Detailed Explanation of the Calculations for Coarse Woody Debris stocks and fluxes, BCI 50ha plot annual census data

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This document gives an explanation of the calculations performed in
Lily F. Pitcher, and Helene C. Muller-Landau. 2025. Data processing methods and code for deadwood dynamics census data, Barro Colorado Island, Panama , Zenodo
to estimate deadwood stores and fluxes in the 50ha plot, Barro Colorado Island, Panama. The material is based on the ForestGEO woody debris protocol documents which can be found here: *https://forestgeo.si.edu/protocols/woody-debris*

1 Sample level calculations

This first section contains the explanation for the sample level calculations for standing and fallen coarse woody debris, which can be found in **density_calculation_bci50deadwood correctedtoprocessed.rmd**.

1.1 Density of Samples

Density was calculated from penetrometer measurements following the methods described in Gora et al. 2019 and Larjavaara et al. 2010.

Penetration mm per hit

A penetrometer is used to measure the density of individual woody samples for standing and falling for censuses conducted from 2009-2020. The first step is to calculate the millimeters in which the penetrometer penetrated the sample per hit.

For samples in which a total of 20 hits were performed and the end penetration in micrometers was measured, the penetration per hit (Pen.hit.mm) is calculated by dividing the measured penetration by 20.

For samples where the penetrometer reached 200 mm depth (max penetration) in less than 20 hits, the penetration per hit (Pen.hit.mm) is calculated by dividing 200 by the number of hits.

Calculating density of sample from penetrometer measurements.

In 2010, destructive sampling of woody debris was carried out to establish the relationship between the actual density (defined as the dry mass divided by the fresh volume of the disks removed from the field samples) and the depth of penetration measured using a dynamic penetrometer.

A linear relationship was calculated between the log10-transformed penetrometer penetration per hit (mm) and the log10-transformed dry density ($\mathrm{kg/m^3}$). This relationship was then used to predict log10-transformed density values from penetration per hit measurements.

The predicted log density values were converted back to density (kg $\mathrm{m^{-3}}$) by multiplying with a first-order correction factor (CF), following the approach described in Chave et al., 2005

$$CF = 10^{\frac{RSE^2}{2}}$$

where RSE is the residual standard error.

For samples in which no penetrometer was used, the mean density of the plot taken from Gora et al., 2019 was used (271 kg $\mathrm{m^{-1}}$).

1.2 Residence time

For fallen and standing samples, the number of years the sample is present in the dataset is calculated by counting the number of years within which that sample occurs. The first year of appearance is taken from the first census year the code of piece for that sample appears in the dataset and the last appearance is the last census year where the piece was measured with a diameter above 200 mm.

1.3 Sample level calculations for Fallen CWD

For fallen samples, the diameter width of the samples is measured where the sample crosses the transect section, which is subsequently used in the following calculations.

Cross Section Mass of Downed woody debris

For fallen samples, the cross-sectional mass is calculated using the following equation:

$$M_{cs} = \rho \cdot \pi \cdot \left(\frac{D}{2}\right)^2$$

Where M_{cs} is the cross-sectional mass (kg m^{-3}), ρ is the sample density (kg m^{-3}), and D is the diameter of the sample where it crosses the transect (m).

Diameter Squared For fallen samples, the diameter squared of the cross section is also calculated as:

$$D^2$$

where D is the diameter in m.

1.4 Standing sample piece level measurements

Height and Diameter at Breast Height (DBH) are measured for standing samples which are subsequently used in the following calculations.

Equivalent diameter at 1.3m height using taper correction model

For samples where the diameter was not measured at 1.3m (DBH) due to buttresses or the height of the sample being less than 1.3m, the equivalent DBH was calculated using the following taper correction model from Table 1, model 1 of Cushman et al., 2014

$$D_E = D_i \cdot e^{b \cdot (POM - 1.3)}$$

Where D_i is the measured diameter, POM is the height of measurement (m), and b is the taper correction parameter. b is calculated using Model 2 of Cushman et al., 2021 - parameters can be found in Table 2, model 2, and in Table S9.

$$b = 0.156 - 0.023 \cdot \ln(D_i) - 0.021 \cdot \ln(POM) + 0.00057$$

Volume of Standing sample

The volume of individual standing samples are calculated using three approaches, depending on whether the sample has all branches present, partial branches or no branches. This is following the methods described in Gora et al., 2019.

a. For samples with all branches present, the volume is calculated using the following equation:

$$V = \pi \cdot H \cdot \left(\frac{D}{2}\right)^2$$

where V is the volume (m^3), H is the height of the standing piece (m), and D is the equivalent diameter at 1.3 m (m).

b. For samples with part of the canopy remaining, the equation above is used and then multiplied by 0.875, assuming half of the canopy is lsot (which is assumed to make-up a quarter of the total above ground volume).

c. For samples without branches, they are treated as truncated cones, and the volume is calculated using the following equation:

$$V = \frac{1}{3} \cdot \pi \cdot H \cdot \left[\left(\frac{D}{2}\right)^2 + \left(\frac{d}{2}\right)^2 + \frac{D \cdot d}{4} \right]$$

where V is the volume (m^3), H is the height of the standing piece (m), D is the equivalent diameter at 1.3 (m), and d is the diameter at the top of the piece, calculated using the taper correction model.

Mass of standing woody pieces

The mass of individual standing samples are calculated using three approaches, depending on whether the sample has all branches present, partial branches or no branches.

a. For samples with all branches, above ground biomass (AGB) is calculated using the equation described in Chave et al., 2014 and used in Gora et al., 2019:

$$AGB = \exp\left(-1.803 - 0.976 \cdot E + 0.976 \cdot \ln(\rho) + 2.673 \cdot \ln(D) - 0.0299 \cdot \ln(D^2)\right)$$

where AGB is aboveground biomass in kg, E is a region specific environmental parameter (0.0561 for BCI), D is DBH (mm), and ρ is sample density (kg m^{-3}).

b. For trees with only part of the canopy present, the equation above is used and then multiplied by 0.875 to again assume half of the canopy is lost.

c. For samples with no branches, the mass (kg) of the samples is calculated by multiplying the volume by the density of the sample (either the average density or penetrometer estimated density in kgm^{-3}).

1.5 Decomposition rate constant of sample

The yearly decomposition rate of individual pieces was calculated from the diameter and cross-sectional mass (for fallen pieces) or the total volume and mass (for standing pieces) using the following equation:

$$K = \ln\left(\frac{C_{t-1}}{C_t}\right)$$

where K is the decomposition constant of a piece for time t, and C_{t-1} and C_t is the value for the target variable the year prior $(t-1)$ and the target year (t), respectively.

See Table 1. in Appendix for the definitions of the new columns generated from the calculations in **density calculation bci50deadwood correctedtoprocessed.Rmd** which can be found in the data files located in Data3_Processed.

2 Scaling Up Sample-Level Estimations

The following calculations are detailed in **report_bci50CWD_2017-24.Rmd** .

2.1 Subplot-Level Estimations

Fallen CWD Mass

The subplot-level estimated average mass (M) of fallen CWD in kg m^{-2} is calculated using the following equation:

$$M = \frac{\pi}{2L} \cdot \sum M_{cs}$$

where L is the total length of all the transects in the subplot (160 m). M_{cs} is the cross-sectional mass (kg/m).

Downed CWD Volume

The subplot-level estimated average volume (V) of downed CWD in m^3 m^{-2} is calculated using the following equation:

$$V = \frac{\pi^2}{8L} \cdot \sum D^2$$

Where L is the total length of the transects in the subplot (160 m). D is the diameter of the sample where it crosses the transect (m).

Standing CWD Mass

The subplot-level estimated average mass (M) of standing CWD in kg m^{-2} is calculated by summing the total mass of all pieces within the subplot area and dividing by the subplot area:

$$M = \frac{\sum M_p}{A}$$

Where M_p is the mass of individual standing pieces (kg). A is the subplot area (16000m^2).

Standing CWD Volume

The subplot-level estimated average volume (V) of standing CWD in m^3 m^{-2} is calculated by summing the total volume of the pieces within the subplot and dividing by the subplot area:

$$V = \frac{\sum V_p}{A}$$

Where V_p is the volume of each piece (m^3) and A is the area of the subplot (16000m^2)

3 Annual Estimations

3.1 Total Annual Estimates of CWD Stocks

The total annual estimated volume (m^3 ha^{-1}) and mass (Mg ha^{-1}) of standing and fallen CWD for the 50 ha plot is calculated by finding the mean for all subplots each year.

3.2 Inputs and Outputs of Volume and Mass of CWD

We identified the new pieces of deadwood for each year based on the first appearance of the unique identifying codes (Subplot, transect letter, code of piece) and classified these as inputs for each year. The volume and mass of the inputs for each subplot per year were calculated using the equations described above.

To calculate the woody debris loss (outputs) per subplot per year, the following equation was used:

$$Output_t = Total_{t-1} + Input_t - Total_t$$

This was done for both volume and mass.

3.3 Estimated Residence Time

We estimated the mean residence time of CWD using a steady-state model; we divided the mean stocks for all years by the mean inputs for all years:

$$R = \frac{MeanStocks}{MeanInputs}$$

4 Bibliography

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., Henry, M., Martínez-Yrízar, A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E.M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan, C.M., Saldarriaga, J.G. and Vieilledent, G. (2014), Improved allometric models to estimate the aboveground biomass of tropical trees. Glob Change Biol, 20: 3177-3190. https://doi.org/10.1111/gcb.12629

Cushman, K.C., Muller-Landau, H.C., Condit, R.S. and Hubbell, S.P. (2014), Improving estimates of biomass change in buttressed trees using tree taper models. Methods Ecol Evol, 5: 573-582. https://doi.org/10.1111/2041-210X.12187

Cushman, K. C., Bunyavejchewin, S., Cárdenas, D., Condit, R., Davies, S. J., Duque, Á., Hubbell, S. P., Kiratiprayoon, S., Lum, S. K. Y., Muller-Landau, H. C. (2021). Variation in trunk taper of buttressed trees within and among five lowland tropical forests. Biotropica, 53, 1442–1453. https://doi.org/10.1111/btp.12994

Gora, E.M., Kneale, R.C., Larjavaara, M. et al. Dead Wood Necromass in a Moist Tropical Forest: Stocks, Fluxes, and Spatiotemporal Variability. Ecosystems 22, 1189–1205 (2019). https://doi.org/10.1007/s10021-019-00341-5

Larjavaara, M. & Muller-Landau, H. 2010. Woody Debris Research Protocol: CWD Dynamics. CTFS Global Forest Carbon Research Initiative. Version January 2010.

5 Appendix

Table 1: Dictionary of new columns in the data files located in Data 3 Processed, generated from calculations found in density calculation bci50deadwood correctedtoprocessed.Rmd

Column name	Units	Defintion	Fallen	Standing
Pen.hit.mm	mm	The depth the penetrometer pentrated the sample for a single hit.	TRUE	TRUE
pendensity.Kgm3	kg m^{-3}	The predicted density of the sample.	TRUE	TRUE
pen density	NA	Defines whether the sample density was predicted from a penterometer measurement. TRUE -meaning it was predicted from penetrometer. FALSE- average density was assigned.	TRUE	TRUE
pen crossmassKgm	kg m^{-1}	The cross section mass of the fallen sample, calculated from the density multiplied with cross section area.	TRUE	TRUE
diam sqr m	m	The diameter of the cross section squared	TRUE	FALSE
habitat	NA	The habitat type of the subplot within the 50ha plot following the BCI habitat classification system.	TRUE	TRUE
b	NA	The taper correction parameter calculated using from Model 2 of Cushman et al. 2021 Biotropica DOI:10.1111/btp.12994 - parameters in Table 2, model 2, and in Table S9.	FALSE	TRUE
mean diameter at1.3mm	mm	The diameter at 1.3m correcting for point of measurement using model from Table 1, model 1 of of Cushman et al. 2014 Methods Ecology and Evolution DOI:10.1111/2041-210X.12187.	FALSE	TRUE
Diameter.at.top .of.snag	mm	The diameter at the top of the standing sample calculated using model from Table 1, model 1 of of Cushman et al. 2014 Methods Ecology and Evolution DOI:10.1111/2041-210X.12187.	FALSE	TRUE
Volume m3	m^3	The estimated volume of the standing sample.	FALSE	TRUE
AGB.Kg.dry.mass	kg	The estimated mass of the standing sample.	FALSE	TRUE
K.diameter.yr	mm y^{-1}	The exponential decay rate calculated from the diameter of fallen pieces.	TRUE	FALSE
K.csmass.yr	kg m^{-1} y^{-1}	The exponential decay rate calculated from the cross-section area of fallen pieces.	TRUE	FALSE
K.volume.yr	m^3 y^{-1}	The exponential decay rate calculated from the volume of standing pieces.	FALSE	TRUE
K.mass.yr	kg y^{-1}	The exponential decay rate calculated from the mass of standing pieces.	FALSE	TRUE