Allometric Equation Evaluation Guidance Document

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June 2016

WINROCK INTERNATIONAL

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Acknowledgements: This document is based on: Walker SM, Murray, L, Tepe, T. 2015. Allometric Equation Evaluation Guidance Document – Guidance Document for Lao PDR. Developed by Winrock International, on behalf Lao PDR. Funded by JICA.

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OVERVIEW

The study of carbon stored in forests is based on the assessment of biomass stocks found in various vegetation types, along with the carbon stored in the soil. While it is not possible to directly measure the mass of carbon or vegetation in a forest area without harvesting and weighing all tree and vegetation biomass, indirect measurement methods and sampling techniques can be applied to reliably estimate biomass stocks. Allometric equations are the dominant indirect measurement method for estimating tree biomass stocks.

For countries or regions where allometric equations have not yet been developed, options include 1) verifying existing equations for applicability to their own national forests and 2) exploring the need and subsequent process of developing country-specific allometric equations. The object of this manual is to provide guidance on the field methods to examine applicability of existing equations and for developing new allometric equations through destructive sampling.

This guidance covers an overview of existing potentially applicable equations, verifying existing equations, as well as procedures and concepts for developing a new allometric equation including sampling design, implementation, and recommended field methods. Although this document does provide an overview on creating new allometric equations, it is not meant to provide comprehensive guidance on how to statistically analyse collected data to create new equations.

1. TREE BIOMASS ESTIMATION

Overview of Allometric Equation Approach

The biomass of a tree is proportional and can typically be directly related with the size of certain morphological features of the tree. This relationship or ‘allometry’ can be described in models or equations, allowing for the biomass to be inferred by supplying the model with measurement of certain parts of the tree. For example, the diameter of the trunk (measured as diameter at breast height; 1.3m DBH), has been found to be highly correlated with the total aboveground biomass (Brown et al. 1989, Brown 1997, Chave et al. 2005, Stas 2011).

To create an allometric equation for estimating aboveground tree dry biomass, a study is conducted where trees across a specific geographic, species, and tree size range are destructively harvested to estimate their biomass. Morphological features of the specific tree that are easy to measure, such as tree height and trunk diameter, are compared to the tree’s total dry aboveground biomass. A range of equation types and variables are examined to determine which combination creates the most accurate and unbiased predictors of dry biomass. This equation can then be used to estimate the biomass of other trees without damaging them. The quantity of carbon can then be estimated by converting biomass to carbon using the IPCC default carbon fraction of 0.47. Belowground tree root biomass is commonly estimated as a ratio of the aboveground tree biomass.

When developing or assessing the applicability of an equation, destructive sampling should take place across the across the area of interest. The approach for collecting sample data must consider the fact that tree allometry may vary across the area of interest as trees within different forest types and land use histories may vary in morphology. Thus, it is recommended that the area of interest be stratified. Stratification can be based on ecological factors such as soil, climate, and species composition, as well as anthropogenic factors such as human disturbance, management practices, and land use history.

The field measurements necessary to apply allometric biomass equations varies, and are highly dependent on forest type and conditions. Common variables within allometric equations include:

- Diameter at breast height (DBH)
- Height
- Species
- Wood density
- Site quality
- Age
- Crown width
- Climate (environmental stress factor)
- Basal area

Of these variables, DBH measurements and wood density values are generally the most easily attained and reliable inputs. Although height has been shown to produce less biased estimates of above ground biomass (Rutishauser et al., 2013, Chave et al., 2014; Banin et al., 2012; Feldpausch et al., 2011), accurately measuring tree heights in closed-canopy forests often challenging because it is difficult to decipher between adjacent trees (King & Clark 2011; Primack & Corlett 2011; Chave et al., 2014, Larjavaara & Muller-Landau 2013) and because measuring angles in an accurate, consistent manner in hilly topography is even more difficult to do. As a result, existing methods to estimate height result in estimates with high degrees of random and systematic error. There is therefore a lack of consensus as to whether height measurements collected through ground inventory should be used as a predictor of AGB in tropical forests (Larjavaara & Muller-Landau 2013), and this may be a particularly relevant consideration in geographies where the terrain is hilly.

Species-specific equations may increase accuracy, although this may not always be the case (Rutishauser et al., 2013; Fayolle et al., 2013). Relationships between diameter and tree height have been found to vary across environmental conditions, reducing importance of species type in determining accuracy of equation (Banin et al 2012, Feldpausch et al., 2011 in Fayolle et al., 2013). In addition, Chave et al., (2005) showed that a single equation including trunk diameter, wood specific gravity, and total tree height already provides an accurate estimate of above-ground biomass, and that including site, successional status, continent or forest type only slightly improves the quality of the fit. Including wood density allows for the incorporation of a species-specific factor into an overall equation. Similarly, including climatic factors can allow equations to address differences based on elements unique to different regions.

Existing Aboveground Biomass Equations

A selection of published equations are summarized in Table 1. If an existing allometric equation is selected, it must be verified as appropriate for use with local data, as described in the next section.

The variables used in these equations include:

AGB=Total aboveground biomass (kg)
D=DBH (cm)
H=Height (m)
ρ=Wood density (g/cm^3)
BA=Basal area (cm^2)
E=Environmental stress (unitless)
Calculated as $E = (0.178 * TS - 0.938 * CWD - 6.61 * PS) * 10^{-3}$
Where
TS = temperature seasonality
CWD = climatic water deficit
PS = precipitation seasonality

Table 1 Potentially applicable allometric equations

	Geography/Life Zone/ Vegetation type	Equation	n	R^2 (adj)	RSE	Tree size	Source
1	Tropical Forests **Dry**	$AGB = 34.4703 - 8.0671 * D + 0.6589 * D^2$	32	0.67		5<D<130cm	Brown et al 1989
2	Tropical Forests **Moist**	$AGB = 38.4908 - 11.7883 * D + 1.1926 * D^2$	168	0.78			
3		$AGB = \exp(-3.1141 + 0.9719 * \ln(D^2 * H))$	168	0.97			
4		$AGB = \exp(-2.4090 + 0.9522 * \ln(D^2 * H * \rho))$	94	0.99			
5		$H = \exp(1.0710 + 0.5677 * \ln(D))$	3824	0.61			
6	Tropical Forests **Wet**	$AGB = 13.2579 - 4.8945 * D + 0.6713 * D^2$	69	0.90			
7		$AGB = \exp(-3.3012 + 0.9439 * \ln(D^2 * H))$	69	0.90			
8		$H = \exp(1.2017 + 0.567 * \ln(D))$	69	0.74			
9	Tropical Forests **Dry**	$AGB = \exp(-2.187 + 0.916 * \ln(\rho * D^2 * H))$	316	0.99		5<D<133cm	Chave et al 2005
10		$AGB = \rho * \exp(-0.667 + 1.784 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	316	0.99			
11	Tropical Forests	$AGB = \exp(-2.977 + \ln(\rho * D^2 * H))$	1349	0.99			

12	**Moist**	$AGB = \rho * \exp(-1.499 + 2.148 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	1349	0.99			
13	Tropical Forests	$AGB = \exp(-2.557 + 0.940 * \ln(\rho * D^2 * H))$	143	0.97			
14	**Wet**	$AGB = \rho * \exp(-1.239 + 1.980 * \ln(D) + 0.207 * (\ln(D))^2 - 0.0281 * (\ln(D))^3)$	143	0.97			
15	Pantropical	$AGB = 0.0673 * (\rho * D^2 * H)^{0.976}$	4004		0.357	5<D<156cm	Chave et al 2014
16		$AGB = \exp(-1.803 - 0.976 * E + 0.976 * \ln(\rho) + 2.673 * \ln(D) - 0.0299 * (\ln(D))^2)$	4004		0.361		

Given the multitude of allometric equations available, generalized pan-tropical equations, such as Chave et al 2005, are extremely useful. The validity of this equation has been confirmed in studies across the tropics, although a degree of uncertainty associated with climatic variations was present in the model. Chave et al. (2014) subsequently published an improved allometric equation inclusive of a variable representative of climatic effects on tree growth that is applicable to a wide variety of forest types as it was developed using destructive sampling data from 4004 trees representing a wide range of climatic conditions and vegetation types.

As stated, most allometric equations require data on DBH and some also use wood density as an input, including Chave et al. (2004 & 2005). Brown et al (1989) and Chave et al. (2005 & 2014) offer pantropical equations both with and without height measurements required.

The Chave et al (2014) allometric equation is particularly flexible and therefore often recommended for estimating biomass tropical forests. In cases where height data are not available, it can be derived using an allometric relationship for height was developed based on DBH and an environmental stress factor. This environmental stress factor is a function of temperature seasonality, climatic water deficit, and precipitation seasonality and was developed using global datasets (see http://chave.ups-tlse.fr/pantropical_allometry.htm for data layers). In cases where neither height nor an environmental stress factor are applicable, the appropriate equation from Chave et al (2005) may be used.

While the environmental stress factor offers a valid way to derive height, Chave et al. (2014) recommends the use of locally-derived diameter-height relationships, where available. This can be done by measuring the DBH and height of a selection of trees within the area of interest, across the range of species and sizes. A relationship between diameter and height can then be developed and used within existing allometric equations. Alternatively, Feldpausch et al. (2012) offer asymptotic Weibull height-diameter functions that could be used to derive height, based on DBH measurements.

In some cases, the Chave et al. (2014) equation may not be appropriate and geographically-specific equations may be more accurate in reflecting specific growth patterns or conditions. This may be true where forest types are highly dependent on management types, specific growth patterns, and unique species compositions such as young regenerating forests, areas of shifting cultivation mosaic, areas undergoing heavy selective cutting resulting in stunted trees, and abandoned plantations. Furthermore, in forest areas with a dominance of lianas, palms, and/or bamboo, it is recommended that equations specific to these vegetation types be used along with the equation(s) selected to estimate the biomass in the trees. Some of the forest types for which specific allometric equations may need to be developed are discussed below.

Dry dipterocarp forests, otherwise known as deciduous dipterocarp forests, are typically more open and are sometimes characterized as woodlands rather than forest. These types of forests become increasingly open along gradients of environmental stress and therefore canopy cover can range from more closed canopy to savannah woodlands (Rundel 1999). The limited and relatively unique species composition whose biomass varies according to environmental stresses may warrant the use of specific allometric equations for this forest type.

Shifting cultivation mosaics are complex ecological systems that are highly dependent on local management practices. Factors that affect the growth form of trees in shifting cultivation mosaics include the dominance of coppicing (resprouting from existing root stalks) and/or seed derived tree growth, average fallow time, terrain, and land use history. It is common for coppicing trees to regrow with multiple stems, a morphological variation that may cause significant allometry differences. At the minimum, trees in shifting cultivation areas will be on average smaller than trees in other forest types and thus may be less accurate at estimating the biomass of small diameter trees.

The biomass stocks of *bamboo*, although technically a grass, can also be estimated through allometric equations. For obvious reasons, allometric equations for bamboo typically require measurement inputs that are different from trees such as culm diameter rather than diameter at breast height. As bamboo species may vary in structure and biomass content, it may also be appropriate to apply species-specific equations, especially if common bamboo species are found to contain relatively high amounts of biomass per unit area.

The allometry of *palms* results in diameter not being highly correlated with biomass. Palm equations often include measurements of palm height, although number and length of palm fronds are sometimes also included (Table 3). Depending on the variability of palm growth forms, species or genus specific equations may need to be developed.

The biomass of *woody shrubs* can also be measured through the development of allometric equations. The variables in such equations will be very dependent on the growth form, however examples include height, number of stems, and canopy area. This can also include shrub crops, such as tea. Where forest land cover types do not contain large amounts of shrubs, it is not recommended for shrub equations to be created. Instead, shrubs can be measured as part of non-tree vegetation in destructively sampled ‘clip plots’ during the forest inventory.

Root Biomass Equations

Root biomass, typically referred to in this context as *below ground biomass* (BGB) is an important component of stored carbon in forests. However, as with aboveground biomass, it is not practical to measure the BGB directly because it is extremely laborious to extract, dry, and weigh the entire root structures of trees. For these reasons, it is also very difficult and resource-intensive to develop specific forest type or country-specific allometric equations for root biomass. Instead, it is acceptable for below-ground biomass to be indirectly using available equations that reliably predict root biomass based on shoot (i.e. aboveground) biomass.

Published root:shoot ratios are summarized in table 3 below. The ratio developed by Mokany et al. (2006; also reported in the IPCC 2006 GL) offers specific ratios based on forest type and climate zone and are applicable when the aboveground biomass estimate (shoot) is reported at the stand level (not for individual trees). For an individual tree, Mokany et al. (2006) propose the following relationship (R^2=0.78):

$$BGB = 0.26 * AGB$$

Where:

BGB = below ground biomass carbon of one tree

AGB = aboveground biomass carbon of one tree

Table 3. Root to shoot ratios for tropical forests

Geography	Ratio to AG biomass	Source
Tropical/subtropical moist forest/plantation	• *IF* AGB > 62.5 t C/ha: BGB =0.235* AGB • *IF* AGB ≤ 62.5 t C/ha: BGB =0.205* AGB *Where:* BGB = below ground biomass carbon AGB = aboveground biomass carbon	Mokany et al. (2006)
Tropical/subtropical dry forest/plantation	• *IF* AGB > 20 t C/ha: BGB =0.275* AGB • *IF* AGB ≤ 20 t C/ha: BGB =0.563* AGB	
Global tropical forests	0.18	Gremer & Sauerborn, 2007
Pasoh Forest Reverve, Peninsular Malaysia	0.18	Niiyama et al. 2010
Tropical forests	0.221 n=17 R^2=0.816	Luo et al. 2012

Angiosperms (global)	0.205	Reich et al., 2014
Gymnosperms (global)	0.192	

The Mokany et al. root:shoot ratios are commonly applied for estimating belowground biomass in tropical forests and thus it is recommended that these ratios be applied unless a specific study has been conducted for the area of interest that has produced root estimates significantly different from those estimated using Mokany et al. (2006).

Verify existing equation or develop a new equation?

The use of an existing allometric equation is often the most cost-effective approach, in light of the fact that a wide range of allometric equations are available that were developed based on expansive datasets representing a great number of trees. If this approach is chosen, the applicability of any existing allometric equation must nevertheless be verified.

Since live trees contain the majority of biomass in most forests, the careful assessment and verification of models applied to derive estimates of live tree biomass is perhaps the most important step in forest biomass inventories. Chave et al. (2005) confirms that while there are multiple sources of error in the estimation of aboveground biomass in tropical forests (see below section on error), model error from the use of an allometric equation to convert direct measurements to biomass estimates has been shown to be a significant source of error.

The basic initial step when exploring which allometric equation to employ is developing a full understanding of the population of trees that were destructively harvested to produce the model. This includes considering:

- Range in diameter and height
- Species
- Geographic range
- Soil type, particularly if trees grew on atypical, non-zonal soil (e.g., very sandy spodosol or highly organic histosol)
- Tree density

As all of these variables have a significant impact on growth behavior and aboveground biomass, the allometric equation selected to estimate the aboveground biomass of the population of interest must have been developed by studying trees with comparable biophysical characteristics and growth conditions.

If an existing allometric equation is deemed potentially appropriate, its applicability can be verified through measurement or limited destructive sampling and additional series of statistical tests. Destructive sampling typically involves harvesting a representative sample of trees (at least five, including at least three of these to have DBH >50 cm, but preferably more) from the forest strata of interest so that the biomass can be directly measured (i.e., dry weight of sample trees). Strict protocols must be followed during the destructive harvesting process to ensure scientific integrity (see *SOP Destructive Sampling of Trees* in Appendix 2).

Alternatively, existing databases may offer relevant measurements for the geographic area of interest that can be used to test the applicability of the model. For example, the BAAD (Biomass and Allometry Database) database provides data on woody plant measurements of at least 678 species from 176 different studies (Falster et al 2015). This database includes measurements from individual plants (rather than stand averages), direct measurements of biomass (i.e., data derived through destructive harvesting, rather than estimated using allometric equations), and offers appropriate associated metadata (location, light, management, vegetation type, etc.).

It is recommended that multiple methods of statistical analysis be employed to determine the adequacy of the chosen allometric equation (Tedeschi 2006). As a first step, the biomass of the harvested trees can be plotted along with the curve of biomass against diameter as predicted by the allometric equation. The predictive accuracy can be assessed by calculating the error between the predicted biomass and the biomass from the harvested tree and by plotting the residuals (Pickard et al 2012). Ngommanda et al (2014) used three validation criteria in assessing the applicability of site-specific equations compared with pantropical equations: relative bias, relative root mean square error, and the proportion of observations outside an approximate confidence interval for predictions (e.g. 95% confidence interval).

In general, if the measured biomass of harvested trees are evenly distributed both above and below the predicted biomass using the equation, the equation has demonstrated that it is a good predictor for tree biomass in the area of interest.

In situations where all examined biomass equations produce very biased estimates, it is recommended that additional field data be developed and either used to develop a new equation or to calibrate existing equations. The estimates of carbon stocks, both at the tree and at the site level, will include a certain amount of error (See section on error). It is recommended that the error associated with the use of the allometric equation be incorporated into calculating total biomass error.

Error and Uncertainty in Allometric Equation Estimates

It is not possible to avoid errors entirely when conducting forest inventories or biomass estimation. It is important, however, to know how to identify sources of error and minimize them. There are numerous sources of potential error in estimating biomass and carbon stocks. Types of error include the following:

- Sampling error – the difference between a population value and a sample estimate, measured as the standard error of the sample estimate
- Measurement error – the difference between a measured value and the true value errors in collecting data from the plots
- Model error – error due to the use of models such as allometric equations or diameter-height relationships

Sampling error is the easiest of these to quantify, while measurement and model error can be difficult to identify. Measurement error can be estimated by comparing two sets of repeated measurements for a limited percent of the sample. Model error can be estimated based on goodness-of-fit of the original model, or by validating the models used and estimating error through use of destructive sampling or conversion factors.

Estimating overall error when multiple error sources are combined can be done by either simple propagation of errors of through the use of a Monte Carlo analysis.

The following equation is used for error propagation, as recommended by IPCC:

$$U_E = \frac{\sqrt{(U_1 * E_1)^2 + (U_2 * E_2)^2 + \dots (U_n * E_n)^2}}{(E_1 + E_2 + \dots E_n)}$$

Where:

UE = percentage uncertainty of the sum of the quantities (half the 95% confidence interval divided by the total (i.e. mean) and expressed as a percentage)

Un = percentage uncertainty associated with each source

En = the uncertain quantity (e.g. biomass of the tree or of the stand)

The Monte Carlo approach is recommended by IPCC (2006) as an advanced alternative to simple error propagation. A Monte Carlo analysis selects random values of the data being evaluated and uses them in calculations, repeating this many times to build the overall probability of obtaining the mean outcome. It is a method for iteratively evaluating a deterministic model using sets of random numbers from a given distribution for each parameter as inputs. Using this model it is possible to substitute a range of values for any factor with uncertainty, thereby creating a stochastic model. A deterministic model yields the same result with each recalculation, while a stochastic model introduces probability and randomness so that the results are different with each recalculation. If sources of errors are uncorrelated and have a normal distribution, then simple error propagation (deterministic model) is acceptable. It is advised to use a stochastic model when the functions are complex or nonlinear, uncertainty is high, there are multiple sources of uncertainty, correlations exist between datasets, or distribution is not normal.

Developing New Allometric Equations

There may be a need to develop a new allometric equation in cases where (1) efforts to verify an existing equation have resulted in the conclusion that the equation is not appropriate, (2) where there are many trees with unique forms or densities, or (3) where forests dominated by a unique and limited set of specific species (e.g., only 1-2 species). The development of a new equation necessitates that at least 30 trees covering the full range of diameter classes are harvested. If the regression based on the 30 trees does not result in a statistically significant relationship (high r-squared value), then additional trees will need to be harvested.

Harvesting a sufficient number of trees to develop new regression equations is very time and resource intensive. As such, it is worthwhile to thoroughly assess whether existing equations from the literature could be used. If destructive sampling is undertaken for the purpose of developing a new equation, an overview an approach using sample data to create an allometric equation is offered in Appendix 1 (as taken from Dietz and Kuyah, 'ICRAF 2011 Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling with notes in bold from authors of this manual, Destructive Sampling Guidance'.) SOPs for destructive harvesting of trees, saplings, palms, bamboo, and non-tree woody biomass are also included in Appendix 3.

Summary

In conclusion, different equations render different estimates for biomass because each are designed to reflect specific forest and climate types. Any existing allometric equations that may be applicable to the species or vegetation type of interest should be properly investigated to explore whether it is appropriate to apply species-specific or vegetation-type specific allometric equations. Some extent of destructive sampling will likely be necessary for the development a new biomass regression equation or for the verification of an existing one. The field measurement design and field measurement methods for destructive sampling for both these procedures is covered in this manual, including accessible methods to conduct preliminary statistical analyses. Both verification of existing equation and development of a new equation have uncertainty and error associated with them that should also be quantified.

2. DESTRUCTIVE SAMPLING - FIELD MEASUREMENT DESIGN

The previous chapter provided an overview of how tree biomass is estimated and the use of allometric equations. This chapter talks specifically about the field measurements and the design of such measurements in order to destructively sample and estimate the biomass of trees. This guidance is applicable to both the verification of existing equations and the development of new equations. The major difference being the quantity of trees destructively sampled.

Existing data on land cover type, DBH ranges, and climatic variables will guide the sample design for both the verification and development of allometric equations. In particular, spatial delineation of land cover classes serves as the foundation for effectively sampling and estimating forest carbon in a country.

Stratification for Destructive Sampling

Sampling design should allow for the sample population to be truly reflective of the population the allometric equation is supposed to reflect. Generally, this means a large quantity of sample sites are chosen at random. However, because destructive sampling is very resource intensive, stratification of the population into homogeneous landscape types (strata) can and should be utilized instead. This will reduce the overall sampling effort. Key tenants when considering sampling distribution for the purposes of field data collection include how representative the sample is of the:

i. forest type

ii. topographic conditions
iii. present tree classes

Recent national forest surveys and data from national inventories should inform sampling to ensure appropriate coverage of all land classes.

Sampling Distribution DBH and Topographic Conditions

Once the strata have been chosen, the range of DBH class sizes to be sampled should be selected. Pre-existing data on tree measurements in the area are very useful in selecting the DBH ranges to be sampled. For example, if a significant percentage of the landscape is comprised of trees of small DBH, the selected range should include these DBH sizes. Similarly, the selected range should also capture trees of larger DBH found within the population (forest areas being sampled).

Large trees significantly influence total forest biomass and therefore must be captured in destructive sampling. For example one tree with a DBH of 100 cm and wood density of 0.6 t/m^3 contains about 13.7 t biomass (based on moist equation in Chave et al. 2005) and can account for up to 20% of the total biomass of a scaled sample plot (i.e. t/ha) (Walker et al. 2015). As such, while sufficient data should be collected to reflect the full range of tree sizes, there should be particular attention focused on destructively harvesting trees from the larger end of the DBH spectrum. It is suggested that at least half of the sampled trees have DBHs that fit in the upper quantile of the DBH range.

The sites selected to be sampled within each stratum should be done so randomly (See *Determine Sampling Locations using stratified two-stage sampling* SOP below in Appendix 2). This will create a statistically robust stratified random sampling design. Trees within each class size should be randomly selected as well without attention paid to species. This will provide a generic allometric equation for the area. Following, the species type that does show up most often in the sampling can assume to be a dominate species and can be crossed reference with any species abundance data for the area, if available.

As field sampling campaigns are typically highly resource intensive, it makes sense to carefully plan which data are to be collected, with a focus on inclusivity. It makes sense to more comprehensively collect other types of input data required for any subsequent Forest Inventory (e.g., deadwood, wood density, sapling weight, nontree vegetation, etc.) while teams are already deployed to the field to take advantage of the fixed costs and economy of scale associated with field work. The location for such sampling could be located in association with locations sampled for destructive tree sampling. This effort can serve to provide the necessary data for an analysis of the role of carbon pools beyond live tree biomass and/or if there is a desire to include additional carbon pools in the National Forest Inventory.

Whether sampling is undertaken to verify an existing model or to develop new equations, the sampling effort should be designed so that the biomass evaluation is appropriate to use for the entire country. It will be important to avoid concentrated sampling (i.e. all in one location), but the constraints of limited resources available should be considered carefully in the plan. A reasonable overall strategy to sampling should be to target sampling locations in areas that are more easily accessible, and where there is a presence of multiple strata. A detailed structure for 2-stage sampling design is offered in the *SOP Determining Sampling Locations using stratified two-stage sampling* included in Appendix 2.

Before data collection, an assessment of existing data on trees in each strata should be conducted and DBH values should be divided into four classes:

Class 1: below lower quartile of DBH range
Class 2: Trees falling between lower quartile and median of DBH range
Class 3: Trees falling between median and upper quartile and of DBH range
Class 4: above upper quartile of DBH range

For either verification or development of a new biomass regression equation, at least five separate sites should be sampled per stratum. In general, to ***verify the applicability*** of an existing selected biomass regression equation, it is recommended that >5 samples of each forest class be destructively sampled. Trees sampled should be in the larger size classes. If a ***new biomass regression equation*** is to be developed, at least 30 samples covering the full range of sizes need to be harvested. This must include the largest diameter trees found for each forest type. Data to collect per sampling location are described below for both verification of the applicability of an existing equation, as well as for the development of a new equation.

Table 2 Recommended number of sampling to take place per sampling location when verifying the applicability of an existing equation

	Tree	Saplings	Non-tree woody vegetation clip plots	Dead wood
	1 tree DBH Class 2 or 3			6 samples from various stages of decomposition
	1 tree in DBH class 4			
TOTAL	2 trees	10 sapling	10 samples	6 samples

Table 3 Recommended number of sampling to take place per sampling location when developing new tree allometric equation

	Tree	Saplings	Non-tree woody vegetation clip plots	Dead wood
	1 tree DBH Class 1			6 samples from various stages of decomposition
	1 tree DBH Class 2			
	2 trees DBH class 3			
	2 trees DBH class 4			
TOTAL	6 trees	10 saplings	10 samples	6 samples

If palms or bamboo exist in the forest types sampled, separate sampling must take place for these vegetation types.

A finalized sampling design should include a map of the locations where sampling will take place along with a table listing exactly what data will be collected in each location.

Once field crews have arrived at the GIS derived GPS location, the trees to sampled must be selected randomly. For example, a 10 m wide transects in a North, South, East, and West direction can be taken from the GPS location. The first appropriate tree (e.g. meeting the DBH range for that sampling location) encountered along this 10 m wide transect shall be selected for destructive sampling. This can be repeated for the other trees to be sampled at this location. As stated in the standard operating procedures below, prior to initiating destructive sampling, all tree variables must be measured using the same measurement methods that would be used during the Forest Inventory. The respective standard operating procedures should be followed for such methods.

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APPENDIX 1: GENERAL GUIDANCE ON DEVELOPING NEW EQUATIONS - EXCERPT FROM ICRAF'S 'GUIDELINES FOR ESTABLISHING REGIONAL ALLOMETRIC EQUATIONS FOR BIOMASS ESTIMATION THROUGH DESTRUCTIVE SAMPLING'

The data processing guidance provided in the ICRAF 'Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling' (2011) developed by Dietz and Kuyah (2011) is presented below. This text is taken directly from this manual

Box 1. Excerpt from: ICRAF 'Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling' (2011)

Data setup:

1. Transfer field data and laboratory datasheets to an Excel spreadsheet
2. Review field data and clean typos.
3. Create scatter diagrams and identify outliers or questionable data to potentially verify
4. Assess the relationships between measured variables and measured biomass using either Excel or statistical software:

Excel:

- 'Normalize' or transform the data using natural logarithm to attain a linear graphic relationship (x_2 = ln (x_1))
- Multiply the estimate by a correction factor to the biomass estimates to address error introduced in the normalization. The equation for doing this is below:

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

Where:

CF Correction Factor

RSE Residual standard Error

If using statistical software package:

5. Apply the 'generalized linear models of regression analysis' option on logarithmized data. **There are many model forms that have been tested extensively in terms of identifying an equation to fit these types of data from destructive tree sampling. We suggest starting with the form chosen in Chave et al. (2005) and (2014). and restricting statistical analysis to this form unless a fit is not found.**

6. Run regression analysis of the power function in the form of y = $a + x^b$, with its linear equivalent, y = e^a x x^b when deriving it from a logarithmic form where y is the dependent and x is the independent variable, while *a* is the intercept coefficient and *b* is the slope coefficient.
7. **Optional**: Use multiple regression to test the influence of additional explanatory variables on the model fit and accuracy. **The variables that influence allometric equations for trees is well known. Run regression analysis based on the variables that were decided to be included and were captured in field sampling.**
8. A combination of diameter, height, and/or wood density can be fitted either independently or using their compound derivatives (e.g. dbh^2 x H or dbh^2 x ρ) as a single predictor.
9. Select the best fitting model according to the highest r^2 for equations with a single explanatory variable and adjusted r^2 for equations with two or more explanatory variables.
10. Validate the regression using holdout samples[1].
11. Apply the F test to determine significance of the regression.
12. Determine the predictive accuracy of the equation by calculating the error (%) between the predicted biomass produced by the equation and the actual biomass calculated for each harvested tree (Chave et al. 2005). The equation for calculating the error is:

$$Error\ (\%) = \left(\frac{predicted\ ABG - measured\ AGB}{measured\ AGB}\right) * 100$$

In addition, a more detailed approach on exploring fit and validation through statistical methods is given in the *Manual for building tree volume and biomass allometric equations. From field measurements to prediction* (Picard et al. 2012).

[1] Holdout samples are randomly selected destructively harvested trees from each diameter class (typically one representative per diameter class). used to validate the equation under development.

APPENDIX 2: STANDARD OPERATING PROCEDURES (SOPs)

SOP Determining Sampling Locations using stratified two-stage sampling

This sampling design consists of selecting primary sampling units (PSUs) at the first stage and then selecting secondary sampling units (SSUs) at the second stage of sampling. This ensures that any location has an equal probability of being sampled.

The initial sampling units are chosen by using a systematic sampling with a random start approach. A 'grid' is placed across the area to be sampled in a randomly selected orientation. The grid cells will then serve as the 'primary sampling unit' (PSUs). Once the PSUs are chosen, a particular location within the PSU is randomly chosen to initiate field sampling. This is referred here to as the SSU1.

Thus, the definition of these terms is:

- **PSU-grid** cell: an individual grid cell of a known and defined size (e.g., 5 x 5 km square) within the grid that has been superimposed across the area to be sampled. PSU-grid cell is given a unique ID. This ID number will then be used within the identification of a PSU.
- **PSU_i** – this is the spatial extent of the stratum *i* within a given PSU-grid cell. The label of the PSU shall correspond to the PSU-grid ID and include stratum notation (here denoted as *i*).
- **SSU_i** – this is a point, representing the sampling location where destructive sampling will take place. The SSU_i is located within selected PSU_i.

The following steps 2 to 4 to implement two-stage list sampling design shall be repeated for each stratum separately. The entire gridded area shall be used to determine selected PSUs for each stratum and thus each PSU-grid cell shall have an equal probability to be selected during the list sampling selection for all stratum. If one PSU-grid happens to be selected for both strata A and B, this is allowable. There will then a PSU_A for stratum A and a PSU_B for stratum B, and thus two SSU points located within the boundary of this PSU, one for stratum A and one for stratum B.

STEP 1: Create PSU-grid (3 x 3 km)

First, the size of the grids needs to be defined (Figure 1). The size of the grid cells takes into consideration other field surveys that may have occurred to facilitate a future national forest monitoring system (NFMS) for the country. The PSU-grid cell size shall be small enough so that a sufficient quantity of PSU-grid cells will be available for sampling yet large enough to ensure both that the field cluster plot design can fit within a PSU selected and that sample plots are well distributed across the landscape.

To create a PSU-grid across the area to be sampled, a raster dataset with desirable cell size (3 km) needs to be created in ArcGIS. If the grid layout does not need to be aligned with other sampling grids taking place, then the orientation of the grid shall be chosen randomly. The raster will be converted to polygon shapefile to maintain, unique identification number (ID) for each PSU-grid (PSU_ ID).

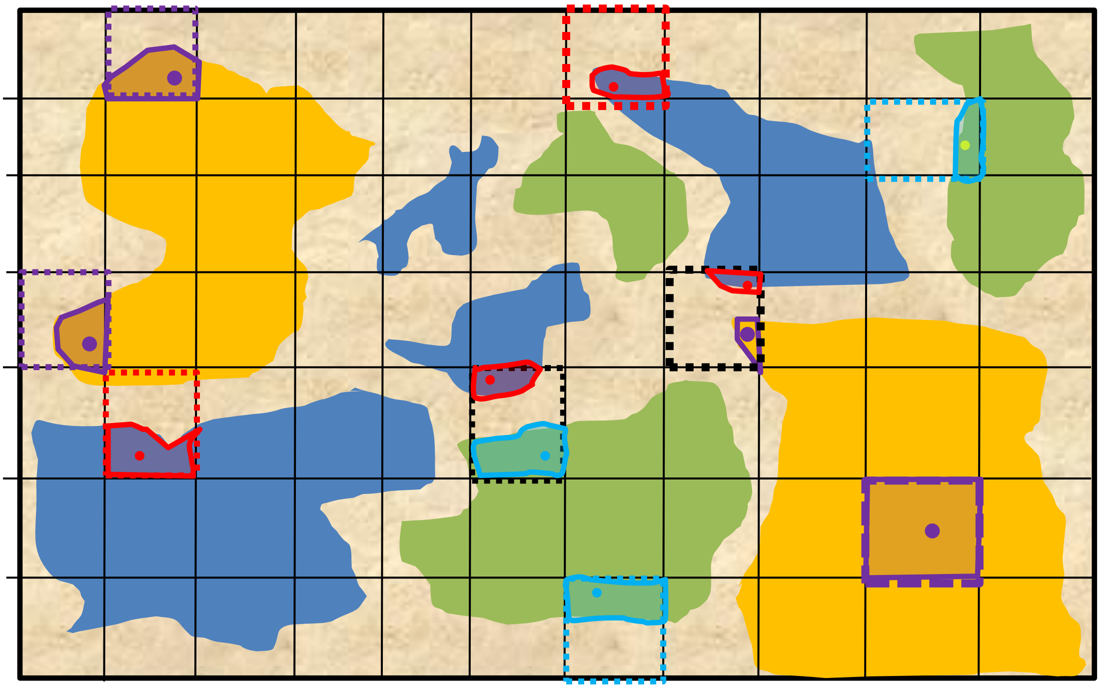


Figure 1: Example of selected PSU-grids in dashed lines and selected PSUs (polygons) with SSUs (dots) assigned within. Note, some PSU-grids may randomly be selected for two different stratum.

STEP 2: Create a list of PSUs for the stratum of interest

To create PSU_is for each stratum, use Intersect function in ArcGIS to combine the PSU-grid shapefile with land use map. Next calculate the area of each PSU_i for each stratum in ArcGIS. If the area of the PSU_i is less than the minimum area in the forest definition, exclude that PSU_i in the two stage list sampling procedure (in consideration of the minimum threshold area for defining forest, thus only PSUs with area greater than such threshold should be included in the PSUs grid list.). A list of all PSUs should be created and the attribute table exported as DBF table, maintaining record of PSU_i_ID and area in hectares.

STEP 3: Select PSUs with probability proportional to size

To ensure all locations within a stratum have an equal probability of being measured, the probability that a given PSU_i will be selected must be made proportional to its area. To select PSU_is with probability proportional to their size, use the list of PSUs from Step 2 and calculate the cumulative area of each stratum associated with each PSU. Cumulative area is defined as sum of all PSUs in the list up to and including the PSU itself. Once the cumulative areas are calculated, a random number between the smallest and the largest cumulative area should be generated. To select a PSU for forest sampling, the random number should be less than PSU's cumulative area and larger than the cumulative area for the previous PSU in the list.

All of the operations conducted in Excel are explained below:

1. After opening the DBF file in Excel, calculate the cumulative area for each PSU in a new column.

2. In the next column, create a list of random numbers between the minimum and maximum cumulative area of the PSUs grid list shall be generated created using following formula:

=RAND ()*(B - A) + A

Where:

B is the maximum cumulative area, and

A is the minimum cumulative area for the list of PSUs

Once the random numbers have been created, convert the formula in each cell into a number to prevent new random numbers from being generated.

To select a PSU_i for sampling, the random number should be compared to the cumulative PSU area. The PSU_i shall be selected when the random number is smaller than the PSU cumulative area and greater than the previous PSU in the list cumulative area. For example, if the random number is 26,446.42 and the cumulative area for PSU_i with ID=1151 is 32,689.23 ha and the cumulative area for the previous PSU is equal to 22,758.71 ha, the PSU ID=1151 will be selected, because 26,446.42 (random number) < 32,689.23 (PSU_i cumulative area) and 26,446.42>22758.71 (cumulative area of the previous PSU in the list)

A table of selected PSU_is following the order of random number generated shall be created containing information on PSU ID, PSU_i area, PSU_i cumulative area, the order of the generated random number and random number itself.

STEP 4: Assign sampling location

The table of selected PSUs in Excel shall be imported to ArcGIS and joined to the land use classes PSUs shapefile to identify the selected PSUs. Generate random points to identify the location where sampling will take place. Accessibility constraints may also be incorporated.

Determining trees to destructively sample

Once the sampling point has been randomly identified from the above process (stratified two-stage sampling), assign each sampling location the tree size classes to be sampled. Navigate to the sampling location and find the GPS point. From the GPS point, using a compass, find direct north and start walking north. Destructively sample the first tree of the tree size class within 20 m of the line walking north. If the randomly selected tree of the correct size class cannot be safely felled, select the next closest tree within the same size class.

SOP Use of a clinometer

A clinometer is a piece of equipment used to measure angles. This equipment is widely used in the field for multiple reasons, among them: measuring slope of the terrain, and measuring tree height. Usually a clinometer has two sets of units for measuring angles:

Right side: percent (%)

Left side: degrees

The Clinometer will indicate the units. For example, if using a Suunto® Clinometer, look into the clinometer and tilt your head back to look all the way up. The right side will say %.

To measure an angle using a clinometer:

1. Holding the clinometer string, bring it up to your dominant eye (the string on the clinometer should be below the eye piece, stretching downward)
2. Keep both eyes open and simultaneously aim at the object you want to measure in the distance and look at the numbers through the clinometer
3. Record the % or degrees at the point that crosses what you are measuring.

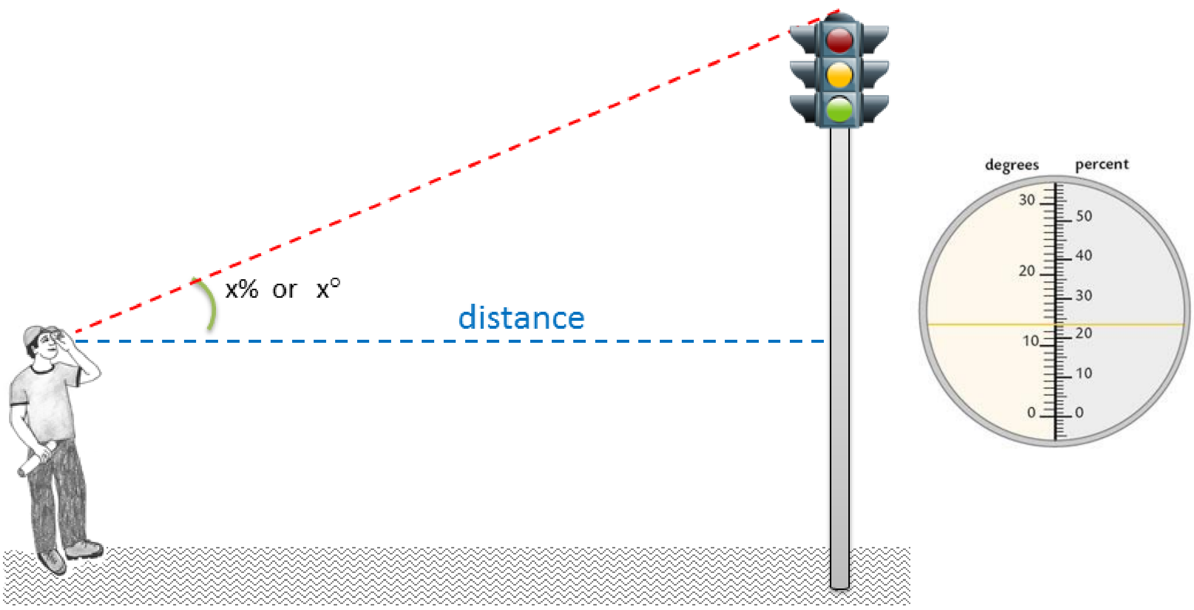


Figure: Measuring angle degrees or % using clinometer

SOP Measurement of Height

Field equipment:
Clinometer
Laser Range Finder or >50m measuring tape
Relascope (optional)

The height of trees, palms, and other things is usually done by creating two right triangles. The distance from the object and the person measuring is measured and two angles are measured. The actual height is then calculated using trigonometry during data analysis.

1. Walk around the tree and find the best location to view the top of the tree.
2. Stand far enough away from the tree so that the top of the tree is less than 90 degrees above the line of sight.
3. Measure total tree height (see Figure below):
    a. Always stand up-slope of the tree. Standing down-slope of the tree should only take place when no other option exists.
    b. Using clinometer, measure the angle in % to top of the canopy of the tree (a%)
    c. Using clinometer, measure the angle in % to base of the tree (b%)
    d. Using Laser Range Finder or measuring tape, measure distance from eye of person measuring tree to the tree (dis_{tree}) in meters. Be certain that the distance measured is horizontal and not along the slope. Record the horizontal distance to the nearest 0.01 meter
4. Repeat measurements in another location, thus measuring tree height in two locations.
5. If you are not able to stand far enough from the tree so that the top of the tree is less than 90% above you, then take the measurements (a) and (b) in degrees (units on left side of clinometer). CAREFULLY NOTE ON THE DATA SHEET THE CHANGE IN UNITS! Tree height must be calculated differently if degrees are used!

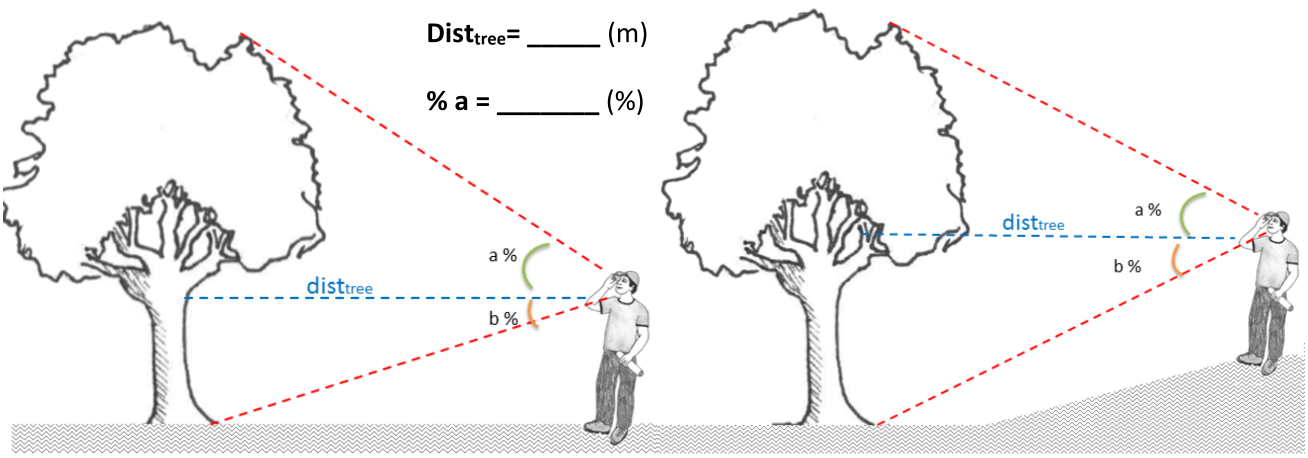


Figure Tree height field measurements

SOP Destructive Sampling of Saplings

Field Equipment:
Handsaws
Machetes
DBH tape
Clinometer
5 kg scale
~500 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
Marker (to label bags and samples)
'Calibration weights' (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

The biomass of saplings can be estimated by counting the number of saplings in each tree-plot and then using an estimate of the 'weight of the average sapling' to estimate total sapling biomass. Therefore, the weight of an average sapling must also be estimated through destructive sampling. The same definition of sapling as presented in *SOP Measurement of Trees* shall be used.

Prior to Field Sampling

Create 'calibration weights' to calibrate hanging scales: Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.

1. Ensure the laboratory scales are calibrated
2. Medium hanging scale (5 kg):
    a. Find an item that weighs about 3 kg and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
    b. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.
3. Small hanging scale (~300 g):

a. Find an item that weighs 100-250 g and does not change weight when wet (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
b. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

Field Measurements

At the beginning of the fieldwork campaign, saplings must be harvested and weighed to calculate the weight of an 'average' sapling. Saplings harvested should span a range of typical sapling types (species, diameters, heights, etc.). At least 30 individual saplings must be weighed. If saplings vary significantly from one land cover type/stratum to another, weights should be measured for each stratum.

1. Calibrate hanging scales at start of each day with 'calibration weights'.
2. At each tree destructive sampling location, 10 saplings shall be chosen at random. These can be randomly selected along the 10 m wide transect used for selecting the large tree to be harvested, or in another location.
3. For each sapling:
    a. Cut sapling at base
    b. Weigh empty piece of plastic sheeting. Record weight of plastic sheeting.
    c. Place all of harvested sapling on plastic sheeting and weigh. Record weight of sapling.
    d. Select a representative subsample of sapling.
    e. Weigh the subsample bag empty. Record weight.
    f. Weigh the subsample bag with the subsample inside. Record weight.
    g. Label the subsample bag with the sapling name, identification number, subsample identification number, and weight of subsample
    h. Until samples are taken to the laboratory, place samples in location that allows air drying to occur.
    i. Later, the subsample will be oven dried to constant weight at 70C, weighed, and the ratio of dry weight to fresh weight will be calculated.

SOP Destructive Sampling of trees

Field Equipment:
Professional chainsaw operator
Chainsaw
Handsaws
Machetes
DBH tape
Clinometer
Laser Range Finder or measuring tape (to measure height)
Tree corer
50 kg scale
5 kg scale
~300 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
'Diameter fork' (see below)
Marker (to label bags and samples)
10 m of rope, 1 – 2 cm thick (to tie up scale and to weigh branches)
'Calibration weights' (see below)
Laboratory Equipment:
Drying oven
Laboratory scale

Prior to Field Sampling

1. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.
    a. Ensure the laboratory scales are calibrated
    b. Large hanging scale (50 kg):
        i. Find an item that weighs about 10-30 kg and does not change weight when wet (e.g. metal tool of some sort) or over time. Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        ii. Calibrate hanging field scale using this 'calibration weight' item and the average recorded weight. Do this every day prior to weighing items in field. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Ideally the item used to calibrate the scale should be a piece of field or base-camp equipment of an appropriate weight.
    c. Medium hanging scale (5 kg):

i. Find an item that weighs about 3 kg and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.

ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

d. Small hanging scale (~300 g):

i. Find an item that weighs 100-250 g and does not change weight when wet (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.

ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

2. **Create Diameter Fork:** Create a diameter fork that has two openings equating to the size classes that will be used during destructive sampling (see Figure below). For example: 20 cm wide and 10 cm wide. Or create different diameter forks – eg one 20 cm opening and another with a 10 cm opening. The 'diameter fork' can be made out of plastic or aluminum, anything that is relatively stiff and will not break apart easily.

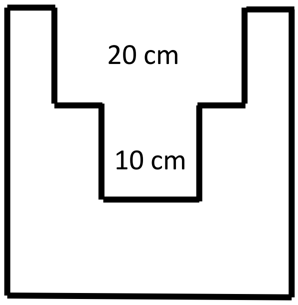


Figure Example of a diameter fork

Destructive Sampling of Trees

Prior to cutting down any tree, it is essential to obtain all necessary permits and secure authority to cut down the trees. Where possible, it is highly advisable to implement the destructive sampling of trees in locations where trees are being commercially harvested. It is recommended that a professional undertake the task of cutting the tree down. Felling trees is dangerous work, and everyone participating should observe the highest safety standards. To minimize the risk, it is recommended that information on the condition of the bole be ascertained by the chain saw user (generally common practice by professionals). If for example, the center of a tree is rotten, cutting into it with a chainsaw can cause the tree to collapse suddenly. If possible, have the tree cutter fell the tree in a location that will make measurements easy to obtain but above all in a safe location. People who are not cutting the tree should receive direction from the professional tree cutter and stand very far away from the tree in case it starts to fall in an unexpected direction.

If the diameter of the tree to be measured is less than 20 cm, then the size classes of tree components can be altered to include leaves, twigs, and branches <10 cm in diameter, and branches 10-20 cm in diameter.

Prior to Tree felling

Before the tree is cut down, measure all tree parameters used in all potential biomass regression equations that may be applicable (e.g. DBH, total height, height to first branch, species). Care must be taken to measure all tree parameters using the exact same methods that would normally be used in the field.

1. Assign one person to record the data
2. Measure all the tree parameters that will be potentially used in the allometric equation to be developed and those in existing equations (eg DBH, DSH, H) for the tree to be destructively sampled prior to felling. For trees with more than one stem, the parameters for each stem must be measured separately and the weight of each stem must be measured separated. The height of the bole prior to branching must also be measured. It is important that the diameter tape is used properly using the following steps to ensure consistency of measurements:
    a. Record the name of the tree, based on tree naming system developed prior to field data collection.
    b. **Tree Pole placement**: For each tree, place the Tree Pole (1.3 m plastic pole) against the tree to indicate the location of measurement (eg DBH). Placement of the Tree Pole depends on the slope of the ground, leaning angle of the tree, and shape of the tree bole (see Figure below for correct placement of diameter tape).
        i. **Slope:** Always place tree pole and measure diameter on the *upslope* side of the tree
        ii. **Leaning tree**: Always measure the height of a measurement (1.3 m) parallel with the tree, *not* perpendicular to the ground. Therefore, if the tree is leaning, measure underneath the lean, parallel with angle of tree. If a tree is not straight, a tape measure must be used to measure the bole distance from ground to DBH.
        iii. **Dead tree**: If a tree is in dead class 1 (see *SOP Measurement of Standing Dead Wood*), mark as dead on data sheet. Trees are considered alive if there are green leaves present. Even if there are only one or two green leaves present the tree is considered alive. However, in deciduous

forests during a season when trees drop their leaves (ie dry season) a branch or the stem must be cut to verify that the cambium is alive in order to determine if the tree is alive or dead.

iv. **Multi-stem tree**: If the tree is multi-stemmed with forking below the point of measurement (eg 1.3 m), measure the diameter on each stem and tag the stems that exceed the minimum diameter for the nest. Record it as if each stem were a different tree on the data sheet, but with a note that the stems make up one tree.

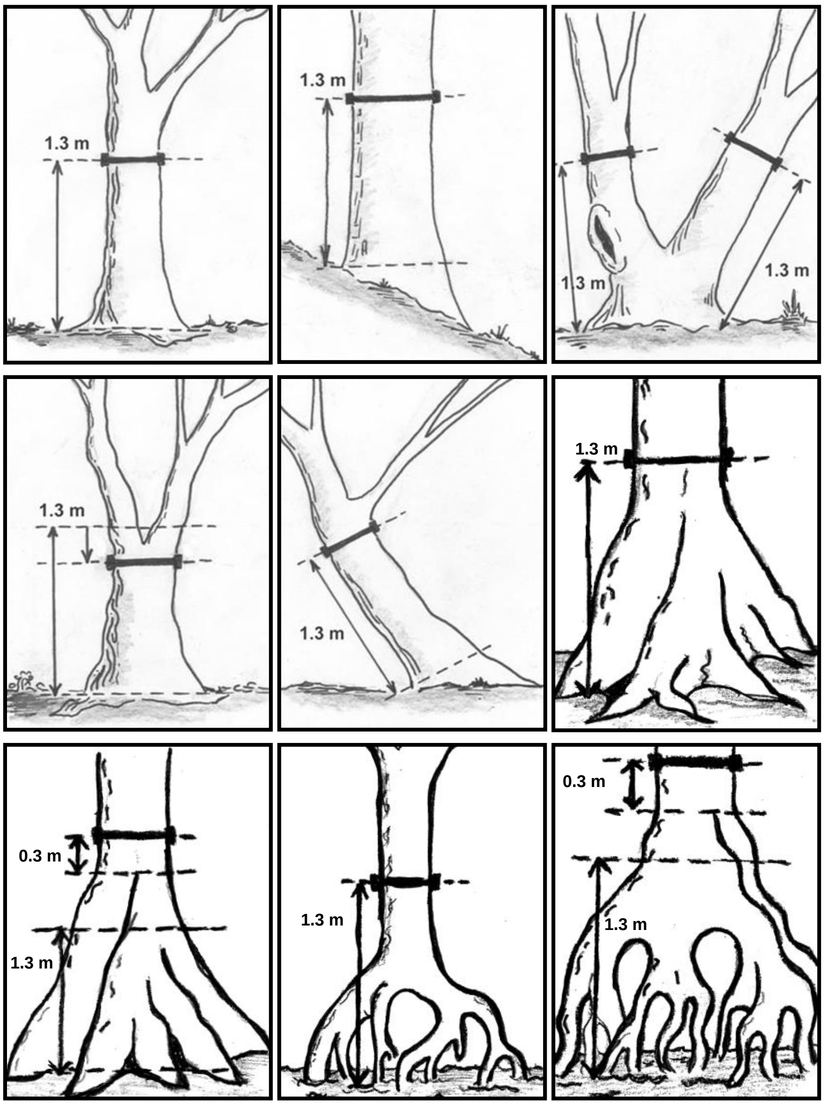


Figure: Proper placement of diameter tape

v. **Buttressed tree**

1. If the buttress is shorter than 1.3 m, measure the DBH at the standard (1.3 m) height.

2. If the buttress is taller than 1.3 m, measure the diameter at 30 cm above top of buttress as shown in figure below. In cases where buttress is too tall and out of reach, the following procedure shall be followed:

   i) Use portable retractable ladder and lean ladder against tree to allow for measurement of DBH 30 cm above from the top of the buttress.

   ii) If ladder is unavailable, and taking into consideration the safety of field crew, climb the tree to take measurement 30 cm above the top of the buttress. In fluted buttress, it is possible to carve steps on the buttress itself to allow climbing to top of buttress. Extreme caution should be employed and climbing should only be performed when conditions are deemed safe by field crew leader.

   iii) If ladder is unavailable, and climbing is considered unsafe, retractable poles should be use. Poles shall be placed against the tree, at the edge of its circumference, projecting the diameter at exactly 30 cm above top of buttress down to the ground. An observer is required to ensure poles are properly placed at the very edge of tree's circumference in a way that linear distance between poles represents the diameter of tree at 30 cm above end of buttress. The **linear distance** between the two poles shall be measured. At least two measurements shall be taken on opposite sides of tree using this method, and then averaged to estimate tree DBH.

   Note: The distance between poles shall be measured linearly, and thus proper measuring tape shall be used. Poles can be made from tall saplings found outside the sampling plot in the forest or by linking Tree Poles together (e.g. with pvc connectors).

c. **Diameter measurement:** Tree diameter should be measured to the nearest 0.1 cm (eg diameter of 10.2 cm *not* 10 cm).

   i. If the diameter tape has a hook, push the hook into the bark of the tree slightly to secure it and pull the tape to the right. The diameter tape should always start left and be pulled right around the tree, even if the person taking the measurement is left-handed. As the diameter tape wraps around the tree and returns to the hook the tape should be above the hook. The tape should not come around the tree below the hook. The tape should not be upside down; the numbers must be right side up. (see Figure below)

   ii. If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure the tree's diameter. If possible, pull the liana away from the trunk and run the diameter tape underneath. If the liana is too big to pull away from the trunk, estimate the diameter of the liana and subtract from total tree diameter. Cutting a liana from a tree should only be done if there are no other options. The same standard should be followed for any other type of natural organisms (mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.

   iii. Place chalk mark on the tree to indicate to crew members that the tree has been measured.

Figure: Measurement of diameter using a diameter tape and tree pole

d. **Other tree parameters:** Measure all other tree parameters included in the biomass regression equation to be used. If the allometric equation to be used requires height as an input for each tree/palm measured, two measurements of height should be taken to improve the precision of measurements, especially if it is difficult to identify the top of the tree/palm measured. See *SOP Measurement of Height* on how to measure tree height.

Tree Felling

1. Calibrate hanging scales at start of each day with 'calibration weights'.
2. A chainsaw operator must undertake the task of cutting the tree down and cutting the tree into components
3. After the tree is cut down the following measurements need to be made (see Figure below):
    a. Length of tree (from the stump to the top of the crown) (in meters to the nearest 0.01 m)
    b. Length of bole (from the stump to the first main branch) (in meters to the nearest 0.01 m)
    c. Diameter of stump (in cm to the nearest 0.1 cm)
    d. Diameter at breast height (in cm to the nearest 0.1 cm)
    e. Diameter at the center of bole (in cm to the nearest 0.1 cm)
    f. Diameter at top of bole (in cm to the nearest 0.1 cm)
    g. Where possible, after these measurements are made, the chainsaw operator should cut, or mark, the length of the bole that would be extracted for timber.
    h. Length of the commercial log and the diameter at both ends of the log (in meters to the nearest 0.01 m)

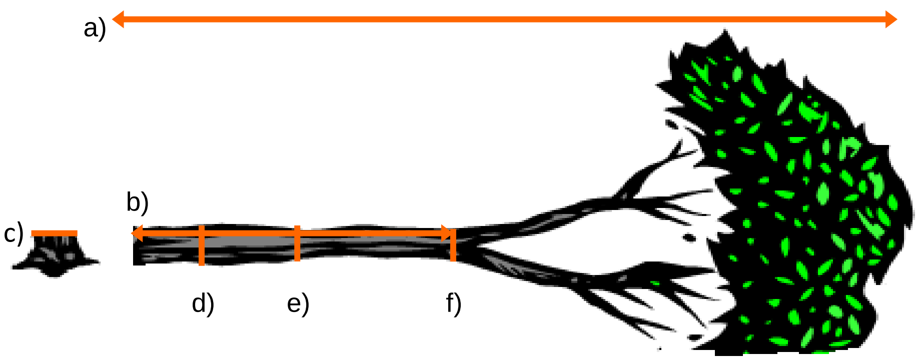


Figure Location of measurements following cutting down of tree

4. Attach a 50-kilogram (kg) scale to either a tripod or a strong branch (if the tree is smaller, a smaller scale can be used)
5. Divide tree into size classes and estimate weights:
   a. **Bole**: The bole is the main trunk of the tree, from the stump to the first major branch. To estimate bole biomass, volume measurements will be taken and a density value applied.
      i. Measurements to estimate volume of bole (see Figure below):
         a) Measure the total length of the bole
         b) Measure the diameter at ~5 m intervals along the bole to the first branch. Record the diameter and the length of each interval. Be sure to measure the diameter at the bottom and the top of the bole.

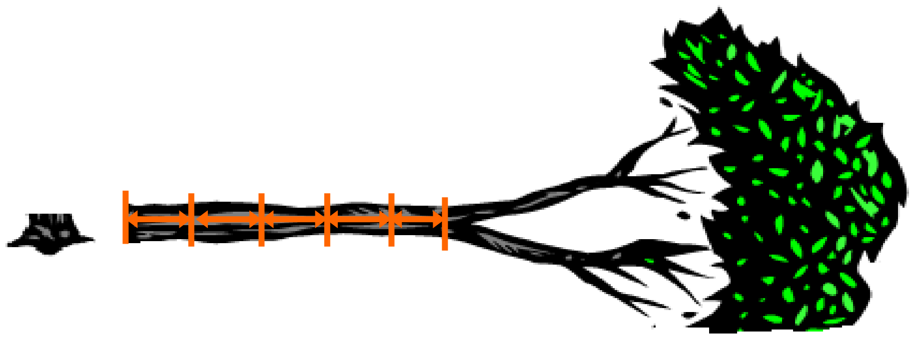


Figure Measurements of diameter and length along the bole of tree

1.

      ii. Estimate Wood Density:
         a) If verifying applicability of existing equation AND published wood density of species exists, the published wood density estimates will be used. No field measurements of wood density shall be taken. (See *SOP Wood Density* Reyes et al. 1992)

b) If creating new equation OR no published wood density of species exists, samples must be taken to estimate wood density. Disk samples must be taken from the main bole at several locations along its length.

i) Cut 5 disc samples from different sections of bole(if a commercial log will be extracted from tree then it may be difficult to obtain a sample from several places—instead collect a sample from top of the stump and bottom on the crown.)

ii) Record the dimensions of the disc (see Figure below). If the discs are too big to fit into any of the cloth or paper subsample bags, after the dimensions are measured carefully cut the disc into pieces and place the pieces into one bag. Try to minimize the wood fiber loss when cutting the discs. It is better to avoid cutting the disc if possible.

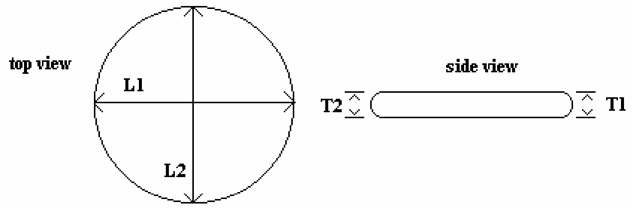


Figure: Wood disc measurement locations

iii) If the discs are too large and heavy to return to the laboratory they can be subsampled: either halved or quartered. Field sheets need to be annotated to this effect. The volume of the subsection will be estimated as either a quarter or half of the total volume estimated from the diameter and thickness measurements.

iv) Until samples are taken to the laboratory, place samples in location that allows air drying to occur.

v) Take discs to laboratory to estimate density. The fresh weights of disc samples do not need to be taken.

vi) Subsamples must be dried until a constant weight and weighed. To estimate density, divide dry subsampled weight by fresh volume of subsample. Alternatively, density may be estimated using the water displacement method. The calculated density will be used to estimate the weight of the entire bole.

b. <u>Buttress:</u>

i. If there is a buttress, the weight will need to be estimated.

ii. Cut the buttress into pieces and weigh on the scale. Record weight of each piece

iii. Take 2 sub-samples:

a. Cut two ‘pie pieces’ out of the buttress (be sure both the center and edge of the buttress is included in a ‘pie piece’)

b. Weigh each ‘pie piece’

c. Label each subsample and record weight

d. Take subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire buttress.

c. **Stump:**

   i. If stump is relatively small:
      a. After the bole and the other parts of the tree are measured cut the stump as close to the ground as possible.
      b. Cut the stump into pieces and weigh on the scale.
      c. Take 2 sub-samples:
         i. Cut two ‘pie pieces’ out of the buttress
         ii. Weigh each ‘pie piece’
         iii. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
         iv. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire stump.
   ii. If it is too big to cut up and weigh, estimate the volume of the stump through measurements. Measure the diameter at the base and top of the stump, along with the length of the stump. Tree density obtained from the bole measurements can be used to estimate the density of the stump.

d. **Branches from 10-20 cm in diameter.**

   i. Use the diameter fork to select branches that have a diameter from 10 to 20 cm.
   ii. Use a chainsaw or hand saw to cut the branches and place them in a pile on the large plastic tarp
   iii. Weigh the branches.
      a. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
      b. Branches can be then placed on plastic and weighed.
      c. Alternatively, some branches can be weighed directly on scale.
   iv. Record the weights of all branches on the data sheet, noting if branches weighed on plastic or if were weighed directly.
   v. Take 5 sub-samples:
      d. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches found.
      e. Weigh the subsample bag empty. Record weight.
      f. Weigh the subsample bag with the subsample inside. Record weight.
      g. Label the subsample bag with the tree name, tree identification number, subsample identification number, and total weight of subsample and subsample bag.
      h. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample

will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all branches 10-20 cm in diameter.

e. <u>Leaves and branches < 10 cm in diameter:</u>

i. Lay a large plastic tarp on the ground. Collect all the branches with a diameter <10 cm and all leaves. Note: the leaves **do not** need to be removed from the branches. Place vegetation on plastic tarp.
ii. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
iii. Put a pile of the small branches and leaves onto the plastic and weigh. Record weight
iv. Repeat until all small branches and leaves have been weighed
v. Take 5 sub-samples:
   a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches and leaves.
   b. Weigh the subsample bag empty. Record weight.
   c. Weigh the subsample bag with the subsample inside. Record weight.
   d. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
   e. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all the leaves and branches <10 cm in diameter.

SOP Destructive Sampling of Bamboo

Field Equipment:
Handsaws
Machetes
DBH tape
Clinometer
5 kg scale
~300 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
Marker (to label bags and samples)
'Calibration weights' (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

To ***verify the applicability*** of an existing selected biomass regression equation, select >5 samples to be destructively sampled. When developing ***new biomass regression equations***, ***at least*** 30 samples covering the full range of sizes need to be harvested (if the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested).

If a new equation is being developed an assessment shall be made to determine what sampling strategy may be used to estimate bamboo biomass. This will vary depending on the growth structure of a given bamboo species. For some bamboo types, it may be determined that bamboo biomass will be estimated using the *SOP Measurement of Non-woody Vegetation*. In this case a regression equation is not used and this step should not take place.

1. If an existing equation is being verified all variables included in the equation shall be measured. If a new equation is being created, measure all variables that may serve as a good indicator of biomass. This would include such things as: diameter at 0.30 cm, DBH, total height of each stem, number of stems, and basal area of culm. Care must be taken to measure all parameters using the exact same methods that would normally be used in the field.
2. Calibrate hanging scales at start of each day with 'calibration weights'.
3. Cut down all stems in sample
4. Weigh each stem and re-measure each stem. Record weights and height of each stem.
5. Weigh all stems
6. Take total of 5 sub-samples of stems from sample:

a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of stems.
b. Weigh the empty subsample bag. Record weight of just the bag.
c. Weigh the subsample bag with the subsample inside. Record weight.
d. Label the subsample bag with the bamboo identification number, subsample number, and weight of subsample
e. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the bamboo.

SOP Destructive Sampling of Non-tree woody vegetation (shrubs)

Field Equipment:
Handsaws
Machetes
DBH tape
Clinometer
5 kg scale
~300 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
Marker (to label bags and samples)
'Calibration weights' (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

Prior to the creation of a new non-tree woody vegetation equation, research shall be conducted to determine whether any non-tree woody vegetation equations applicable to the non-tree woody vegetation found within the land use class exist. It must also be determined if a species specific or a general 'non-tree woody vegetation' allometric equation will be created.

To *verify the applicability* of an existing selected biomass regression equation, select >5 individuals to be destructively sampled. These individuals should focus on the upper range of sizes found in the sample population. When developing ***new biomass regression equations***, ***at least*** 30 individuals covering the full range of sizes need to be harvested (if the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested).

1. If an existing equation is being verified all parameters included in the equation shall be measured. If a new equation is being created, measure all parameters that may serve as a good indicator of biomass. Care must be taken to measure all parameters using the exact same methods that would normally be used in the field. This would include such things as:
    a. diameter of each stem at 0.30 cm
    b. DBH of each stem
    c. total height of each stem
    d. number of stems
    e. total height of non-tree woody vegetation
    f. diameter of the crown in North-South direction and East-West direction
    g. diameter at narrowest point and diameter at widest point.
2. Cut down entire individual and weigh
3. Take total of 5 sub-samples from sample:
    a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of stems and leaves.
    b. Weigh the empty subsample bag. Record weight of just the bag.
    c. Weigh the subsample bag with the subsample inside. Record weight.
    d. Label the subsample bag with the non-tree woody vegetation identification number, subsample number, and weight of subsample
    e. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the non-tree woody vegetation.

SOP Measurement and Estimation of Dead Wood Density Classes

Field Equipment:
Measuring tape
Chainsaw or handsaw
Cloth bags
Permanent marking pen

Laboratory Equipment:
Drying oven
Laboratory scale
1L Graduated cylinder with milliliter markings and wide mouth
Very fine elongated rod/needle

--TO BE CONDUCTED ONE TIME ON EVERY STRATUM DURING FIELD SAMPLING--

In the field, dead wood is classified into three dead wood density classes. This SOP provides the field measurement, laboratory measurements, and data analysis methods that shall be used to estimate the average density that will be assigned to each dead wood density class.

This field work and analysis needs to take place one time during a field sampling effort. This must take place for each stratum where dead wood will be measured. If only the standing dead wood pool is being measured, then only the density of 'sound wood' needs to be estimated. After the densities are determined, this SOP does not need to be repeated unless a new stratum is identified and measured.

Prior to Field Sampling:

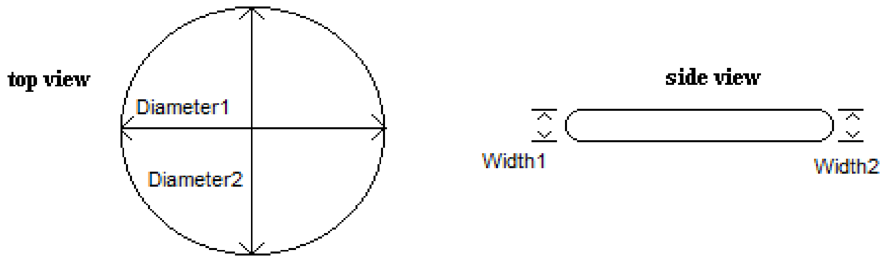
1. Determine which type(s) of dead wood will be measured (standing and/or lying).
2. Determine where samples will be collected. The location where samples are collected should be representative of the stratum, however it is not necessary for samples to be collected in a random distribution throughout the stratum.
3. Randomly collect a small amount of around 30 samples of dead wood at various stages of decomposition from each of the stratum. These pieces will only be used to agree upon density classes and therefore can be collected close to any base camp directly prior to field measurements taking place.
4. All dead wood will be classified into three density classes: sound, intermediate, and rotten. These classes can be determined using the 'machete test'. The 'machete test' consists of raising the machete up to shoulder height and allowing it come down to the dead wood piece with the force of gravity. No additional force should be applied to the motion of the machete.
    a. Sound: : Machete does not sink into the piece (bounces off)—this does not necessarily mean the wood shows no sign of decomposition—lying dead wood can lose all the sapwood and bark but yet the heartwood is still sound—this would be classified as sound
    b. Intermediate: Machete sinks partly into the piece, and there has been some wood loss
    c. Rotten: Machete sticks into the piece, there is more extensive wood loss, and the piece is crumbly—the key here is that the dead wood is decomposed throughout and very soft and crumbly

5. Agreement shall be made on which pieces of wood fit into which dead wood density class. All field team members must be trained on all agree on consistent classes of dead wood.

Field measurements:

Collect wood samples for each density class for density determination (dry weight per green volume). The number of wood samples will depend on the variability between tree species within the forest. A minimum of 10 samples should be collected for each density class of each species group. For example, for a forest containing mixed broadleaf and palm species , a minimum of 10 samples of dead wood from each tree group should be collected per density class—for a total number of 30 samples for broadleaf species and 30 for palms.

1. For sound class of dead wood:
    a. Using a chainsaw or a handsaw, cut a complete disc from the selected piece of dead wood.
    b. Measure the diameter (L1 and L2) and thickness (T1 and T2) of the disc to estimate volume (Figure below). The dimensions of the sample should be recorded on data sheet. The fresh weight of the disc does not have to be recorded.
    c. All samples shall be placed in a labeled cloth bag.
    d. Samples shall be stored in location in manner that allows for air drying to take place prior to laboratory measurements.
    e. This sample will then be taken to the laboratory



2.

Figure: Measurements to be taken on disc cut from coarse dead wood samples

2. For intermediate and rotten classes:
    a. Collect a contiguous sample of the dead wood that is not too small nor too large (i.e. that fit in the graduated cylinder).
    b. Place sample in a bag, label the bag. Make sure sample doesn't break into smaller pieces when transporting it. If the sample is very crumbly, it can be placed on a piece of clear plastic wrap (e.g. cling wrap as used in food storage), and tightly wrapped around the piece of wood.
    c. This sample will be taken to the laboratory. Carefully transport sample to laboratory where it volume will be measured.
3. Train all field crew members on how different pieces of dead wood are should be classified, based on the sampling that was conducted.

Laboratory Measurements and Data Analysis:

1. Dry Weight: Place samples in drying oven at 70°C until sample reaches constant weight (i.e. all moisture is evaporated). Record the dry weight (g).
2. Volume: If the wood disc sampled from the field is a regular shape (eg circular disk) the 'calculated volume' method below can be used. If the wood disc is an irregular shape, the 'water displacement volume' method shall be used.
   a. Calculated Volume Estimate Method:
      i. Calculate the volume using the measurements taken in the field:

$$Volume = \pi * \left(\frac{Diameter_1 + Diameter_2}{2} \Big/ 2 \right)^2 * \left(\frac{Width_1 + Width_2}{2} \right)$$

3. Where:
   4. Volume = Volume of sample;cm^3
   5. $Diameter_1$ = First diameter of sample; cm
   6. $Diameter_2$ = Second diameter of sample; cm
      7. $Width_1$ = First width of sample; cm
      8. $Width_2$ = Second width of sample; cm

      ii. Calculate density using the following formula:

9. $$\text{Density} = \frac{Dry\_weight}{Volume}$$

10. Where:
    11. Density = Density of sample; g/cm^3
    12. Volume = Volume of sample; cm^3
        Dry Weight = measured dry weight of sample; g

      iii. Calculate the mean the density for that wood density class.
   b. Water Displacement Method: The most commonly used technique to measure the volume of irregularly shaped objects.
      i. Create a subsample from the wood sample brought from the field. This subsample must fit inside the graduated cylinder to be used.
      ii. Weigh the subsample created and record weight.
      iii. Fill the graduated cylinder to a known volume (e.g. 1L). Make sure there is enough water to submerge the piece and enough empty room in the graduated cylinder to allow water to rise without spilling over.
      iv. Place dead wood sample inside the graduated cylinder.
      v. Using the very fine elongated needle, push sample under the water until completely submerged. Make sure water doesn't spill over or rise above the last milliliter marking on the graduated cylinder.
      vi. On the data sheet, record the volume of water displaced by submerging the sample. That is the volume of the sample collected.
      vii. Calculate density using the following formula:

13. $$\text{Density} = \frac{Dry\_weight}{Volume}$$

14. Where:

15. Density = Density of sample; g/cm^3

16. Volume = Volume of sample; cm^3

17. Dry Weight = measured dry weight of sample; g

c. Calculate the mean the density for that wood density class.

SOP Destructive Sampling of Regenerating Vegetation / Fallow Cropland

Regenerating vegetation following cropping is often comprised of a variety of vegetation types, and therefore will require destructive sampling of saplings, small diameter trees, as well as non-tree woody vegetation. Prior to the undertaking of field data collection, a comprehensive assessment of shifting cultivation regimes should be conducted on shifting cultivation systems, fallow lengths, and geophysical conditions to determine appropriate strata. This process may elucidate the need to create specific allometric equations for different types of fallow cropland altogether.

At least five sites should be sampled per stratum, and vegetation classes should be delineated into woody herbaceous vegetation, bamboo, saplings, and trees. To ***verify the applicability*** of an existing selected biomass regression equation, select >5 samples of each vegetation class (i.e. woody herbaceous vegetation, bamboo, etc.) to be destructively sampled. When developing ***new biomass regression equations***, ***at least*** 30 samples covering the full range of sizes need to be harvested. If the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested.

Trees

Although trees will likely be present in some fallow cropland areas, it is unlikely that large diameter trees will be growing in fallow cropland. Trees across the range of diameter classes should be targeted for measurement, including the upper range of DBH sizes.

Prior to Tree Felling

1. Assign one person to record the data
2. Measure all the tree parameters that will be potentially used in the allometric equation to be developed and those in existing equations (eg DBH, DSH, H) for the tree to be destructively sampled prior to felling. It is important that the diameter tape is used properly and protocols for tree measurement defined in *SOP Destructive Sampling of Trees* are followed.

Tree Felling

1. Calibrate hanging scales at start of each day with 'calibration weights'.
2. A chainsaw operator must undertake the task of cutting the tree down and cutting the tree into components

3. After the tree is cut down the following measurements need to be made (see Figure below):
   i. Length of tree (from the stump to the top of the crown) (in meters to the nearest 0.01 m)
   j. Length of bole (from the stump to the first main branch) (in meters to the nearest 0.01 m)
   k. Diameter of stump (in cm to the nearest 0.1 cm)
   l. Diameter at breast height (in cm to the nearest 0.1 cm)
   m. Diameter at the center of bole (in cm to the nearest 0.1 cm)
   n. Diameter at top of bole (in cm to the nearest 0.1 cm)
   o. Where possible, after these measurements are made, the chainsaw operator should cut, or mark, the length of the bole that would be extracted for timber.
   p. Length of the commercial log and the diameter at both ends of the log (in meters to the nearest 0.01 m)

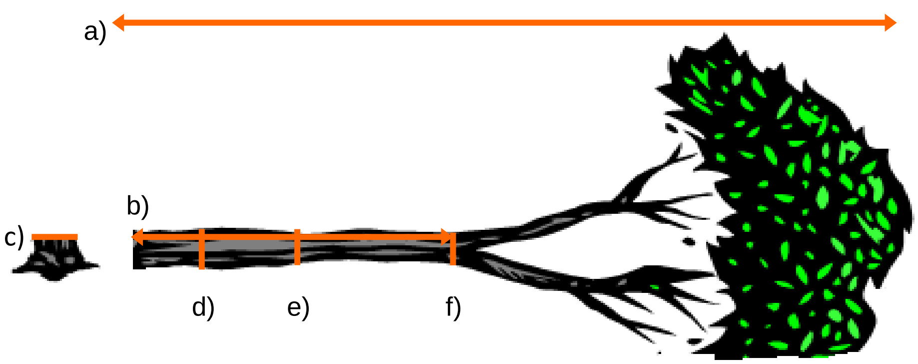


Figure Location of measurements following cutting down of tree

4. Attach a 50-kilogram (kg) scale to either a tripod or a strong branch
5. Divide tree into size classes and estimate weights:
   b. **<u>Bole</u>**: The bole is the main trunk of the tree, from the stump to the first major branch. To estimate bole biomass, volume measurements will be taken and a density value applied.
      iii. Measurements to estimate volume of bole (see Figure below):
         a) Measure the total length of the bole
         b) Measure the diameter at ~5 m intervals along the bole to the first branch. Record the diameter and the length of each interval. Be sure to measure the diameter at the bottom and the top of the bole.

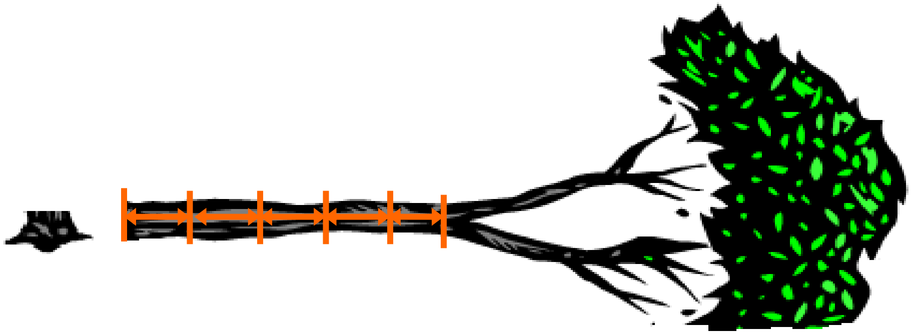


Figure Measurements of diameter and length along the bole of tree

18.

iv. Estimate Wood Density:

c) If verifying applicability of existing equation AND published wood density of species exists, the published wood density estimates will be used. No field measurements of wood density shall be taken. (See *SOP Wood Density* Reyes et al. 1992)

d) If creating new equation OR no published wood density of species exists, samples must be taken to estimate wood density. Disk samples must be taken from the main bole at several locations along its length.

vii) Cut 5 disc samples from different sections of bole(if a commercial log will be extracted from tree then it may be difficult to obtain a sample from several places—instead collect a sample from top of the stump and bottom on the crown.)

viii) Record the dimensions of the disc (see Figure below). If the discs are too big to fit into any of the cloth or paper subsample bags, after the dimensions are measured carefully cut the disc into pieces and place the pieces into one bag. Try to minimize the wood fiber loss when cutting the discs. It is better to avoid cutting the disc if possible.

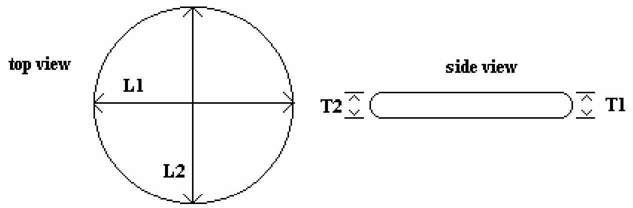


Figure: Wood disc measurement locations

ix) If the discs are too large and heavy to return to the laboratory they can be subsampled: either halved or quartered. Field sheets need to be annotated to this effect. The volume of the subsection will be estimated as either a quarter or half of the total volume estimated from the diameter and thickness measurements.

x) Until samples are taken to the laboratory, place samples in location that allows air drying to occur.

xi) Take discs to laboratory to estimate density. The fresh weights of disc samples do not need to be taken.

xii) Subsamples must be dried until a constant weight and weighed. To estimate density, divide dry subsampled weight by fresh volume of subsample. Alternatively, density may be estimated using the water displacement method. The calculated density will be used to estimate the weight of the entire bole.

f. <u>Buttress:</u>

iv. If there is a buttress, the weight will need to be estimated.

v. Cut the buttress into pieces and weigh on the scale. Record weight of each piece

vi. Take 2 sub-samples:

   a. Cut two 'pie pieces' out of the buttress (be sure both the center and edge of the buttress is included in a 'pie piece')
   b. Weigh each 'pie piece'
   c. Label each subsample and record weight
   d. Take subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire buttress.

g. <u>Stump:</u>

iii. If stump is relatively small:

   d. After the bole and the other parts of the tree are measured cut the stump as close to the ground as possible.
   e. Cut the stump into pieces and weigh on the scale.
   f. Take 2 sub-samples:
      i. Cut two 'pie pieces' out of the buttress
      ii. Weigh each 'pie piece'
      iii. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
      iv. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to

occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire stump.

iv. If it is too big to cut up and weigh, estimate the volume of the stump through measurements. Measure the diameter at the base and top of the stump, along with the length of the stump. Tree density obtained from the bole measurements can be used to estimate the density of the stump.

h. Branches from 10-20 cm in diameter.

vi. Use the diameter fork to select branches that have a diameter from 10 to 20 cm.
vii. Use a chainsaw or hand saw to cut the branches and place them in a pile on the large plastic tarp
viii. Weigh the branches.
  i. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
  j. Branches can be then placed on plastic and weighed.
  k. Alternatively, some branches can be weighed directly on scale.
ix. Record the weights of all branches on the data sheet, noting if branches weighed on plastic or if were weighed directly.
x. Take 5 sub-samples:
  l. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches found.
  m. Weigh the subsample bag empty. Record weight.
  n. Weigh the subsample bag with the subsample inside. Record weight.
  o. Label the subsample bag with the tree name, tree identification number, subsample identification number, and total weight of subsample and subsample bag.
  p. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all branches 10-20 cm in diameter.

i. Leaves and branches < 10 cm in diameter:

vi. Lay a large plastic tarp on the ground. Collect all the branches with a diameter <10 cm and all leaves. Note: the leaves **do not** need to be removed from the branches. Place vegetation on plastic tarp.
vii. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
viii. Put a pile of the small branches and leaves onto the plastic and weigh. Record weight
ix. Repeat until all small branches and leaves have been weighed

x. Take 5 sub-samples:
   f. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches and leaves.
   g. Weigh the subsample bag empty. Record weight.
   h. Weigh the subsample bag with the subsample inside. Record weight.
   i. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
   j. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all the leaves and branches <10 cm in diameter.

APPENDIX 3: DATA ANALYSIS METHODS

Calculation of field measurements

(Text taken directly from: Goslee, K, SM Walker, A Grais, L Murray, F Casarim, and S Brown. 2014. Module C-CS: Calculations for Estimating Carbon Stocks. LEAF Technical Guidance Series for the development of forest carbon monitoring systems for REDD+. USAID funded LEAF project. Winrock International.)

Destructive sampling of trees may be conducted to validate existing or develop new allometric equations. This section provides the necessary calculations to calculate tree biomass based on data collected during destructive sampling. Consult the SOPs for guidance on how to conduct destructive sampling. The steps required to validate or develop allometric equations are outside the scope of this module.

Information required to complete the analysis:

- Field data of relevant parameters, including tree species and DBH
- Field data of volume and/or wet weight for relevant tree components: bole, stump, buttress, leaves, and branches[2].
- Wood density for each relevant tree component

Calculation Steps:

1. Calculate the biomass of the bole:
    A. Calculate the total volume of the bole by summing the volume of all of the sections. Note that the volume of each section is calculated using the equation for the volume of a frustrum.

$$VOL = \sum \frac{1}{3} * \pi * L * \left(\left(\frac{D_T}{2} \right)^2 * (D_T * D_B) * \left(\frac{D_B}{2} \right)^2 \right) * 10^{-6} \quad (1)$$

Where:

VOL	= volume (m^3)
L	= length (cm)
D_T	= top diameter of section (cm)
D_B	= bottom diameter of section (cm)

    B. Use the density (calculated or found in literature) and the volume to calculate the biomass:

[2] See *SOP Destructive sampling of trees, saplings, palms, and bamboo* in Walker et al, 2013.

$DW_{bole} = Dens * Vol * 1000$ (2)

Where:

DW$_{bole}$ = biomass of the bole (kg)
Dens = bole density (g cm^{-3})
Vol = volume (m^3)

2. Calculate the biomass of the stump, based on weight (A), volume (B), or a combination of weight and volume (C).
   A. To calculate biomass by weight multiply total wet weight by the dry-to-wet ratio obtained by drying samples.

$DW_{stump,w} = \sum FW_i * DFR$(3)

Where:

DW$_{stump,w}$ = biomass of the stump (kg), calculated by weight

WW$_i$ = wet weight (kg) of pieces of the stump, as scale allows

DWR = dry-to-wet ratio, determined by taking the fresh and oven-dried weight of at least three subsamples, finding the ratio, and averaging across all samples

   B. To calculate biomass by volume, identify the shape the stump most closely resembles, frustrum, cube, or cylinder, use the appropriate volume equation, and multiply the volume by wood density.

$DW_{stump,v} = VOL * WD * 1000$(4)

Where:

DW$_{stump,v}$ = biomass of the stump (kg), calculated by volume

VOL = volume (m^3)

WD = wood density (g cm^{-3})(see SOP Wood Density)

Where volume is calculated based on shape:

19. For Cube: $V_{cube}\ (m^3) = Length\ (m) * Width\ (m) * Height\ (m)$(5)

20. For Cube: $V_{cylinder}\ (m^3) = \pi * radius^2\ (m) * Height\ (m)$(6)

21. For Frustrum: $V_{frustrum}\ (m^3) = \frac{1}{3} * \pi * Height\ (m) * LargeRadius\ (m) * SmallsRadius\ (m)$(7)

C. To calculate biomass by both weight and volume, simply calculate $DW_{stump,w}$ and $DW_{stump,v}$ and sum them. This is useful when it is easier to take volume measurements for some of the stump and weight measurements for the rest.

3. Calculate the biomass of the buttress:

$$DW_{buttress} = \sum WW_i * DFR \quad (8)$$

Where:

$DW_{buttress}$ = dry weight biomass of the buttress (kg)

WW_i = wet weight (kg) of pieces of the buttress, as scale allows

DWR = dry-to-wet ratio, determined by taking the fresh and oven-dried weight of at least three subsamples, finding the ratio, and averaging across all samples

4. Calculate the biomass of the leaves and branches. This should be done separately for leaves and branches <10cm in diameter, for branches 10-20 cm in diameter, and for branches >20 cm in diameter:

$$DW_{branch} = \sum WW_i * DFR \quad (9)$$

Where:

DW_{lb} = biomass of the leaves and/or branches (kg)

WW_i = partial wet weight (kg) of leaves and/or branches, as scale allows

DWR = dry-to-wet ratio, determined by taking the fresh and oven-dried weight of at least three subsamples, finding the ratio, and averaging across all samples

5. Sum the biomass of all tree components.

$$DW_{all} = DW_{bole} + DW_{stump} + DW_{buttress} + DW_{branch} \tag{10}$$

Where:

DW_{all} = biomass of the entire tree (kg)

APPENDIX 4: WOOD DENSITY FOR TROPICAL FORESTS FROM REYES ET AL. 1992

Table 2.-Wood densities (g/cm^3) of tree species for tropical regions of three continents

Species	Wood density
Tropical Asia	
Acacia arabica	0.70*
Acacia catechu	0.88
Acacia confusa	0.75
Acacia leucophloea	0.76
Acacia richii	0.69
Adina cordifolia	0.58, 0.59+
Aegle marmelo	0.75
Agathis dammara	0.41
Agathis spp.	0.44
Agathis vitiensis	0.45
Aglaia diffusa	0.70
Aglaia iloilo	0.53
Aglaia llanosiana	0.89
Alangium longiflorum	0.65
Alangium meyeri	0.63
Albizzia amara	0.70*
Albizzia falcataria	0.25
Albizzia lebbek	0.55, 0.66+
Albizzia odoratissima	0.76
Albizzia procera	0.52*, 0.59+
Aleurites moluccana	0.25
Aleurites trisperma	0.43
Alnus japonica	0.43
Alphitonia philippinensis	0.40
Alphitonia zizyphoides	0.50
Alphonsea arborea	0.69
Alseodaphne longipes	0.49
Alstonia macrophylla	0.62
Alstonia scholaris	0.36
Alstonia spp.	0.37
Amoora aherniana	0.58
Amoora macrocarpa	0.55
Amoora spp.	0.60
Anisophyllea zeylanica	0.46*
Anisoptera aurea.	0.53
Anisoptera spp.	0.54
Anisoptera thurifera	0.54
Anogeissus latifolia	0.78, 0.79+
Anthocephalus chinensis	0.36, 0.33+
Antidesma pleuricum	0.59
Aphanamixis cumingiana	0.58
Aphanamiris perrottetiana	0.52
Araucaria bidwillii	0.43
Artocarpus blancoi	0.43
Artocarpus heterophylla	0.60
Artocarpus lakoocha	0.53*
Artocarpus ovata	0.47
Artocarpus spp.	0.58
Azadirachta indica	0.69
Azadirachta spp.	0.52
Balanocarpus spp.	0.76
Barringtonia edulis *	0.48
Bauhinia spp.	0.67
Beilschmiedia tawa	0.58
Berrya cordifolia	0.78*
Bischofia javanica	0.54, 0.58, 0.62+
Bleasdalea vitiensis	0.43
Bombax ceiba	0.33
Bombycidendron vidalianum	0.53
Boswellia serrata	0.50
Bridelia retusa	0.50
Bridelia squamosa	0.50
Buchanania lanzan	0.45
Buchanania latifolia	0.45
Bursera serrata	0.59
Butea monosperma	0.48
Calophyllum blancoi	0.51
Calophyllum inophyllum	0.57
Calophyllum neo-ebudicum	0.50
Calophyllum obliquinervium	0.58
Calophyllum spp.	0.53
Calophyllum vitiense	0.50
Calycarpa arborea	0.53
Cananga odorata	0.29
Canarium asperum var. *asperum*	0.50, 0.60+
Canarium hirsutum forma *scabrum*	0.40
Canarium luzonicum	0.51
Canarium spp.	0.44
Canarium vanikoroense	0.54
Canarium vitiense	0.54
Canarium vrieseanum forma *stenophyllum*	0.56
Canthium monstrosum	0.42
Carallia calycina	0.66*
Cassia fistula	0.71
Cassia javanica	0.69
Cassia spectabilis	0.48
Castanopsis philippensis	0.51
Casuarina equisetifolia	0.83
Casuarina nodiflora	0.85
Cedrela odorata	0.38
Cedrela spp.	0.42
Cedrela toona	0.43
Ceiba pentandra	0.23
Celtis luzonica	0.49
Chisocheton cumingianus	0.52
Chisocheton pentandrus	0.52
Chloroxylon swietenia	0.76, 0.79, 0.80+
Chukrassia tabularis	0.57
Cinnamomum mercadoi	0.65
Cinnamomum spp.	0.43
Citrus grandis	0.59
Cleidion speciflorum	0.50
Cleistanthus collinus	0.88
Cleistocalyx operculatus	0.66
Cleistocalyx spp.	0.76
Cochlospermum gossypium+religiosum	0.27
Cocos nucifera	0.50
Colona serratifolia	0.33
Combretodendron quadrialatum	0.57
Cordia spp.	0.53
Cotylelobium spp.	0.69
Crataeva religiosa	0.53*
Cratoxylon arborescens	0.40
Cryptocarya spp.	0.59
Cubilia cubili	0.49
Cullenia excelsa	0.53

Table 2.-Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)

Species	Wood density	Species	Wood density
Cynometra insularis	0.76, 0.91+	*Enterolobium cyclocarpum*	0.35
Cynometra ramiflora	0.70	*Epicharis cumingiana*	0.73
Cynometra spp.	0.80	*Erythrina fusca*	0.25
Dacrycarpus imbricatus	0.45, 0.47+	*Erythrina suberosa*	0.32
Dacrydium elatum	0.48	*Erythrina subumbrans*	0.24
Dacrydium nausoriensis	0.52	*Erythrophloeum densiflorum*	0.65
Dacrydium nidulum	0.52	*Eucalyptus citriodora*	0.64
Dacrydium spp.	0.46	*Eucalyptus deglupta*	0.34
Dacryodes spp.	0.61	*Eugenia* spp.	0.65
Dalbergia latifolia	0.75	*Fagraea gracilipes*	0.84
Dalbergia paniculata	0.64	*Fagraea* spp.	0.73
Decussocarpus philippinensis	0.50	*Ficus benjamina*	0.65
Decussocarpus vitiensis	0.37	*Ficus botryocarpa*	0.43
Degeneria vitiensis	0.35	*Ficus minahassae*	0.42
Dehaasia triandra	0.64	*Ficus* spp.	0.39
Dialium spp.	0.80	*Ficus variegata*	0.28
Dillenia luzoniensis	0.69	*Ganua obovatifolia*	0.59
Dillenia megalantha	0.69	*Garcinia myrtifolia*	0.65
Dillenia pentagyna	0.53	*Garcinia* spp.	0.75
Dillenia philippinensis	0.61	*Gardenia latifolia*	0.64
Dillenia spp.	0.59	*Gardenia turgida*	0.64
Diospyros embryopteris	0.63*	*Garuga pinnata*	0.51
Diospyros inclusa	0.68	*Gluta* spp.	0.63
Diospyros melanoxylon	0.68	*Gmelina arborea*	0.41, 0.45+
Diospyros mindanaensis	0.69	*Gmelina vitiensis*	0.54
Diospyros nitida	0.71	*Gonocaryum calleryanum*	0.64
Diospyrosphilippensis	0.81	*Gonystylus bancanus*	0.52
Diospyros pilosanthera	0.80	*Gonystylus macrophyllus*	0.52
Diospyros poncei	0.81	*Gonystylus punctatus*	0.57
Diospyros pyrrhocarpa	0.60	*Grewia multiflora*	0.46
Diospyros spp.	0.70	*Grewia tiliaefolia*	0.68
Diplodiscus paniculatus	0.63	*Hardwickia binata*	0.73
Dipterocarpus caudatus	0.61	*Harpullia arborea*	0.62
Dipterocarpus eurynchus	0.56	*Heritiera ornithocephala*	0.68
Dipterocarpus gracilis	0.61	*Heritiera* spp.	0.56
Dipterocarpus grandiflorus	0.62	*Heritiera sylvatica*	0.77
Dipterocarpus kerrii	0.56	*Hevea brasiliensis*	0.53
Dipterocarpus kunstlerii	0.57	*Hibiscus tiliaceus*	0.57
Dipterocarpus spp.	0.61	*Homalanthus populneus*	0.38
Dipterocarpus warburgii	0.52	*Homalium* spp.	0.76
Dracontomelon dao	0.52	*Hopea acuminata*	0.62
Dracontomelon edule	0.46	*Hopea foxworthyi*	0.64
Dracontomelon spp.	0.50	*Hopea plagata*	0.88
Dryobalanops spp.	0.61	*Hopea* spp.	0.64
Drypetes bordenii	0.75	*Intsia bijuga*	0.61, 0.68, 0.74+
Durio spp.	0.53	*Intsia palembanica*	0.68
Durio zibethinus	0.44, 0.53+	*Kayea garciae*	0.53
Dyera costulata	0.36	*Kingiodendron alternifolium*	0.48
Dysoxylum altissimum	0.42	*Kleinhovia hospita*	0.36
Dysoxylum decandrum	0.51	*Knema* spp.	0.53
Dysoxylum euphlebium	0.63	*Koompassia excelsa*	0.63
Dysoxylum quercifolium	0.49	*Koompassia malaccensis*	0.72
Dysoxylum richii	0.49	*Koordersiodendron pinnatum*	0.65, 0.69+
Elaeocarpus serratus	0.40*	*Kydia calycina*	0.72
Emblica officinalis	0.80	*Lagerstroemia parviflora*	0.62
Endiandra laxiflora	0.54	*Lagerstroemia piriformis*	0.50
Endospermum macrophyllum	0.40	*Lagerstroemia speciosa*	0.53
Endospermum peltatum	0.31	*Lagerstroemia* spp.	0.55
Endospermum spp.	0.38	*Lannea coromandelica*	0.54
		Lannea grandis	0.50

Table 2.-Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)

Species	Wood density
Leucaena leucocephala	0.64
Litchi chinensis ssp. *philippinensis*	0.88
Lithocarpus celebica	0.68
Lithocarpus llanosii	0.63
Lithocarpus soleriana	0.63
Litsea garciae	0.34
Litsea leytensis	0.35
Litsea perrottetii	0.45
Litsea spp.	0.40
Lophopetalum spp.	0.46
Macaranga bicolor	0.29
Macaranga denticulata	0.53
Madhuca fulva	0.53
Madhuca longifolia var. *latifolia*	0.74
Madhuca oblongifolia	0.53
Mallotus multiglandulosus	0.42
Mallotus philippensis	0.64
Mangifera altissima	0.55
Mangifera indica	0.52, 0.59+
Mangifera merrillii	0.52
Mangifera spp.	0.52
Maniltoa grandiflora	0.76
Maniltoa minor	0.76
Mastixia philippinensis	0.47
Melanorrhea spp.	0.63
Melia dubia	0.40
Melicope triphylla	0.37
Meliosma macrophylla	0.27
Melochia umbellata	0.25
Mesua ferrea	0.83, 0.85+
Metrosideros collina	0.70, 0.76+
Michelia platyphylla	0.51
Michelia spp.	0.43
Microcos stylocarpa	0.40
Micromelum compressum	0.64
Miliusa velutina	0.63
Mimusops elengi	0.72*
Mitragyna parviflora	0.56
Myristica castaneifolia	0.49
Myristica chartacea	0.49
Myristica gillespieana	0.49
Myristica spp.	0.53
Neesia spp.	0.53
Neonauclea bernardoi	0.62
Neotrewia cumingii	0.55
Ochna foxworthyi	0.86
Ochroma pyramidale	0.30
Octomeles sumatrana	0.27, 0.32+
Oroxylon indicum	0.32
Ougenia dalbergiodes	0.70
Palaquium fidjiense	0.48
Palaquium hornei	0.70
Palaquium lanceolatum	0.55
Palaquium luzoniense	0.45
Palaquium philippense	0.41
Palaquium spp.	0.55
Palaquium tenuipetiolatum	0.50
Palaquium vitilevuense	0.48
Pangium edule	0.50
Parashorea malaanonan	0.51
Parashorea spp.	0.44
Parashorea stellata	0.59
Paratrophis glabra	0.77
Parinari corymbosa	0.76
Parinari insularum	0.65
Parinari spp.	0.68
Parkia roxburghii	0.34
Payena spp.	0.55
Peltophorum pterocarpum	0.62
Pentace spp.	0.56
Phaeanthus ebracteolatus	0.56
Phyllocladus hypophyllus	0.53
Pinus caribaea	0.48
Pinus insularis	0.47, 0.48+
Pinus merkusii	0.54
Pisonia umbellifera	0.21
Pittosporum pentandrum	0.51
Planchonella vitiensis	0.77
Planchonia spectabilis	0.58
Planchonia spp.	0.59
Podocarpus neriifolius	0.52
Podocarpus spp.	0.43
Polyalthia flava	0.51
Polyscias nodosa	0.38
Pometia pinnata forma pinnata	0.58
Pometia spp.	0.54
Pouteria villamilii	0.47
Premna tomentosa	0.96
Pterocarpus indicus	0.52
Pterocarpus marsupium	0.67
Pterocymbium macrorater	0.47
Pterocymbium tinctorium	0.28
Pyge'um vulgare	0.57
Quercus spp.	0.70
Radermachera pinnata	0.51
Salmalia malabarica	0.32, 0.33+
Samanea saman	0.45, 0.46+
Sandoricum koetjape	0.44
Sandoricum vidalii	0.43
Sapindus saponaria	0.58
Sapium luzontcum	0.40
Schleichera oleosa	0.96
Schrebera swietenoides	0.82
Semicarpus anacardium	0.64
Serialbizia acle	0.57
Serianthes melanesica	0.48
Sesbania grandiflora	0.40
Shorea agsaboensis	0.35
Shorea almon	0.42
Shorea assamica forma *philippinensis*	0.41
Shorea astylosa	0.73
Shorea ciliata	0.75
Shorea contorta	0.44
Shorea gisok	0.76
Shorea guiso	0.68
Shorea hopeifolia	0.44
Shorea malibato	0.78
Shorea negrosensis	0.44
Shorea palosapis	0.39
Shorea plagata	0.70

Table 2. -*Wood densities* (g/cm^3) *of tree species for tropical regions of three continents*—(*Continued*)

Species	Wood density
Shorea polita	0.47
Shorea polysperma	0.47
Shorea robusta	0.72
Shorea spp. *balau group*	0.70
Shorea spp. *dark red meranti*	0.55
Shorea spp. *light red meranti*	0.40
Shorea spp. *white meranti*	0.48
Shorea spp. *yellow meranti*	0.46
Shorea virescens	0.42
Sloanea javanica	0.53
Soymida febrifuga	0.97
Spathodea campanulata	0.25
Stemonurus luzoniensis	0.37
Sterculia ceramica	0.27
Sterculia foetida	0.47*
Sterculia urens	0.67
Sterculia vitiensis	0.31
Stereospermum suaveolens	0.62
Strombosia philippinensis	0.71
Strychnos potatorum	0.88
Swietenia macrophylla	0.49, 0.53+
Swintonia foxworthyi	0.62
Swintonia spp.	0.61
Sycopsis dunni	0.63
Syzygium cumini	0.70
Syzygium luzoniense	0.63
Syzygium nitidum	0.74
Syeygium simile	0.56
Syzygium spp.	0.69, 0.76+
Tamarindus indica	0.75
Tectona grandis	0.50, 0.55+
Teijsmanniodendron ahernianum	0.90
Terminalia arjuna	0.68
Terminalia belerica	0.72
Terminalia catappa	0.52
Terminalia chebula	0.96
Terminalia citrina	0.71
Terminalia copelandii	0.46
Terminalia foetidissima	0.55
Terminalia microcarpa	0.53
Terminalia nitens	0.58
Terminalia pterocarpa	0.48
Terminalia tomentosa	0.73, 0.76, 0.77+
Ternstroemia megacarpa	0.53
Tetrameles nudiflora	0.30
Tetramerista glabra	0.61
Thespesia populnea	0.52
Toona calantas	0.29
Trema orientalis	0.31
Trichospermum richii	0.32
Tristania decorticata	0.91
Tristania micrantha	0.89
Tristania spp.	0.80
Turpinia ovalifolia	0.36
Vateria indica	0.47*
Vatica mangachapoi	0.65
Vatica obscura	1.04*
Vatica pachyphylla	0.78
Vatica spp.	0.69
Vitex parviflora	0.70
Vitex peduncularis	0.96
Vitex spp.	0.65
Vitex turczaninowii	0.49
Wallaceodendron celebicum	0.55, 0.57+
Weinmannia luzoniensis	0.49
Wrightia tinctorea	0.75
Xanthophyllum excelsum	0.63
Xanthostemon verdugonianus	1.04
Xylia xylocarpa	0.73, 0.81+
Zanthoxylum rhetsa	0.33
Zizyphus spp.	0.76
Zizyphus talanai	0.53
Zizyphus xylopyra	0.85
Tropical America	
Albizzia caribaea	0.64
Albizzia spp.	0.52
Alcornea latifolia	0.49
Alcornea spp.	0.34
Alexa grandiflora	0.60
Alexa imperatricis	0.41, 0.51+
Alnus ferruginea	0.38
Alnus jorullensis	0.38
Anacardium excelsum	0.41
Anacardium spruceanum	0.42
Anadenanthera macrocarpa	0.86
Anadenanthera rigida	0.63
Andira inermis	0.63, 0.64+
Andira retusa	0.67
Aniba perutilis	0.50
Aniba riparia lduckei	0.62
Aniba spp.	0.38, 0.60+
Antiaris africana	0.38
Apeiba aspera	0.23
Apeiba echinata	0.36
Apeiba spp.	0.20, 0.24+
Apeiba tibourbon	0.12
Artocarpus communis	0.70
Aspidosperma album	0.68
Aspidosperma cruentum	0.71
Aspidosperma dugandii	0.77
Aspidosperma marchravianum	0.68
Aspidosperma megalocarpum	0.71, 0.81+
Aspidosperma spp. (araracanga group)	0.75
Aspidosperma spp. (peroba group)	0.62, 0.65+
Astronium graveolens	0.75, 0.80, 0.84, 0.89+
Astronium lecointei	0.73
Bagassa guianensis	0.68, 0.69+
Banara guianensis	0.61
Basiloxylon exelsum	0.58
Beilschmiedia pendula	0.54
Beilschmiedia sp.	0.61
Bertholletia excelsa	0.59, 0.63+
Bixa arborea	0.32
Bombacopsis quinatum	0.38, 0.45, 0.51+
Bombacopsis sepium	0.39
Borojoa patinoi	0.52
Bowdichia nitida	0.77
Bowdichia spp.	0.74
Brosimum acutifolium	0.55

Table 2.—Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)

Species	Wood density
Brosimum parinarioides	0.57
Brosimum potabile	0.53
Brosimum rubescens	0.73
Brosimum sp.	0.64, 0.84+
Brosimum spp. (alicastrum group)	0.64, 0.66+
Brosimum spp. (utile group)	0.43
Brosimum utile	0.41, 0.46+
Brysenia adenophylla	0.54
Buchenauia capitata	0.61, 0.63+
Buchenavia huberi	0.59, 0.79+
Bucida buceras	0.93
Bulnesia arborea	1.00
Bursera simaruba	0.29, 0.34+
Byrsonima aerugo	0.62
Byrsonima coriacea	0.64
Byrsonima coriacea var. *spicata*	0.61
Byrsonima spp.	0.61, 0.64, 0.75+
Cabralea cangerana	0.55
Caesalpinia spp.	1.05
Calophyllum brasiliense	0.51, 0.54, 0.55+
Calophyllum mariae	0.46
Calophyllum sp.	0.65
Calycophyllum candidisimum	0.67
Campnosperma panamensis	0.33, 0.50+
Carapa guianensis	0.56
Carapa sp.	0.47
Caryocar nr. *barbinerve*	0.62
Caryocar spp.	0.69, 0.72+
Caryocar villosum	0.72
Casearia arborea	0.53
Casearia guianensis	0.70
Casearia praecox	0.69*
Casearia sp.	0.62
Cassia moschata	0.71
Cassia *multijuga*	0.57
Casuarina equisetifolia	0.81
Catostemma commune	0.51
Catostemma spp.	0.55
Cecropia *peltata*	0.29, 0.30, 0.36+
Cecropia spp.	0.36
Cedrela angustifolia	0.36
Cedrela huberi	0.38
Cedrela odorata	0.43, 0.44, 0.45+
Cedrela spp.	0.40, 0.46+
Cedrelinga catenaeformis	0.41, 0.53+
Ceiba pentandra	0.23, 0.24, 0.25, 0.29+
Centrolobium paraense var. *orinocensis*	0.69
Centrolobium spp.	0.65
Cespedesia macrophylla	0.63
Chaetocarpus schomburgkianus	0.80
Chlorophora tinctoria	0.71, 0.75+
Clarisia racemosa	0.53, 0.57+
Clathrotropis brunnea	0.82
Clathrotropis spp.	0.89
Clusia rosea	0.67
Cochlospermum orinocensis	0.26
Copaifera duckeilreticulata	0.62
Copaifera officinalis	0.59
Copaifera spp.	0.46, 0.55+
Cordia alliodora	0.42, 0.47, 0.50, 0.57+
Cordia apurensis	0.66
Cordia bicolor	0.43, 0.49+
Cordia borinquensis	0.70
Cordia collococca	0.47
Cordia exaltata	0.41
Cordia fallax	0.36
Cordia goeldiana	0.50
Cordia sagotii	0.50
Cordia spp. (gerascanthus group)	0.74
Cordia spp. (alliodora group)	0.48
Cordia sulcata	0.60
Couepia sp.	0.70
Couma macrocarpa	0.50, 0.53+
Couratari pulchra	0.50, 0.54+
Couratari spp.	0.50
Couratari stellata	0.65, 0.78+
Croton xanthochloros	0.48
Cupressus lusitanica	0.43, 0.44+
Cyrilla racemiflora	0.53
Dactyodes colombiana	0.51
Dacryodes excelsa	0.52, 0.53+
Dalbergia nigra	0.68
Dalbergia retusa.	0.89
Dalbergia stevensonii	0.82
Declinanona calycina	0.47
Dialium guianensis	0.87
Dialyanthera spp.	0.36, 0.48+
Dicorynia guianensis	0.60, 0.65+
Dicorynia paraensis	0.60
Didymopanax morototoni	0.36, 0.40, 0.45+
Didymopanaxpittieri	0.43
Didymopanax sp.	0.74
Dimorphandra mora	0.99*
Diplotropis purpurea	0.76, 0.77, 0.78+
Dipterix odorata	0.81, 0.86, 0.89+
Drypetes variabilis	0.69
Dussia lehmannii	0.59
Ecclinusa guianensis	0.63
Endlicheria cocvirey	0.39
Enterolobium cyclocarpum	0.34, 0.45+
Enterolobium schomburgkii	0.82
Eperua spp.	0.78
Eriotheca longipedicellatum	0.45
Eriotheca sp.	0.40
Erisma uncinatum	0.42, 0.48+
Erythrina sp.	0.23
Eschweilera amara	0.85
Eschweilera corrugata	0.66
Eschweilera grata	0.88
Eschweilera hologyne	0.76
Eschweilera odora	0.81, 0.85+
Eschweilera sagotiana	0.82
Eschweilera spp.	0.71, 0.79, 0.95+
Eschweilera subglandulosa	0.87, 0.89+
Eschweilera tenax	0.62
Eschweilera trinitensis	0.77
Eucalyptus robusta	0.51
Eugenia compta	0.68
Eugenia pseudosidium	0.62
Eugenia stahlii	0.73

Table 2.—*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Euxylophora paraensis	0.68, 0.70+
Fagara aff. F. *martinicense*	0.41
Fagara sp.	0.57
Fagara spp.	0.69
Ficus *citrifolia*	0.40
Ficus sp.	0.32
Genipa americana	0.57, 0.58, 0.66+
Genipa spp.	0.75
Goupia glabra	0.67, 0.72+
Guarea *chalde*	0.52
Guarea spp.	0.52
Guarea trichiloides	0.51, 0.52+
Guatteria spp.	0.36
Guazuma ulmifolia	0.52, 0.50+
Guettarda scabra	0.65
Guillielma gasipae	0.95, 1.25+
Gustavia sp.	0.56
Helicostylis tomentosa	0.68, 0.72+
Hernandia sonora	0.29
Hevea brasiliense	0.49
Himatanthus articulata	0.40, 0.54+
Hirtella davisii	0.74
Humiria balsamifera	0.66, 0.67+
Humiriastrum melanocarpum	0.60
Humiriastrum procera	0.70
Hura crepitans	0.36, 0.37, 0.38+
Hyeronima alchorneoides	0.60, 0.64+
Hyeronima laxiflora	0.59
Hymenaea courbaril	0.54, 0.76, 0.77+
Hymenaea davisii	0.67
Hymenolobium excelsum	0.63
Hymenolobium sp.	0.64
Inga alba	0.53
Inga capitata	0.64
Inga coruscans	0.72
Inga floribunda	0.56
Inga ingoides	0.50
Inga laurina	0.62
Inga marginata	0.72
Inga sp.	0.49, 0.52, 0.58, 0.64+
Inga splendens	0.55
Inga vera	0.59
Iryanthera grandis	0.63
Iryanthera hostmanii	0.50
Iryanthera spp.	0.46
Jacaranda copaia	0.35
Jacaranda hesperia	0.35
Jacaranda sp.	0.55
Joannesia heveoides	0.39
Lachmellea speciosa	0.73
Laetia procera	0.68
Lecythis davisii	0.82
Lecythis ollaria	0.72
Lecythis paraensis	0.88
Lecythis sp.	0.83
Lecythis spp.	0.77
Licania aff. *micrantha*	0.86
Licania alba	0.91
Licania apetala	0.64, 0.78+
Licania densiflora	0.80
Licania hypoleuca	0.90
Licania macrophylla	0.76
Licania parviflora	0.76
Licania sp.	0.61, 0.79+
Licania spp.	0.78
Licaria cayennensis	0.99
Licaria spp.	0.82
Lindackeria sp.	0.41
Linociera domingensis	0.81
Lonchocarpus sericens	0.78
Lonchocarpus spp.	0.69
Lonchocarpus straminens	0.75
Loxopterygium sagotii	0.56
Lucuma spp.	0.79
Luehea cymulosa	0.55
Luehea spp.	0.50
Lueheopsis duckeana	0.64
Mabea piriri	0.59
Machaerium spp.	0.70
Macoubea guianensis	0.40*
Magnolia *sororum*	0.50
Magnolia splendens	0.59
Magnolia spp.	0.52
Maguira sclerophylla	0.57
Mammea americana	0.62
Mangifera indica	0.55
Manilkara bidentata	0.82, 0.84, 0.85+
Manilkara sp.	0.89
Marila sp.	0.63
Marmaroxylon racemosum	0.78*
Matayba domingensis	0.70
Matisia hirta	0.61
Maytenus ficiformis	0.67
Maytenus spp.	0.71
Mezilaurus itauba	0.68
Mezilaurus lindaviana	0.68
Michropholis garciniaefolia	0.64
Michropholis spp.	0.61
Minquartia guianensis	0.76, 0.79+
Mora excelsa	0.80
Mora gonggrijpi	0.80
Mora magistosperma	0.88
Mora sp.	0.71
Mouriria guianensis	0.80
Mouriria huberi	0.75
Mouriria pseudo-germinata	0.65
Mouriria sideroxylon	0.88
Myrcia paivae	0.73
Myrcia splendens	0.80
Myrciaria floribunda	0.73
Myristica spp.	0.46
Myroxylon balsamum	0.74, 0.76, 0.78+
Nectandra antillana	0.42
Nectandra concinna	0.54, 0.56+
Nectandra coriacea	0.51
Nectandra rigida	0.59
Nectandra rodioei	0.91
Nectandra rubra	0.55
Nectandra sp.	0.43, 0.48, 0.72+

Table 2.-Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)

Species	Wood density	Species	Wood density
Nectandra spp.	0.52	Pouteria melinonii	0.63*
Ocotea glandulosa	0.46	Pouteria multiflora	0.74
Ocotea leucoxylon	0.45	Pouteria pomifera	0.76
Ocotea moschata	0.61	Pouteria sp.	0.73
Ocotea rodioei	0.85, 0.86+	Pouteria spp.	0.64, 0.67+
Ocotea rubra	0.54, 0.55, 0.56+	Prioria copaifera	0.40, 0.41+
Ocotea spathulata	0.62	Protium crenatum	0.54
Ocotea spp.	0.51	Protium decandrum	0.56
Onychopetalum amazonicum	0.64	Protium heptaphyllum	0.40, 0.55+
Ormosia krugii	0.50	Protium neglectum	0.58, 0.64+
Ormosia lignivalvis	0.58	Protium sp.	0.73
Ormosia spp.	0.59	Protium spp.	0.53, 0.64+
Ouratea sp.	0.66	Protium tenuifolium	0.60
Pachira acuatica	0.43	Pseudolmedia laevigata	0.64
Paratecoma peroba	0.60	Pterocarpus officinalis	0.32, 0.50+
Parinari campestris	0.69	Pterocarpus rohrii	0.41
Parinari excelsa	0.64	Pterocarpus sp.	0.46, 0.50+
Parinari rodolfi	0.72	Pterocarpus spp.	0.44
Parinari spp.	0 . 6 8	Pterocarpus vernalis	0.59
Parkia belutina	0.42	Pterogyne nitens	0.66
Parkia multijuga	0.38	Pterygota excelsa	0.58
Parkia oppositifolia	0.24	Qualea albiflora	0.50
Parkia pendula	0.51	Qualea cf. lancifolia	0.58
Parkia spp.	0.39	Qualea dinizii	0.58
Peltogyne porphyrocardia	0.92	Qualea spp.	0.55
Peltogyne spp.	0.79	Quararibaea guianensis	0.54
Pentaclethra macroloba	0.65, 0.68+	Quercus alata	0.71
Peru glabrata	0.65	Quercus costaricensis	0.61
Peru schomburgkiana	0.59	Quercus eugeniaefolia	0.67
Persea spp.	0.40, 0.47, 0.52+	Quercus spp.	0.70
Petitia domingensis	0.66	Raputia sp.	0.55
Pinus caribaea	0.51	Rheedia spp.	0.72
Pinus oocarpa	0.55	Rollinia exsucca	0.32
Pinus patula	0.45	Rollinia sp.	0.34, 0.36+
Piptadenia communis	0.68	Rollinia spp.	0.36
Piptadenia macrocarpa	0.83*	Saccoglottis cydonioides	0.72
Piptadenia pittieri	0.62, 0.76+	Sapium biglandulosum	0.45
Piptadenia psilostachya	0.67	Sapium cf. jenmanni	0.41
Piptadenia rigida	0.73	Sapium laurocerasus	0.38
Piptadenia sp.	0.58	Sapium sp.	0.38, 0.48+
Piptadenia suaveolens	0.72	Sapium ssp.	0.47, 0.72+
Piranhea longepedunculata	0.90	Schinopsis spp.	1.00
Piratinera guianensis	0.96	Sclerobium aff. chrysophyllum	0.62
Pithecellobium guachapele (syn. Pseudosamea)	0.56	Sclerobium guianensis	0.56
Pithecellobium saman	0.48	Sclerobium paniculatum	0.34
Platonia insignis	0.70'	Sclerobium spp.	0.47
Platymiscium pinnatum	0.80, 0.81+	Sickingia spp.	0.52
Platymiscium polystachium	0.73	Simaba multiflora	0.51
Platymiscium spp.	0.71, 0.84+	Simarouba amara	0.32, 0.34, 0.38+
Podocarpus oleifolius	0.46	Sloanea berteriana	0.80
Podocarpus rospigliossi	0.40	Sloanea grandiflora	0.80
Podocarpus spp.	0.46	Sloanea guianensis	0.79
Pourouma aff. apiculata	0.45	Spondias lutea	0.38
Pourouma aspera	0.28	Spondias mombin	0.30, 0.40, 0.41+
Pourouma aff. guianensis	0.33	Sterculia apetala	0.33, 0.36
Pourouma aff. melinonii	0.32	Sterculia pilosa /speciosa	0.53
Pouteria carabobensis	0.68	Sterculia pruriens	0.46
Pouteria egregia	0.89	Sterculia spp.	0.55
Pouteria eugeniifolia	1.08	Stryphnodendron polystachum	0.52
Pouteria gonggrijpii	0.84	Stylogyne spp.	0.69

Table 2.-Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)

Species	Wood density	Species	Wood density
Swartzia spp.	0.95	*Warszewicsia coccinea*	0.56
Swietenia macrophylla	0.42, 0.45, 0.46, 0.54+	*Xanthoxylum martinicensis*	0.46
Symphonia globulifera	0.68	*Xanthoxylum* spp.	0.44
Tabebuia guayacan	0.82	*Xylopia columbiana*	0.51
Tabebuia heterophylla	0.58	*Xylopia emarginata*	0.59
Tabebuia heterotricha	0.82	*Xylopia frutescens*	0 64"
Tabebuia pentaphylla	0.51	Tropical Africa	
Tabebuia rosea	0.54		
Tabebuia serratifolia	0.92, 0.95, 0.99+	*Afzelia bipindensis*	0.66"
Tabebuia spectabilis	1.07	*Afzelia pachyloba*	0.63*
Tabebuia spp. (lapacho group)	0.91	*Afzelia* spp.	0.67
Tabebuia spp. (roble)	0.52	*Aidia ochroleuca*	0.78*
Tabebuia spp. (white cedar)	0.57	*Albizia ferruginea*	0.47*
Tabebuia stenocalyx	0.55, 0.57+	*Albizia glaberrima*	0.52"
Tachigalia myrmecophylla	0.56	*Albizia gummifera*	0.51*
Talisia sp.	0.84	*Albizia* spp.	0.52
Tapirira guianensis	0.47*	*Albizia zygia*	0.46*
Terminalia amatonia	0.66	*Allanblackia floribunda*	0.63*
Terminalia catappa	0.59	*Allophyllus africanus* f. *acuminatus*	0.45
Terminalia guianensis	0.63	*Alstonia congensis*	0.33
Terminalia lucida	0.65	*Amphimas ferrugineus*	0.63*
Terminalia sp.	0.50, 0.51, 0.58+	*Amphimas pterocarpoides*	0.63*
Tetragastris altisima	0.61	*Anisophyllea obtusifolia*	0.63*
Tetragastris balsamifera	0.63, 0.67+	*Annonidium mannii*	0.29*
Tetragastris panamensis	0.71	*Anopyxis klaineana*	0.74*
Tetragastris spp.	0.71	*Anthocleista keniensis*	0.50*
Toluifera balsamum	0.74	*Anthonotha macrophylla*	0.78*
Tornubia cuspidata	0.47	*Anthostemma aubryanum*	0.32*
Tornubia sp.	0.52	*Antiaris africana*	0.37
Toulicia pulvinata	0.63	*Antiaris* spp.	0.38
Tovomita guianensis	0.60	*Antrocaryon klaineanum*	0.50*
Trattinickia burserifolia	0.44	*Aucoumea klaineana*	0.37
Trattinickia rhoifolia	0.37	*Autranella congolensis*	0.78
Trattinickia sp.	0.38	*Baillonella toxisperma*	0.71
Trichilia propingua	0.58	*Balanites aegyptiaca*	0.63*
Trichosperma mexicanum	0.41	*Baphia kirkii*	0.93*
Triplaris sp.	0.64	*Beilschmiedia corbisieri*	0.63*
Triplaris spp.	0.56	*Beilschmiedia diversiflora*	0.63*
Triplaris surinamensis	0.51	*Beilschmiedia kweo*	0.56*
Trophis sp.	0.54	*Beilschmiedia louisii*	0.70*
Vatairea lundellii	0.64	*Beilschmiedia membranifolia*	0.50*
Vatairea spp.	0.60	*Beilschmiedia nitida*	0.50*
Virola sebifera	0.48	*Berlinia bracteosa*	0.60*
Virola spp.	0.40, 0.44, 0.48+	*Berlinia confusa*	0.56*
Virola surinamensis	0.37, 0.42+	*Berlinia* spp.	0.58
Vismia spp.	0.41	*Blighia welwitschii*	0.74*
Vitex divaricata	0.62	*Bombax buonopozense*	0.32*
Vitex gaumeri	0.56	*Bombax chevalieri*	0.41*
Vitex orinocensis	0.53	*Bombax rhodognaphalon*	0.36*
Vitex spp.	0.52, 0.56, 0.57+	*Bombax* spp.	0.40
Vitex stahelii	0.60	*Brachystegia cynometroides*	0.56*
Vochysia ferruginea	0.42, 0.47+	*Brachystegia laurentii*	0.45*
Vochysia guianensis	0.45	*Brachystegia mildbraedii*	0.50*
Vochysia hondurensis	0.33	*Brachystegia* spp.	0.52
Vochysia lehmannii	0.48	*Bridelia grandis*	0.50*
Vochysia maxima	0.46	*Bridelia micrantha*	0.47*
Vochysia spp.	0.40, 0.47, 0.79+	*Calpocalyx heitzii*	0.66*
Vochysia tetraphylla	0.48	*Calpocalyx klainei*	0.63*
Vochysia tomentosa	0.36	*Canarium schweinfurthii*	0.40*
Vouacapoua americana	0.79	*Canthium rubrocostratum*	0.63*

Table 2.—Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)

Species	Wood density	Species	Wood density
Carapa procera	0.59	*Enantia chlorantha*	0.42"
Casearia battiscombei	0.50	*Endodesmia calophylloides*	0.66"
Cassipourea euryoides	0.70*	*Entandrophragma angolensis*	0.45
Cassipourea malosana	0.59*	*Entandrophragma candollei*	0.59
Ceiba pentandra	0.26	*Entandrophragma cylindricum*	0.55
Celtis brieyi	0.50"	*Entandrophragma utile*	0.53
Celtis mildbraedii	0.56*	*Eribroma oblongum*	0.60*
Celtis spp.	0.59	*Eriocoelum microspermum*	0.50"
Celtis zenkeri	0.59"	*Erismadelphus exsul*	0.56*
Chlorophora ercelsa	0.55	*Erythrina vogelii*	0.25"
Chrysophyllum albidum	0.56*	*Erythrophleum ivorense*	0.72
Cleistanthus mildbraedii	0.87*	*Erythroxylum mannii*	0.50
Cleistopholis patens	0.36*	*Fagara heitzii*	0.41*
Coelocaryon preussii	0.56"	*Fagara macrophylla*	0.69
Cola cordifolia	0.50*	*Ficus iteophylla*	0.40"
Cola gigantea	0.46"	*Ficus mucuso*	0.39*
Cola gigantea var. *glabrescens*	0.46*	*Funtumia africana*	0.40*
Cola natalensis	0.70"	*Fumtumia latifolia*	0.45*
Cola sp.	0.70"	*Gambeya africana*	0.63
Combretodendron macrocarpum	0.70	*Gambeya lacourtiana*	0.63*
Conopharyngia holstii	0.50*	*Gambeya madagascariensis*	0.56*
Copaifera mildbraedii	0.63*	*Gambeya* spp.	0.56*
Copaifera religiosa .	0.50"	*Garcinia gerardii*	0.66*
Cordia africana	0.40*	*Garcinia mannii*	0.78"
Cordia millenii	0.34	*Garcinia punctata*	0.78"
Cordia platythyrsa	0.36"	*Gilbertiodendron dewevrei*	0.65"
Corynanthe gabonensis	0.56"	*Gilbertiodendron grandiflorum*	0.66"
Corynanthe pachyceras	0.63"	*Gilbertiodendron mayombense*	0.63"
Coda edulis	0.78*	*Gilletiodendron mildbraedii*	0.87"
Croton macrostachyus	0.50*	*Gossweilerodendron balsamiferum*	0.40
Croton megalocarpus	0.57	*Guarea cedrata*	0.48
Cryptosepalum staudtii	0.70*	*Guarea laurentii*	0.56"
Ctenolophon englerianus	0.78*	*Guarea thompsonii*	0.55"
Cylicodiscus gabonensis	0.80	*Guibourtia arnoldiana*	0.64
Cynometra alexandri	0.74	*Guibourtia demeusei*	0.70"
Dacryodes buettneri	0.53"	*Guibourtia ehie*	0.67
Dacryodes edulis	0.50"	*Guibourtia pellegriniana*	0.74"
Dacryodes igaganga	0.53"	*Guibourtia* spp.	0.72
Dacryodes klaineana	0.70"	*Guibourtia tessmannii*	0.74*
Dacryodes le-testui	0.50"	*Hannoa klaineana*	0.28"
Dacryodes normandii	0.50*	*Harungana madagascariensis*	0.45"
Dacryodes spp.	0.61	*Hexalobus crispiflorus*	0.48"
Daniellia klainei	0.45*	*Holoptelea grandis*	0.59"
Daniellia ogea	0.40*	*Homalium letestui*	0.66*
Daniellia soyaunii	0.45"	*Homalium* spp.	0.70
Desbordesia pierreana	0.87"	*Hylodendron gabonense.*	0.78"
Detarium senegalensis	0.63*	*Hymenostegia afzelii*	0.78"
Dialium bipindense	0.83"	*Hymenostegia pellegrini*	0.78"
Dialium dinklagei	0.72	*Irvingia gabonensis*	0.71
Dialium excelsum	0.78*	*Irvingia grandifolia*	0.78"
Didelotia africana	0.78"	*Julbernardia globiflora*	0 . 7 8
Didelotia brevipaniculata	0.53	*Khaya grandifoliola*	0.60
Didelotia letouzeyi	0.50	*Khaya ivorensis*	0.44
Diospyros kamerunensis	0.78*	*Khaya senegalensis*	0.60
Diospyros spp.	0.82	*Klainedoxa gabonensis*	0.87
Discoglypremna caloneura	0.32*	*Lannea welwitschii*	0.45"
Distemonanthus benthamianus	0.58	*Lecomtedoxa klainenna*	0.78:"
Drypetes gossweilleri	0.63*	*Letestua durissima*	0.87"
Drypetes sp.	0.63*	*Lophira alata*	0.87"
Ehretia acuminata	0.51*	*Lovoa trichilioides*	0.45"

Table 2.-*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Macaranga conglomerata	0.40*
Macaranga kilimandscharica	0.40*
Maesopsis eminii	0.41
Malacantha sp. aff. *alnifolia*	0.45”
Mammea africana	0.62
Manilkara cuneifolia	0.81*
Manilkara lacera	0.78”
Markhamia hildebrandtii	0.50*
Markhamia platycalyx	0.45*
Memecylon capitellatum	0.77”
Microberlinia bisulcata	0.63”
Microberlinia brazzavillensis	0.70
Microcos coriaceus	0.42”
Milletia laurentii	0.70”
Milletia spp.	0.72
Mitragyna ciliata	0.45
Mitragyna stipulosa	0.47
Monopetalanthus coriaceus	0.45*
Monopetalanthus durandii	0.50*
Monopetalanthus heitzii	0.39
Monopetalanthus letestui	0.50”
Monopetalanthus pellegrinii	0.47”
Musanga cecropioides	0.23
Nauclea diderrichii	0.63
Neopoutonia macrocalyx	0.32”
Nesogordonia fouassieri	0.70”
Nesogordonia papaverifera	0.65
Newtonia buchananii	0.48*
Newtonia glandulifera	0.74”
Ochtocosmus africanus	0.78’
Odyendea gabonensis	0.32”
Odyendea spp.	0.32
Oldfieldia africana	0.78*
Ongokea gore	0.72
Oxystigma oxyphyllum	0.53
Pachyelasma tessmannii	0.70”
Pachypodanthium confine	0.58*
Pachypodanthium staudtii	0.58”
Paraberlinia bifoliolata	0.56”
Parinari excelsa	0.69
Parinari glabra	0.87”
Parinari goetzeniana	0.78”
Parkia bicolor	0.36”
Pausinystalia brachythyrsa	0.56”
Pausinystalia cf. *talbotii*	0.56”
Pentaclethra eetveldeana	0.63”
Pentaclethra macrophylla	0.78”
Pentadesma butyracea	0.78”
Phyllanthus discoideus	0.76”
Pierreodendron africanum	0.70;”
Piptadenia gabunensis	0.70*
Piptadeniastrum africanum	0.56
Plagiostyles africana	0.70”
Poga oleosa	0.36
Polyalthia suaveolens	0.66”
Premna angolensis	0.63”
Pteleopsis hylodendron	0.63*
Pterocarpus angolensis	0.59
Pterocarpus soyauxii	0.61
Pterygota bequaertii	0.56*
Pterygota spp.	0.52
Pycnanthus angolensis	0.40
Randia cladantha	0.78*
Rauwolfia macrophylla	0.47*
Ricinodendron heudelotii	0.20
Saccoglottis gabonensis	0.74”
Santiria trimera	0.53*
Sapium ellipticum	0.50*
Schrebera arborea	0.63*
Sclorodophloeus zenkeri	0.68*
Scottellia chevalieri	0.50*
Scottellia coriacea	0.56
Scyphocephalium ochocoa	0.48
Scytopetalum tieghemii	0.56”
Sindoropsis letestui	0.56*
Staudtia stipitata	0.75
Stemonocoleus micranthus	0.56”
Sterculia oblonga	0.61
Sterculia rhinopetala	0.64
Strephonema pseudocola	0.56*
Strombosia glaucescens	0.80
Strombosia grandifolia	0.74*
Strombosiopsis tetrandra	0.63”
Swartzia fistuloides	0.82
Symphonia globulifera	0.58”
Syzygium cordatum	0.59*
Tarrietia densiflora	0.63
Tarrietia utilis	0.54”
Terminalia superba	0.45
Tessmania africana	0.85”
Testulea gabonensis	0.60
Tetraberlinia bifoliolata	0.54*
Tetraberlinia tubmaniana	0.60”
Tetrapleura tetraptera	0.50”
Tieghemella africana	0.55
Tieghemella heckelii	0.55”
Trema guineensis	0.40”
Trema sp.	0.40*
Trichilia heudelotii	0.50”
Trichilia prieureana	0.63”
Trichoscypha arborea	0.59”
Triplochiton scleroxylon.	0.32
Uapaca spp.	0.60
Vepris undulata	0.70”
Vitex doniana	0.40
Xylopia aethiopica	0.50”
Xylopia chrysophylla	0.70*
Xylopia hypolambra	0.63”
Xylopia quintasii	0.70”
Xylopia staudtii	0.36*

+The wood densities specified pertain to more than one bibliographic source.

* Wood density value is derived from the regression equation given in the text,

APPENDIX 5: DATA SHEETS

DEAD WOOD DENSITY DATA SHEET

Stratum: ___________ Location:_____________________

Date: ______/______/______ Data recorded by:_____________________

Notes:

Calibrating 1 kg scale:

Object weight: _________ g

Name of object: ____________ g

Calibrating 300 g scale:

Object weight: _________ g

Name of object: ____________ g

Weight of sheet: _______ g

A minimum of 10 samples should be collected for each density class at the beginning of the field sampling effort. Diameter and width should be recorded for each sample. Volume and Dry Weight to be measured in the laboratory.

Photo #	Dead Wood ID	Wood Density Class: S, I, R*	Diameter2 (cm)	Diameter2 (cm)	Width1 (cm)	Width2 (cm)	Volume (cm^3)	Dry weight (g)

* S = sound, I = intermediate, R = rotten

DATA SHEET FOR SAPLINGS

Stratum:___________ Location:_______________________
Date:___________ Data recorded by:__________________
Notes:
At least 30 saplings must be cut and weighed.

Calibrating 1 kg scale: **Weight of sheet: _______ g**
Object weight: _________ g
Name of object: ____________ g
Calibrating 300 g scale:
Object weight: _________ g
Name of object: ____________ g

Plot ID	Sapling ID	DBH	Species	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

DESTRUCTIVE SAMPLING DATA SHEET

Plot ID:_______Location:__________GPS____________Lat:_________ Long:___________
Date:___________ Team Leader:________Timestart:___________Time end:____________
Tree ID: _____________Stratum:_____________Photo ID: _______________________

MEASUREMENTS BEFORE TREE CUT

Species: __________________ DBH: _______________ cm
Tree Height:

Height Measurement 1		Height Measurement 2	
Clinometer Height Measurement (m)	Distance to tree (m)	Clinometer Height Measurement (m)	Distance to tree (m)

MEASUREMENTS AFTER TREE CUT

Bole measurements

Diameter at bottom of bole: _______cm
Diameter at top of bole:_______cm
Diameter at center of bole _______ cm
DBH of bole: _______cm
Length of bole: _______m
Length of tree: _______m

Starting at the bottom of the bole, divide the bole into 2-m sections and list the dimensions of each section below:

Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)	Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)

For density determination:

Subsample disc 1	Subsample disc 2	Subsample disc 3
Label: __________	Label: ________	Label: __________
L1: ________ cm	L1: ________ cm	L1: ________ cm
L2: ________ cm	L2: ________ cm	L2: ________ cm
T1: ________ cm	T1: ________ cm	T1: ________ cm
T2: ________ cm	T2: ________ cm	T2: ________ cm

If disc is cut, check below by how much. Only do this if absolutely necessary and you ensure you are taking either half (½) or a quarter (¼) of the weight of the subsample; this needs to be as precise as possible.

Disc 1: ☐½ ☐

Disc 2: ☐½ ☐

Disc 3: ½ ☐ ¼ ☐

Stump measurements

Weight of plastic sheet A: ____________ g
Weight of plastic sheet B: ____________ g
Weight of plastic sheet C: ____________ g

Calibrating 100 kg scale:
Object weight: _________ g
Name of object: ____________ g
**Directions for calibrating scale: Weigh object on a high quality digit laboratory scale. If there is a difference in weight between field scale and laboratory scale, adjust data below accordingly.

Calibrating 5~~1~~ kg scale:
Object weight: _________ g
Name of object: ____________ g

Calibrating 5~~3~~00 g scale:
Object weight: _________ g
Name of object: ____________ g

If entire stump is weighed at once: Total fresh weight: _______kg
Weight of plastic sheet (or sheet name): _______________ g
If entire or a portion of the stump is weighed in sections (kg):

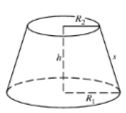
Weight	Sheet Name	Weight	Sheet Name	Weight	Sheet Name
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

Subsamples for determination of dry:wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g) * this is sample weight – bag weight	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

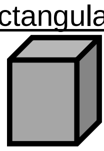
Volume estimates: If stump is cut and part of it is estimated by volume rather than weighing the whole stump, pick shape and note its dimensions:

Frustum:



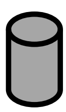
D_{bottom} ________ cm
D_{top} ________ cm
________ cm

Rectangular Prism:



Length ________ cm
Width ________ cm
Height ________ cm

Cylinder:



Dia1 ________ cm
Dia1 ________ cm
H1 ________ cm

Height of stump ______________ ______________ H2 ________ cm

Dimensions of disc sample for determining density:

L1: __________ cm W1: _________ cm
L2: __________ cm W1: _________ cm

If disc is cut, check below by how much. Only do this if absolutely necessary and you ensure you are taking either half (½) or a quarter (¼) of the weight of the subsample; this needs to be as precise as possible.

Disc 1: ☐ ½ ☐
Disc 2: ☐ ½ ☐
Disc 3: ½ ☐ ¼ ☐

Buttress Measurements:

If entire buttress is weighed at once: Total fresh weight: _______kg
If entire buttress is weighed in sections (kg):

Weight	**Sheet Name**	**Weight**	**Sheet Name**	**Weight**	**Sheet Name**
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

Subsamples for determination of dry:wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Tree Crown Measurements:

Leaves and branches <10 cm:

If weighed at once: Total fresh weight: _______kg

If leaves and branches weighed in sections (kg):

Weight	**Sheet Name**	**Weight**	**Sheet Name**	**Weight**	**Sheet Name**
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

Subsamples for determination of dry:wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Branches 10-20 cm:
If weighed at once: Total fresh weight: ______kg
If branches 10-20 cm weighed in sections (kg):

Weight	**Sheet Name**	**Weight**	**Sheet Name**	**Weight**	**Sheet Name**
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

Subsamples for determination of dry:wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Branches >20 cm:
If weighed at once: Total fresh weight: ______kg
If branches >20 cm weighed in sections (kg):

Weight	**Sheet Name**	**Weight**	**Sheet Name**	**Weight**	**Sheet Name**
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

Subsamples for determination of dry:wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Volume Estimates:

If volume is estimated instead of weight for branches >20 cm, then mentally divide the branch into sections and list the dimensions of each section below:

Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)	Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)

For density determination: Only need for branches you estimated volume for (did not weigh with scale).

Subsample disc 1		Subsample disc 2		Subsample disc 3	
Label: ___________		Label: _________		Label: ___________	
L1:	_________ cm	L1:	_________ cm	L1:	_________ cm
L2:	_________ cm	L2:	_________ cm	L2:	_________ cm
T1:	_________ cm	T1:	_________ cm	T1:	_________ cm
T2:	_________ cm	T2:	_________ cm	T2:	_________ cm

If disc is cut, check below by how much. Only do this if absolutely necessary and you ensure you are taking either half (½) or a quarter (¼) of the weight of the subsample; this needs to be as precise as possible.

Disc 1: ☐ ½ ☐

Disc 2: ☐ ½ ☐

Disc 3: ½ ☐ ¼ ☐

NOTES FOR DESTRUCTIVE SAMPLING MEASUREMENTS

BAMBOO DESTRUCTIVE SAMPLING DATA SHEET

Plot # or Name________Stratum: ___________ Location:______________________
Date: ______/______/______ Data recorded by:______________________
Notes:

Calibrating 1 kg scale:

Weight of sheet: _______ g

Object weight: _________ g
Name of object: ____________ g

Calibrating 300 g scale:

Object weight: _________ g
Name of object: ____________ g

A minimum of 30 samples (individuals) should be collected for each size class at the beginning of the field sampling effort. Size class is a guide to make sure sampling covers all stem sizes. You may group data into size classes when doing analysis if you think this is important for the allometric equation. Perhaps consider 10 per DBH size class. Diameter, height and weight should be recorded for each sample. Empty bag weight should be recorded.

Possible Size Classes:

2-3 cm
3-4 cm
4-5 cm
5-6 cm
> 7cm

Before cutting, measure:

Basal Area around entire clump (cm): _____________
Number of stems in clump (#): ________

Record Below - Height of all stems (m): _____________
Record Below - Diameter at 0.3 of all steams (cm): _____________
Record Below – DBH of all stems (if decide)(cm): ______________

After cutting, measure for each stem:

Clump ID #	Stem #	Height while standing (m)	Diameter at 0.3 (cm)	DBH (cm)	Height after cut (m)	Total Stem Weight (kg)

Subsamples

Weights of Subsamples (kg)

Clump ID	Subsample weight 1	Subsample weight 2	Subsample weight 3	Subsample weight 4	Subsample weight 5

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