EXTENDED ABSTRACT

Live Tree Carbon Stock Equivalence of Fire and Fuels Extension to the Forest Vegetation Simulator and Forest Inventory and Analysis Approaches

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The carbon reports in the Fire and Fuels Extension (FFE) to the Forest Vegetation Simulator (FVS) provide two alternate approaches to carbon estimates for live trees (Rebain 2010). These are (1) the FFE biomass algorithms, which are volume-based biomass equations, and (2) the Jenkins allometric equations (Jenkins and others 2003), which are diameter based. Here, we compare FFE and Jenkins-based carbon in aboveground live trees with the component ratio method (CRM) approach (Heath and others 2009) provided in the Forest Inventory and Analysis (FIA) database and focus on identifying where alternate approaches produce equivalent estimates of stand level aboveground live tree carbon.

We have three major objectives in this study where our focus is on the equivalence of alternate approaches when applied to a common set of inventory data:

(1) Test if estimates of live aboveground carbon stocks produced from the CRM, FFE, and Jenkins methods are statistically equivalent

(2) Determine if the relative differences between the estimates are consistent across each of the geographic variants, or are variant-specific

(3) Within variants, identify equivalence or patterns in equivalence by forest type groups and at successively greater levels of aggregations such as all softwood or hardwood forests or whole variants.

We use equivalence testing to address these objectives. Equivalence testing essentially reverses the burden of proof, based on the idea that failure to reject a null hypothesis does not mean that the null hypotheses is true. So, in contrast to more common approaches to hypothesis testing where the null hypothesis is "no significant difference" the null hypothesis of an equivalence test is "the populations/groups are significantly different." An overview of equivalence testing can be found in Parkhurst (2001) and Brosi and Biber (2009). An essential feature is that equivalence bounds are set by the investigator to reflect a value that constitutes a meaningful difference. In this case, we test for equivalence defined as a difference between alternate estimates of carbon stock within ± 5 percent or 10 percent of the mean.

Inventory data were obtained from the Forest Inventory and Analysis Data Base (FIADB), which is compiled and maintained by FIA (USDA Forest Service 2016). The specific data in use here were downloaded from http://apps.fs.fed.us/fiadb-downloads/datamart.html on May 13, 2016 and include the most recent evaluations—or cycle of the permanent inventory plots across each State—encompassing the conterminous United States plus southern coastal Alaska and measurements obtained on plots from 2004 through 2015. For consistency, only those plots representing a single forested condition are used in FVS simulations (USDA Forest Service 2016). We exclude non-stocked or very young (i.e., under 10 year) plots from the analysis because the lack of trees on these forest plots results in a zero-difference in carbon, an artifact biasing the resampling needed to develop the equivalence tests. We used the

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Citation for proceedings: Keyser, Chad E.; Keyser, Tara L., eds. 2017. Proceedings of the 2017 Forest Vegetation Simulator (FVS) e-Conference. e-Gen. Tech. Rep. SRS-224. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 200 p.

FIA2FVS utility to produce the required files to run FVS, and conducted FVS runs for each State and variant (variant version number 1778, April 07, 2016) to generate plot-level live aboveground live carbon estimates for all trees ≥1 inch diameter at 4.5 foot height using the FFE default and Jenkins methods. Plot level estimates were calculated for CRM (USDA Forest Service 2016) directly from the FIADB.

Equivalence tests presented here are paired-sample tests (Feng and others 2006, Mara and Cribbie 2012), with plot-level pairs on each plot (e.g., CRM and FFE). A distribution of mean difference was obtained through bootstrap resampling. The test statistic is the confidence interval about that distribution of mean difference between paired estimates as applied in two one-sided tests of the null hypothesis (Berger and Hsu 1996). Equivalence—rejection of the null hypothesis that the two approaches are different—is the conclusion when the test statistic (95 percent CI) falls entirely within the specified equivalence threshold (e.g., within ±10 percent of mean carbon stock). See Hoover and Smith (2017) for expanded presentation of these methods.

We conducted equivalence tests at several levels of aggregation: whole-variant, by hardwood or softwood type groups within each variant, and by the FIA forest type groups within each variant. The Western United States is covered by 15 major FVS variants, each with different parameters and equations, while the Eastern United States is represented by four variants. In some cases, a user's study area may include more than one variant. Examining the mean variant-wide difference between carbon stock estimates calculated by each method (Jenkins minus CRM, Jenkins minus FFE, and CRM minus FFE), there is a general pattern of Jenkins estimates being generally higher than the CRM or FFE estimates, as noted by (Domke 2012), with the CRM and FFE approaches exhibiting the smallest average difference. This is an expected outcome, since both the CRM and FFE methods are based on the volume-to-biomass approach. There is no consistent pattern across variants; while the CRM and FFE estimates are most often equivalent, this is not always true. In some variants, such as Central States, none of the estimates are equivalent, while all of the estimates are equivalent in the Southern and Klamath Mountains variants, for example.

At the forest type group within variant level, patterns of equivalence are highly variable, with some forest type groups more likely to have at least one pair of equivalent estimates across multiple variants (e.g., lodgepole pine in the West) while other type groups are rarely equivalent (e.g., aspen/birch in the West). In many cases, several different volume equation sets are in use within a variant (fig. 1); part of the variability among forest type groups or variants may be attributed to the many combinations of volume equations underlying the estimates. In general, softwood groups are slightly more likely to have at least one of the pairs of carbon stock estimates identified as equivalent than are the hardwood groups. The paired CRM and FFE approaches more frequently produce equivalent estimates than do the other two paired approaches, but none of these results are consistent across all variants. Each of these results—more common equivalence of softwoods and the CRM-FFE pair—become more apparent at increasing levels of aggregation, particularly in the East (table 1). When comparing carbon stock estimates generated using different methods, scale of the assessment is important to consider because the trend of greater equivalence with aggregation suggests that estimates for larger spatial extents are less sensitive to the choice of estimation method.

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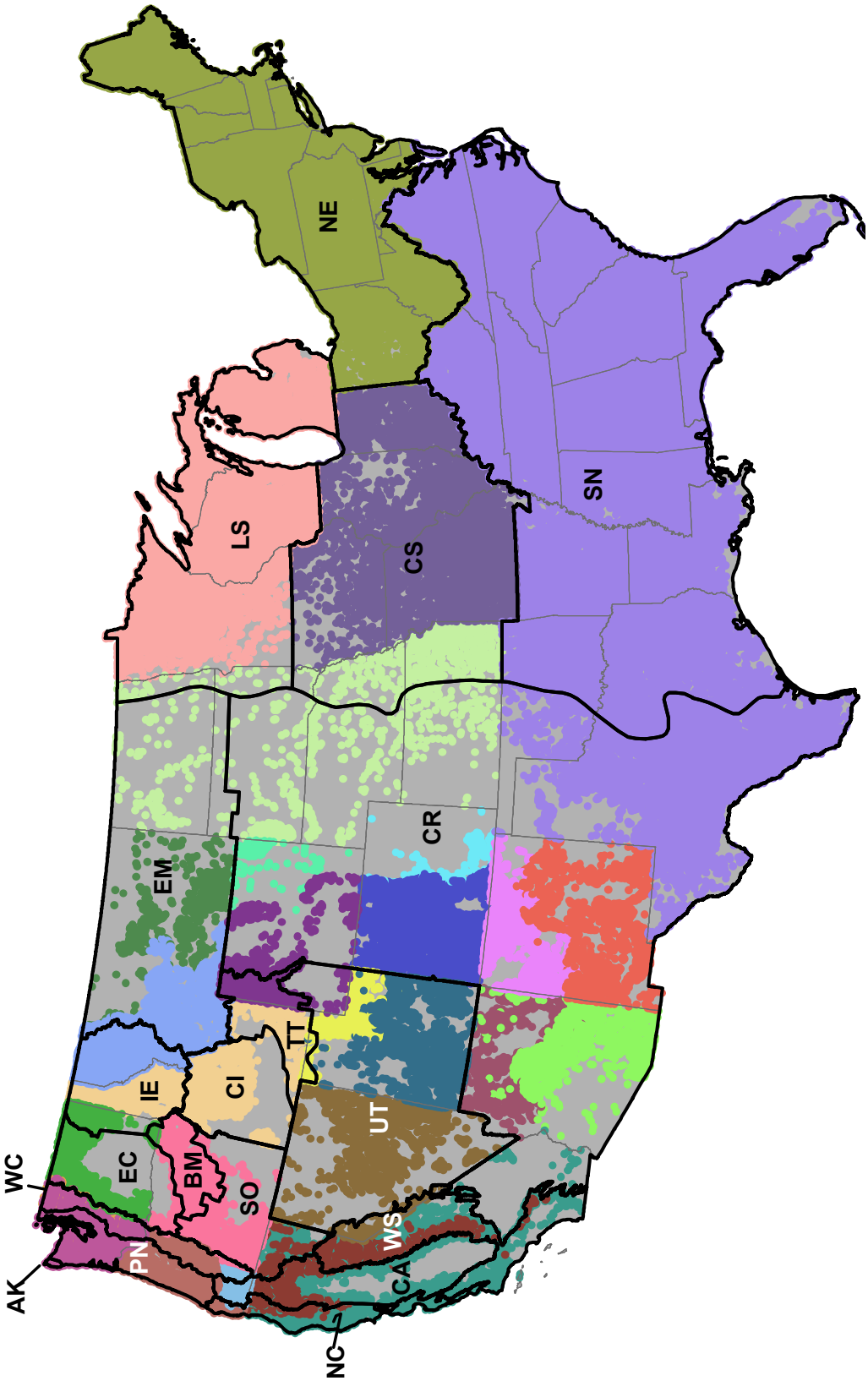

Figure 1—Location of the 19 FVS variants (lines) and the regional volume equations underlying the CRM approach (colors). See FVS or the FIADB documentation for details.

Table 1—Equivalence results from aggregating all western and eastern softwood and hardwood type groups for the three estimation approaches

Estimation approach	Equivalence Level[a]	Western Softwoods[b]	Eastern Softwoods[c]	Western Hardwoods[b]	Eastern Hardwoods[c]
Jenkins- CRM	5%	No	Yes	No	No
	10%	No	Yes	No	No
Jenkins - FFE	5%	No	No	No	No
	10%	No	Yes	No	No
CRM-FFE	5%	No	Yes	No	Yes
	10%	Yes	Yes	Yes	Yes

[a] Equivalence levels tested are 5 and 10% of the mean difference between pairs.
[b] Western is defined as all other variants, including Alaska.
[c] Eastern is defined as the Lake States, Northeast, Central States, and Southern variants.

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