) equations were 11.3 percent, 15.2 percent, and 17.0 percent greater, respectively, than the observed mean, while the predicted mean was 3.4 percent lower than the observed for trembling aspen. RMSE error was 12.1 percent, 11.3 percent, and 64.0 percent lower for the red maple, bigtooth aspen, and trembling aspen Jenkins et al. (2003) equations, respectively, than the FIA sapling equation, but was 16.3 percent greater for the birch species.

DISCUSSION

The FIA sapling equations substantially underestimated woody biomass of the hardwood species in this investigation. Although the equations are used to facilitate a smooth transition of biomass estimates to larger trees estimated with the CRM, the substantial underestimation relative to observed values of sapling biomass is the likely cause of a 34 percent decrease in sapling woody biomass estimates for Maine, where nearly 24 percent of the forest land is dominated by sapling-size stands. Our investigation had small sample sizes, but the 15 percent and 37 percent underestimation corroborates the reported decreases in sapling biomass in Maine.

Comparatively, the Jenkins et al. (2003) equations overestimated sapling woody biomass for three of the species. Because the observed data typically occurred between the estimates of the Jenkins et al. (2003) equations and the FIA sapling equations, it may be useful in the future to modify the species-specific sapling adjustment factors to conform to observed field data. For instance, the current adjustment factor for red maple is 0.74, but using the data from this investigation, we find an adjustment factor of 0.90 multiplied by the Jenkins et al. (2003) estimates would provide estimates identical to the mean observed woody biomass. Other potential species-specific sapling adjustment factors calculated using the observed data in this investigation are shown in Table 3. Of course, more field data will be necessary to calibrate the sapling adjustment factors across sites and regions and include more species, but this may be a worthwhile venture given the poor estimates of sapling woody biomass found in this investigation and the drastic reductions in sapling woody biomass in Maine.

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Table 3.—Species-specific sapling adjustment factors calculated as the ratio of the observed mean woody biomass and predicted mean from the Jenkins et al. (2003) equations

Species	Sapling Adjustment Factor
Red maple	0.90
Birch species	0.87
Bigtooth aspen	0.85
Trembling aspen	1.03

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