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Population estimate differences for forest biomass, merchantable volume, and carbon pools as a result of modeling system updates in the United States

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ABSTRACT

The USDA Forest Service Forest Inventory and Analysis (FIA) program, as mandated by US Congressional legislation, provides statistically valid and unbiased estimates of forest characteristics across the United States and territories, which underlie a variety of analyses supporting ecological, economic, and policy needs across spatial scales. New allometric models have been implemented in the FIA program database based on a recent National Scale Volume and Biomass (NSVB) study for updated tree biomass and carbon estimates. Moreover, newer soil and litter carbon models with corresponding new estimates implemented in the FIA database, dependent on live tree biomass inputs. To understand effects of these updated models on forest carbon estimates, we compared estimates between previous and new (current) models. The most significant differences in total carbon (i.e., combined total carbon stock across various forest pools, including soil organic matter, litter, and live and dead tree biomass) were driven by larger estimates of soil organic carbon and smaller estimates of litter carbon. Overall, live tree merchantable volume, aboveground live biomass and carbon, and belowground live biomass estimates, were larger with the new models. Magnitude of differences varied by attribute, region, forest type, species, and tree sizes, as expected. Importantly, because previous models underestimated biomass in tops and limbs, there is now a higher estimated proportion of total tree biomass in these components and a lower proportion in the merchantable bole. We discuss some implications in the context of voluntary carbon accounting and forest carbon projects under the different registries and the potential influence of the new model system to timber market analyses and associated asset valuations.

1. Introduction

The USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) program[1] provides data, population estimates, and associated analytics about forest attributes across the United States and territories that are essential for addressing ecological, forest management and economic analyses, and to inform policy at strategic scales (Domke et al., 2021, Coulston et al., 2023). From its origins as a Congressional Authorization in 1928 (McSweeney-McNary Forest Research Act; P.L. 70–466), the FIA program has evolved in response to available program resources, increasing user needs, and emerging technology. Importantly, in 1999 (Farm Bill, Public Law 105–185), and reaffirmed in 2014 (Farm Bill,

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[1] https://research.fs.usda.gov/programs/fia

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Public Law 113–179), Congress mandated that the FIA program transition its sampling design from periodic to annual surveys, provide uniform and consistent data collection and reporting of attributes such as volume and biomass (core variables), and report information on renewable biomass supplies and carbon stocks from the local to national level. Adapting a consistent FIA data collection, warehousing, and reporting structure accommodates efficiently incorporating refined modeling approaches, such as those associated with tree allometry and carbon pool models.

In 2010, FIA implemented a set of biomass and carbon equations termed the "Component Ratio Method" (CRM, Woodall et al., 2011, Heath et al., 2009). Despite the national consistency imbued by CRM, associated biomass and carbon estimates depended on numerous regional cubic-foot volume models which were tied to administrative jurisdictions rather than ecologically aligned spatial classifications and assumed fixed carbon fractions (50 %). Subsequently, as needs for model refinement have emerged, the USFS FIA program initiated a national research initiative to develop a compatible volume and biomass modeling system that realizes the full benefit of FIA's adaptable program architecture. This coordinated effort was called the National Scale Volume and Biomass (NSVB) project whose focus was to develop consistent tree-level volume, biomass and carbon models. Further, in a separate activity, new litter and soil carbon models were developed based on new FIA field samples. The results of all these new models were implemented during a major update of the FIA database (FIADB) on September 30, 2023.

The NSVB project was a collaborative effort among seven U.S. universities,[2] private forest sector,[3] and USFS[4] to develop a modeling system that would allow for nationally consistent tree-level predictions of volume, biomass, and carbon. Specifically, the objectives were to enhance accuracy of total stem wood volume and total aboveground biomass estimates and ensure tree components were additive. This effort identified the greatest gaps in empirical data to develop predictive tree-level models and then sampled multiple data points from over 3000 felled trees to fill those gaps. The study focused on the top 20 species in the eastern United States and the top 10 species in the western United States (based on total volume for both). These 30 species represented 67 % and 81 % of volume in the eastern and western U.S., respectively Frank et al., 2019, Westfall et al., 2024). Data collected as part of the NSVB project were supplemented by a literature review and historical data curation to incorporate an additional 290,000 felled trees (Radtke et al., 2015, Radtke et al., 2023).

The NSVB project introduced several key components that enhanced reliability and precision of tree-level volume, biomass, and carbon predictions. Unlike previous models that predicted non-merchantable biomass based on predictions from the merchantable portion of a tree (i.e., component ratio method; CRM), NSVB biomass and carbon models were developed from direct measurements of all tree components, including branches and other non-merchantable parts. Moreover, numerous modeling approaches were tested to arrive at reliable, consistent, compatible estimates of tree volume and biomass, ensure additivity of tree components (Westfall et al., 2024), while also adopting species-specific carbon-to-biomass ratios (carbon fractions) as compared to the traditional, non-species specific 0.5 multiplier (Doraisami et al., 2022).

In conjunction with incorporating NSVB models, soil organic carbon (SOC) (Amichev and Galbraith, 2004) and litter (Smith et al., 2006) carbon pool models were updated by incorporating the more contemporary models, described in Domke et al. (2017) and Domke et al. (2016). The SOC predictions used previously by FIA relied on lookup tables of average soil carbon by forest type, based on the State Soil Geographic (STATSGO) database, which often did not reflect specific soil characteristics of varied forest environments, potentially leading to inaccurate forest SOC stock assessments (Schwarz and Alexander, 1995, Amichev and Galbraith, 2004). Moreover, the Natural Resources Conservation Service (NRCS) database, which provided the underlying data in the STATSGO database, contains primarily agricultural soils, so forest soils in the data underlying these look-up tables are poorly represented (Domke et al., 2017). The updated SOC models leverage empirical soil data collected directly from FIA plots since 2001 and auxiliary environmental information from PRISM,[5] NRCS (Schwarz and Alexander, 1995) and U.S. Geological Survey (Danielson and Gesch, 2011), within a machine learning modeling approach (random forests, Breiman 2001, Domke et al., 2017), facilitating more accurate predictions of SOC density.

Earlier litter carbon predictions relied on a generic country-specific model that resulted in overestimations, likely due to being based on data from the literature with only geographic region, forest stand age, and species composition as predictors (Smith and Heath, 2002). By incorporating data from over 5000 newly available field measurements from FIA plots, Domke et al. (2016) redefined predictions of litter carbon using a random forest model, improving carbon stock estimates in a nationally consistent manner.

Model performance for NSVB, litter carbon, and soil carbon were documented by Westfall et al. (2024), Domke et al. (2016), and Domke et al. (2017). However, given the reliance upon FIA data to inform forest management, conservation strategies, policy decisions that support sustainable forest management, and economic decisions made by the forest products sector, it is important to understand how adopting these new models affects population estimates and to understand how the changes may influence future decisions. To understand extent of changes across different regions, forest types, and diameter classes due to the new models our objective was to compare forest volume, biomass and carbon estimates derived from the new NSVB and updated SOC and litter models with those from the previous models used in the FIA database (FIADB). Our analyses focused on quantifying not only the mean differences between population estimates, but also associated shifts in variance of estimates. It is important to note that our goal was to determine differences in forest biomass and carbon estimates resulting from adapting new models compared to the previous models using a consistent FIA dataset to address programmatic differences rather than looking at actual trends in forest carbon stocks over time.

2. Methods

2.1. Data retrieval and variable comparison

We used the EVALIDator API[6] as the primary system to retrieve estimates from the most recent set of inventory data, per state, from the new and previous version of the FIADB (Burrill et al., 2024). We selected EVALIDator over other platforms due to its built-in functions to construct estimates by different criteria and its ability to provide the variance of the estimate (Bechtold and Patterson, 2005). Moreover, EVALIDator is the accepted standard when benchmarking FIA data retrieval and summaries conducted using other technological approaches, i.e., SQL/SQLite queries of FIADB, state-level Visual Basic for Applications (macro-spreadsheets), and Forest Inventory ESTimation and Analysis (FIESTA, Frescino et al., 2022, 2023).

[2] University of Maine, Virginia Tech, Oregon State University, Michigan State University, University of Montana, University of Georgia, and N. Arizona University.

[3] The National Council for Air and Stream Improvement, Inc. (NCASI), Rayonier, Potlach, Weyerhaeuser

[4] The U.S. Forest Service Forest (USFS) Management Service Center and USFS FIA, including representatives of the Pacific Northwest, Rocky Mountain, Northern, and Southern Research Stations and the Washington Office.

[5] http://prism.oregonstate.edu

[6] https://apps.fs.usda.gov/fiadb-api/evalidator

Our analyses used EVALIDator v2.1.4.24282 (application revision update: October 8, 2024), associated with FIADB version 1.9.3 released in October 2024 (update of the FIADB version 1.9.1 released in September 2023), which contained the new NSVB, carbon, and soil carbon models, hereafter the "new" version of "the models," and EVALIDator v2.0.7, corresponding to FIADB version 1.9.0.02 or "previous" version of "the models." Because the tree-level data remained unchanged, our primary objective was to evaluate differences from adapting the new model system (NSVB, new litter and SOC models) versus the previous models' population estimates. Moreover, because the new models provided more tree-level detail (such as tops and limbs) for volume and biomass, the new database had additional fields and population definitions compared to the previous database. We were careful to compare variables and use queries that would retrieve comparable data from each version of the database. Details are available in Appendix A.

2.2. Estimating differences due to adapting new models

The metric we used to evaluate effect of implementing new allometric, SOC, and litter carbon models was the difference in population estimates between the two database versions:

$$Estimate_{diff} = Estimate_{new} - Estimate_{previous}$$

When the difference of the estimates was positive the new estimate was greater than the previous estimates. Conversely, when the difference of the estimates was negative. The corresponding percentage difference was calculated as:

$$Estimate_{diff\%} = \left(Estimate_{new} - Estimate_{previous}\right)/Estimate_{previous}$$

Because the variance of the estimate was also of interest, we calculated the relative efficiency (Wackerly et al., 2008) between estimates in the two FIADB versions, as:

$$RE = \frac{V(Etimate_{new})}{V(Estimate_{previous})}$$

where *RE* is the relative efficiency, $V(Estimate_{new})$ is the variance of the estimate from the new version and $V(Estimate_{previous})$ is the variance of estimates from the previous version. Because the field measurements are unchanged and we are evaluating the effect of new models implemented in the FIADB, *RE* simply compared the variances of the new and previous estimates as a ratio. Values of *RE* equal to one indicated no change, whereas values above one suggested that the variance of the estimate increased using the new models. However, the *RE* metric in those cases, in particular for SOC and litter carbon, could be interpreted as indicative, given the dependency of these carbon pool models on live tree attribute estimates. Moreover, we evaluated percent sampling errors for FIADB data versions, as a metric that takes into account the standard error of the estimate (squared root of variance of the estimate) scaled by the estimate of the attribute evaluated.

Since new and previous population estimates are based on the same tree measurements, the assumption of sample or observational independence for mean and variance comparison is violated, which in turn precludes the application of any hypothesis testing.

2.3. Analytical classifications

To assess effects of adapting new models, we focused our analyses on forestlands (woodlands excluded) and delineated the conterminous U.S. into West, Pacific Northwest, North, and South regions (Fig. 1). Moreover, estimates of volume and biomass growth were not available for Wyoming due to insufficient data from remeasured plots. We also coforest types across the U.S. based on FIA species groups of softwood versus hardwood differentiation and stand origin (i.e., artificial versus natural regeneration) as: 1) upland hardwood (oak/hickory, maple/beech/birch, aspen/birch, alder/maple, tanoak/laurel, and other hardwoods, tropical hardwoods, and exotic hardwoods groups); 2) bottomland hardwood (oak/gum/cypress and elm/ash/cottonwood groups); 3) mixed softwood-hardwood (oak/pine group); 4) naturally-regenerated softwood (all pines, spruce/fir, Douglas-fir, fir/spruce/mountain hemlock, hemlock/Sitka spruce, Western larch, redwood, other western softwoods, California mixed conifer, and exotic softwoods groups where stand origin was recorded as natural); and 5) planted softwood (same as naturally-regenerated softwood and oak/pine groups where stand origin was recorded as artificial).

3. Results

3.1. Total carbon

Our results suggest that incorporating NSVB, SOC, and litter models resulted in larger estimates of total carbon by 13 billion tonnes or about 32 % (Table 1). With the exception of Northern natural softwoods, all combinations of region and forest types exhibited larger carbon estimates by implementing the new models. The largest increases in carbon estimates occurred in upland hardwood, followed by natural softwood, whereas the largest increase by region occurred in the South and West regions. Variance of carbon estimates across the U.S. increased 60 % (*RE*), with some combinations of regions and forest types showing *RE* over 100 % (Table 2). However, percent sampling errors remained at acceptable FIA population estimate levels for the new database compared to the previous database (data not shown), indicating that increased variance of the estimate was proportional to the increase of estimated total.

New total carbon population estimates were larger than previous ones, a positive difference mostly (93 %) explained by soil organic carbon (Table 3). Aboveground live tree carbon accounted for 10 %, and other carbon pools (carbon in down dead, carbon in standing dead trees, and carbon in understory aboveground and belowground) accounted for 14 % of the change. These increases amounted to 116 % but were partially offset by a 16 % reduction in litter carbon when using the new models (Table 3).

3.2. Above-ground live biomass (AGB) and carbon (AGC)

Across all regions and forest types, new AGB[7] and AGC[8] exhibited larger estimates by 13 % and 10 %, respectively (Table B1 and Table 1). Differences between the new and previous models for AGB and AGC, increased except for planted softwoods in the Pacific Northwest. Moreover, southern planted pine's AGB for the DBH class 22.9 – 27.8 cm (Figure B1) and AGC for DBH classes in the range of 17.8 – 22.8 cm (Figure B2) decreased. There were also some decreases for AGC in southern bottomland hardwoods in DBH classes in the 17.8 – 22.8 cm range (Figure B2). Estimates for AGB and AGC indicated that the single carbon fraction of 50 % was generally an overestimate (Table B2). Overall, population estimate differences between model systems for other regions along the DBH distribution appeared more consistent for AGB and AGC. Across all regions and forest types, NSVB variance of ABG and AGC was 21 % and 16 % higher than CRM (Table B3 and Table 2), but percent sampling errors remained unchanged.

[7] FIA attribute #10, "Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes.

[8] FIA attributes #53 and #53000 in the previous and new database versions, "Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land" converted to tonnes.

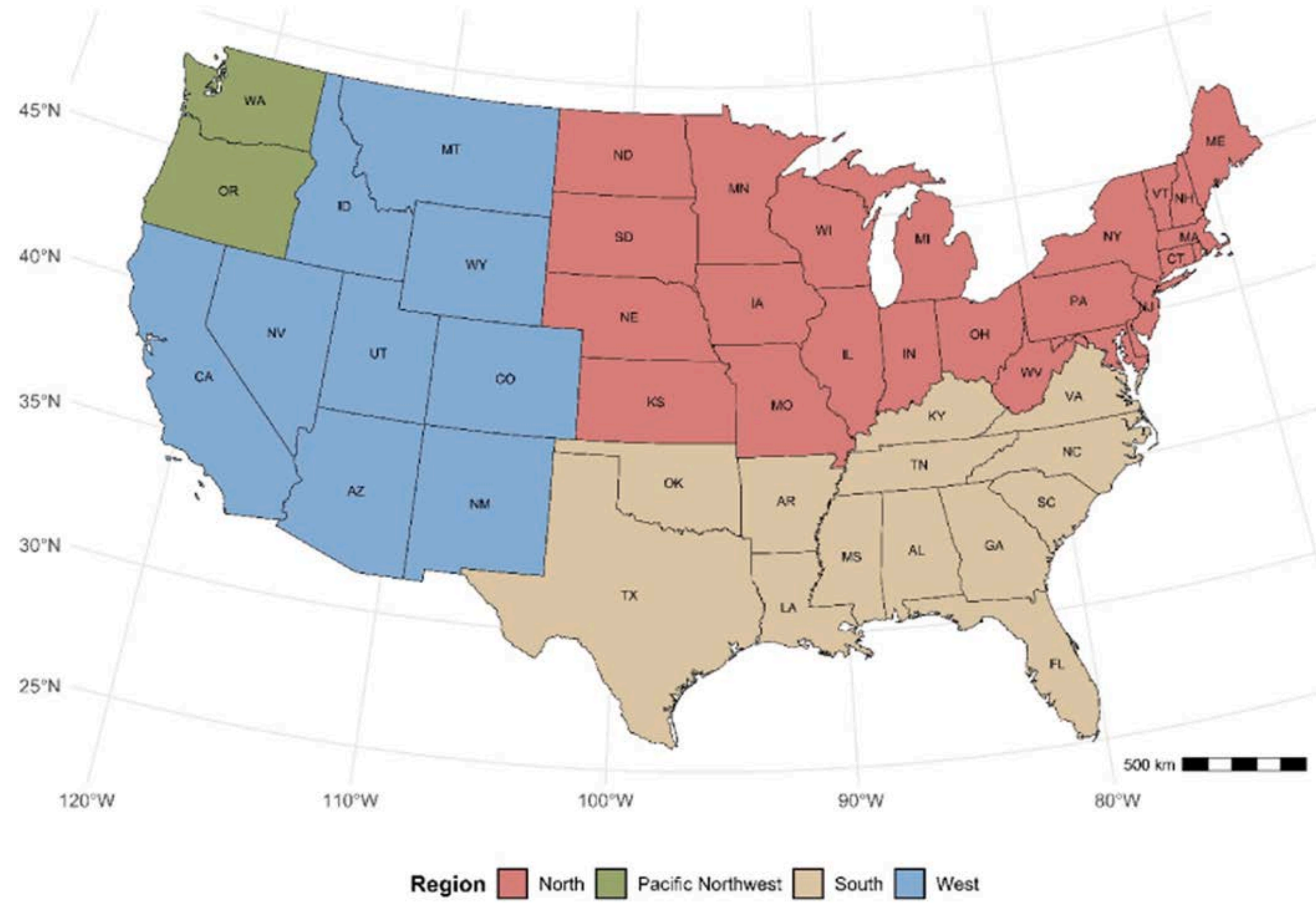

Fig. 1. Regions used for the analyses. Alaska and Hawaii were excluded.

3.2.1. AGB growth

Overall, NSVB predicted 104 million tonnes/year (19 %) more AGB growth[9] than CRM (Table B1). All regions exhibited increases in AGB growth, except for the Pacific Northwest, which showed a slight decrease. The difference in AGB growth by DBH classes due to model changes was similar to the AGB biomass distribution, except for the West region that depicted a very different structure (Figure B3). Overall, the variances of AGB growth estimates based on the new model were 38 % larger (Table B3). However, the variance of AGB growth in the Pacific Northwest decreased using the new models, especially for planted softwoods (Table B3). As noted for AGB and AGC, the percent sampling errors remained approximately equal.

3.2.2. Stem component distribution

As a result of the new models, biomass in treetops and limbs was 7.7 % larger, whereas the biomass in merchantable bole and stump were 7 % and 0.7 % smaller, respectively (Table B4). The largest decrease in merchantable bole biomass occurred for bottomland hardwoods in the West region. However, decreases in merchantable bole biomass in planted softwoods in the Pacific Northwest and South regions were 2.3 % and 2.6 %, respectively. Because this result may have economic implications, we analyzed cubic foot volume in more detail to identify under which circumstances merchantable volume decreased.

3.2.3. Cubic-foot volume and cubic-foot volume growth

The overall difference in merchantable volume[10] was 769 million cubic meters or 2.4 % (Table B5). However, there were some regional variation, with the South and North regions showing positive differences while the Pacific Northwest and West regions showing negative differences (Table B5). Moreover, there was some additional variation within regions regarding contribution of forest type to the differences. For example, planted softwood in the South presented a negative difference between the two model systems (Table B5); main differences occurred on most commercially predominant DBH classes, i.e., 12.7–17.7, 17.8–22.8, 22.9–27.8, and 27.9–32.9 cm (Figure B4). A similar effect was observed for all forest types in the Pacific Northwest region, for which virtually all DBH classes had negative differences (Figure B4). Overall, there was an increase in variance (*RE*) when comparing the two model systems implemented in the FIADB, with most combinations of region and forest type presenting the same trend (Table B6). Nevertheless, percent sampling errors remained unchanged.

Across all regions and forest types, merchantable volume growth[11] showed a positive difference of 45 million cubic meters/year, or the equivalent of 6.2 %, between the two model frameworks (Table B5). Except for the Pacific Northwest, all regions experienced positive differences in merchantable volume growth. Similarly, all forest types

[9] FIA attribute #311, "Average annual net growth of aboveground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes/yr.

[10] FIA attribute #15, "Net merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land" converted to cubic meter.

[11] FIA attribute #202, "Average annual net growth of merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land" converted to cubic meter/yr.

Table 1
Carbon difference (million tonnes) between new and previous model systems implemented in the FIADB by pool, region, and forest type. Numbers in parentheses represent the percentage difference.

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Total carbon[a]	2903 (20.9)	1229 (22.3)	4247 (30.3)	4698 (60.3)	13,077 (31.8)
Bottomland hardwood	87 (6.9)	9 (25.6)	314 (12.3)	15 (43.2)	423 (10.9)
Mixed softwood-hardwood	110 (27.3)		309 (29.5)		420 (28.9)
Natural softwood	−108 (−4.5)	981 (24.3)	663 (26.7)	3820 (62.1)	5355 (35.5)
Planted softwood	32 (8.3)	156 (16.2)	372 (15.4)	46 (57.1)	606 (15.8)
Upland hardwood	2782 (29.6)	83 (17.3)	2589 (47.1)	818 (53.5)	6273 (37.1)
Aboveground live tree carbon[b]	581 (13.7)	62 (3.3)	420 (8.2)	251 (10.7)	1314 (9.7)
Bottomland hardwood	37 (11.7)	1 (8.6)	36 (4.1)	2 (29.4)	76 (6.3)
Mixed softwood-hardwood	20 (14.8)		36 (8.5)		55 (10.0)
Natural softwood	95 (21.6)	64 (4.6)	28 (3.2)	248 (13.0)	436 (9.3)
Planted softwood	22 (22.8)	−3 (−1.1)	7 (0.9)	4 (22.2)	30 (2.5)
Upland hardwood	407 (12.5)	1 (0.4)	314 (14.7)	−4 (−0.9)	717 (12.1)
Belowground carbon[c]	24 (2.9)	4 (1.0)	−9 (−0.9)	−10 (−1.9)	9 (0.3)
Bottomland hardwood	−2 (−2.7)	0 (−1.4)	−5 (−3.0)	0 (−2.9)	−7 (−2.9)
Mixed softwood-hardwood	1 (5.2)		−1 (−0.7)		1 (0.7)
Natural softwood	3 (2.8)	8 (2.3)	−1 (−0.6)	0 (0.0)	9 (0.9)
Planted softwood	5 (20.8)	−1 (−2.1)	−11 (−6.3)	0 (3.5)	−8 (−3.0)
Upland hardwood	17 (2.7)	−2 (−6.2)	9 (2.2)	−10 (−11.9)	14 (1.24)
Carbon in litter[d]	−405 (−33.2)	−420 (−57.5)	−132 (−15.6)	−1249 (−65.6)	−2206 (−47.0)
Bottomland hardwood	0 (−0.8)	−1 (−48.4)	6 (6.7)	−6 (−74.1)	−1 (−0.8)
Mixed softwood-hardwood	−42 (−64.1)		−15 (−19.6)		−57 (−40.0)
Natural softwood	−131 (−48.0)	−354 (−59.3)	−78 (−37.2)	−934 (−62.9)	−1498 (−58.4)
Planted softwood	−9 (−27.5)	−52 (−52.6)	−24 (−15.4)	−10 (−53.9)	−95 (−31.0)
Upland hardwood	−223 (−27.8)	−13 (−39.9)	−21 (−6.8)	−299 (−76.4)	−556 (−36.3)
Soil organic carbon[e]	2365 (35.8)	1346 (76)	3500 (59.2)	5378 (254.0)	12,589 (76.7)
Bottomland hardwood	32 (4.2)	9 (64.6)	226 (17.9)	18 (155.4)	284 (13.9)
Mixed softwood-hardwood	119 (78.6)		249 (65.7)		368 (69.4)
Natural softwood	−111 (−7.5)	1053 (91.4)	612 (61.5)	4205 (260.9)	5759 (110.0)
Planted softwood	2 (0.8)	195 (51.5)	308 (28.5)	52 (185.5)	555 (32.8)
Upland hardwood	2324 (58.1)	90 (39.4)	2105 (96.1)	1104 (238.3)	5623 (81.7)

Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.
[a] Attribute #97, "Total carbon, in short tons, on forest land." Converted to tonnes.
[b] Attributes #53 and #53000 in the previous and new model systems implemented in the FIADB, respectively, "Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land." Converted to tonnes.
[c] Attributes #54 and #54000 in the previous and new model systems implemented in the FIADB, respectively, "Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land." Converted to tonnes.
[d] Attribute #51, "Carbon in litter, in short tons, on forest land." Converted to tonnes.
[e] Attribute #52, "Carbon in organic soil, in short tons, on forest land." Converted to tonnes.

Table 2
Efficiency of new estimates relative to previous estimates (variance ratio) implemented in the FIADB by pool, region, and forest type.

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Total carbon[a]	1.5	1.4	1.6	2.1	1.6
Bottomland hardwood	1.2	1.5	1.2	2.0	1.2
Mixed softwood-hardwood	1.7		1.7		1.7
Natural softwood	1.0	1.4	1.5	2.1	1.6
Planted softwood	1.3	1.3	1.3	2.3	1.3
Upland hardwood	1.7	1.3	2.1	2.1	1.8
Aboveground carbon[b]	1.3	1.1	1.2	1.1	1.2
Bottomland hardwood	1.2	1.3	1.1	1.5	1.1
Mixed softwood-hardwood	1.3		1.2		1.2
Natural softwood	1.5	1.1	1.0	1.1	1.1
Planted softwood	1.5	0.9	1.0	1.4	1.0
Upland hardwood	1.3	1.0	1.4	1.0	1.3
Belowground carbon[c]	1.1	1.1	1.0	1.0	1.0
Bottomland hardwood	0.9	1.0	0.9	0.9	0.9
Mixed softwood-hardwood	1.1		1.0		1.0
Natural softwood	1.1	1.1	1.0	1.0	1.1
Planted softwood	1.6	1.0	0.9	1.1	1.0
Upland hardwood	1.0	0.9	1.1	0.9	1.0
Carbon in litter[d]	0.4	0.2	0.7	0.2	0.3
Bottomland hardwood	1.1	0.2	1.3	0.1	1.0
Mixed softwood-hardwood	0.1		0.7		0.3
Natural softwood	0.3	0.2	0.4	0.2	0.2
Planted softwood	0.5	0.3	0.8	0.2	0.4
Upland hardwood	0.4	0.3	0.9	0.1	0.3
Soil organic carbon[e]	1.6	2.8	2.2	11.0	2.5
Bottomland hardwood	1.1	2.6	1.2	6.7	1.2
Mixed softwood-hardwood	3.3		2.8		3.0
Natural softwood	0.8	3.4	2.7	11.5	3.1
Planted softwood	1.1	2.3	1.5	8.1	1.7
Upland hardwood	2.4	1.9	3.3	10.2	3.0

Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.
[a] Attribute #97, "Total carbon, in short tons, on forest land."
[b] Attributes #53 and #53000 in the previous and new model systems implemented in the FIADB, respectively, "Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land."
[c] Attributes #54 and #54000 in the previous and new model systems implemented in the FIADB, respectively, "Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land."
[d] Attribute #51, "Carbon in litter, in short tons, on forest land."
[e] [5] Attribute #52, "Carbon in organic soil, in short tons, on forest land."

showed positive differences in merchantable volume growth, except for planted softwoods, driven especially by the negative differences in growth between model predictions for that forest type in the Pacific Northwest and South regions (Table B5). Merchantable volume growth differences by DBH classes showed a similar pattern to merchantable volume with slight variations in the Northern region (Figure B5). Overall, the variance of merchantable volume growth was larger for new population estimates, but with a reduction for planted softwoods in the

Table 3
Percent change of carbon in pools with respect to total carbon difference between new and previous model systems implemented in the FIADB by region and forest type.

Forest type	Pools	Region				Total
		North	Pacific Northwest	South	West	
Bottomland hardwood	Aboveground	42.9	11.9	11.4	16.8	18.0
	Belowground	−2.0	−0.4	−1.6	−0.3	−1.6
	Litter	−0.4	−16.3	2.1	−41.1	−0.3
	Soil organic	36.5	101.6	72.0	120.3	67.0
	Other	23	3.2	16.1	4.3	16.9
Mixed softwood-hardwood	Aboveground	17.9		11.6		13.2
	Belowground	1.3		−0.2		0.2
	Litter	−37.8		−4.8		−13.5
	Soil organic	107.9		80.4		87.6
	Other	10.7		13.0		12.5
Natural softwood	Aboveground	−87.5	6.5	4.3	6.5	8.1
	Belowground	−2.5	0.8	−0.2	0.0	0.2
	Litter	121.2	−36.1	−11.8	−24.5	−28.0
	Soil organic	102.7	107.4	92.3	110.1	108.0
	Other	−33.9	21.4	15.4	7.9	11.7
Planted softwood	Aboveground	69.6	−2.0	1.9	8.6	5.0
	Belowground	14.2	−0.9	−3.1	0.3	−1.4
	Litter	−27.3	−33.3	−6.5	−21.3	−15.7
	Soil organic	5.5	124.6	82.7	111.9	91.7
	Other	38.0	11.6	25.0	0.5	20.4
Upland hardwood	Aboveground	14.6	0.7	12.1	−0.5	11.4
	Belowground	0.6	−2.2	0.3	−1.3	0.2
	Litter	−8.0	−15.6	−0.8	−36.6	−8.9
	Soil organic	83.5	107.6	81.3	135	89.6
	Other	9.3	9.5	7.1	3.4	7.7
Total	Aboveground	20.0	4.7	9.7	5.0	9.7
	Belowground	0.8	0.3	−0.2	−0.2	0.1
	Litter	−14.0	−31.9	−3.0	−25.1	−16.3
	Soil organic	81.5	102.0	80.5	108.0	92.9
	Other	11.7	24.9	10.3	12.3	13.6

Aboveground: attributes #53 and #53000 in the previous and new model systems implemented in the FIADB, respectively, "Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land."
Belowground: attributes #54 and #54000 in the previous and new model systems implemented in the FIADB, respectively, "Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land."
Litter: attribute #51, "Carbon in litter, in short tons, on forest land."
Soil organic: attribute #52, "Carbon in organic soil, in short tons, on forest land."
Other: other carbon pools, i.e., carbon in down dead, carbon in standing dead trees, and carbon in understory aboveground and belowground.
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

Pacific Northwest and South (Table B6). Percent sampling errors remained unchanged.

3.3. Below-ground live biomass (BGB), BGB growth, and below-ground carbon (BGC)

There was an overall difference of 3.2 % in BGB[12] with a negligible difference for BGC[13] associated with NSVB (Table B1 and Table 1). Almost all combinations of region and forest type showed positive changes in BGB, whereas most region and forest type combinations exhibited a negative or negligible difference in BGC. Negative differences for BGB for southern planted pine were concentrated in diameter classes in the range of 12.7–17.7 cm, but spread across the diameter distribution for BGC (data not shown). Variance estimates were larger 7 % and 4 %, respectively, for BGB and BGC (Table B3 and Table 2), but percent errors remained unchanged.

The new model system for BGB increased FIADB estimates an additional 7 million tonnes/year, or 6.2 % more than the previous model (Table B1). The BGB growth estimates for the Pacific Northwest and planted softwoods remained virtually unchanged. BGB growth distribution by DBH classes depicted some slight differences in the North and South regions (data not shown). NSVB models presented 10 % more variance than the previous models (Table B3), but percent errors remained unchanged.

3.4. Carbon in litter

Across the U.S., new litter[14] models estimated less carbon than the previous model system, by an estimated 2.2 billion tonnes, or 47 % (Table 1). The West region exhibited the highest negative difference, while the South region showed a moderate negative difference. Regarding forest types, natural softwoods presented the largest negative difference, whereas the reduction in bottomland hardwood was considered negligible. The new litter model and its population estimates showed a substantial (75 %) larger variance (Table 2), but percent standard error remained unchanged.

3.5. Soil carbon

Estimates of soil organic carbon[15] exhibited a positive difference of 12.6 billion tonnes, or 77 %, compared to previous estimates (Table 1). The largest positive difference occurred in the West region, followed by

[12] FIA attribute #59, "Belowground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land."
[13] FIA attributes #54 and #54000 for the previous and new database, respectively, "Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land."
[14] FIA attribute #51, "Carbon in litter, in short tons, on forest land."
[15] FIA attribute #52, "Carbon in organic soil, in short tons, on forest land."

the South. For forest types, natural softwood and upland hardwood exhibited the largest positive differences. Northern natural softwood showed negative differences. The new organic soil carbon estimates from the new models had a variance 2.5 times higher than the previous estimate (Table 2), but percent standard error remained unchanged.

4. Discussion

The NSVB modeling system, compared to the CRM, can be considered an improvement as it simplifies tree volume (biomass and carbon) estimation and predictions in a nationally consistent manner, favors ecologically sound geographic boundaries over administrative ones, uses empirical measurements that enable more robust evaluations of uncertainty, provides consistent model behavior across tree sizes, is additive across tree components, and provides more accurate carbon estimations based on species-specific carbon fractions (Westfall et al., 2024). However, the adaptation of NSVB, and soil carbon and litter carbon models, has potential effects on FIA stakeholders that use these data, including analytics and decision-making. For example, FIA data are extensively used to conduct wood basket analyses that rely on volume and volume growth estimates, suggesting that effects of implementing the new modeling system should be considered when reviewing an outlook of local and regional timber markets. Updates in the FIA database structure to implement the new models will affect data streams that were constructed based on the previous FIADB schema and EVALIDator variables (appendix A). Forest carbon market protocols and entity-level (Murray et al., 2024) voluntary carbon reporting methodologies use FIA-derived data as their baseline and conversion factors (e.g., tons C per thousand cubic feet of wood) to estimate carbon emissions and sinks. National reports, such as Resource Planning Act assessments (RPA; USFS 2023a), U.S. inventories of greenhouse gas (GHG) emissions and sinks (EPA, 2024), and forestry and agriculture sector mitigation analyses (Ohrel et al., 2024), will no longer be compatible with their previous versions and may require reanalysis and reconciliation of summary statistics or consideration of general effects when considering differences in reports over time.

Changes between the modeling systems evaluated in this research are similar to those reported preliminarily by Westfall et al. (2024) and Johnson et al. (2024). The direction (sign) of differences by region is also consistent with the preliminary evaluation conducted by Westfall et al. (2024). In addition to region as a relevant factor to be considered in the assessment between the implementation of model systems, our research is the first analysis that presents an evaluation of AGB, AGC, and cubic-foot volume by forest type and DBH classes and relative efficiency of estimates (variance ratio between FIADB population estimate versions) for total carbon, AGB, AGC, BGB, BGC, SOC, and litter.

Overall, NSVB corrects an underestimation of the CRM for treetops and limbs, in turn increasing AGB and AGC (Westfall et al., 2024). However, because of the NSVB improvements, ratios of biomass shifted among individual tree components, such as estimating more carbon in the treetop and limbs compared to that of the merchantable bole. This finding leads to two direct conclusions. First, the NSVB's reduction of merchantable volume for planted softwood in the South and Pacific Northwest regions may affect financial valuations of timberland assets and, in general, might affect the economic outlook of timber markets and forest product firms. Second, as a consequence of the change in biomass and carbon allocation, less carbon will be accounted for in harvested wood products, and more carbon could be assumed to be left on harvesting sites as logging residues. Both of these results have forest carbon market and carbon reporting implications that should be analyzed further in future work. Furthermore, percent-based coarse root biomass estimates are still based on the Jenkins et al. (2003) species-group equations used earlier in the FIADB and that continued to be used in the updated CRM framework (Heath et al. (2009). These coarse root estimates are now using cubic-foot volume input from the NSVB (USFS 2023b), leading to convoluted sources of change for BGB estimates. Moreover, volume growth, and AGB and BGB growth changes, pose ecological and economic implications. One example is the growth-to-drain ratio that uses removals in the denominator, which, although in principle is affected by NSVB, its dynamic nature could be substantially different than growth (numerator), suggesting that previously estimated growth-to-drain ratios are not compatible with estimates calculated using the new models.

Estimates arising from NSVB tree biomass and carbon models exhibit larger variance than their CRM counterparts. Instead of being a negative result, this reflects that NSVB models may better capture the inherent variability of ecoregions for tree components and the species-specific carbon fractions that improve accuracy in carbon estimates. Moreover, the percent standard errors remained the same, indicating that the increase in variance was proportional to the increase in the estimated mean, consistent with USDA Forest Service's efforts to improve carbon estimation and reporting (Woodall, 2012)

Changes in carbon in soil and litter were shown to drive most of the total carbon change. The new SOC model was developed using data from 3636 FIA plots representative of forest soil dynamics, incorporated prevalent soil-forming drivers (e.g., latitude, longitude, elevation, forest type group, precipitation, maximum temperature, climate moisture index (precipitation to potential evapotranspiration ratio), soil order, and surficial geological description), and allows for estimating carbon in the organic and mineral layers of soil separately (Domke et al., 2017). The new litter model implemented in the current FIADB version provides site-specific estimates, incorporates vegetation changes, and reflects effect of temperature and precipitation on forest floor carbon dynamics of litter accumulation and decomposition (Domke et al., 2016).

Estimates for SOC and litter C have contrasting effects on uncertainty. The new model system estimates that the SOC pool is actually 77 % larger, which also comes with a variance estimate 2.5 times larger than previously estimated, a step forward in capturing the actual spatial variability of SOC. On the other hand, regarding litter estimates, Domke et al. (2016) highlighted that using a random forest model and its advantages in generalizing litter estimation came at the expense of artificial reductions, which are not necessarily associated with an actual biological and ecological change in litter. We present SOC and litter C uncertainty estimates to provide a reference compared to the previous models, but variance comparisons between the previous and new models are not straightforward. For this reason, SOC and litter uncertainty estimates and their corresponding comparisons should be used with caution.

Importantly, results of our study suggest that refining the estimation of attributes of forest ecosystem components (e.g., carbon in trees, dead wood, or soils) may be a continuous process as in situ observations of individual forest components across finer spatial resolutions become increasingly available. Just as nationally consistent observations of individual tree components coupled with modern modeling approaches (Westfall et al., 2024) refined our understanding of the distribution of carbon throughout the standing trees in forests of the US, improved observations of wood density and structural attributes across various stages of decay of dead wood (Domke et al., 2011) may refine future estimates of forest dead wood carbon cycle (Wijas et al., 2024). The advent of terrestrial laser scanning and associated technologies on handheld devices, such as personal phones, within a data ecosystem (i.e., artificial intelligence opportunities), coupled with appropriate modeling approaches, may usher in a period of rapid refinement of forest modeling (Woodall et al., 2025), enabling forest attribute estimation to dynamically adapt to global change.

5. Conclusions

Adopting NSVB models improved estimates of volume, biomass, and carbon across populations of trees but also among the ratios of tree components. Although such adoption fundamentally modifies our understanding of the distribution of critical forest ecosystem attributes, such as carbon, across the diverse structures and composition of US forests, improvements based on research are necessary to modernize models used in FIADB using empirical data, advanced statistical estimation techniques, with more appropriate biological and ecological assumptions of forest dynamics. Overall, AGB, AGC, BGB, and volume increased whereas BGC remained unchanged. The NSVB also allocates more volume and biomass to treetops and limbs at the expense of the merchantable bole section, which has economic and carbon accounting implications. Moreover, new models for SOC and litter induce larger and smaller population estimates, respectively, in their carbon stocks. For all carbon pools, there are variations across regions, among forest types, and along the DBH class distribution, as expected. Regarding variance of estimate assessments, all improvements of NSVB implemented in the FIADB may indicate a reduction of precision, reflecting the inherent natural variability of volume, biomass, and carbon, but an increase in accuracy. However, percent standard errors remained unchanged indicating that mentioned variance increases were proportional to estimated means.

CRediT authorship contribution statement

Philip J. Radtke: Writing – review & editing, Validation. **Renate Bush:** Writing – review & editing, Validation. **Stephen P. Prisley:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Erik Schilling:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Investigation, Conceptualization. **Coulston John W.:** Writing – review & editing, Validation. **Christopher W. Woodall:** Writing – review & editing, Validation. **Héctor I. Restrepo:** Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Holly L. Munro:** Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they do not have any competing interests, personal or professional relationships that could have appeared to influence the work reported in this paper.

Appendix A. - Variable mapping

Table A1
Total number of variables associated with the FIADB TREE table and affected by NSVB by database version and land basis

Tree variable	Previous			New			Difference
	Forestland	Timberland	Total	Forestland	Timberland	Total	
Tree basal area	2	2	4	2	2	4	0
Tree carbon	4*	4**	8	6	6	12	4
Tree dry weight	12***	10	22	20	20	40	18
Tree green weight	10	9	19	7	7	14	−5
Tree number	3	3	6	4	4	8	2
Tree total-stem volume				22	22	44	44
Tree volume	10	8	18	23	20	43	25
Total	41	36	76	84	81	165	88

*The total number of tree carbon variables for forestland is 4 after relocating attribute #47, "Aboveground and belowground carbon in standing dead trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land" that appears misclassified in the CONDITION table in the previous database instead of the TREE CARBON table as it is in the new database version.
**The total number of tree carbon variables for timberland is 4 after relocating attribute #61, "Aboveground and belowground carbon in standing dead trees (at least 1 in. d.b.h./d.r.c), in short tons, on timberland" that appears misclassified in the CONDITION table in previous database instead of the TREE CARBON table as it is in the new version.
***The total number of tree dry weight (biomass) variables is 12, after relocating attribute #96, "Aboveground biomass of standing dead trees (at least 5 in. d.b.h./d.r.c.), in dry short tons, on forest land" that appears misclassified in the CONDITION table in the previous database to the corresponding TREE table. The variable is classified correctly in the new database.

Forestland volume

The previous database presents ten tree volume variables for forestlands, whereas the new database has 23 variables, six existing in the previous version and 17 new variables (Table 11). However, four variables present in the previous version were discontinued, i.e., 14, 23, 24, and 92 (Table 11).

Table A2
Forestland volume variable equivalence between database versions

Previous		New	
14	Net merchantable bole volume of live trees (at least 5 in. d.b.h./d.r.c.), in cubic feet, on forest land		
15	Net merchantable bole volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land	15	Net merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land
16	Net sawlog volume of sawtimber trees, in cubic feet, on forest land	16	Net sawlog wood volume of sawtimber trees, in cubic feet, on forest land
20	Net sawlog volume of sawtimber trees, in board feet (International 1/4-inch rule), on forest land	20	Net sawlog wood volume of sawtimber trees, in board feet (International 1/4-inch rule), on forest land

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Table A2 (*continued*)

Previous		New	
22	Gross sawlog volume of sawtimber trees, in board feet (International 1/4-inch rule), on forest land	22	Gross sawlog wood volume of sawtimber trees, in board feet (International 1/4-inch rule), on forest land
23	Gross bole volume of live trees (at least 5 in. d.b.h./d.r.c.), in cubic feet, on forest land		
24	Sound bole volume of live trees (at least 5 in. d.b.h./d.r.c.), in cubic feet, on forest land		
92	Net merchantable bole volume of standing dead trees (at least 5 in. d. b.h./d.r.c.), in cubic feet, on forest land		
131	Sound sawlog volume of sawtimber trees, in cubic feet, on forest land	131	Sound sawlog wood volume of sawtimber trees, in cubic feet, on forest land
1020	Net sawlog volume of sawtimber trees, in board feet (Doyle rule), on forest land	1020	Net sawlog wood volume of sawtimber trees, in board feet (Doyle rule), on forest land
		11005	Gross stump wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11006	Gross stump bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11007	Sound stump wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11008	Sound stump bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11009	Gross bole bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11010	Gross stem-top (above 4-inch top diameter) wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11011	Gross stem-top (above 4-inch top diameter) bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11012	Sound bole bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11013	Sound stem-top (above 4-inch top diameter) wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11014	Sound stem-top (above 4-inch top diameter) bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11015	Net bole bark volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		11252	Net merchantable bole wood volume of standing dead trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		574171	Net merchantable bole wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		574173	Gross bole wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		574174	Sound bole wood volume of live trees (timber species at least 5 in. d.b.h.), in cubic feet, on forest land
		574200	Net sawlog wood volume of sawtimber trees, in board feet (Scribner rule), on forest land
		574202	Gross sawlog wood volume of sawtimber trees, in board feet (Scribner rule), on forest land

Forestland tree biomass

The previous database has 12 variables, whereas the new database has 20. Three variables were discontinued from the new database version, i.e., 75, 76, and 94 (Table 12). FIA attributes #75 and #76 correspond to legacy variables from older regional methods. There were 11 new variables added to the new database to present a more granular biomass estimation of tree components, which is probably the reason FIA attribute #94 was discontinued. The FIA attribute codes for some variables also changed, e.g., FIA attribute 11 in the previous database vs FIA attribute 11000 in the new database, for transparency regarding the variable description that includes wood in the new version. However, the SQL query associated with both are equivalent, suggesting compatibility

Table A3
Forestland biomass variable equivalence between database versions

Previous		New	
10	Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c), in dry short tons, on forest land	10	Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land
11	Merchantable bole biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land	11000	Merchantable bole bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
56	Top and limb biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land	56000	Top and limb bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
57	Aboveground biomass of live saplings (timber species at least 1 and less than 5 in. d.b.h.), in dry short tons, on forest land	57000	Aboveground biomass of live saplings (timber species at least 1 and less than 5 in. d.b.h.), in dry short tons, on forest land
58	Stump biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land	58000	Stump bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
59	Belowground biomass of live trees (at least 1 in. d.b.h./d.r.c), in dry short tons, on forest land	59	Belowground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land

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Table A3 (*continued*)

Previous		New	
60	Aboveground biomass of live trees (woodland species at least 1 in. d.r.c.), in dry short tons, on forest land	60000	Aboveground biomass of live trees (woodland species at least 1 in. d.r.c.), in dry short tons, on forest land
75	Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c), in dry short tons, on forest land calculated with retired regional methods		
76	Merchantable bole biomass of live trees (at least 5 in. d.b.h./d.r.c), in dry short tons, on forest land calculated with retired regional methods		
94	Bark biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land		
96*	Aboveground biomass of standing dead trees (at least 5 in. d.b.h./d.r.c.), in dry short tons, on forest land	96	Aboveground biomass of standing dead trees (at least 5 in. d.b.h./d.r.c.), in dry short tons, on forest land
133	Sawlog biomass of sawtimber trees, in dry short tons, on forest land	133000	Sawlog bark and wood biomass of sawtimber trees, in dry short tons, on forest land
		11016	Total-stem (from ground line to tree tip) wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
		11017	Total-stem (from ground line to tree tip) bark biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
		11018	Stump bark biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
		11019	Merchantable bole bark biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
		11020	Foliage biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land
		11021	Foliage biomass of live trees (at least 5 in. d.b.h./d.r.c.), in dry short tons, on forest land
		11022	Foliage biomass of live trees (woodland species at least 1 in. d.r.c.), in dry short tons, on forest land
		11023	Branch (excluding any part of the stem) biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land
		11032	Branch (excluding any part of the stem) biomass of live trees (timber species at least 1 in. d.b.h.), in dry short tons, on forest land
		11213	Foliage biomass of live trees (timber species at least 1 in. d.b.h.), in dry short tons, on forest land
		11266	Aboveground biomass of standing dead trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land

* Appears in the CONDITION table in the previous database.

Forestland tree carbon

Two variables were added to the forestland tree carbon variables to address carbon in dead trees (Table 13). Please note the thousand factors added to the FIA attribute codes to reflect that SQL queries are slightly different, but the final estimates are equivalent between the two database versions.

Table A4
Forestland tree carbon variable equivalence between database versions

Previous		New	
47*	Aboveground and belowground carbon in standing dead trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land	47000	Aboveground and belowground carbon in standing dead trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land
53	Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land	53000	Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land
54	Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land	54000	Belowground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land
55	Aboveground and belowground carbon in live trees (at least 1 in. d.b.h./d.r.c), in short tons, on forest land	55000	Aboveground and belowground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land
		11268	Aboveground carbon in standing dead trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land
		47001	Aboveground and belowground carbon in standing dead trees (at least 5 in. d.b.h./d.r.c.), in short tons, on forest land

* It appears in the carbon table in the previous database instead of the tree carbon table in the new database.

Appendix B. – Forest biomass and merchantable volume

Table B1
Above- and below-ground biomass (million tonnes) and growth (million tonnes/year) comparison between new and previous model systems implemented in the FIADB by region and forest type. Numbers in parentheses represent the percentage change

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Aboveground biomass[1]	1511 (17.8)	87 (2.3)	1406 (13.8)	538 (11.4)	3543 (13.0)
Bottomland hardwood	105 (16.5)	3 (11.3)	177 (10.2)	6 (34.3)	290 (12.0)

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Table B1 (*continued*)

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Mixed softwood-hardwood	46 (17.4)		117 (13.8)		163 (14.7)
Natural softwood	203 (23.2)	100 (3.4)	138 (7.7)	501 (13.1)	942 (10.0)
Planted softwood	43 (21.8)	−20 (−3.4)	83 (5.2)	7 (19.4)	112 (4.7)
Upland hardwood	1115 (17.1)	5 (1.8)	892 (21)	25 (3.0)	2037 (17.1)
Aboveground biomass growth[2]	57 (43.9)	−1 (−2.2)	46 (12.9)	3 (24.3)	104 (18.7)
Bottomland hardwood	5 (53.7)	0 (−0.1)	5 (14.4)	0 (43.3)	10 (21.8)
Mixed softwood-hardwood	2 (33.3)		4 (14.7)		5 (17.5)
Natural softwood	6 (45.5)	1 (2.3)	6 (7.7)	1 (10.5)	14 (11.1)
Planted softwood	2 (38.6)	−2 (−7)	7 (5.3)	0 (15.1)	8 (4.6)
Upland hardwood	42 (43.6)	0 (1.2)	25 (26.6)	1 (−81.2)	68 (35.3)
Belowground biomass[3]	111 (6.5)	−1 (−0.1)	88 (4.2)	−14 (−1.3)	184 (3.2)
Bottomland hardwood	2 (1.4)	0 (0.7)	9 (2.6)	0 (0.6)	11 (2.3)
Mixed softwood-hardwood	4 (7.3)		7 (4.2)		11 (4.9)
Natural softwood	8 (4.0)	8 (1.2)	15 (3.8)	1 (0.1)	32 (1.5)
Planted softwood	8 (19.1)	−6 (−4.5)	−9 (−2.4)	0 (1.2)	−6 (−1.1)
Upland hardwood	89 (7.0)	−3 (−5.2)	65 (7.8)	−15 (−8.6)	136 (5.8)
Belowground biomass growth[4]	7 (28.9)	0 (−0.28)	4 (5.9)	−5 (−179.0)	7 (6.2)
Bottomland hardwood	1 (32.1)	0 (2.6)	1 (10.3)	0 (10.7)	1 (14.3)
Mixed softwood-hardwood	0 (29.2)		1 (9.1)		1 (12.1)
Natural softwood	1 (26.1)	0 (5.3)	1 (7.4)	−5 (−167.8)	−2 (−6.9)
Planted softwood	1 (38.8)	0 (−5.5)	0 (−0.2)	0 (−1.6)	0 (0.3)
Upland hardwood	5 (28.4)	0 (−0.6)	2 (11.8)	0 (96.7)	7 (18.8)

[1] Attribute #10, "Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes.
[2] Attribute 311, "Average annual net growth of aboveground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes/yr.
[3] Attribute #59, "Belowground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes.
[4] Attribute #317, "Average annual net growth of belowground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land" converted to tonnes/yr.
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

Table B2
Average carbon fraction by region and forest type for the new model system implemented in the FIADB

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Bottomland hardwood	0.479	0.488	0.472	0.482	0.475
Mixed softwood-hardwood	0.489		0.476		0.480
Natural softwood	0.494	0.505	0.479	0.500	0.497
Planted softwood	0.504	0.512	0.479	0.511	0.490
Upland hardwood	0.480	0.493	0.474	0.481	0.478
Total	0.482	0.505	0.476	0.497	0.485

Table B3
Efficiency of new estimates relative to previous estimates (variance ratio) of above-and below-ground biomass and their growth by region and forest type

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Aboveground biomass[1]	1.4	1.0	1.3	1.0	1.2
Bottomland hardwood	1.4	1.4	1.2	1.7	1.3
Mixed softwood-hardwood	1.3		1.3		1.3
Natural softwood	1.5	1.1	1.1	1.0	1.1
Planted softwood	1.5	0.9	1.1	1.3	1.1
Upland hardwood	1.4	1.0	1.6	1.0	1.4
Aboveground biomass growth[2]	1.6	0.9	1.5	1.2	1.4
Bottomland hardwood	1.7	1.0	1.6	1.8	1.6
Mixed softwood-hardwood	1.4		1.4		1.4
Natural softwood	1.7	0.9	1.6	1.2	1.3
Planted softwood	2.0	0.9	1.2	1.2	1.1
Upland hardwood	1.5	1.2	1.8	1.1	1.5
Belowground biomass[3]	1.1	1.1	1.1	1.0	1.1
Bottomland hardwood	1.0	1.1	1.1	1.0	1.0
Mixed softwood-hardwood	1.2		1.1		1.1
Natural softwood	1.2	1.1	1.1	1.0	1.1
Planted softwood	1.6	0.9	1.0	1.0	1.0
Upland hardwood	1.1	0.9	1.2	0.9	1.1
Belowground biomass growth[4]	1.3	0.9	1.1	1.0	1.1
Bottomland hardwood	1.2	1.1	1.3	1.1	1.3
Mixed softwood-hardwood	1.3		1.2		1.2
Natural softwood	1.2	0.9	1.2	1.0	1.1

(*continued on next page*)

Table B3 (*continued*)

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Planted softwood	1.7	0.9	1.0	0.9	1.0
Upland hardwood	1.3	1.0	1.2	1.0	1.2

[1] Attribute #10, "Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land."
[2] Attribute #311, "Average annual net growth of aboveground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land."
[3] Attribute #59, "Belowground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land."
[4] Attribute #317, "Average annual net growth of belowground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land."
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

Table B4
Percentage changes in the biomass distribution among the stem components comparing the new and previous model systems implemented in the FIADB

Forest type	Stem component	Region				Total
		North	Pacific Northwest	South	West	
Bottomland hardwood	Merchantable bole	−13.3	−8.3	−7.6	−15.0	−9.3
	Stump	−0.4	−0.6	0.5	−0.2	0.3
	Top and limbs	13.8	8.9	7.1	15.3	9.0
Mixed softwood-hardwood	Merchantable bole	−8.2		−5.8		−6.4
	Stump	−0.5		−0.5		−0.5
	Top and limbs	8.8		6.2		6.9
Natural softwood	Merchantable bole	−10.7	−1.8	−2.0	−8.2	−5.3
	Stump	−0.4	−0.9	−1.0	−0.8	−0.8
	Top and limbs	11.2	2.7	3.0	9.0	6.1
Planted softwood	Merchantable bole	−4.9	−2.3	−2.6	−10.1	−2.9
	Stump	−1.0	−1.1	−1.4	−0.5	−1.3
	Top and limbs	6.0	3.4	4.0	10.6	4.2
Upland hardwood	Merchantable bole	−8.4	−5.0	−8.7	−9.8	−8.5
	Stump	−0.7	−0.5	−0.5	−0.1	−0.6
	Top and limbs	9.1	5.5	9.2	9.9	9.1
Total	Merchantable bole	−8.9	−2.2	−6.4	−8.5	−7.0
	Stump	−0.7	−0.9	−0.6	−0.7	−0.7
	Top and limbs	9.6	3.1	7.0	9.1	7.7

Merchantable bole: attributes #11 and #11000 in the previous and new model systems implemented in the FIADB, "Merchantable bole bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land."
Stump: attributes #58 and #58000 in the previous and new model systems implemented in the FIADB, "Stump bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land."
Top and limbs: attributes #56 and #56000 in the previous and new model systems implemented in the FIADB, "Top and limb bark and wood biomass of live trees (timber species at least 5 in. d.b.h.), in dry short tons, on forest land."
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

Table B5
Merchantable volume and volume growth difference (million cubic meters and million cubic meters/year, respectively) between new and previous model systems implemented in the FIADB by region and forest type. Numbers in parentheses represent the percentage difference

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Merchantable volume[1]	672 (7.8)	−99 (−1.6)	386 (3.7)	−189 (−2.8)	769 (2.4)
Bottomland hardwood	27 (4.3)	0 (0.3)	20 (1.2)	−1 (−3.0)	46 (2.0)
Mixed softwood-hardwood	29 (9.9)		34 (3.9)		63 (5.4)
Natural softwood	53 (4.7)	−31 (−0.6)	85 (3.9)	−82 (−1.4)	26 (0.2)
Planted softwood	63 (22.0)	−44 (−4.9)	−55 (−2.7)	1 (1.3)	−36 (−1.1)
Upland hardwood	500 (8.0)	−25 (−5.9)	302 (7.9)	−107 (−11.0)	671 (5.8)
Merchantable volume growth[2]	34 (20.9)	−3 (−2.9)	12 (2.7)	2 (12.1)	45 (6.2)
Bottomland hardwood	2 (12.4)	0 (0.1)	1 (1.6)	0 (−4.0)	2 (4.2)
Mixed softwood-hardwood	2 (21.3)		1 (4.3)		3 (8.1)
Natural softwood	5 (17.3)	0 (−0.4)	6 (5.6)	2 (15.0)	12 (7.0)
Planted softwood	3 (26.5)	−2 (−5.2)	−3 (−1.6)	0 (1.3)	−2 (−0.7)
Upland hardwood	23 (15.5)	−1 (−6.8)	7 (7.0)	0 (26.7)	29 (13.3)

[1] Attribute #15, "Net merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land." Converted to cubic meters.
[2] Attribute #202, "Average annual net growth of merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land." Converted to cubic meters/yr.
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

Table B6
Efficiency of new estimates relative to previous estimates (variance ratio) of merchantable volume and volume growth by region and forest type

Forest type	Region				Total
	North	Pacific Northwest	South	West	
Merchantable volume[1]	1.2	1.0	1.1	1.0	1.0
Bottomland hardwood	1.0	1.1	1.0	0.9	1.0
Mixed softwood-hardwood	1.2		1.1		1.1
Natural softwood	1.2	1.1	1.1	1.0	1.0
Planted softwood	1.6	0.9	1.0	1.0	1.0
Upland hardwood	1.1	0.9	1.2	0.9	1.1
Merchantable volume growth[2]	1.3	1.0	1.0	1.0	1.0
Bottomland hardwood	1.1	1.2	1.0	0.9	1.0
Mixed softwood-hardwood	1.5		1.1		1
Natural softwood	1.2	1.0	1.1	0.9	1.0
Planted softwood	1.6	0.9	1.0	1.0	1.0
Upland hardwood	1.3	0.9	1.1	1.0	1.1

[1] Attribute #15, "Net merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land."
[2] Attribute #202, "Average annual net growth of merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land."
Note: Attribute numbers (found in FIADB's REF_POP_ATTRIBUTE table) are unique identifiers of specific forest population attributes.

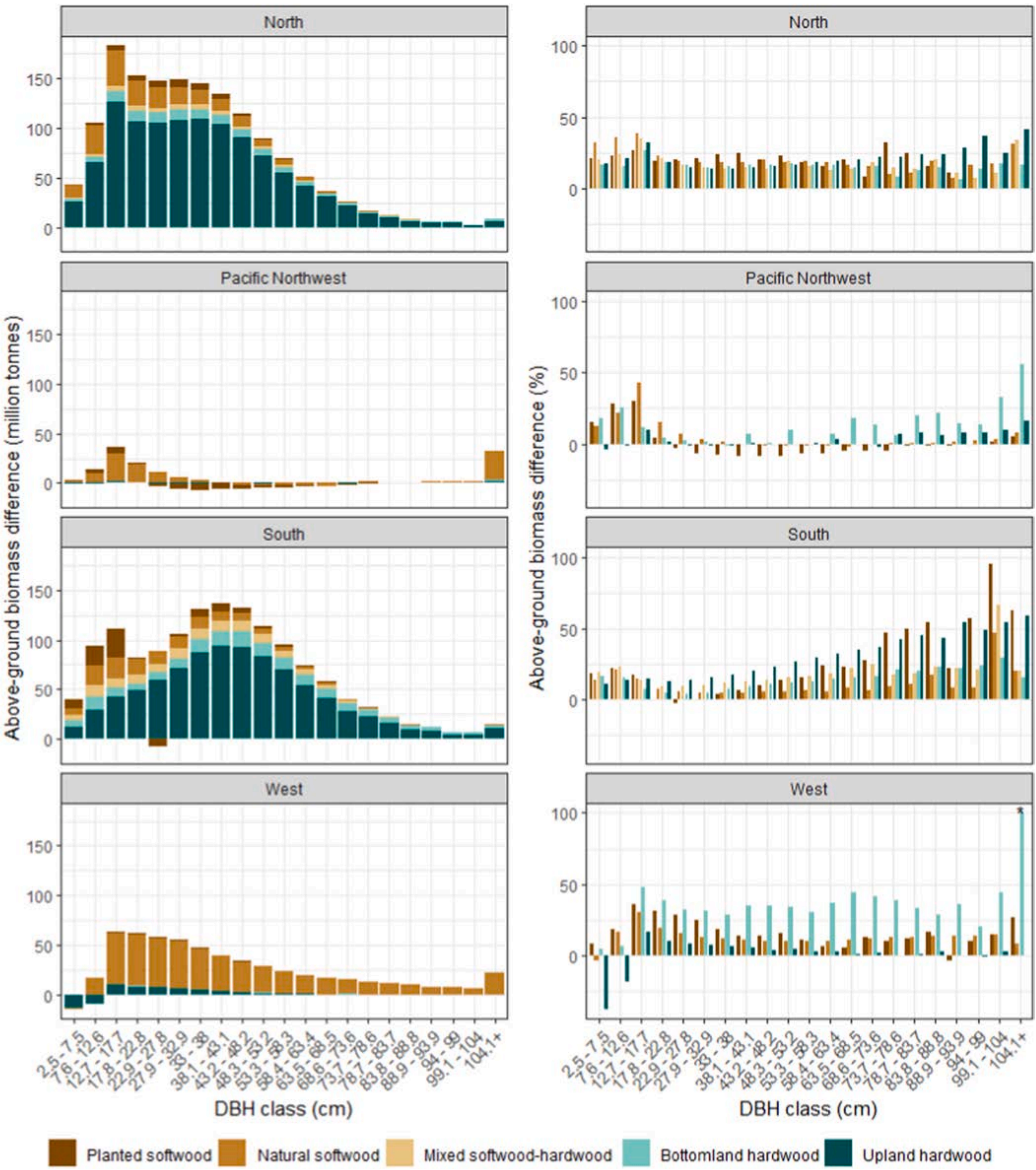

Figure B1. Difference between new and previous model systems implemented in the FIADB by region, forest type and diameter classes. Attribute #10 in FIADB's REF_POP_ATTRIBUTE table "Aboveground biomass of live trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land." DBH classes and AGB converted to cm and tonnes, respectively. The star (*) in the percentage difference indicates a difference greater than 100 %

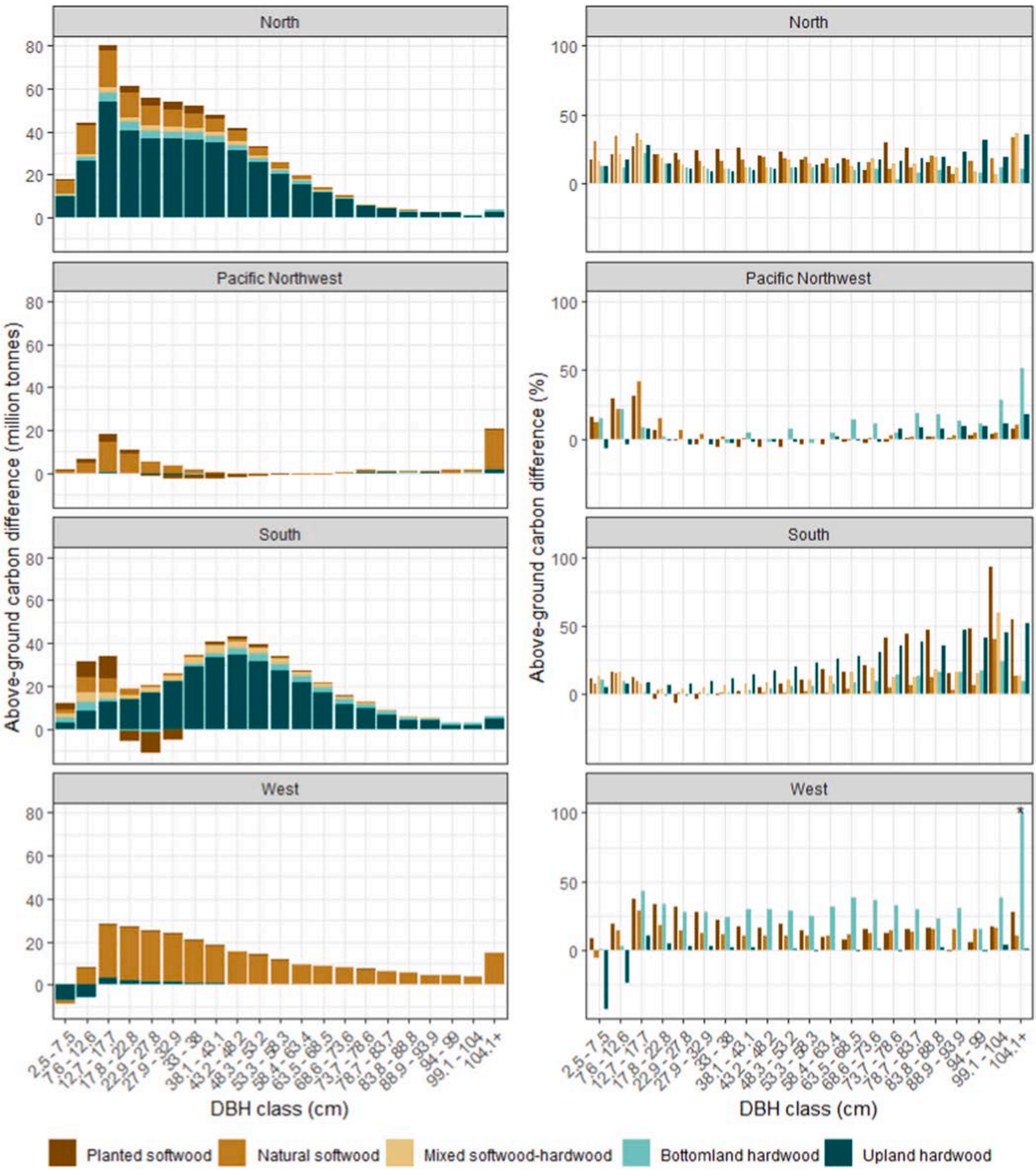

Figure B2. Difference between new and previous model systems implemented in the FIADB by region, forest type and diameter classes. Attributes #53 and #53000 in the previous and new FIADB's REF_POP_ATTRIBUTE tables "Aboveground carbon in live trees (at least 1 in. d.b.h./d.r.c.), in short tons, on forest land." DBH classes and AGC converted to cm and tonnes, respectively. The star (*) in the percentage difference indicates a difference greater than 100 %

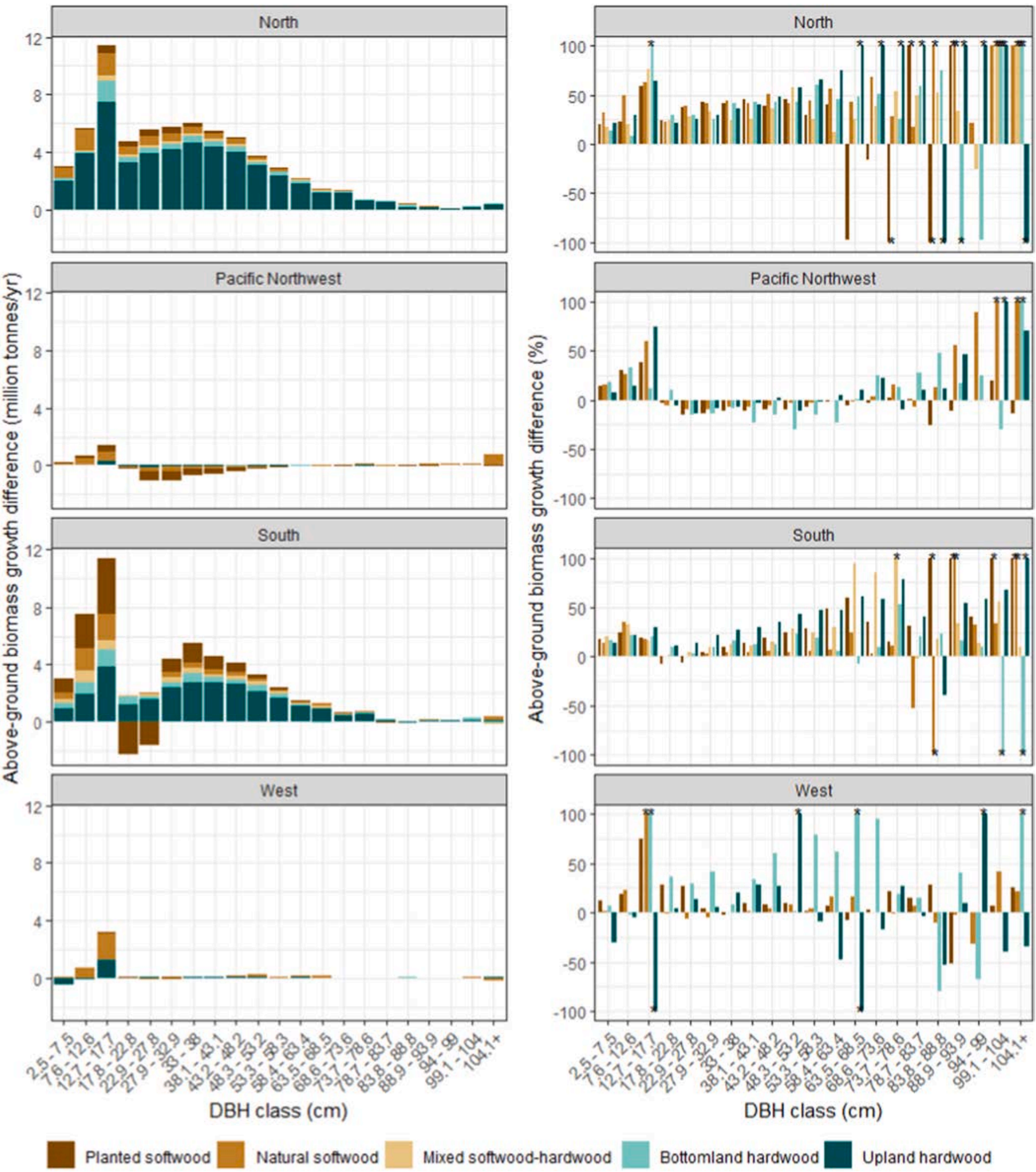

Figure B3. Difference between new and previous model systems implemented in the FIADB by region, forest type and diameter classes. Attribute #311 in FIADB's REF_POP_ATTRIBUTE table "Average annual net growth of aboveground biomass of trees (at least 1 in. d.b.h./d.r.c.), in dry short tons, on forest land." DBH classes and AGB growth converted to cm and tonnes/yr, respectively. The star (*) in the percentage difference indicates a difference greater than 100 %

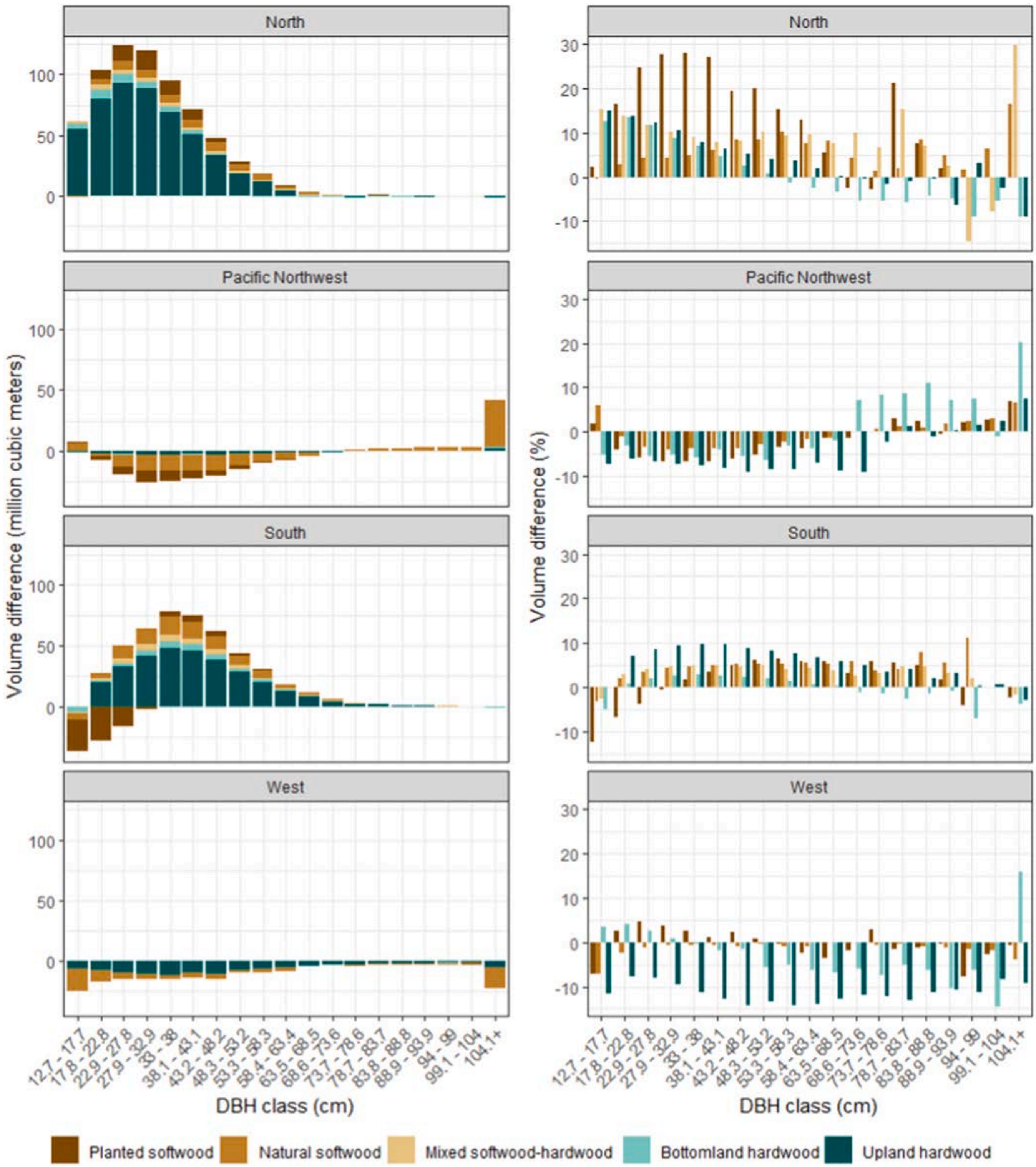

Figure B4. Difference between new and previous model systems implemented in the FIADB by region, forest type and diameter classes. Attribute #15 in FIADB's REF_POP_ATTRIBUTE table, "Net merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land." DBH classes and volume converted to cm and cubic meters, respectively

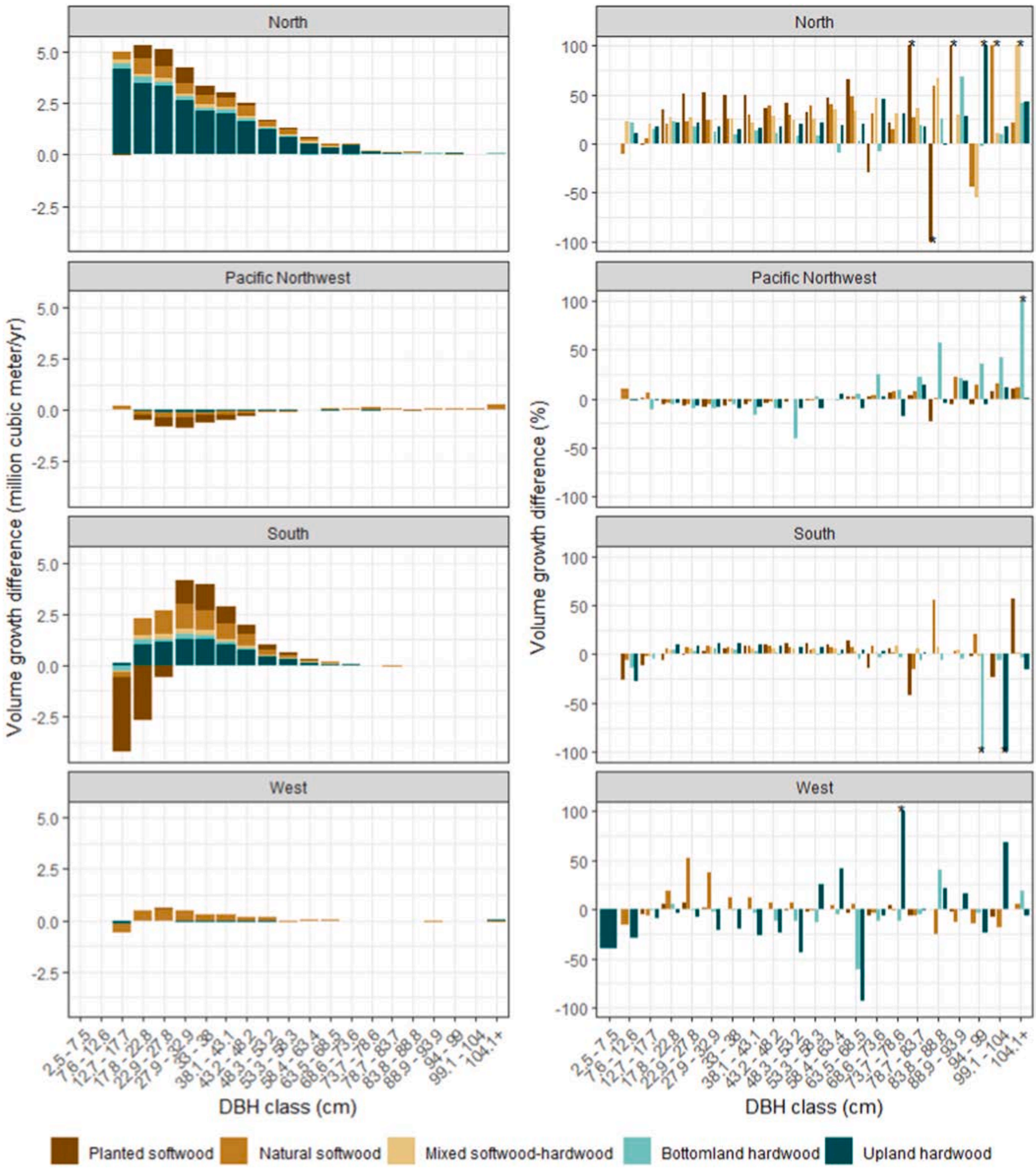

Figure B5. Difference between new and previous model systems implemented in the FIADB by region, forest type and diameter classes. Attribute #202 in FIADB's REF_POP_ATTRIBUTE table, "Average annual net growth of merchantable bole wood volume of growing-stock trees (at least 5 in. d.b.h.), in cubic feet, on forest land." DBH classes and volume growth converted to cm and cubic meters/yr, respectively. The star (*) in the percentage difference indicates a difference greater than 100 %

Data availability

The USDA Forest Service's FIA data is publicly available and free.

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