Manual for coarse woody debris measurement in RAINFOR plots
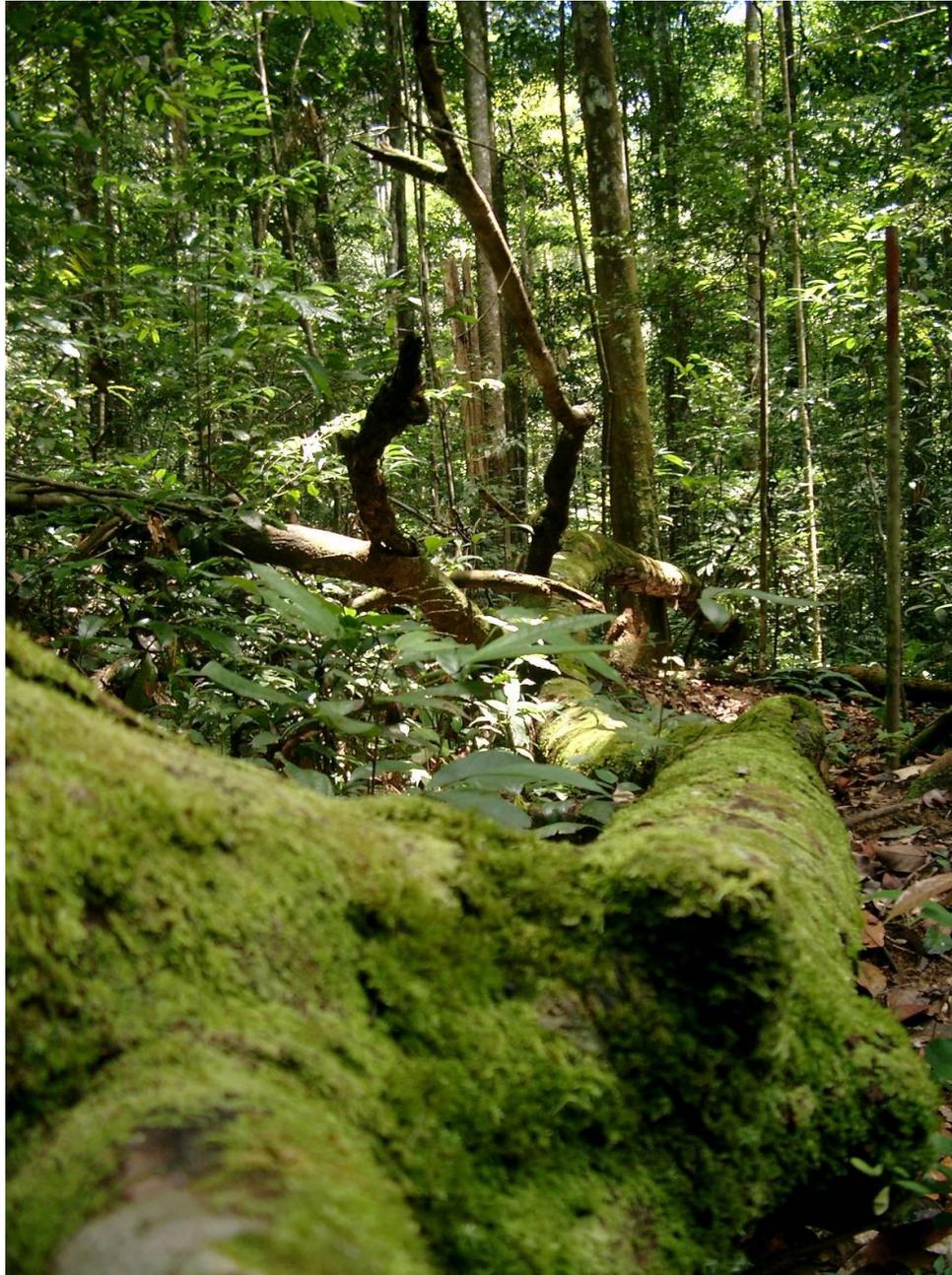
T.R. Baker, K.J. Chao

Version 2 - May 2011

GORDON AND BETTY
MOORE
FOUNDATION

rainfor

NATURAL
ENVIRONMENT
RESEARCH COUNCIL

Introduction

Coarse woody debris (CWD) is an important carbon store in tropical forest ecosystems, with maximum estimates of >60 Mg ha^{-1}, or up to 33 % of the above ground living biomass of trees $\geq$10 cm diameter [1]. Stocks of CWD vary widely between forests, related to variation in forest structure, disturbance history and environmental factors such as soil fertility.

For example, evidence of previous disturbance is given where stocks are substantially higher than the quantity estimated under steady state conditions [3].

This manual therefore sets out protocols to answer the following questions:

1. What is the pattern of CWD stocks across the RAINFOR plot network?
2. What environmental factors correlate with CWD stocks across the RAINFOR network?
3. Are CWD stocks in equilibrium with inputs from tree mortality across the RAINFOR plots?

Methods

Both plot-based and line intercept methods are available for the measurement of CWD; both methods have been used in existing studies of CWD stocks in RAINFOR plots. Plot-based methods are useful for studies that compare stocks of CWD with inputs from tree mortality within existing one hectare permanent plots. Line intercept methods are useful for assessing questions about the stocks of CWD at larger scales – for assessing, for example, the degree to which the plots are representative of the wider landscape.

Field measurements

Plot-based measurements

Fallen dead trees and branches

The length and diameter at both ends of all pieces of fallen wood, including lianas, with diameter larger than 10 cm within the plot should be measured. Note that:

- For logs tapering to less then 10 cm diameter, measurements are made only up to the point where the log tapers to less than 10 cm diameter.
- Branches greater than 10 cm diameter attached to fallen trunks should be measured separately, in approximately linear segments.
- Measurements of length are made to the plot border, regardless of whether the tree is rooted inside or outside the plot.
- For measurements at the bases of fallen, buttressed trunks, diameters are measured above the buttress.

- Only one diameter need to be measured in the centre of fallen, dead palm stems, because palm stems maintain a similar shape and diameter along their length.
- If the piece of CWD is not approximately circular or partly buried by the litter and soil, and it is hard to measure the diameter, two perpendicular dimensions should be measured along the longest axis and perpendicular to that axis.
- Pieces of wood that have greater than a 180 degree circumference but are incompletely circular, should be measured as if a solid circle; a subsequent void space correction accounts for the missing wood to calculate the CWD volume.

Standing dead trees (snag)

The diameter of standing dead trees is measured at 1.3 m height, or the lowest part of the trunk without buttress roots. Note that:

- The height of the snag should be measured with a clinometer, or laser range finder.
- If the trunk decreases in size to below 10 cm, the height should be measured to the point where it is 10cm diameter.
- The small-end diameter of broken snags should be measured from the log formed by the fallen top.
- If the top of broken end is not found, the small-end diameters of snags should be estimated visually.
- The dimensions of major branches >10 cm diameter still attached to a standing dead tree should be visually estimated.
- For stumps less than 1.3m tall, the height and top diameter should be measured.

Decomposition classes

The state of decomposition should be classified in the field into one of 5 classes, based on simple characteristics of the dead wood:

Class 1: Solid wood, recently fallen, with intact bark and fine branches still attached.
Class 1.5: Solid wood, but with no fine branches, and bark starting to fall off.
Class 2: Non-solid wood, in poorer condition, but where it is still difficult to push a nail into the wood by hand.
Class 2.5: Soft, rotten wood, where a nail can be pushed into the wood easily.
Class 3: Soft, rotten wood, which collapses easily when stepped on.

Some studies use only three decomposition classes (i.e. combine class 1 with 1.5, and class 2 with 2.5): in a study in Peru [4], the three decay classes revealed comparable patterns to five decay classes.

If required, the five class system can be simplified to the three class system during analysis.

Calculation of CWD volume

The volume of dead palm trees and stumps should be calculated as a cylinder.

For other pieces, CWD volume, V (m^3) should be calculated using Smalian's formula as:

$$V = L\left[\frac{\pi(D_1/2)^2 + \pi(D_2/2)^2}{2}\right]$$

where L (m) is the length of the piece of CWD, and D is the diameter (m), at either end. Smalian's formula gives the correct volume if each piece of CWD is a frustum of a quadratic paraboloid or a cylinder. If the log tapers as a frustum of a cone, then Smalian's formula will lead to an overestimate of volume, proportional to the length and degree of taper.

Line intercept sampling

Line intersect sampling provides a fast method to obtain landscape-level estimates of CWD stocks and allow sampling for the calibration of the decomposition classes and measurement of CWD void space outside the permanent plots. A total of 2 km of line transect, divided into several smaller units is recommended to provide reasonable precision: five, 400m transects produced CWD estimates with a standard error of 20% of the mean in a southwestern Amazon forest [1]. Ideally, line transects should always be more than 20m apart, to maintain independence, and be established in random directions across the landscape, to avoid bias from directional mortality events due to topography or the predominant wind direction. Often, line transects are established in two perpendicular directions, combining ease of set up with these objectives.

- For every piece of CWD that crosses the perpendicular plane passing through the line transect, diameter, and decay class should be recorded.
- For non-circular pieces of CWD, two measurements should be made along the longest axis and perpendicular to that axis and the geometric mean calculated for use for calculating the CWD volume.

Standing dead trees

Line intercept sampling only provides information on fallen dead wood. If only line intercept sampling is used, then belt transects 10 m wide on either side of the transect line [5] should be used to measure, in addition, all standing dead trees and stumps, as described in the previous section.

Calculation of CWD volume

The CWD volume is calculated as:

$$V = \left(\pi^2 \times \Sigma d_i{}^2\right)/8L$$

where *V* is the CWD volume per unit area, d_i is the diameter (cm) of log *i* and *L* (m) is the length of the transect line [6]. The variance of the volume (σ^2) for *n* transects is weighted by transect lengths (L_j), as recommended by De Vries [7] cited in [2], as :

$$\sigma^2 = [\Sigma L_j (V_j - \overline{V})^2]/[(n-1) \times \Sigma L_j]$$

Density of decomposition classes and measurement of void space

A range of studies have calibrated the subjective decomposition classes in different forests in Amazonia [4]. The density values obtained for different decomposition classes are site specific but can be estimated from the species composition of the surrounding living trees [4]. In humid, lowland neotropical forests, density of each CWD decay class (ρ_d, g cm^{-3}) is closely related to the plot-level living wood density [4]. Thus, ρ_d was estimated as a function of the plot-average wood density of live trees. For estimating three decay class:

$\rho_{d=1} = 1.17\ [\rho_{BA\ j}] - 0.21$

and

$\rho_{d=2} = 1.17\ [\rho_{BA\ j}] - 0.31$

where $\rho_{d=1}$ and $\rho_{d=2}$ represent the CWD densities in decay class (*d*) one and two, respectively, and $\rho_{BA\ j}$ (g cm^{-3}) is the wood density of living trees of plot *j*, weighted by their basal area. For CWD in decay class three, the average value of density for debris in 'decay class three' from published studies of humid, lowland neotropical forests (0.29 g cm^{-3}) can be used, as suggested by [4].

Site-specific measurements of decomposition class density

- For the site-specific calibration of the decomposition classes, samples for density measurements are taken at 5 cm intervals from the centre of each chosen piece of CWD in one of four randomly chosen directions (top, bottom, left, right).
- For relatively hard pieces, a chain saw can be used to cut a cylindrical radial section, and rectangular or cylinder solid wood plugs taken from each radial section by a machete. Power drill sampling methods may be suitable where wood is particularly hard (e.g. [2]).
- The volume of these samples is calculated by direct measurement using vernier

calipers in three length dimensions (l_1, l_2 and l_3) for a rectangular solid shape, or radius (r) and length (l) for a cylindrical sample, or volumes of irregular shape samples are determined by the water displacement measurement, to the nearest 0.5 mm, using a graduated plastic cylinder.

- For very decomposed CWD (class 3) sampling is performed with a container of known volume.
- The samples are dried at 65°C, weighed, and density calculated as dry mass divided by fresh volume.

Fig 1. Sampling CWD for calibrating the density of different decomposition classes
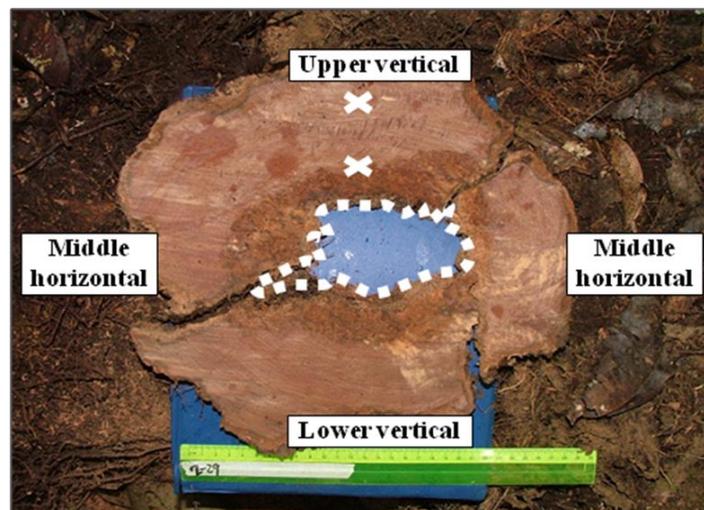

Fig 2. Position of samples for calibrating density of decomposition classes (crosses) and definition of void space (dots)

Void space

The proportion of void space of the different decomposition classes can be measured by taking cross-sectional pieces of a random sample of CWD pieces stratified by decomposition class.

- Cross sections of selected CWD pieces should be cut at the point where the line crosses the piece, where the decomposition assessment was made.
- Digital photos should be taken of the cross-sections, with a scale item, such as a ruler.
- Void space, defined as a region enclosed by more than 180 degrees of solid CWD, is measured as the proportion of the total area occupied by void space calculated using ImageJ software. Note that void space may extend to the exterior of the piece of CWD, for incompletely circular pieces of CWD.

Calculating the mass of CWD

To estimate the mean mass of CWD, M (Mg ha^{-1}), in each decomposition class, n, external CWD volume (V, m^3) is multiplied by the mean proportion of solid wood ($S = 1 - $ *proportion void space*) and by the wood density values (ρ, g cm^{-3} $\equiv$ Mg m^{-3}) of the different decomposition classes. If void space, wood density and volume measurements for each plot or transect are not correlated [1], the standard error for M can be calculated assuming independent random errors [8], as:

$$SE(M)_n = (M)_n \left(\sqrt{ \left(\frac{(SE_V)_n}{V_n} \right)^2 + \left(\frac{(SE_S)_n}{S_n} \right)^2 + \left(\frac{(SE_\rho)_n}{\rho_n} \right)^2 } \right)$$

The mean total mass of CWD is calculated by summing the mass of each decomposition class, and the standard error calculated conservatively as the sum of errors of the constituent classes [8].

Plot based **necromass census:** Place _____ Recorder _____ Census date ___/___/___

Quadrat	Sub-quadrat	Piece No.	D 1 (cm)	D 2 (cm)	Length of Piece (m)	Current state[a]	Degree of decay[b]	Notes

a Current State	**b** State of decay
A Standing	**1** died recently
B On the ground	**1.5** slightly damaged
C Leaning/ Suspended	**2** damaged and in bad condition
	2.5 somewhat rotten
	3 rotten

References

1.	Baker, T.R., et al., *Low stocks of coarse woody debris in a south-west Amazonian forest.* Oecologia, 2007. **153**: p. 495-504.
2.	Keller, M., et al., *Coarse woody debris in undisturbed and logged forest in the eastern Brazilian Amazon.* Global Change Biology, 2004. **10**: p. 784-792.
3.	Rice, A., et al., *Carbon balance and vegetation dynamics in an old-growth Amazonian forest.* Ecological Applications, 2004. **14**: p. 555-571.
4.	Chao, K.J., O.L. Phillips, and T.R. Baker, *Wood density and stocks of coarse woody debris in a northwestern Amazonian landscape.* Canadian Journal of Forest Research, 2008. **38**: p. 795-805.
5.	Palace, M., et al., *Necromass in undisturbed and logged forests in the Brazilian Amazon.* Forest Ecology and Management, 2007. **238**: p. 309-318.
6.	van Wagner, C.E., *The line intersect method in forest fuel sampling.* Forest Science, 1968. **24**: p. 469-483.
7.	De Vries, P.G., *Sampling Theory for Forest Inventory. A Teach-yourself Course.* 1986, Berlin: Springer-Verlag.
8.	Taylor, J.R., *An Introduction to Error Analysis.* 2nd ed. 1997, Sausalito, USA: University Science Books.
9.	Palace, M., M. Keller, and H. Silva, *Necromass production: studies in undisturbed and logged Amazon forests.* Ecological Applications, 2008. **18**: p. 873-884.
10.	Chambers, J.Q., et al., *Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest.* Forest Ecology and Management, 2000. **5348**: p. 1-12.