

**A Streamlined Approach to the Component Ratio Method for RGGI
U.S. Forest Projects Outside of California, Oregon, Washington,
Alaska and Hawaii**

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Background on the Component Ratio Method

The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service in 2009 adopted a process for estimating non-sapling and non-woodland tree biomass called the component ratio method (CRM) (Heath et al. 2009). The purpose of this methodology was to harmonize differences in biomass estimation between the different FIA regions (Woodall et al. 2011). Forest carbon projects located outside of California, Oregon, Washington, Alaska and Hawaii must use the CRM so that project-level calculations are consistent with the FIA calculations that were used to determine Common Practice for the assessment areas in those states. The remainder of this document pertains to projects located outside of California, Oregon, Washington, Alaska and Hawaii.

For trees ≥ 5.0 inches in diameter, the CRM computes aboveground biomass as the sum of three components: bole of the tree, stump of the tree, and top of the tree (including limbs, but not foliage). The biomass of the tree bole is calculated using regional volume equations, while the biomass of additional tree components is calculated using a series of ratios established in Jenkins et al. (2003). It is important to note that while the RGGI U.S. Forest Projects Offset Protocol (protocol) includes foliage in its definition of aboveground biomass, the foliage portion of the tree is not included in the FIA calculations using the CRM. Therefore, foliage must be excluded from a project's aboveground biomass calculations using the CRM for the purposes of maintaining consistent comparisons with Common Practice.

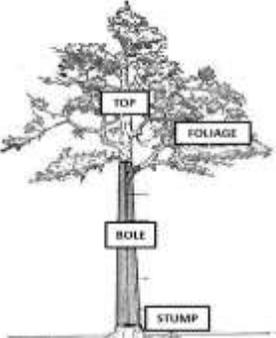
For woodland trees ≥ 5.0 inches diameter (trees where diameter is measured at the root collar), biomass is estimated based on volume for the entire aboveground portion of the tree with no component break-down. For all trees between 1.0 and 5.0 inches in diameter (i.e. saplings), total biomass is directly estimated from the total aboveground biomass equation in Jenkins et al. (2003), minus the foliage component, and adjusted with a sapling adjustment factor. No biomass estimates are made for trees < 1.0 inch in diameter (Woodall et al. 2011).

Streamlined Approach to the Component Ratio Method

The following simplified approach to using the CRM may be used for projects located outside of California, Oregon, Washington, Alaska and Hawaii in order to calculate aboveground biomass for non-woodland trees ≥ 5.0 inches diameter. This method results in an equivalent output to the CRM (see Appendix A: Demonstration of Formulaic Equivalencies), and is thus functionally equivalent to methods used by FIA to calculate aboveground biomass. It differs from the CRM as described in Heath (2009), Appendix J of the FIA User Manual (2009), and Woodall et al. (2011) by simplifying the calculations required using formulaic equivalencies as shown in Appendix A of this document.

The remainder of this document presents guidance for undertaking a simplified approach to the CRM. Table 1 describes the main steps to this approach, and is followed by step-by-step instructions. Please note that the original CRM approach, as described in Heath (2009), Appendix J of the FIA User Manual (2009), and Woodall et al. (2011) is accepted by RGGI, if project developers choose to use this method for projects outside of California, Oregon, Washington, Alaska, and Hawaii.

Table 1. Key Steps to the Alternative Approach for Calculating Aboveground Biomass
 The steps outlined below correspond to the instructions provided in Section 3 of this document.

Equation Reference	Step Reference	Related Portion of Tree
Jenkins total aboveground biomass (JTAGB)	<p>Step 6a: The Jenkins equation produces a total aboveground estimate that includes top, foliage, bole (including both wood and bark), and stump. This estimate is referred to as JTAGB.</p>	
Foliage biomass	<p>Step 6b: Foliage biomass must be estimated since it is not included in the Common Practice estimates. Foliage is estimated using a ratio applied to JTAGB.</p>	
Bole biomass according to both Jenkins and regional equations	<p>Step 6c: The Jenkins bole component is determined by applying a bark ratio and a wood ratio to JTAGB.</p> <p>Step 7a: Regional bole is determined using regional volume, bark percentage, and density equations. This estimate (without the bark) is also used as a factor in determining Harvested Wood Products (as the sum of the portion of harvested trees delivered to mills).</p>	
Adjustment factor (AdjFac)	<p>Step 8a: An adjustment factor is developed by dividing the regional bole estimate by the Jenkins bole estimate.</p>	
Final aboveground biomass	<p>Step 8b: Jenkins total aboveground biomass is adjusted by subtracting foliage and multiplying by the adjustment factor to get final aboveground biomass.</p>	

Instructions

Step 1. Identify which Supersection the project is located in using the Assessment Area Data File and related files located on the www.rggi.org.

Step 2. Identify the appropriate volume equation for each species in the project by Supersection in the following spreadsheet, *Volume Equation References and Coefficients by Species for Supersections outside of California, Oregon, Washington, Alaska, and Hawaii*. The coefficients for the equations are provided in the same document.

Step 3. Calculate gross cubic foot volume for each tree bole, using the equations provided in *Volume Equations for the United States outside of California, Oregon, Washington, Alaska, and Hawaii*. This will yield the value for VOLCFGRS, which must then be converted to VOLCFSND (sound cubic foot volume) by subtracting rotten and missing cull volume (additional data provided).

Step 4. Download *Biomass Coefficients for use with the Component Ratio Method*, and follow the steps outlined in this guidance. While the instructions presented here should be adequate, the following resources may serve as helpful reference materials: *Biomass Estimation using the Component Ratio Method (Appendix J, 2009)*, and *Investigation into Calculating Tree Biomass and Carbon in the FIADB Using a Biomass Expansion Factor Approach: An Article Describing the Component Ratio Method (Heath et al. 2009)*. These resources can be found on www.rggi.org.

Step 5. Collect the information needed for the Jenkins and CRM estimates, including:

- The Jenkins biomass and component coefficients for the appropriate species, which can be found in *Biomass Coefficients for use with the Component Ratio Method*, including:
 - Specific Gravity of Bark (SG_BARK), labeled BARK_SPGR_GREENVOL_DRYWT
 - Specific Gravity of the Wood (SG_WOOD), labeled WOOD_SPGR_GREENVOL_DRYWT
 - Bark as a percent of wood volume (BRK_VOL_PCT)
 - JENKINS_TOTAL_B1; JENKINS_TOTAL_B2
 - JENKINS_STEM_WOOD_RATIO_B1; JENKINS_STEM_WOOD_RATIO_B2
 - JENKINS_STEM_BARK_RATIO_B1; JENKINS_STEM_BARK_RATIO_B2
 - JENKINS_ROOT_RATIO_B1; JENKINS_ROOT_RATIO_B2
 - JENKINS_FOLIAGE_RATIO_B1; JENKINS_FOLIAGE_RATIO_B2
- The volume of sound wood estimates calculated in Step 3 (VOLCFSND)

- Density of Water = 62.4

Step 6. Calculate Jenkins Total Aboveground Biomass and Various Components (adapted from Appendix J Table J-3)

Step 6a. Calculate Jenkins total aboveground biomass (lbs.) =

$$= (e^{(JENKINS_TOTAL_B1 + JENKINS_TOTAL_B2 * \ln(DBH*2.54))}) * 2.2046$$

Step 6b. Calculate Jenkins foliage biomass (lbs.) =

$$Jenkins\ Foliage = (Jenkins\ total\ aboveground) * Jenkins\ foliage\ component\ ratio$$

Where:

- Jenkins foliage component ratio:

$$= e^{(JENKINS_FOLIAGE_RATIO_B1 + \frac{JENKINS_FOLIAGE_RATIO_B2}{(DBH*2.54)})}$$

Step 6c. Calculate Jenkins bole biomass (lbs.) =

$$= (Jenkins\ total\ aboveground) * (Jenkins\ stem\ bark\ component + Jenkins\ wood\ component)$$

Where:

- Jenkins stem bark component:

$$= e^{(JENKINS_STEM_BARK_RATIO_B1 + \frac{JENKINS_STEM_BARK_RATIO_B2}{(DBH*2.54)})}$$

- Jenkins stem wood component:

$$= e^{(JENKINS_STEM_WOOD_RATIO_B1 + \frac{JENKINS_STEM_WOOD_RATIO_B2}{(DBH*2.54)})}$$

Step 7. Calculate Biomass using Regional Equations (adapted from Appendix J Table J-4)

Step 7a. For trees ≥ 5" diameter, calculate bole biomass (lbs.):

$$DRYBIO_BOLE = VOLCFSND * \left(Density\ of\ Water * SG_BARK * \left(\frac{BRK_VOL_PCT}{100} \right) \right) + (VOLCFSND * Density\ of\ Water * SG_WOOD)$$

Where:

- DRYBIO_BOLE = Bole Biomass
- VOLCFSND = Sound Cubic Foot Volume
- SG_BARK = Bark Specific Gravity
- BRK_VOL_PCT = Bark as a percent of wood volume
- Density of Water = 62.4 lbs./cubic foot

- SG_WOOD = Wood Specific Gravity

Step 8. Make Adjustments to Jenkins Total Aboveground Biomass (lbs.)

Step 8a. Calculate an adjustment factor for the relationship between regional bole biomass and Jenkins bole biomass:

$$\text{AdjFac} = \text{DRYBIO_BOLE} / \text{Jenkins bole}$$

Step 8b. Subtract foliage component from Jenkins total aboveground biomass, and multiply by adjustment factor:

$$\text{AG_Biomass} = (\text{Jenkins total aboveground} - \text{Jenkins foliage}) * \text{AdjFac}$$

Step 9. Calculate belowground biomass (lbs.):

$$\text{BG_Biomass} = \text{Jenkins total aboveground} * \text{root component} * \text{AdjFac}$$

Where:

- Root component:

$$= \exp\left(\frac{\text{JENKINS_ROOT_RATIO_B1} + \frac{\text{JENKINS_ROOT_RATIO_B2}}{(\text{DBH} * 2.54)}}{1}\right)$$

Step 10. Calculate final tree biomass (lbs.):

$$\text{Final_Tree_Biomass} = \text{AG_Biomass} + \text{BG_Biomass}$$

Conversions

Step 1: Convert pounds to metric tons

- 1 pound = 0.000453592 metric tons

Step 2: Convert biomass to carbon

- 1 metric ton biomass = 0.5 metric tons carbon

Step 3: Convert carbon to CO₂

- 1 metric ton carbon = 3.67 metric tons CO₂

References

Forest Inventory and Analysis. 2009. Appendix J. In: DRAFT FIA Database Description and Users Manual for Phase 2, version 4.0, revision 2. U.S. Department of Agriculture, Forest Service.

Heath, Linda S.; Hansen, Mark; Smith, James E.; Miles, Patrick D.; Smith, Brad W. 2009. Investigation into calculating tree biomass and carbon in the FIADB using a biomass expansion factor approach. In: McWilliams, Will; Moisen, Gretchen; Czapslewski, Ray, comps. Forest Inventory and Analysis (FIA) Symposium 2008; October 21-23, 2008; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 26 p.

Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A. 2003. National scale biomass estimators for United States tree species. *Forest Science*. 49: 12-35.

Woodall, Christopher W.; Heath, Linda S.; Domke, Grant M.; Nichols, Michael C. 2011. Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the U.S. forest inventory, 2010. Gen. Tech. Rep. NRS-88. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 30 p.

Appendix A Demonstration of Formulaic Equivalencies

Developed using equations provided in Appendix J of the FIA User Manual, Tables J-3 and J-4 and Heath et al. 2009.

Table A.1 Definitions Used in this Document

Equation	Formula	Reference
Equation 1	$\begin{aligned} \text{bole_biomass_Jenkins} \\ &= \text{stem_biomass_Jenkins} \\ &+ \text{bark_biomass_Jenkins} \end{aligned}$	Appendix Table J-3
Equation 2	$\begin{aligned} \text{top_biomass_Jenkins} \\ &= \text{total_AG_biomass_Jenkins} \\ &- \text{stem_biomass_Jenkins} \\ &- \text{bark_biomass_Jenkins} \\ &- \text{foliage_biomass_Jenkins} - \text{stump_biomass} \end{aligned}$	Appendix Table J-3
Equation 3	$\text{AdjFac} = \text{DRYBIO_BOLE} / \text{bole_biomass_Jenkins}$	Appendix Table J-4
Equation 4	$\text{DRYBIO_STUMP} = \text{stump_biomass} * \text{AdjFac}$	Appendix Table J-4
Equation 5	$\text{DRYBIO_TOP} = \text{top_biomass_Jenkins} * \text{AdjFac}$	Appendix Table J-4
Equation 6	$\begin{aligned} \text{AGBIOT5 (Aboveground Biomass of Trees } \geq 5'' \text{ d.b.h.)} \\ &= \text{DRYBIO_BOLE} + \text{DRYBIO_STUMP} + \text{DRYBIO_TOP} \end{aligned}$	Heath et al. 2009, p. 11
Equation 7	$\begin{aligned} &(\text{total_AG_biomass_Jenkins} - \text{foliage_biomass_Jenkins}) \\ &* (\text{AdjFac}) \\ &= (\text{bole_biomass_Jenkins} * \text{AdjFac}) \\ &+ (\text{stump_biomass} * \text{AdjFac}) \\ &+ (\text{top_biomass_Jenkins} * \text{AdjFac}) \end{aligned}$	This document
Equation 8	$\begin{aligned} &(\text{total_AG_biomass_Jenkins} - \text{foliage_biomass_Jenkins}) \\ &* (\text{AdjFac}) \\ &= \text{DRYBIO_BOLE} + \text{DRYBIO_STUMP} \\ &+ \text{DRYBIO_TOP} \end{aligned}$	This document

Step 1

Rearrange **Equation 2** by adding stem_biomass_Jenkins, bark_biomass_Jenkins, and stump_biomass to each side, resulting in the following:

$$\begin{aligned} total_AG_biomass_Jenkins - foliage_biomass_Jenkins \\ = top_biomass_Jenkins + stem_biomass_Jenkins + bark_biomass_Jenkins \\ + stump_biomass \end{aligned}$$

Step 2

Replace stem_biomass_Jenkins + bark_biomass_Jenkins with bole_biomass_Jenkins according to **Equation 1**, resulting in the following:

$$\begin{aligned} total_AG_biomass_Jenkins - foliage_biomass_Jenkins \\ = bole_biomass_Jenkins + stump_biomass + top_biomass_Jenkins \end{aligned}$$

Step 3

Multiply each side by AdjFac, resulting in the following:

$$\begin{aligned} (total_AG_biomass_Jenkins - foliage_biomass_Jenkins) * (AdjFac) \\ = (top_biomass_Jenkins + bole_biomass_Jenkins + stump_biomass) * (AdjFac) \end{aligned}$$

Step 4

Multiply through, resulting in **Equation 7** as follows:

Equation 7:

$$\begin{aligned} (total_AG_biomass_Jenkins - foliage_biomass_Jenkins) * (AdjFac) \\ = (bole_biomass_Jenkins * AdjFac) + (stump_biomass * AdjFac) \\ + (top_biomass_Jenkins * AdjFac) \end{aligned}$$

Step 5

Rearrange **Equation 3** by multiplying each side by bole_biomass_Jenkins, resulting in the following:

$$bole_biomass_Jenkins * AdjFac = DRYBIO_BOLE$$

Step 6

Replace **Equation 7** with equivalent terms from **Equation 4**, **Equation 5**, and the rearranged **Equation 3** from Step 5, resulting in **Equation 8** as follows:

Equation 8:

$$\begin{aligned} (total_AG_biomass_Jenkins - foliage_biomass_Jenkins) * (AdjFac) \\ = DRYBIO_BOLE + DRYBIO_STUMP + DRYBIO_TOP \end{aligned}$$

Conclusion

Since **Equation 6** and **Equation 8** are equivalent, calculating $(total_AG_biomass_Jenkins - foliage_biomass_Jenkins) * (AdjFac)$ is equivalent to calculating aboveground biomass using the Component Ratio Method.