Adjusting Standing Dead Tree Carbon Pool for Structural Loss and Density

Background:

All U.S. Forest offset projects that submit a listing application on or after January 1, 2015 are required to use the updated protocol version (11/14/14). Previously listed projects may also opt to apply the updated version of the protocol to their next OPDR. Section A.3 of the Compliance Offset Protocol U.S. Forest Projects (Forest Protocol) requires an Offset Project Operator (OPO) or Authorized Project Designee (APD) to develop a forest carbon inventory methodology. This inventory methodology must describe a standardized procedure for field measurements when used to calculate biomass. The inventory methodology includes an estimate of the standing dead tree carbon pool, including how missing or rotten portions of standing dead trees should be treated and how deductions are determined. Verifiers are expected to review the standing dead tree portion of the inventory for conformity with the protocol. Guidance on how to estimate volume and biomass for standing dead trees are provided below; as of 1/1/2015, new density reductions factors and structural loss adjustment requirements have been adopted for all projects outside of California, Oregon, and Washington. Guidance is based upon the referenced Domke (2011) paper: "Accounting for density reduction and structural loss in standing dead trees: Implications for forest biomass and carbon stock estimates in the United States." This paper provides equations and examples to estimate above and belowground standing dead tree biomass and carbon (C) stocks.

Applicability:

All project operators located in states outside of California, Oregon, and Washington, using the current Forest Protocol (11/14/14) must adjust their standing dead wood carbon pool for rotten and missing portions of each tree using a density reduction factor and structural loss adjustment as described in Domke (2011).

Documents:

1. Woodall et al 2011. Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the U.S. forest inventory, 2010.
2. Coefficients for Woodall: Zip file download here
3. Domke et al 2011. Accounting for density reduction and structural loss in standing dead trees: Implications for forest biomass and carbon stock estimates in the United States. Carbon Balance and Management and "Additional File: Standing dead tree biomass equations and example calculations". The "Additional File" presents equations necessary to estimate above and belowground standing dead tree biomass and carbon stocks and provides example calculations.
4. Harmon et al. 2011. Differences between standing and downed dead tree wood density reduction factors: a comparison across decay classes and tree species.
5. Component Ratio Method Appendix J

Note:

- Before using this Domke guidance please refer to the Woodall paper to calculate gross and sound volume for standing dead trees. The sound volume (VOLCFSND) must be calculated prior to using the calculations in this document.
- The approach for applying deductions for structural loss and density reduction in standing dead trees described here is applied to calculation steps which are part of the Component Ratio Method (CRM). The CRM is explained in detail in Appendix J (link above). It would be helpful to review that method before reading this document.

Applying density reduction factors (DRF) and Structural Loss Adjustments (SLA):

Step 1: *Convert merchantable bole sound volume to oven-dry biomass (kg) of stem wood (B_{odw}) and oven-dry biomass of bark wood (B_{odb}) using equations 1 and 2 in Appendix A below. Data sources for variables are described below:*

1. Specific gravity values for bole and bark (SG_{gw} and SG_{gb}, respectively) for each species can be found in the REF_SPECIES workbook, see columns "WOOD_SPGR_GREENVOL_DRYWT" for stem and "BARK_SPGR_GREENVOL_DRYWT" for bark.
2. Density Reduction Factors (DRF) can be found in Harmon (2011) Appendix B and D.
   a. Appendix B provides density reduction factors for species that have been directly sampled; for those species that have not been directly sampled, please refer to Appendix D.
   b. Appendix D is a larger compilation of DRFs by species that include: (a) species found in Appendix B that have been directly sampled (identified by code "A"), (b) DRFs that have been estimated for a species based on the genus sampled (identified by code "B"), and (c) DRFs for species that were estimated based upon available literature (identified by code "C").
   c. If a species does not have an associated DRF for the appropriate decay class within Appendix B, look up the species in Appendix D. If the species does not have an associated DRF in Appendix D, identify a related species within the same genus in Appendix D and use the associated DRF for the same decay class (1-4). If a related species within the same genus cannot be identified, use a DRF default value listed in Table 6 by hardwood or softwood.
3. Structural loss adjustment factors (SLA) are listed in Table 2 of Domke (2011) included as Table A.1 below.
4. Bark as a percentage of wood volume (BV%) is found in REF_SPECIES for each species in the "BARK_VOL_PCT" column.

Step 2: Add the total stem wood and total bark biomass (B_{odw} and B_{odt}) to determine total standing dead tree bole biomass (see Appendix A, Equations 1 and 2 in this document).

Step 3: Calculate a "CRM adjustment factor" which is to be used for all standing dead tree biomass calculations by dividing total standing dead biomass (B_{odt}) by the merchantable bole biomass (MST). This "CRM adjustment factor" will be applied to each tree component required using the CRM approach. Note the MST value is derived from the CRM method for calculation of bole biomass "DRYBIO_BOLE" in the CRM-Appendix J document. See Equations in Appendix A with CRM adjustment factor (CRM_{AdjFac}) shown in **PURPLE**.

Step 4: Work through the CRM approach applying the appropriate Structural Loss Adjustment (SLA) factor to the equation for each tree component estimate.

- SLAs for the following components must be applied: Bark and Bole (see Step 1), Stump, Top, and Below-ground. See equations in Appendix A of this document where SLAs are shown in **RED**. When selecting the correct SLA from Table 2 in the Domke (2011) or in Table 1 below, be sure that it corresponds to the correct decay class (1-5) and tree component.

Step 5: Follow the CRM approach to sum the components and convert biomass to carbon.

Appendix A

Table A.1: Structural Loss Adjustment factors (SLA)

Decay Class	Structural loss adjustment factors				
	Top	Bark	Bole	Stump	Roots
1	1.00	0.92	1.00	1.00	1.00
2	0.50	0.66	1.00	1.00	0.95
3	0.20	0.39	1.00	1.00	0.80
4	0.10	0.21	1.00	1.00	0.65
5	0.00	0.00	1.00	1.00	0.50

Equations:

Stem wood biomass:

$$B_{odw} = V_{gw} * SG_{gw} * W * DRF * BOLE\_SLA \quad \text{(eq. 1)}$$

Where:
B_{odw} = oven-dry biomass (kg) of wood
V_{gw} = sound volume of green wood in the central stem (VOLCFSND)
SG_{gw} = basic specific gravity of wood (oven-dry mass of green volume) Found in REF_SPECIES file, column AU
W = weight m^3 of water (1000 kg)
DRF = density reduction factor (found in Appendix D of Harmon et al, 2011 as described above)
Bole_SLA = bole structural loss adjustment factor

Bark biomass:

$$B_{odb} = V_{gw} * BV\% * SG_{gb} * W * DRF * BARK\_SLA \quad \text{(eq. 2)}$$

Where:
B_{odb} = oven-dry biomass (kg) of bark
V_{gw} = sound volume of green wood in the central stem (VOLCFSND)
$BV\%$ = bark as a percentage of wood volume
SG_{gb} = basic specific gravity of bark (oven-dry mass of green volume) Found in REF_SPESIES file, column AW
W = weight m^3 of water (1000 kg)
DRF = density reduction factor (found in Appendix D of Harmon et al, 2011 as described above)
BARK_SLA = bark structural loss adjustment factor

Total standing dead bole (bole and bark) biomass:

$$B_{odt} = B_{odw} + B_{odb} \quad \text{(eq. 3)}$$

Where:
B_{odt} = total standing dead oven-dry biomass (kg)
B_{odw} = oven-dry biomass (kg) of stem wood
B_{odb} = oven-dry biomass (kg) of bark

Standing dead CRM adjustment factor:

$$CRM_{AdjFac} = \frac{B_{odt}}{MST} \quad \text{(eq. 4)}$$

Where:
CRM_{AdjFac} = component ratio method adjustment factor for standing dead tree components derived from Jenkins et al. (2004) and Raile (1982)
B_{odt} = total standing dead oven-dry biomass (kg) (eq. 3)
MST = merchantable oven-dry bole biomass (kg) (Jenkins et al. 2004)

Stump volume:

$$S_{vosb\ or\ visb} = \left(\frac{\pi(dbh)^2}{4(144)}\left[\left((A-B)^2h + 11B(A-B)\ln(h+1) - \frac{30.25}{h+1}B^2\right)\right]_a^b\right)0.02832 \quad \text{(eq. 5)}$$

Where:
$S_{vosb\ or\ visb}$ = stump volume inside bark (*visb*) or outside bark (*vosb*) (m^3)
A = Coefficient (species parameter) from Table 2 in Raile (1982)
B = Coefficient (species parameter) from Tables 1 and 2 in Raile (1982)
h = height aboveground (ft)
ln = natural logarithm
a = lower stump height (ft) – 0 ft in FIADB
b = upper stump height (ft) – 1 ft in FIADB

Stump wood biomass:

$$S_{odsw} = S_{visb} * SG_{gw} * W \quad \text{(eq. 6)}$$

Where:
S_{odsw} = oven-dry biomass (kg) of stump wood
S_{visb} = stump volume inside the bark (eq. 5)
SG_{gb} = basic specific gravity of wood (oven-dry mass of green volume)
W = weight m^3 of water (1000 kg)

Stump bark biomass:

$$S_{odsb} = (S_{vosb} - S_{visb})\ SG_{gb} * W \quad \text{(eq. 7)}$$

Where:
S_{odsb} = oven-dry biomass (kg) of stump bark
S_{vosb} = volume (m^3) of stump outside the bark (eq. 5)
S_{visb} = volume (m^3) of stump inside the bark (eq. 5)
SG_{gb} =basic specific gravity of bark (oven-dry mass of green volume)
W = weight m^3 of water (1000 kg)

Total standing dead stump (wood and bark) biomass:

$$S_{odt} = (S_{odsw} + S_{odsb})\ CRM_{AdjFac} * STUMP\_SLA \quad \text{(eq. 8)}$$

Where:
S_{odt} = oven-dry stump biomass (lb)
B_{odw} = oven-dry biomass (lb) of wood (eq. 6)
B_{odb} = oven-dry biomass (lb) of bark (eq. 7)
CRM_{AdjFac} = component ratio method adjustment factor (eq. 4)
STUMP_SLA = stump structural loss adjustment factor

Standing dead top and branch biomass:

$$T_{odt} = (TAB - MST - STP - FOL)\ CRM_{AdjFac} * Top\_SLA \quad \text{(eq. 9)}$$

Where:
T_{odt} = oven-dry biomass (kg) of standing dead top and branches
TAB = total aboveground oven-dry biomass (kg) (Jenkins et al. 2004)
MST = merchantable stem oven-dry biomass (kg) (Jenkins et al. 2004)
STP = stump oven-dry biomass (kg) (Raile 1982)
FOL = foliage oven-dry biomass (kg) (Jenkins et al. 2004)

CRM_{AdjFac} = component ratio method adjustment factor (eq. 4)
Top_SLA = top and branch structural loss adjustment factor

Standing dead belowground biomass:

$BG_{odt} = ROOT * CRM_{AdjFac} * BG\_SLA$ (eq. 10)

Where:
BG_{odt} = oven-dry biomass (kg) of standing dead coarse roots (≥ 0.254 cm diameter)
CRM_{AdjFac} = component ratio method adjustment factor (eq. 4)
BG_SLA = belowground structural loss adjustment factor
ROOT= total_AG_biomass_Jenkins * root_ratio (from Jenkins)

Standing dead tree example calculations

Standing dead biomass calculation for a 26.7 cm quaking aspen tree in decay class 3 in the Lake States region (please note values may not be exact due to rounding).

Volume to merchantable bole biomass

1. Gross volume (VOLCFGRS) = 0.377 m^3
2. Sound volume (VOLCFSND) = 0.202 m^3

Proposed SDT decay and bark structural reductions: merchantable bole biomass

3. Stem wood biomass (eq. 1): $B_{odw} = V_{gw} * SG_{gw} * W * DRF * BOLE\_SLA$ = 0.202 * 0.35 * 1000 * 0.540 * 1 = 38.18 kg
4. Bole bark biomass (eq. 2): $B_{odb} = V_{gw} * BV\% * SG_{gb} * W * DRF * BARK\_SLA$ = 0.202 * 0.144 * 0.5 * 1000 * 0.540 * 0.39 = 3.06 kg
5. Total bole biomass (eq. 3): $B_{odt} = B_{odw} + B_{odb}$ = 38.18 + 3.06 = 41.3 kg

Merchantable bole biomass to tree component biomass

6. CRM adjustment factor (eq.4): $CRM_{AdjFac} = \frac{B_{odt}}{MST} = \frac{41.3}{201.79} = 0.20$

Proposed SDT structural reductions: tree component biomass

7. Stump volume (eq. 5): $S_{vosb} = \frac{\pi(dbh)^2}{4(144)}\left[\left((A-B)^2h + 11B(A-B)\ln(h+1) - \frac{30.25}{h+1}B^2\right)\right]_a^b = \frac{\pi(10.5)^2}{4(144)}\left[\left((1-0.09658)^2 1 + 11*0.09658(1-0.09658)\ln(1+1) - \frac{30.25}{1+1}0.09658^2\right) - \left((1-0.09658)^2 0 + 11*0.09658(1-0.09658)\ln(0+1) - \frac{30.25}{0+1}0.09658^2\right)\right]0.02832 = 0.0276\ m^3$
   $S_{visb} = \frac{\pi(10.5)^2}{4(144)}\left[\left((0.91882-0.08593)^2 1 + 11*0.08593(0.91882-0.08593)\ln(1+1) - \frac{30.25}{1+1}0.08593^2\right) - \left((0.91882-0.08593)^2 0 + 11*0.08593(0.91882-0.08593)\ln(0+1) - \frac{30.25}{0+1}0.08593^2\right)\right]0.02832 = 0.0230\ m^3$
8. Stump wood biomass (eq. 6): $S_{odsw} = S_{visb} * SG_{gw} * W$ = 0.0230 * 0.35 * 1000 = 8.05 kg
9. Stump bark biomass (eq. 7): $S_{odsb} = (S_{vosb} – S_{visb})SG_{gb} * W$ = (0.0276 – 0.0230)0.5 * 1000 = 2.3 kg
10. Total stump biomass (eq. 8): $S_{odt} = (S_{odsw} + S_{odsb})CRM_{AdjFac} * STUMP\_SLA$ = (8.05 + 2.30)0.20 * 1 = 2.1 kg
11. Top and branch biomass (eq. 9): $T_{odt} = (TAB – MST – STP – FOL)CRM_{AdjFac} * Top\_SLA$ = (277.94 – 201.79 – 10.36 – 5.85)0.20 * 0.20 = 2.5 kg
12. Belowground biomass (eq. 10): $BG_{odt} = ROOT * CRM_{AdjFac} * BG\_SLA$= 52.82 * 0.20 * 0.80 = 8.6 kg

Biomass to carbon

13. Total aboveground biomass = $B_{odt} + S_{odt} + T_{odt}$ = 41.3 + 2.1 + 2.5 = 45.9 kg
14. Total above and belowground biomass = 45.9 + 8.6 = 54.5 kg
15. Total aboveground carbon = $(B_{odt} + S_{odt} + T_{odt})0.5$ = (41.3 + 2.1 +2.5)0.5 = 22.95 kg C
16. Total above and belowground carbon = 54.5 * 0.5 = 27.25 kg