BIOMASS ESTIMATES FOR NATURAL-ORIGIN HARDWOOD SAPLINGS OF SOUTHEASTERN ARKANSAS

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ABSTRACT

Biomass estimates are integral to carbon and feed stocks, fuel loads, and primary productivity. Understories of mature, natural-origin, pine (*Pinus* spp.) and pine-hardwood stands in southeastern Arkansas are dominated by shade-tolerant hardwoods which are poorly represented by existing biomass equations. Destructive sampling of 120 saplings [(0.5–12.2 cm in diameter at breast height (d.b.h.)] was used to develop biomass models for six hardwood species. A linear, two-parameter logarithmic model was used with d.b.h. as the main predictor. Local equations were compared to standard national-scale equations. Although local equations did not outperform standard equations, use of standard equations may result in estimation error of 4–5 kg. The Updated standard equations (Chojnacky and others 2014) had better fit to local data than the Jenkins standard equations (Jenkins and others 2003). A pooled biomass model provided a good fit to observations (R^2 = 0.97) indicating the potential for use of a general equation.

INTRODUCTION

Biomass estimates are essential in carbon and biofuel stock, fuel loads, and primary productivity determinations. Inventories of carbon and biofuel stock rely on individual tree biomass, calculated from allometric equations, that are subsequently aggregated at forest and landscape scales to determine current and projected conditions (Bataineh 2020, Heath and others 2009). Tree biomass derived from allometric equations is also fundamental in calibrating remote sensing datasets to provide biomass maps at regional and landscape scales (Vorster and others 2020). Biomass map validation commonly assumes that plot-level estimates are error free and can be directly compared to biomass predicted from spectral, textural, or vegetation index variables (Lu 2006). However, errors associated with allometric equations are propagated at higher aggregation levels. Consequently, uncertainty associated with allometric equations may even exceed that associated with calibration of remote sensing datasets, especially when an independent dataset is used for the validation (Vorster and others 2020). Although locally developed biomass equations better reflect tree species characteristics and growing conditions, and thus may be expected to be more accurate (Vorster and others 2020, Weiskittel and others 2015), local equations do not necessarily outperform national or standard equations (Nelson and others 2014). In contrast, standard equations may not be applicable to the intended locality leading to significant estimation errors (Nelson and others 2012, Wang and others 2002).

Allometric equations for tree biomass previously focused on large trees of commercial value (Bullock and Burkhart 2003). As interest in forest carbon and biofuel inventories grew, allometric equations for small-diameter trees were developed and expanded to encompass more species, including those commonly dominant in the understories of natural-origin pine (*Pinus* spp.) and pine-hardwood stands (Bragg and Scott 2014). Consistent, national scale, diameter-based allometric equations were later developed to support carbon inventories (Jenkins and others 2003). In these national-scale equations, hereafter referred to as Jenkins standard equations, pseudodata from published diameter-based

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biomass equations were used to develop more generalizable models. Forty published equations were combined in the development of Jenkins standard equations for 21 hardwood species (i.e., mixed hardwood group) that included winged elm (*Ulmus alata*), flowering dogwood (*Cornus florida*), white ash (*Fraxinus americana*), and blackgum (*Nyssa sylvatica*) (Jenkins and others 2003). The 10 Jenkins standard equations were later refined and updated, hereafter referred to as updated equations, to provide 35 allometric equations, 18 updated and refined for hardwood species (Chojnacky and others 2014). Jenkins and the updated standard equations minimum diameters were 2.5 and 3 cm, respectively.

Although Jenkins and the updated equations are best validated using large, representative biomass data encompassing tree species ranges, comparisons with independent datasets not included in the standard equations would highlight the applicability of these equations for a specific locality and determine the need for locally developed biomass equations. The objectives of this study were to 1) develop a local set of total aboveground biomass equations in dry weight terms for saplings ranging in diameter from 0.5 to 12.2 cm of six hardwood species commonly present in the understories of mature, natural-origin pine and pine-hardwood stands of southeastern Arkansas, and 2) compare local models and observations against standard models (Jenkins and updated) to verify standard models using an independent, yet limited, dataset.

MATERIALS AND METHODS

Study Area

Two unmanaged, mature (80–120 years old), natural-origin pine-hardwood stands in Cleveland County, Arkansas, constituted the study area. The stands had a similar disturbance history with a harvest in the late 19th century followed by no management intervention. Stand overstories were composed of a mixture of pine-hardwood with shortleaf pine (*P. echinata*), loblolly pine (*P. taeda*), southern red oak (*Quercus falcata*), cherrybark oak (*Q. pagoda*), post oak (*Q. stellata*), and white oak (*Q. alba*) as main components (Woods and others 2004). Dense hardwood-dominated understories were present with an abundance of shrubs and vines. Stands were 11 km apart. The two stands are within the Upper West Gulf Coastal Plain, which is described as rolling plains punctuated with fluvial terraces, bottomlands, and low cuestas. Climate of the area is warm in summers and mild in winters with 135 cm of mean annual precipitation, most of which occurs from November through May, and a mean annual temperature of 17 °C (Larance and others 1968). Annual frost-free period is 236 days. Forests cover the landscape with loblolly pine, shortleaf pine, sweetgum (*Liquidambar styraciflua*), oak, gum (*Nyssa* spp.), and hickory (*Carya* spp.) as main species (Woods and others 2004). Elevation is between 11 and 213 m above sea level. Soils series of the study area include Savannah (siliceous, semiactive, thermic Typic Fragiudults), which are described as very deep, moderately well drained, and slowly permeable on uplands and terraces; Wehadkee (mixed, active, nonacid, thermic Fluvaquentic Endoaquepts), which are very deep, poorly to very poorly drained along streams and on floodplains in bottomlands; Boswell (mixed, active, thermic Vertic Paleudalfs), which are very deep, moderately well drained, and very slowly permeable fine sandy loams on uplands; Caddo (siliceous, active, thermic Typic Glossaqualfs), which are described as very deep, poorly drained, acidic soils, with little organic matter in upland locations; and Stough (siliceous, semiactive, thermic Fragiaquic Paleudults), which are poorly drained, acidic, of low fertility, coarse loams along stream terraces (Larance and others 1968).

Sampling Design and Measurements

In 2015, 120 saplings were destructively sampled. Six species were selected, namely: flowering dogwood (*Cornus florida*), white ash (*Fraxinus americana*), American holly (*Ilex opaca*), blackgum (*Nyssa sylvatica*), eastern hophornbeam (*Ostrya virginiana*), and winged elm (*Ulmus alata*). Saplings ranged in diameter at breast height (d.b.h.) from 0.5 to 12.2 cm and were 1.5 to 14.4 m tall (table 1). Saplings were selected randomly from each d.b.h. distribution quintile for each stand to ensure a representative sample across the available size ranges. For each of six

Table 1—Characteristics of saplings sampled from two unmanaged stands in Cleveland County, AR, for each of six hardwood species commonly present in the understories of mature, natural-origin pine and pine-hardwood stands of southeastern Arkansas

Species	n	d.b.h.	GLD	Height
		cm	*cm*	*m*
Flowering dogwood (*Cornus florida*)	20	6.2 (1.0–12.2)	8.5 (2.0–16.5)	6.2 (2.3–9.1)
White ash (*Fraxinus americana*)	20	5.4 (0.5–11.4)	7.8 (1.8–16.0)	7.3 (1.8–14.4)
American holly (*Ilex opaca*)	20	2.0 (0.5–4.3)	3.2 (1.3–5.6)	2.8 (1.5–5.2)
Blackgum (*Nyssa sylvatica*)	20	6.2 (1.0–10.7)	8.9 (2.0–15.5)	6.8 (2.3–10.6)
Eastern hophornbeam (*Ostrya virginiana*)	20	3.3 (0.5–10.7)	5.3 (1.5–15.5)	5.3 (1.6–12.2)
Winged elm (*Ulmus alata*)	20	4.5 (1.5–12.2)	6.8 (2.5–17.0)	5.9 (3.0–12.4)

Mean values with ranges in parenthesis.
d.b.h. = diameter at breast height; GLD = groundline diameter.

species, two saplings were sampled within each quintile for a total of 10 individuals per stand, and a total of 20 individuals per species. Saplings near roads, in decline, or showing damage symptoms were not included in sampling. Saplings were measured for d.b.h., groundline diameter, diameter at crown base, height to crown base, and total height. Saplings were cut at the groundline above the root collar. Total aboveground biomass was defined as all aboveground material including foliage, branches, and stem. Cut saplings were oven dried at 100 °C to a constant weight.

Analytical Approach

To develop a local set of total aboveground biomass equations in dry weight terms, the two-parameter logarithmic model was used. This is the same model used in Jenkins and the updated standard equations and is appealing for simplicity in fitting procedures and rescaling of variance to address heteroscedasticity (Baskerville 1972, Parresol 1999). Although the two-parameter logarithmic model is reported to result in underestimates of biomass when antilogarithms are used to backtransform to original units, correction of backtransformed biomass to remedy this downward bias tends to overestimate the true bias and is sample-size dependent (Jenkins and others 2003, Parresol 1999). To keep with Jenkins and the updated standard equations, in this study of comparing local and standard equations, no correction factors were used (Jenkins and others 2003). Local biomass equations were fit for pooled species data as well as each species separately using natural logarithm transformed biomass and d.b.h. values. Scatter plots depicting total aboveground biomass against d.b.h. and other measured dimensions were examined to screen data and determine adequacy of model form (Parresol 1999). All equations were fit using the lm function of the R base package version 3.0.2 (R Development Core Team 2013). No indication of patterns in residual plots were detected as evidence of violation of assumptions of normality and homogeneity of variance, thus no weighting of observations was necessary (Baskerville 1972).

To ensure use of the same model form, transformed model parameters were used to compare local and standard models (Jenkins and updated). Local and standard models were also compared graphically. Observations used to develop local models were used in calculating accuracy and precision metrics for the standard models. Accuracy was evaluated by calculating the root mean square error (RMSE), whereas precision was evaluated using mean absolute error (MAE) for standard models (Vorster and others 2020). Jenkins mixed hardwood group equation was used to estimate total aboveground biomass for five of the six species examined in this study (Jenkins and others 2003). Eastern hophornbeam with a wood specific gravity of 0.63 (Miles and Smith 2009) was estimated using Jenkins hard maple/oak/hickory/beech group equation. In estimating biomass using the updated equations, white ash and eastern hophornbeam had their own generalized equations, whereas the remaining four species were estimated using the mixed hardwood group equation, representing members of the Cornaceae, Ericaceae, Lauraceae, Platanaceae, Rosaceae, and Ulmaceae (Chojnacky and others 2014).

RESULTS AND DISCUSSION

Total aboveground biomass equations were developed for saplings (0.5–12.2 cm in d.b.h.) of six hardwood species commonly present in the understories of mature, natural-origin, pine and pine-hardwood stands of southeastern Arkansas to better reflect local species characteristics and growing conditions (table 2). Goodness of fit measures for each of the individual species' equations indicated overall good model fits with R^2 values ranging from 0.93 to 0.99 (table 2). RMSE values ranged from 0.16 to 0.32 kg, indicating a low level of uncertainty in predicting total aboveground biomass of hardwood saplings. All models had low MAE values not exceeding 0.26 kg. A pooled species equation, n = 120, produced a good model fit with RMSE and MAE values within the range observed for individual species equations, albeit closer to maximum values of the range (table 2). Pooled species equation coefficients were within the range observed for individual species equations (table 2), indicating that a pooled model may be sufficient for estimating aboveground biomass of those six hardwood species (fig. 1).

Local aboveground biomass equation coefficients were similar to those provided by Jenkins and updated (Chojnacky and others 2014, Jenkins and others 2003) standard equations (tables 2 and 3). Local intercept coefficients were, on average, 0.8 higher than the standard equations. Local slope parameter values were, on average, 0.4 lower than those provided by the standard equations. Both Jenkins and updated standard equations showed a good fit to the local data collected in this study, despite having a slightly higher minimum d.b.h. threshold (fig. 2). Although local equations inherently had lower RMSE values, standard equations RMSE values ranged from 0.72 to 5.17 kg for Jenkins equations and from 0.50 to 3.56 kg for updated equations (table 3). MAE values ranged from 0.53 to 3.26 kg for Jenkins equations and from 0.37 to 2.00 kg for updated equations. The updated equations appeared to better fit the local data than the Jenkins standard equations (fig. 2). Generally, standard equations appeared to be applicable to the data collected in this study, in contrast to that reported elsewhere (Nelson and others 2012, Wang and others 2002). Local equations did not seem to drastically outperform national or standard equations at the individual level, which is similar to that reported elsewhere (Nelson and others 2014). However, validation of standard equations using an independent, yet limited, dataset showed that use of standard equations may result in small-diameter tree biomass estimation error of upwards of 4–5 kg, which may be propagated at higher aggregation levels of stands and landscapes (Vorster and others 2020).

Table 2—Total aboveground biomass model {ln(biomass in kg = $\beta_0 + \beta_1$ ln[d.b.h in cm])} coefficients, standard errors, *P*-values, and goodness of fit measures for saplings (0.5–12.2 cm in d.b.h) of six hardwood species commonly present in the understories of mature, natural-origin pine and pine-hardwood stands of southeastern Arkansas

Species	β_0 (SE)	β_1 (SE)	*P*	R^2	RMSE	MAE
Flowering dogwood (*Cornus florida*)	-1.59 (0.11)	2.17 (0.06)	<0.001	0.99	0.16	0.12
White ash (*Fraxinus americana*)	-1.46 (0.15)	2.06 (0.09)	<0.001	0.97	0.30	0.26
American holly (*Ilex opaca*)	-1.25 (0.09)	1.78 (0.11)	<0.001	0.93	0.32	0.25
Blackgum (*Nyssa sylvatica*)	-1.82 (0.20)	2.15 (0.11)	<0.001	0.95	0.26	0.17
Eastern hophornbeam (*Ostrya virginiana*)	-1.16 (0.09)	1.95 (0.07)	<0.001	0.98	0.28	0.22
Winged elm (*Ulmus alata*)	-1.71 (0.15)	2.20 (0.10)	<0.001	0.96	0.22	0.18
Pooled species	-1.34 (0.05)	1.98 (0.03)	<0.001	0.97	0.30	0.23

Coefficient estimates and standard errors (SE) in parenthesis.
d.b.h. = diameter at breast height; RMSE = root mean square error; MAE = mean absolute error.

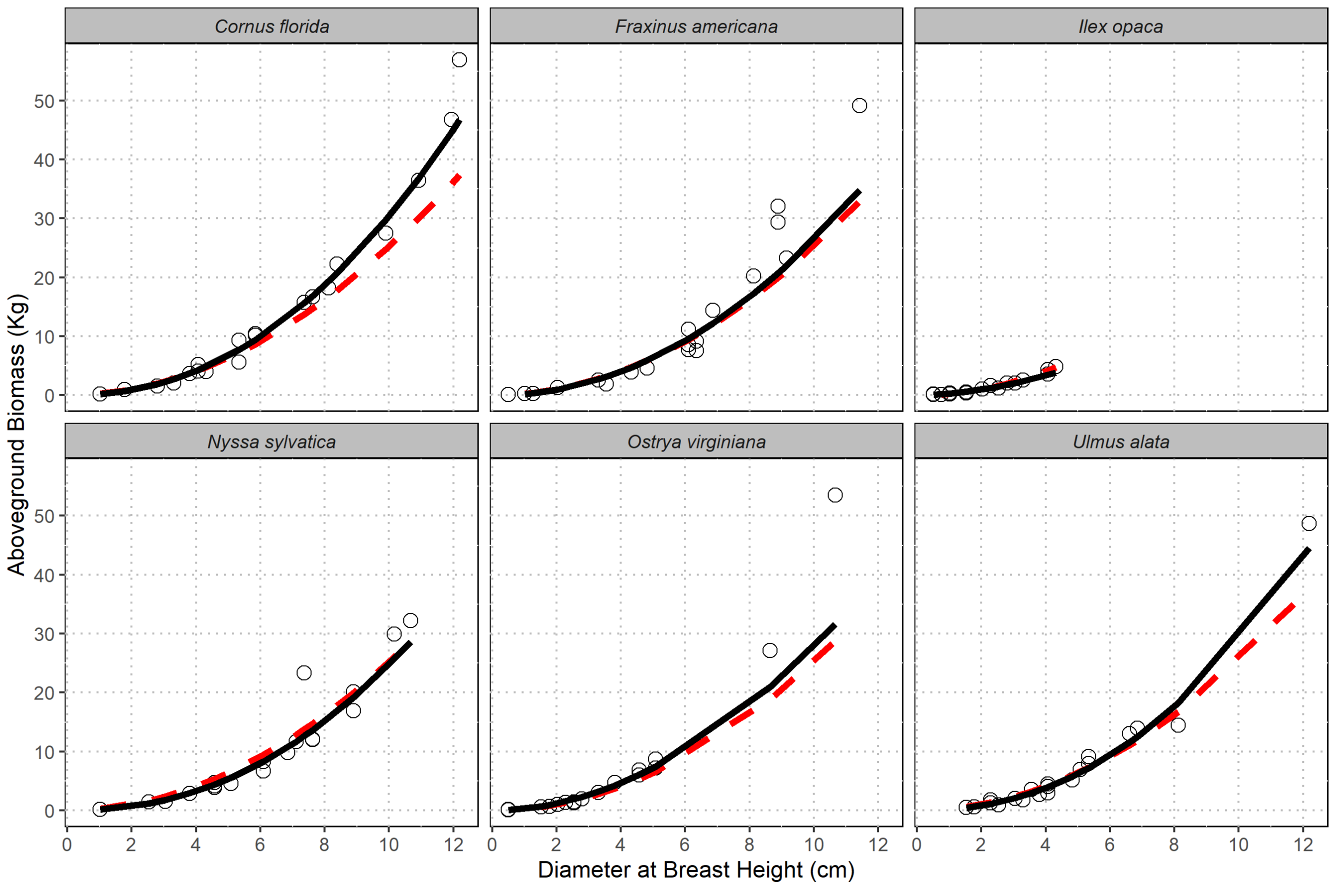

Figure 1—Individual (solid black line) and pooled (dashed red line) species models of total aboveground biomass for saplings (0.5–12.2 cm in d.b.h) of six hardwoods commonly present in the understories of mature, natural-origin, pine and pine-hardwood stands of southeastern Arkansas.

Table 3—Jenkins and updated standard equations {*ln*(biomass in kg = $\beta_0 + \beta_1$ ln[d.b.h in cm])} coefficients as well as precision and accuracy metrics for saplings (0.5–12.2 cm in d.b.h) of six hardwood species commonly present in the understories of mature, natural-origin pine and pine-hardwood stands of southeastern Arkansas

	Species	β_0	β_1	RMSE	MAE
Jenkins equations	**Flowering dogwood (*Cornus florida*)**	-2.48	2.48	4.66	3.26
	White ash (*Fraxinus americana*)	-2.48	2.48	5.17	2.98
	American holly (*Ilex opaca*)	-2.48	2.48	0.72	0.53
	Blackgum (*Nyssa sylvatica*)	-2.48	2.48	3.41	1.83
	Eastern hophornbeam (*Ostrya virginiana*)	-2.01	2.43	2.57	1.02
	Winged elm (*Ulmus alata*)	-2.48	2.48	2.41	1.68
	Pooled species	-2.48	2.48	4.10	2.16
Updated equations	**Flowering dogwood (*Cornus florida*)**	-2.21	2.41	3.07	1.94
	White ash (*Fraxinus americana*)	-1.84	2.35	2.49	1.76
	American holly (*Ilex opaca*)	-2.21	2.41	0.50	0.37
	Blackgum (*Nyssa sylvatica*)	-2.21	2.41	3.56	2.00
	Eastern hophornbeam (*Ostrya virginiana*)	-2.27	2.53	2.80	1.30
	Winged elm (*Ulmus alata*)	-2.21	2.41	1.54	1.16
	Pooled species	-2.21	2.41	3.29	1.64

d.b.h. = diameter at breast height; RMSE = root mean square error; MAE = mean absolute error.

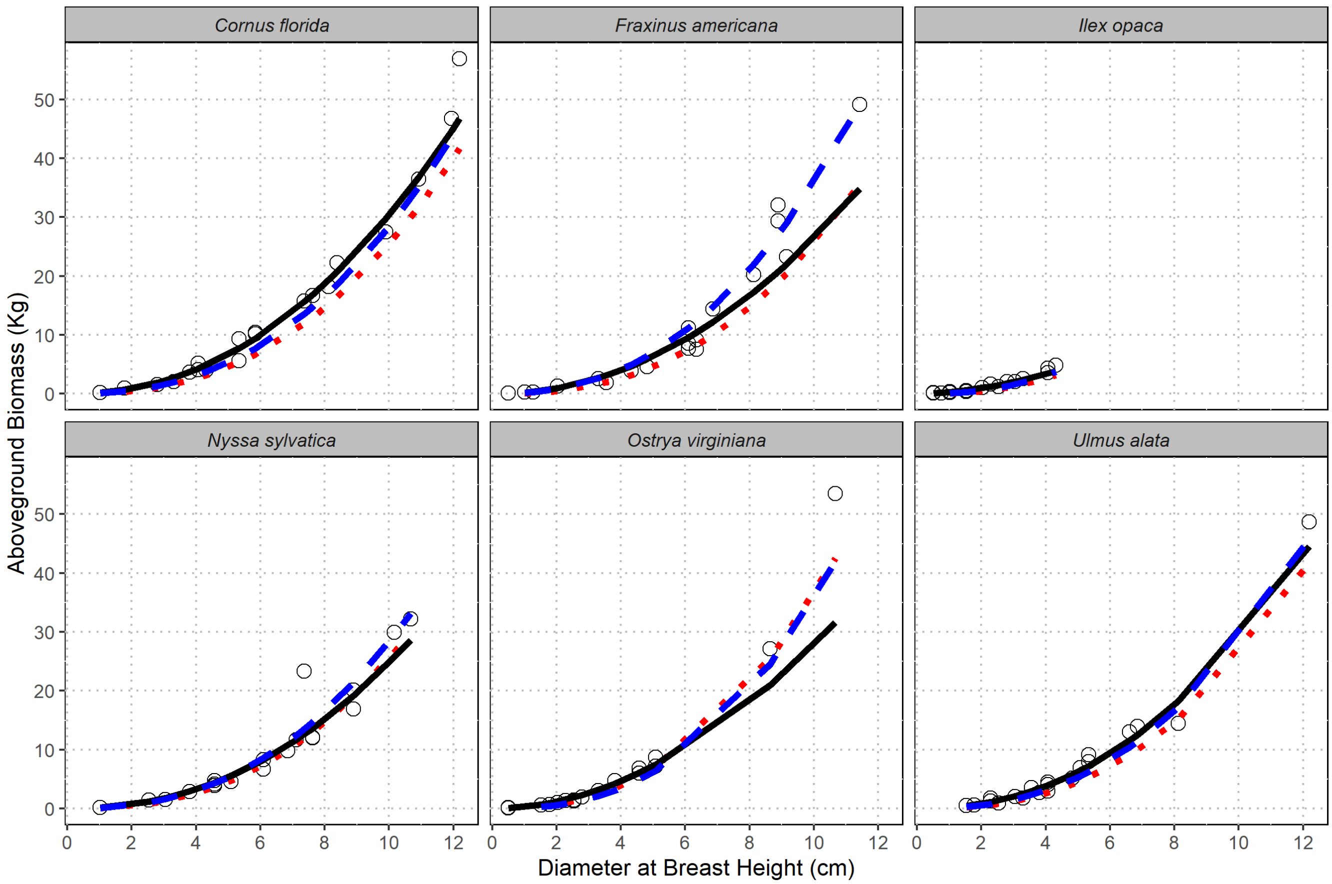

Figure 2—Locally developed total aboveground biomass equations (solid black line) compared to Jenkins standard equations (dotted red line) and updated standard equations (dashed blue line) for saplings (0.5–12.2 cm in d.b.h) of six hardwood species commonly present in the understories of mature, natural-origin, pine and pine-hardwood stands of southeastern Arkansas.

CONCLUSIONS

To better estimate and map regional carbon and biofuel stock, inventories should include understories of mature, natural-origin pine and pine-hardwood stands such as those in southeastern Arkansas. Shade-tolerant hardwood species constituting these understories are poorly represented by existing biomass equations. Before an existing biomass equation can be applied, errors associated with estimating individual tree biomass must be evaluated to determine the applicability of existing equations to the intended locality. A set of local total aboveground biomass equations were developed for small-diameter hardwoods of six commonly occurring understory species in mature, natural-origin, pine and pine-hardwood stands. Local models did not appear to drastically outperform standard, national-scale, diameter-based allometric equations at the individual level. The updated standard equations appeared to provide better fit than the Jenkins standard equations at local scales like those presented in this study. Locality specific applications, however, may still use the provided local equations to better represent intended populations.

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