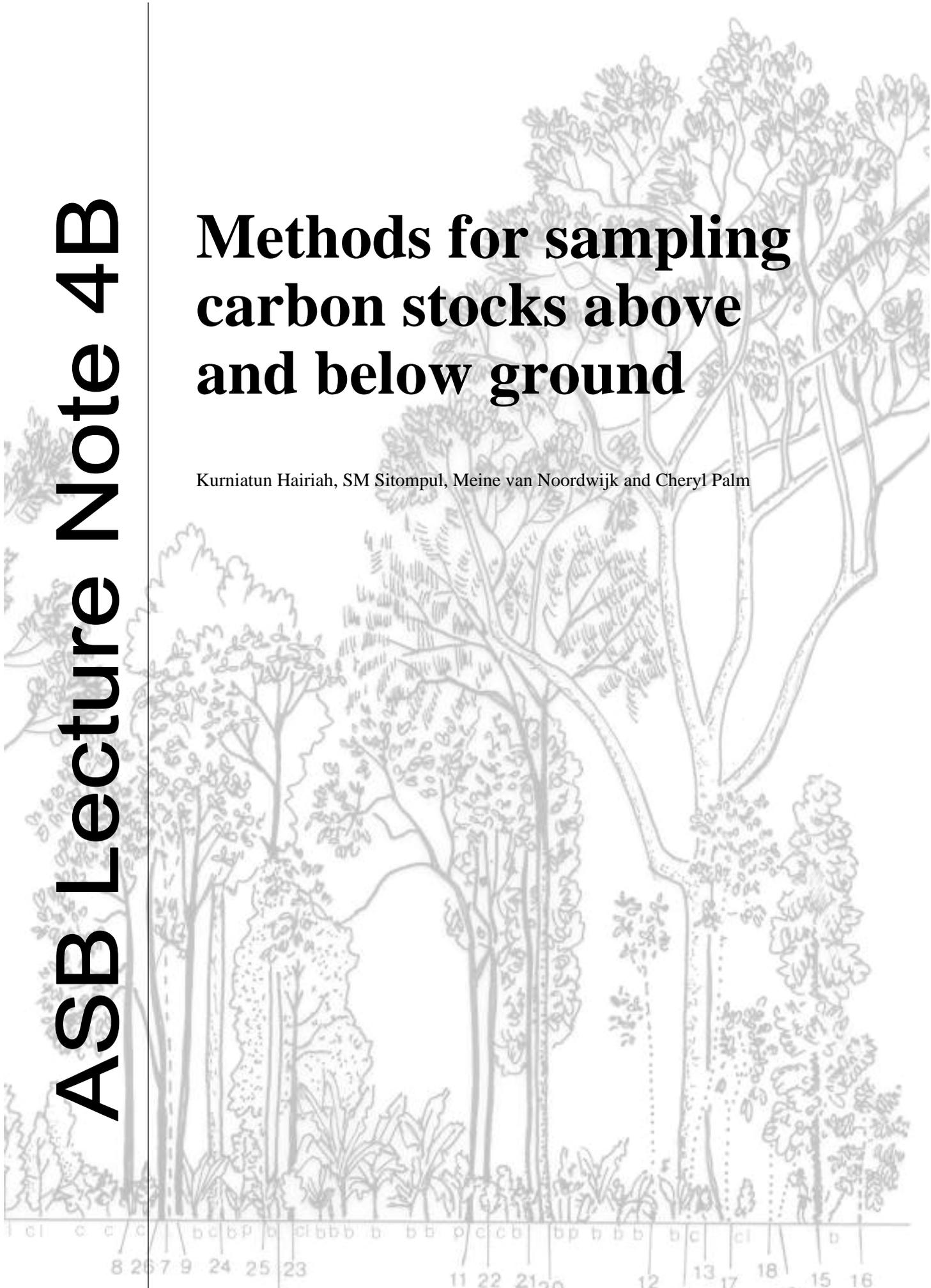


Methods for sampling carbon stocks above and below ground

Kurniatun Hairiah, SM Sitompul, Meine van Noordwijk and Cheryl Palm



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Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns

Meine van Noordwijk, Sandy Williams and Bruno Verbist (Editors)

Background to this series of lecture notes

The lecture notes were developed on the basis of the experiences of the Alternatives to Slash and Burn (ASB) consortium. This consortium was set up to gain a better understanding of the current land use decisions that lead to *rapid* conversion of tropical forests, shifting the forest margin, and of the *slow* process of rehabilitation and development of sustainable land use practices on lands deforested in the past. The consortium aims to relate local activities as they currently exist to the global concerns that they raise, and to explore ways by which these global concerns can be more effectively reflected in attempts to modify local activities that stabilise forest margins.

The Rio de Janeiro Environment Conference of 1992 identified deforestation, desertification, ozone depletion, atmospheric CO₂ emissions and biodiversity as the major global environmental issues of concern. In response to these concerns, the ASB consortium was formed as a system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR), involving national and international research institutes. ASB's objectives are the development of improved land-use systems and policy recommendations capable of alleviating the pressures on forest resources that are associated with slash-and-burn agricultural techniques. Research has been mainly concentrated on the western Amazon (Brazil and Peru), the humid dipterocarp forests of Sumatra in Indonesia, the drier dipterocarp forests of northern Thailand in mainland Southeast Asia, the formerly forested island of Mindanao (the Philippines) and the Atlantic Congolese forests of southern Cameroon.

Acknowledgements

A range of investors (or 'donors') have made the work of the ASB consortium possible over the past years, some by supporting specific parts of the program, others by providing core support to the program as a whole. These lecture notes build on all these investments, but were specifically supported by the ASB Global Steering Group, with funds provided by the Asian Development Bank, the World Bank via the CGIAR, by ICRAF core funds, by the Netherlands' Government through the Direct Support to Training Institutions in Developing Countries Programme (DSO)-project and by the Flemish Office for Development Cooperation and Technical Assistance (VVOB). Both biophysical and policy research was supported by a Regional Technical Assistance Grant from the Asian Development Bank. Many researchers and organisations have contributed to the development of ideas, collection and synthesis of data, and otherwise making the program what it is today. A team at the International Centre for Research in Agroforestry (ICRAF), consisting of Kurniatun Hairiah, Pendo Maro Susswein, Sandy Williams, SM Sitompul, Marieke Kragten, Bruno Verbist and Meine van Noordwijk developed these lecture notes. A first test of their suitability was provided by a course on 'Ecology for Economists' organised by the Economy and Environment Program for Southeast Asia (EEPSEA) program - we thank David Glover, Hermi Francisco and all participants to that course for their suggestions. Key researchers within the consortium provided support and agreed to

act as co-authors on the various chapters. Editorial comments on draft forms of the various lecture notes were obtained from Fahmuddin Agus, Georg Cadisch, Min Ha Fagerström, Merle Faminow, Roeland Kindt, Chun Lai, Ard Lengkeek, Jessa Lewis, Chin Ong, Per Rudebjer, Goetz Schroth, Douglas Sheil, Fergus Sinclair, Sven Wunder and others. Overall responsibility for any shortcomings in the lecture notes remains with the editorial team.

ASB-consortium members

Details of the ASB consortium members and partner organisations can be found at:
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Lecture Note 4B

METHODS FOR SAMPLING CARBON STOCKS ABOVE AND BELOW GROUND

Kurniatun Hairiah¹, S.M. Sitompul¹, Meine van Noordwijk² and Cheryl Palm³

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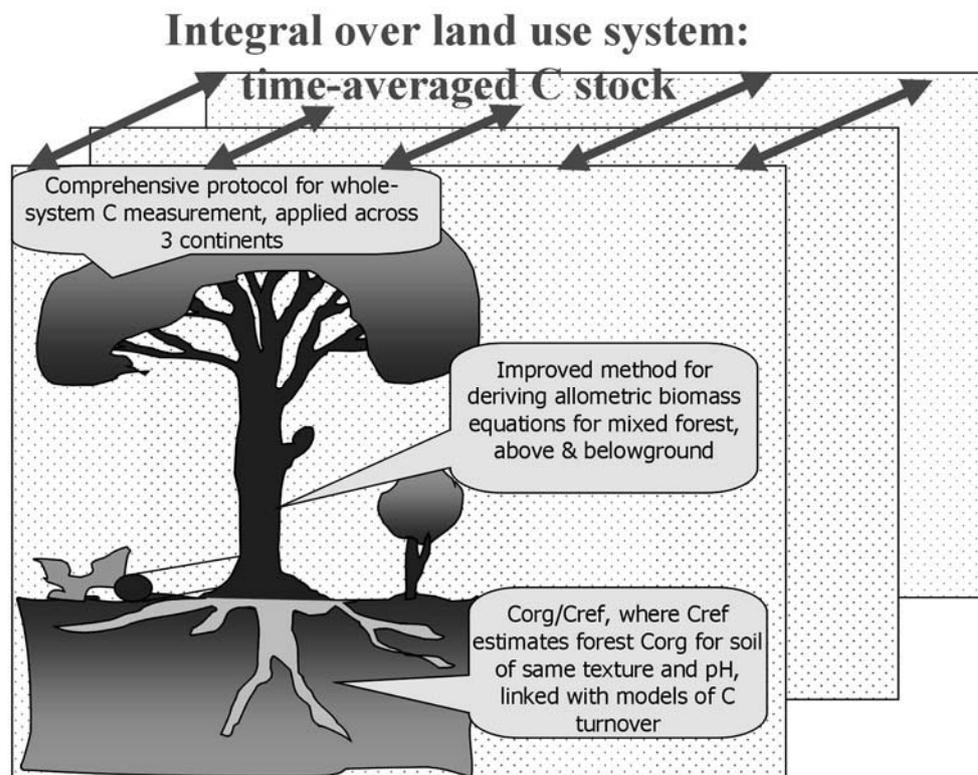
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I. Introduction



1.1 Why are we collecting C-stock data?

General backgrounds of C stock assessments are discussed in the accompanying lecture note (Hairiah, K., Sitompul, S.M., van Noordwijk M., and Palm, C., 2001. *Carbon stocks of tropical land use systems as part of the global C balance: effects of forest conversion and options for 'clean development' activities*. **ASB_Lecture Note 4A**), here we focus on methods for fieldwork and give some details on the use of the Century model. Earlier versions of the ASB protocol for C stock assessment were published by Murdiyarso et al. (1994, 1999).

Assessment of C stocks can be aimed at a specific '*area*', what-ever it's vegetation or land use, or at a specific '*activity*' or form of land use or land cover as found within a specified geographic domain. For either approach, the first step is one of '*stratification*' to obtain a clear, operational definition of the unit of analysis. For the ASB project, we are interested in the measurement of C stocks for a range of land use alternatives in 'benchmark areas', of assumed relevance to the broader domains of the (former) lowland tropical rain forest zone. We thus have to get operational definitions of what these land uses look like in various phases of their own production cycle, what variation in management intensity and style is accepted within the term as used, and then select specific sample sites to represent the broader category. We will not describe the details of that site selection process here, as it was discussed in Lecture Note 2.

The following research protocol was developed as part of the global ASB (Alternatives to Slash and Burn) project for assessment in a given sample area. The data collected can be used:

- Directly to assess the current C stock in above- and belowground pools,
- To extrapolate to the 'time-averaged C stock' of a land use system,
- To initialize the CENTURY (or similar) simulation model for C, N and P dynamics of the various pools of organic matter, and/or,
- Compare biodiversity and profitability assessments with C stock data to study trade-offs among global environmental benefits and private incentives to the farmer.

1.2 Setting-up sample sites

A 'nested' sampling approach is followed, assessing large diameter trees (with a stem diameter above 30 cm) in rectangular plots of 20 x 100 = 2000 m², smaller trees (stem diameter 5 – 30 cm) in subplots of 5 m x 40 m = 200 m² within these, and understorey vegetation and litter in smaller sub-subplots (see below). Sample plots are selected within a plot of at least 1 hectare, avoiding borders of the plot, unless specifically indicated in the sample design. Plot location is randomized if there are marked discontinuities in the vegetation. In other words, first walk around in the area to be sampled and be sure that the sample plots do not all fall in the area with the densest or least vegetation.

Measurement of aboveground biomass in this protocol includes destructive and non-destructive sampling, for the litter, undergrowth layer, and the trees, respectively.

The rectangular plots are chosen as they tend to include more of the within-plot heterogeneity, and thus be more representative than square or circular plots of the same area. The larger the total area sampled the more accurately the estimate reflects the population of interest. Instead of sampling a large, contiguous area it is better to divide the sampling into several, smaller, areas within the field of study (randomly chosen or based on some a priori stratification).

1.3 Overview of methods

Above-ground biomass data collection procedures are summarized in Table 1.

Table 1. Aboveground parameters and methods used in C-stock measurement.

Parameter	Methods
1. Living trees with a stem diameter of <ul style="list-style-type: none"> • 30 cm in standard sample plot (20 * 100 m) • 5<...<30 cm in large area (5 * 40 m) 	Non-destructive measurement of stem diameters, apply allometric equation on the basis of stem diameter
2. Understorey vegetation (including trees < 5 cm in diameter)	Destructive
3. Litter: <ul style="list-style-type: none"> • Coarse/standing litter • Fine litter • Surface roots 	Destructive
4. Charcoal	Destructive
5. Ash	Destructive
6. Dead standing trees	Non-destructive, apply allometric or cylinder equation (for branched & unbranched remains, respectively)
7. Dead felled trees	Non-destructive, apply cylinder (or allometric) equation
8. Stump (trunk) remains in forest	Non-destructive, apply cylinder equation

II. Aboveground biomass

2.1 Biomass and necromass estimation by non-destructive sampling

The total standing above-ground *biomass* of woody vegetation elements is often one of the largest carbon pools. The above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous undergrowth. For agricultural lands, this includes crop and weed biomass. The dead organic matter pool (*necromass*) includes dead fallen trees and other coarse woody debris.

An estimate of the vegetation biomass can provide us with information about the nutrients and carbon stored in the vegetation as a whole, or the amount in specific fractions such as extractable wood. To measure the biomass of vegetation which includes trees is not easy, especially in mixed, uneven-aged stands. It requires considerable labor and it is difficult to obtain an accurate measurement given the variability of tree size distribution. It is hardly ever possible to measure all biomass on a sufficiently large sample area by *destructive sampling* and some form of *allometry* (see next section) is used to estimate the biomass of individual trees to an easily measured property such as its stem diameter.

2.1.1 Plot sizes for nested plots

This nondestructive method is rapid and a much larger area and number of trees can be sampled, reducing the sampling error encountered with the destructive method. Yet, half of the biomass of a natural forest can be in the few trees of the largest diameter class (> 50 cm) and sampling error is still high for a 200 m² transect which can have 0, 1 or 2 large trees included (Table 3). Accuracy can therefore be improved if trees with a DBH above 30 cm are sampled in a 20 * 100 m² sampling area. Under specific conditions, e.g. where large trees that occur at densities of less or equal to 10 trees per ha can be a substantial part of total C stocks, further adjustments of sample size may be needed.

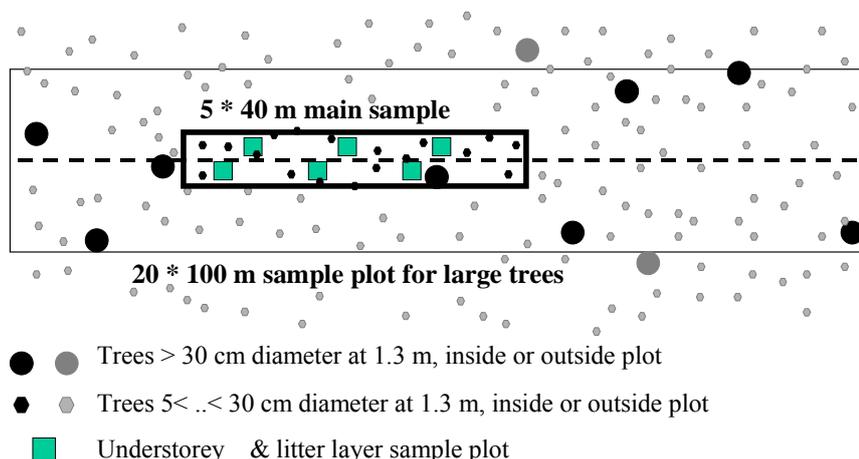


Figure 1. Nested plot design for sampling various C pools at appropriate scales.

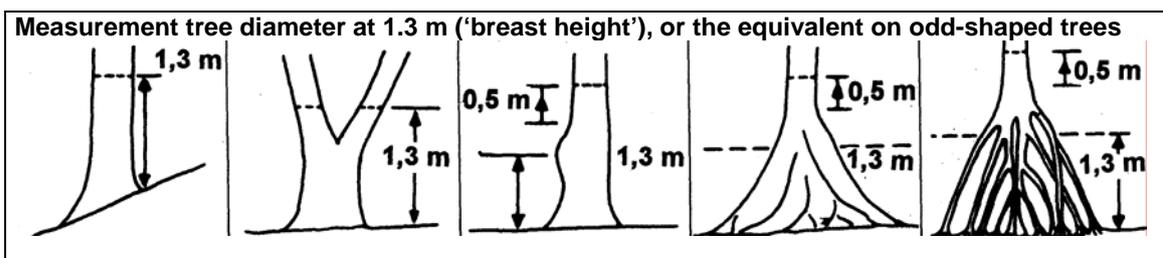
Table 2. Expected number of trees in sample plots of different size; the bold figures refer to the recommended sample size for trees in such a frequency (or size) class

Diameter, cm	Average number per ha	Expected number per plot	
		2 x (5x40 m ²)	20 x 100 m ²
5-10	400	16	80
10-30	200	8	40
30-50	50	2	10
50-70	10	0.4	2
>70	4	0.1	1

Box 1. Sampling protocol for live tree biomass

Equipment:

1. Line for center of transect, 40 m long for standard plot and 100 m for large-tree plot
2. Sticks to measure width, 2.5 m long for standard plot
3. Wooden sticks of 1.3 m length
4. Measurement tape (linear or special ones for tree diameter, which include the factor π)
5. Knife
6. Tree height measurement device (e.g. 'Hagameter' or Suunto clinometer, optional)



Procedure:

Set out two 200 m² quadrats (5m x 40 m), by running a 40 m line through the area and then sampling the **trees 5 cm < diameter < 30 cm** that are within 2.5 meter of each side of the tape, by checking their distance to the central line. For each tree the diameter is measured at 1.3 m above the soil surface, except where trunk irregularities at that height occur (plank woods, tapping or other wounds) and necessitate measurement at a greater height. If trees branch below the measurement height, an equivalent diameter is defined as $\text{SQRT}(\sum D^2)$ on the basis of all D values. Further tree information, e.g. botanical species or local name is optional but can help in getting improved estimates of wood density.

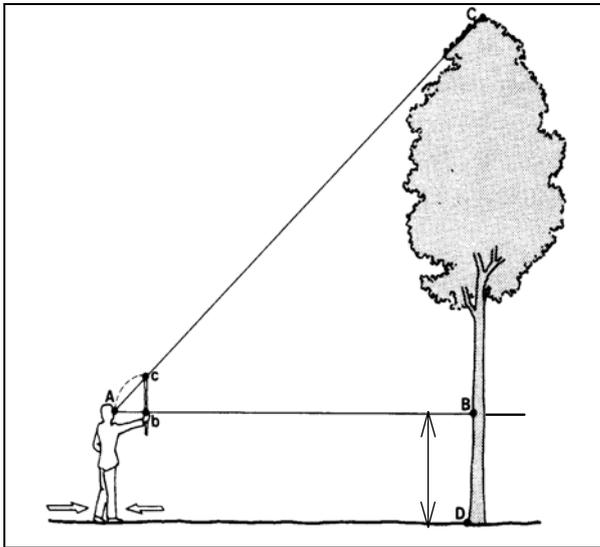
If trees > 30 cm diameter are present in the sampling plot, whether or not they are included in the transect, an additional larger sample of 20 * 100 m² is needed, including all trees with a diameter > 30 cm.

Tree height is optional in the ASB protocol, but can be helpful in establishing parameters for the allometric relationship (see below).

Calculations:

Calculate the tree biomass in kg/tree for each tree using an appropriate allometric equation (see Table 2 if no site or tree specific equations are available). Palms, bamboo's and lianas need a separately established equation. Sum the tree biomass for each quadrat and divide by the sampling area in m².

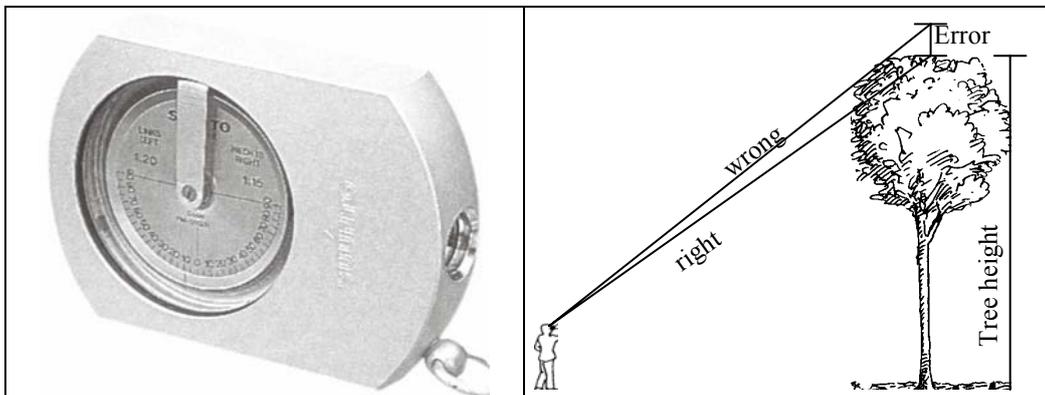
Box 2. Tree height measurement
(Weyerhauser and Tennigkeit, 2000)



The best method to measure tree height based on the geometric relationship between triangles as long as there is enough space. The operator holds a stick in his stretched arm the same length as the distance between his hand and his eye. Then he moves forwards and backwards until the tip of the tree and the top of the stick are in one line. The distance Ab and Ac is the same as the AB and AC . Accordingly, the tree height is the sum of the distance between AB and the measured DB .

The Clinometer (on the left) determines the angle to the tip of the tree based on a fixed distance to the target tree. The tree height can be recorded according to the clinometer scale. In detail the tree height measurement works as follows:
Sight the tip of the target tree and read the scale; sight the bottom of the subject and read the scale. Add the two measurements. This is the subject height.
Systematic errors occur if instead the tip of the tree a point of the crown cover is envisaged (on the right).

Clinometer



(on the left: Suunto clinometer with an integrated height measurement scale based on a baseline distance of either 15 or 20 m. On the right: How to take a bearing from the tip of the tree.

2.1.2 Allometric relationships

The ‘scaling’ relationships, by which the ratio’s between different aspects of tree size change when small and large trees of the same species are compared are generally known as ‘allometric’ relations. Allometric equations can be locally developed by destructive

sampling, derived from literature for supposedly comparable forest types, or estimated from fractal branching analysis (see box 3). They normally use the tree diameter at breast height (DBH, measured 1.3 m above the ground) as basis. Empirical equations for total biomass W on the basis of diameter D have a polynomial form:

$$W = a + b.D + c.D^2 + d.D^3$$

or follow a power function:

$$W = a.D^b,$$

with the b parameter typically between 2 and 3. The polynomial equations are clearly restricted to the range of D (tree diameter at breast height) values used for deriving the model, as for $D = 0$ they predict a biomass of a , and they have one or more points of inclination. The power function is continuously rising and passes through the origin, so its general shape is more attractive and allows for some extrapolation outside of the calibration range. The parameters of allometric models can be derived directly from empirical data by regression analysis, or via the parameters of a fractal branching model as explained in box 3.

Box 3. Allometrics and ‘fractal branching’

Fractal branching models provide a transparent scheme for deriving tree-specific scaling rules on the basis of easily observable, non-destructive methods. Fractal branching models repeatedly apply the same rules (equations) to derive subsequent orders of the branching process. For practical applications, a rule is added for stopping when a certain minimum size is reached. The models can thus predict total tree biomass, but also properties such as total leaf area, branch weight and relative allocation of current growth to leaves, branches, stem or litter. The rules can refer to the diameter, length and/or orientation of the next order of branches.

In a spreadsheet model available through www.cgiar.org/icraf/sea/agromodels/wanulcas/wanulcas.htm, the relations between five input parameters and the parameters of the allometric biomass equation a and b can be explored. Five parameters (n , p , q , L_m and r) can describe the branching process sufficiently for our purpose:

n = number of branches into which the current link splits at the following branching point; $n \geq 2$

$p = D_i^2 / (\sum_j^n D_{i+1,j}^2)$, describes the change in diameter² and hence cross-sectional area (cssa) of the stem from order i to order $i+1$ (with n branch roots) – it is typically close to 1.0

$q = D_{11}^2 / (D_{11}^2 + D_{12}^2)$, for $n = 2$ and $D_{11} > D_{12}$ ($0.5 < q \leq 1$) to describe the relative equity among the branches. With these definitions we obtain for $n = 2$):

$$\begin{aligned} D_{i+1,1} &= D_i \sqrt{pq} \\ D_{i+1,2} &= D_i \sqrt{p(1-q)} \end{aligned} \quad (1)$$

For fractal (scale-independent) models to apply, the parameters p and q should be independent of current diameter D .

Box 3 continued

L_m is the length of a link of minimum diameter, and r is the increment in link length per unit increment in diameter, hence:

$$L(D) = L_m + r D$$

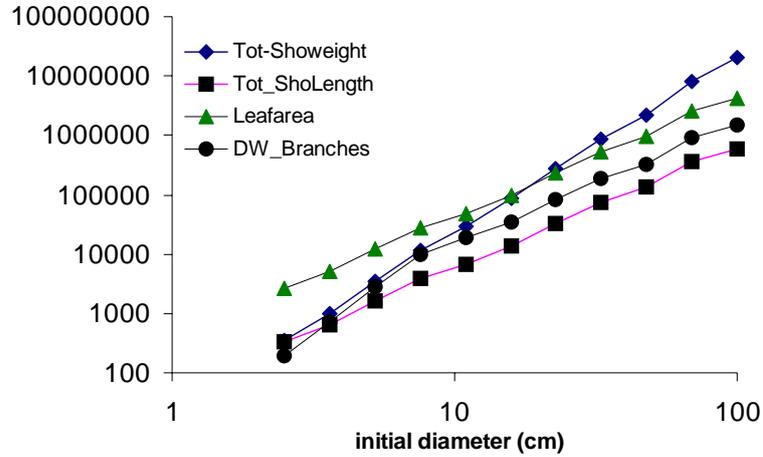


Figure 2. Example of an allometric relation generated by the fractal branching algorithm; the log-log scale allows a direct derivation of the parameters of an allometric scaling relation $Y = a X^b$ (for further details see: Van Noordwijk and Mulia, 2002)

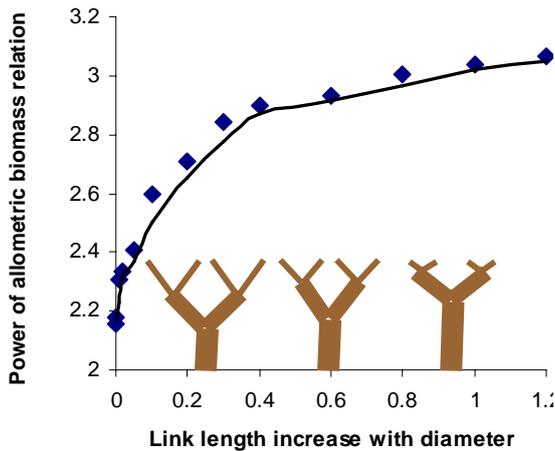


Figure 3. Relationship between the power of an allometric biomass relation and the degree to which link length increases with branch diameter (reflecting branch decay) (for further details see: Van Noordwijk and Mulia, 2002)

For palms, bamboo's and rattans separate equations are needed, as their stem diameter does not increase by secondary thickening and thus does not reflect actual canopy size. If possible, the equations used for estimating biomass should be developed for each location, species, or group of species, and for trees of similar sizes and ages. For example, equations derived from destructive sampling of a virgin forest, where many of the trees have dense wood and are tall, will not be appropriate for estimating biomass of a young secondary forest where there are many soft-wood trees, branching at lower heights.

For the purposes of the Alternatives to Slash and Burn projects, if equations have not been developed at the sites, the equations of Brown (1997) can be used (Table 3). The equations developed by Brown and colleagues are based on diameter (D) at breast height (1.3 m); height of tree (H); and the density of the wood (s). Often only diameter measurements are possible to obtain; however the estimates generally improve with more parameters. Separate equations have been developed for tropical forests in different rainfall regimes : dry < 1500mm rainfall per year; moist 1500-4000mm; and wet > 4000mm.

Table 3. Allometric relations for estimating biomass from tree diameter (for $D > 5$ cm) and height.

Life zone (rainfall, mm/yr)	EQUATION (W = tree biomass, kg/tree; D = dbh, cm; H = height, m; ρ = wood density, g cm^{-3})	Range, cm	Number of trees	R^2
Dry (<1500)	$W = 0.139 D^{2.32}$ (Brown, 1997)	5-40	28	0.89
Moist (1500-4000)	$W = 0.118 D^{2.53}$ (Brown, 1997) $W = 0.049 \rho D^2 H$ (Brown <i>et al.</i> , 1995) $W = 0.11 \rho D^{2+c}$ with c (default 0.62) based on $H = a D^c$ (Ketterings <i>et al.</i> , 2001)	5-148	170	0.9
WET (>4000)	$W = 0.037 D^{1.89} H$ (Brown, 1997)	4-112	160	0.90

Once an allometric equation has been established for different classes of trees in a vegetation, one only needs to measure DBH (or other parameter used as a basis for the equation) to estimate the biomass of individual trees. The sum of the biomass estimates for all trees within the measurement transect can be converted to a biomass in Mg ha^{-1} .

In the ASB project initially the Brown (1997) equation was used. For secondary forests and plantations of fast growing timber trees, however, this equation may lead to an overestimate of nearly a factor 2. Ketterings *et al.* (2001) analyzed the sources of uncertainty and error in the use of allometric equations for the Jambi ASB benchmark area (Sumatra, Indonesia) and concluded that incorporation of the relationship between tree diameter and heights, as well as the average wood density of the tree can lead to improved estimates. Wood density of trees differs between species, as well as with growth rate and local circumstances. A literature survey of wood density of some 2500 trees will soon be made available via the ICRAF SE Asia web site (www.icraf.cgiar.org/sea). For recent data on *Paraserianthes falcataria* for the N. Lampung ASB benchmark area (Sugiharto, 2002) we can indeed confirm that incorporation of the average wood density reported for this species (0.375 Mg m^{-3}) leads to considerably less bias than the Brown (1997) equation (Fig. 2).

Another example where the Ketterings *et al.* (2001) equation gives a reasonable first estimate is the case of pruned coffee. In this case the diameter-height relationship is strongly modified by regular pruning of the trees, but the power of an empirical allometric relationship can be correctly assessed from the '2 + c' rule, with c close to 0 (Table 4).

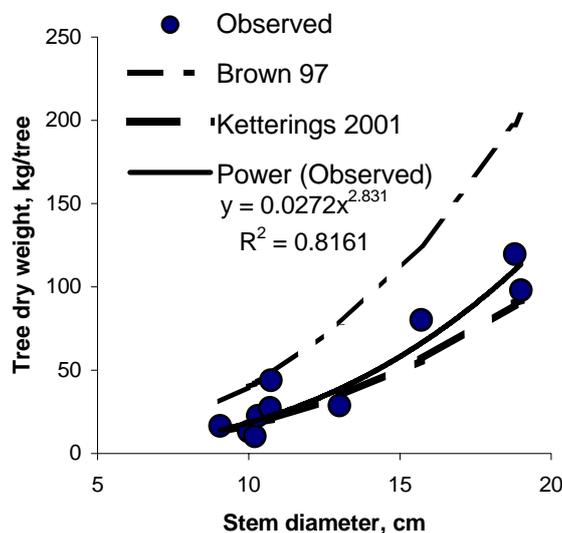


Figure 4. Example of the test of the default tropical forest equation of Brown (1995) and the equation of Ketterings *et al.* (2001) that incorporates wood density, for *Paraserianthes falcataria* trees growing in the ASB N. Lampung benchmark area (assuming a wood density of 0.375 and a c parameter of 0.62)

Table 4. Some special allometric relationships for components of agroforestry systems in Indonesia.

	D_range (cm)	Diameter – Height relationship			Diameter – Dry Weight relationship		
		a, m	b []	r ²	a,kg/tree	b,[]	r ²
Banana (Arifin, 2001)	7-27	0.71	0.684	0.814	0.030	2.13	0.989
Bamboo (Priyadarsini, 1998)	3-7	1.45	0.963	0.941	0.131	2.28	0.954
Coffee (pruned) (Arifin, 2001)	1-10	1.79	0.080	0.844	0.281	2.06	0.946
<i>Paraserianthes falcataria</i> (Sugiharto, 2001)	8-18	-	-	-	0.027	2.83	0.816
<i>Pinus caribbea</i> (Waterloo, 1995)	5-28	0.42	1.17	0.846	0.042	2.66	0.909

For pine trees (and other conifers with a different shape and branching pattern, however, the power of empirical biomass equations does not follow the ‘2 + c’ rule (Figure 5).

2.1.3 Special concerns

After a slash-and-burn event or forest fire, the remaining charred trees, branches and litter can be measured following the same protocol.

Burned (partly burned) litter, charcoal and ash in sampling sites directly after burning

The burned and unburned woody litter, charcoal, and ash are collected and separated from eight 0.5 m x 0.5 m quadrats as described for coarse litter, but no sample washing is necessary.

Establishing site-specific allometric equations

All trees over 5 cm dbh are sampled in a rectangle sampling area 40 x 5m (200 m²). Each tree is cut. Height and dbh are recorded (and can be used later for producing site specific allometric equations). The tree is separated into leaves, small branches (less than 2.5 cm diameter), large branches (greater than 2.5 cm diameter), and trunk (which includes the largest branch to 2.5 cm diameter). Each fraction is weighed fresh in the field. Fresh subsamples are taken and weighed, then dried (80°C) to correct for water content. Subsamples can also be used to determine nutrient contents. If the branching points are described as explained in section 4.2, the validity of the fractal branching model can be tested. Additional samples of specific gravity (g cm⁻³) of the woody fractions, as well as the specific leaf area (m² g⁻¹) and average area per leaf are necessary for a full implementation of the FBA model (see manual FBA manual available at www.cgiar.org/icraf/sea/agromodels/wanulcas/wanulcas.htm).

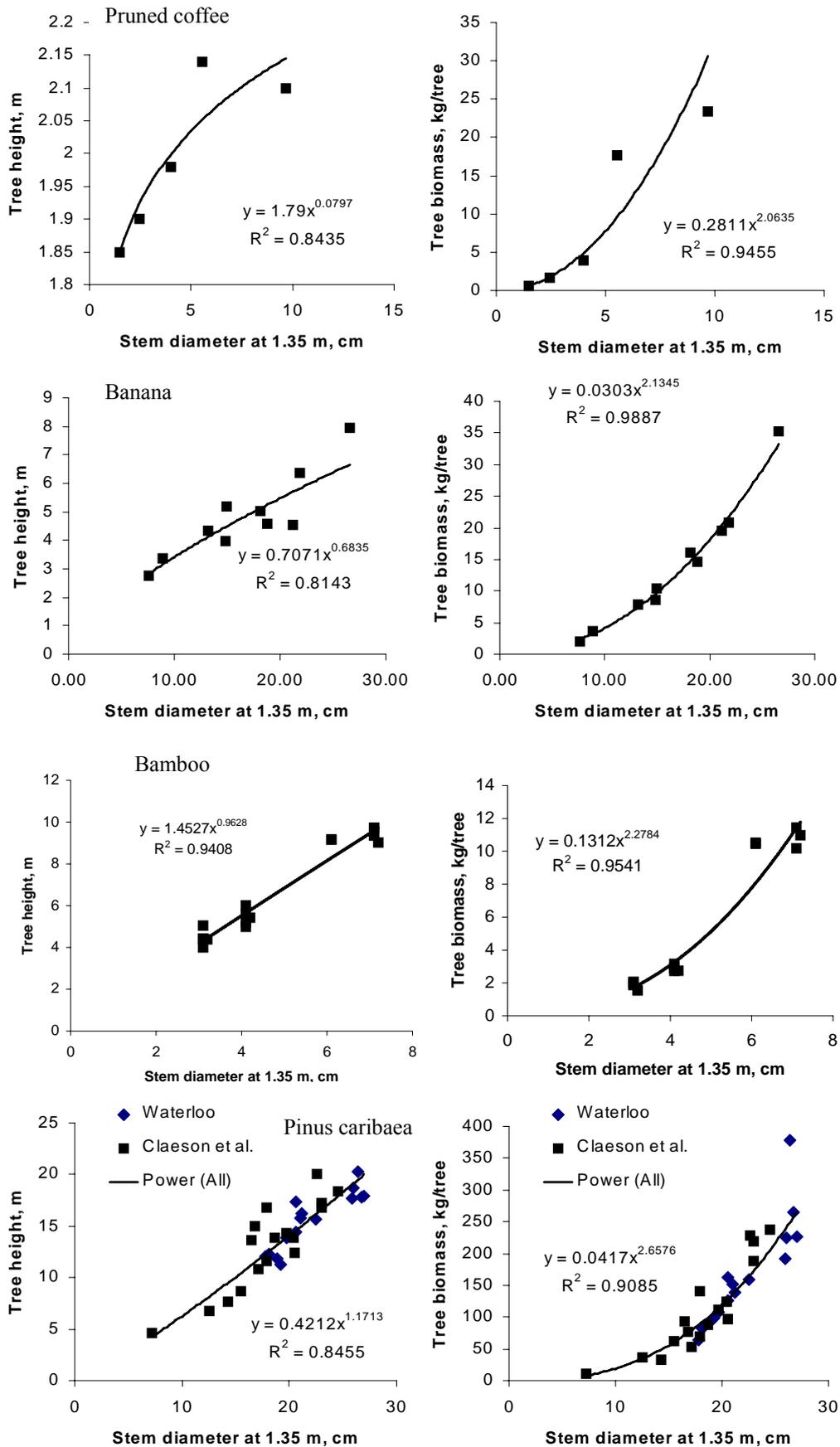
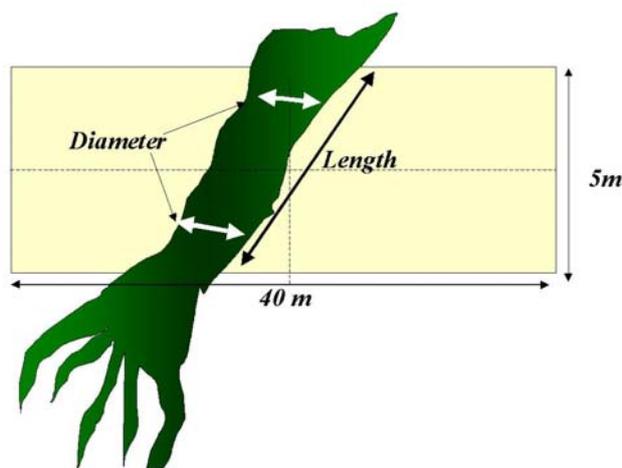


Figure 5. Some special allometric relationships for components of agroforestry systems in Indonesia

Box 4. Sampling protocol for tree necromass

Procedure

Within the plot of 200 m² (5x40 m) all trunks (unburned part), dead standing trees, dead trees on the ground and stumps are sampled that have a diameter >5 cm and a length of > 0.5 m. Their height (length) is recorded within the 5 m wide transect (see Figure 6) and diameter (halfway the length included), as well as notes identifying the type of wood for estimating specific density.



$$\text{Biomass} = \pi r^2, \text{ cm}^2 \times \text{Length, cm} \times \text{wood density g cm}^{-3}$$

Figure 6 Measuring length and diameter to estimate biomass of fallen or felled trees in a transect after slashing and burning

Specific gravity (wood density) of dead wood (optional):

In advanced stages of decomposition standard rings normally used for measuring soil bulk density can be driven into the wood and recovered for drying and weighing. Otherwise drills should be used to obtain a 'plug' of known volume.

Calculations

For the **branched** structures an allometric equation is used, as for live trees.

For **unbranched** cylindrical structures, an equation is based on cylinder volume:

$$\text{Biomass} = \pi D^2 h \rho / 40$$

where, biomass is expressed in kg, h = length (m), D = tree diameter (cm) and ρ = specific gravity (g cm⁻³) of wood. The latter is estimated as 0.5 g cm⁻³ as default value, but can be around 0.8 for dense hardwoods, around 0.3 for very light species, and generally decreases during decomposition of dead wood laying on the soil surface.

2.2 Aboveground biomass: Destructive sampling of understorey and litter layer

In destructive sampling, the vegetation in a given area is cut and weighed (fresh weight), and subsamples of parts of the vegetation (understorey biomass, coarse litter, unburned branches (< 5 cm diameter or < 50 cm length), flowers and fruits are taken, weighed fresh in the field, and weighed again after oven-drying.

Box 5. Field sampling protocol for destructive sampling of understorey biomass and litter layer

Equipment:

1. Quadrat of 1 x 1 m and 0.5 x 0.5 m (Figure 7)
2. Knives and/or scissors
3. Scales: one allowing weights up to 10 kg (with a precision of 10 g) for fresh samples and one with a 0.1 g precision for subsamples
4. Marker pens, plastic & paper bags
5. Sieves with a 2 mm mesh size
6. Trays

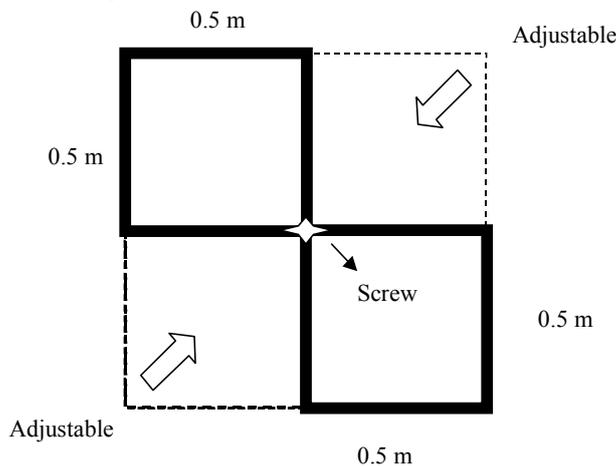


Figure 7. Design of a sampling frame which can be used for 1 x 1 m² samples, or for two adjacent 0.5 x 0.5 m² samples.

Field procedure

Locate sampling frames within the 40 * 5 m² transect, as indicated in Figure 8, placing it once (randomly) in each quarter of the length of the central rope.

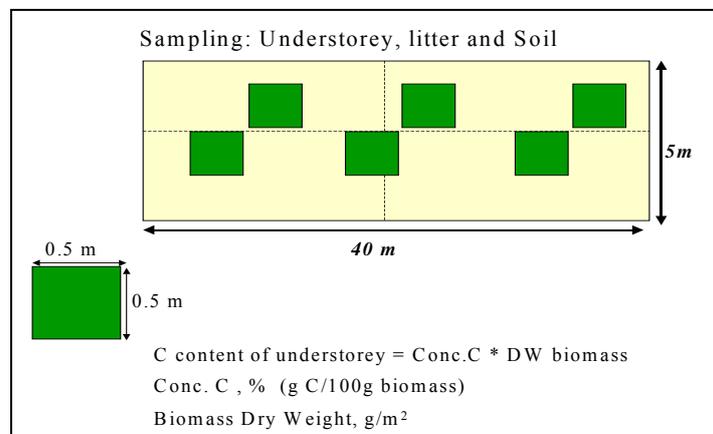


Figure 8. Position of understorey sampling within a 40 * 5 m vegetation transect

Box 5 (continued)

Understorey biomass: All vegetation less than 5 cm dbh is harvested within the 1 x 1 m² quadrat. Weigh the total fresh sample (g m⁻²), mix well and immediately take and weigh a composite fresh sub sample (~300 g), for subsequent oven drying.

Litter is sampled within the same frames in two steps:

- **Coarse litter**, (any tree necromass < 5 cm diameter and/or < 50 cm length, undecomposed plant materials or crop residues, all unburned leaves and branches) is collected in 0.50 m x 0.50 m quadrats (0.25 m²), on a randomly chosen location within the understorey sample. All undecomposed (green or brown) material is collected to a sample handling location.
- **Fine litter:** Subsequently collect the 0-5 cm soil layer in the same quadrats (including all woody roots) and dry-sieve the roots and partly decomposed, dark litter. If time allows, the sieving can be done on-site, but it may be more convenient to collect bags of the topsoil and process elsewhere.

Sample handling for destructive biomass and litter samples

- **Biomass:** Dry the subsample at 80°C for conversion to dry weight and for analysis of C, N, and its quality (lignin and polyphenolic concentration which influence the decomposition rate of organic material); if oven capacity is limited, samples can be sun dried (in a ventilated plastic shelf system) and only sub-subsamples processed in the oven.
- **Coarse litter:** To minimize contamination with mineral soil, the samples should be soaked and washed in water; the floating litter is collected, sun dried and weighed, the rest is sieved on a 2 mm mesh sieve and added to the fine litter fraction. Depending on the total amount, a subsample can be taken at this stage for obtaining an 'oven-dry' correction (oven at 80°C). As alternative to the washing procedure, samples can also be ashed (at 650°C) to correct for mineral soil contamination.
- **Fine litter and roots:** The litter (incl. dead roots) and (live) root material collected on the 2 mm sieve (by dry sieving) is washed and dried. The soil passing through this sieve is collected as 0-5 cm sample for C_{org} or C fraction analysis (see below).

Calculations:

$$\text{Total dry weight (kg m}^{-2}\text{)} = \frac{\text{Total fresh weight (kg)} \times \text{Subsample dry weight (g)}}{\text{Subsample fresh weight (g)} \times \text{Sample area (m}^2\text{)}}$$

Take the average of the 8 samples to record the understorey and litter biomass for the transect replicate.

2.3. Data collection

All collected data should be arranged in a spread sheet within EXCEL program as follow:

Sheet 1

CARBON STOCK – nondestructive measurements

Site number _____

Land Use Type: _____

Location (GPS): _____ E, _____ S

Sample taken by: _____

Farmer name: _____

Date: _____

Sample area: .5 * 40 .m² ... 20 * 100 m²

Live tree (LT), Dead standing tree (DST), Dead, felled tree (DFT),

Big tree (BT = tree diameter > 30 cm, in large sampling area)

Estimated wood density: High, Medium, Low (0.8, 0.5, 0.3 g cm⁻³)

No	Type	Branched? Y_or_N	Tree diameter, cm	Tree height (h) or length, m	Wood density ρ , e.g. H(igh), M(ediu m) or L(ow)	Estimated Biomass DW, kg/tree		
						Cylinder ($\pi/40$) $\rho h D^2$	For branched trees:	
							$0.092 D^{2.60}$ (Brown, 1997)	0.11ρ $D^{2.62}$ (Ketterings 2001)
1	LT	Y						
2	DST	N						
3								
4								
5								
6								
7								
8								
9								
10								
Total per category: kg / sample area								
LT								
DST								
DFT								
BG								

Sheet 2

CARBON STOCK – destructive samples

Site number _____

Land Use Type: _____

Location (GPS): _____ E, _____ S

Sample taken by: _____

Farmer name: _____

Date: _____

Sample area: ...1... m²

W = Fresh weight; DW = Dry weight; S = Sub sample;

Biom = Green biomass Leaf (L), Stem (S), Tuber (T)

CLit = Coarse litter; FLit = Fine litter

No	Type	FW (kg)	SFW (g)	SDW (g)	Tot DW = FW * SDW/(SFW*area) (kg m ⁻²)	Biomass DW = 10 * TotDW (Mg ha ⁻¹)
1	Biom (L)	...				
1	Biom (S)					
1	CLit					
1	FLit					
2	Biom					
2			
..						

Sheet 3

ESTIMATION OF TOTAL C-STOCK, kg/sample area = destructive plant sampling + nondestructive sampling.

Two table calculation should be prepared as follows:

LUS	Tree* Mg ha ⁻¹	DW Understorey Mg ha ⁻¹	DW Necromass Mg ha ⁻¹	DW Root** Mg ha ⁻¹	Total DW, Mg ha ⁻¹ 1+2+3+4	Total C, %	Total C-stock Tot DW * Tot C
	1	2	3	4	5	6	7
1						estimated 40-45	
2							
3							
4							
5							
etc							

*= estimated tree biomass using an allometric equation.

** = Root dry weight in soil layer 0-5 cm only.

LUS	Soil weight 0-5 cm Mg ha ⁻¹	Tot. C, 0-5 cm %	Soil weight 5-15 cm Mg ha ⁻¹	Tot. C, 0-5 cm %	Total Soil C- stock 0-15 cm Mg ha ⁻¹	Total C stock Mg ha ⁻¹
	8	9	10	11	12	13 = 7 + 12
1					= (8x9) + (10+11)	
2						
3						
4						
5						
Etc						

III. Methods for sampling Belowground Organic Pools

The below-ground organic pools includes soil-C, roots and microbial biomass.

3.1 Soil sampling procedures

Two types of soil samples can be distinguished:

- Disturbed soil samples for chemical analysis (where the results will be expressed per unit dry weight of soil); the samples are normally 'composites' obtained by mixing small amounts of soil from different subsamples
- Undisturbed soil samples for physical analysis, especially the 'bulk density' (specific gravity) of the soil which is essential to convert the soil dry weights into soil volume.

Table 5. Soil chemical analysis required for characterization of soil samples; compare Anderson and Ingram (1993) for description of methods

Soil parameters:	Methods
pH _{H2O}	1:1 H ₂ O
pH _{KCl}	1:1 1 M KCl
C-org, %	wet oxidation, Walkley and Black
Total N, %	Kjehldahl
P-Bray2, mg kg ⁻¹	Molybdate blue, spectrophotometer
K-exch, cmol _e kg ⁻¹	1 M NH ₄ OAc pH 7, Flamephotometer
Na-exch, cmol _e kg ⁻¹	1 M NH ₄ OAc pH 7, Flamephotometer
Ca-exch, cmol _e kg ⁻¹	1 M NH ₄ OAc pH 7, Flamephotometer
Mg-exch, cmol _e kg ⁻¹	1 M NH ₄ OAc pH 7, Flamephotometer
Al-exch, cmol _e kg ⁻¹	1 M KCl, Titration method
H-exch, cmol _e kg ⁻¹	1 M KCl, Titration method
ECEC, cmol _e kg ⁻¹	K+Na+Ca+Mg +Al-exch + H-exch
Al-saturation, %	(Al-exch / ECEC) x 100%
Sand, %	pipette
Loam, %	pipette
Clay, %	pipette
LUDOX fractions, Light, Intermediate and Heavy g kg ⁻¹ soil	Size and particle density fractionation (This is especially for study SOM dynamics)

Box 6. Procedure for taking disturbed soil samples for chemical analysis

Field procedure

Locate sampling frames within the 40 * 5 m² transect, as indicated in Figure 1 (see Aboveground manual), placing it once (randomly) in each quarter of the length of the central rope.

1. Continue after removing the 0-5 cm (usually organic) layer (see aboveground sampling methods), and take samples of the 5-10, 10-20 and 20-30 cm soil depth. Approximately 1 kg of fresh soil is sufficient, combining soil from three patches within the 0.5 * 0.5 m² sample grid.
2. Soil samples from the same depth taken in the replicate sampling grids within a single transect can be combined directly in the field, or subsequently mixed in the sample processing site.

Sample processing

3. Mix the composite sample thoroughly, and divide into 3 bags: 1 kg of fresh soil for SOM fractionation, 0.5 kg for chemical analysis and another 0.5 kg of soil for archiving; the remainder can be discarded
4. Air dry the soil of all three subsamples by placing them in a shallow tray in a well ventilated, dust and wind free area. Break up any clay clods, and crush the soil lumps so that gravel, roots and large organic residues can be removed
5. Sieve the soil samples intended for chemical analysis through a 2 mm sieve, and grind them in a mortar in order to pass through a 60 mesh screen.
6. Sieve the soil samples intended for SOM fractionation (without grinding). For further treatment see procedure SOM fractionation in manual....
7. Write clear labels for each sample using a waterproof marker pen of each sample, and wrap into a second plastic bag to prevent it from physical damage during transportation. Send it to laboratory for chemical analysis (Table 5).

Box 7. Procedure for taking (undisturbed) soil sample for soil bulk density measurement

Remember: quality data of this property are scarce and potential land use impacts large

Equipment:

1. Ring samples (stainless steel) with a sharp edge and of known volume and 100-200 cm³, for example 5 cm diameter and height
2. External ring to push ring samples gently into the soil
3. Soil knife to remove the ring and any excess soil adhering to it
4. Plastic bags, rubber bands and marker pen

Procedure:

1. Sample close to the sample sites for destructive samples, but avoid any place with possible soil compaction due to other sampling activities
2. Remove the coarse litter layer and insert the first ring gently directly from the soil surface, to sample the 0-5 cm depth layer; if the sample could not be inserted smoothly (e.g. due to woody roots or stones), try again nearby
3. Excavate the soil from around the ring and cut the soil beneath the ring bottom
4. Remove excess soil from above the ring using a knife: first remove excess soil on top of the sample, then place a cover on top of the ring and turn it upside down to remove soil adhering to the ring and cut a smooth surface at the bottom of the ring
5. Either transport the cleaned ring to the laboratory, or remove all soil from the ring to a plastic bag which is closed immediately
6. On a nearby site, remove the top 5 cm of soil and insert a ring for sampling the 5-10 cm depth layer in a similar way. Repeat for the 10-20 and 20-30 cm depth layer, taking samples around 15 and 25 cm depth
7. One set of ring samples per sample quadrant will give you 8 (16) per land use sample

Box 7. Procedure for taking (undisturbed) soil sample for soil bulk density measurement (Cont.)

Sample processing:

Weigh the samples fresh (W_1 , dry at 105°C for 2 days), and weigh again (W_2)

$$\text{Bulk density} = W_2/V \quad (\text{g cm}^{-3})$$

$$\text{Volumetric soil water content (Theta)} = (W_1 - W_2)/V \quad (\text{cm}^3 \text{ cm}^{-3})$$

Box 8: Data analysis: Soil carbon saturation deficit

As the considerable variation in soil C between soils of different texture and mineralogy under the same land cover type makes it difficult to interpret absolute soil C levels, we can try to estimate this 'background' or **C-ref** value of long term forest cover for the same site, on the basis of easily measured soil properties. We define a dimensionless '**C saturation deficit**', C_{satdef} , as the difference between the current C_{org} content and a reference content, $C_{\text{org, ref}}$ which is supposed to indicate the undisturbed forest condition.

$$C_{\text{satdef}} = (C_{\text{org, ref}} - C_{\text{org}}) / C_{\text{org, ref}} = 1 - (C_{\text{org}} / C_{\text{org, ref}})$$

Van Noordwijk *et al.* (1997) suggested to use a ratio of the measured C_{org} and a reference C_{org} value for forest (top) soils of the same texture and pH as a '**sustainability indicator**'. The current version incorporates a generic C distribution with depth. The equation for $C_{\text{org,ref}}$ for Sumatra is:

$$C_{\text{ref(adjusted)}} = (Z_{\text{sample}} / 7.5)^{-0.42} \exp(1.333 + 0.00994 * \% \text{Clay} + 0.00699 * \% \text{Silt} - 0.156 * \text{pH}_{\text{KCl}} + 0.000427 * \text{Elevation} + 0.834 \text{ (if soil is Andisol)} + 0.363 \text{ (for swamp forest on wetland soils)})$$

Example of calculations:

Sample	Depth (middle of sample), cm	Clay %	Silt %	pH _{KCl}	Elevation, m a.s.l.	Andisol?	Swamp?	Cref, %	Corg, %	Corg/Cref	Csatdef
1	2.5	23	12	4.7	250	0	0	4.39	4.7	1.069	-0.069
2	10	25	11	4.5	250	0	0	2.57	2.6	1.013	-0.013
3	20	27	14	4.4	250	0	0	2.03	2.2	1.084	-0.084

$C_{\text{satdef}} < 1$ means that the soil organic matter content (and probably soil fertility) has declined;

$C_{\text{satdef}} = 1$ soil organic matter content has not changed

$C_{\text{satdef}} > 1$ soil organic matter content is higher than the average for forest soils under the same conditions

3.2 Estimating tree root biomass from proximal roots and allometric relations

Roots as carbon stock or organic inputs in tropical agriculture have often been neglected due to difficulties in measurement. Current root research methods are laborious and can not be directly related to farmers criteria for selecting and judging the performance of trees.

Similar to the approach of aboveground biomass via allometric relations based on stem diameter, the belowground biomass can be estimated from the proximal roots at the stem base. The theoretical basis for this relation is found in the fractal branching properties (see box 8) of root systems.

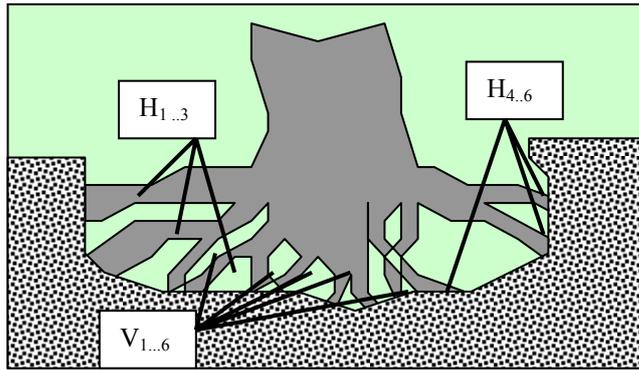


Figure 9. Exposing the proximal roots at the base of a tree stem and measuring root diameters of horizontal (H) and vertically (V) oriented roots, as well as that of the tree stem, can be used in FBA to estimate the overall shoot: root dry weight ratio, if the fractal branching parameters for stem and roots are known for the tree species.

The fractal branching rules apply for root systems as well as aboveground stems, but so far no relation between the parameters describing the above- and those describing the belowground patterns in a given species have been established. The FBA program can predict the total size of each root starting at the stem base on the basis of the 'proximal' diameter at the stem base, and we can thus obtain the root system of the whole tree by summation.

1. Belowground tree biomass = $\sum_i a D_i^b$
2. Belowground tree biomass = Aboveground Biomass/SRratio

where a and b are parameters for a root allometric equation, as derived in FBA, and the D_i refer to all proximal root diameters, measured at the stem base

Default values for the shoot: root ratio (S/Rratio) are 4 for humid tropical forest on normal upland soils, up to 10 on continuously wet sites, and around 1 at very low soil fertility.

IV. The application of century model

The following description of century model version 4.0 is only an introduction to the model, and mainly based on century model handbook (Metherel et al., 1993) which should be consulted for further detail information. The century model is a generic, fortran model developed by Parton et al. (1987 and 1988) to simulate integrated effects of land covers (forest, crops, grasses and savanna), management and global change on C, N, P, S and water dynamics. The model can also simulate the effects of land-use changes such as forest conversion to agriculture crops, and crop rotations including fallow (grasslands). Intercropping systems that involve complex competition for aboveground and belowground factors are not included in the model.

The original version 4.0, the further development of first released version (version 3.0), was also designed to work with "time-zero" (view), in addition to a stand-alone pc version so that model can display a graphic output. The last edition of version 4.0 is not linked to the "time-zero", and produces output in the form of binary file and then ascii file for selected variables. The computer program of century model (century environment) consists of six simulation submodels, twelve input data files, and three utilities. The submodels, obtaining input values from input data files, are soil organic matter (SOM), nitrogen (N), phosphor (P), sulfur (S), plant production, and water budget, submodels.

The input data files contain data on soil, climate, plants (trees, crops and grasses) and cultivation (tillage), fertilization, fire, grazing, harvest, irrigation, organic matter addition. The utilities are used to create or update data files (file100), to create schedule file (event100), and to create ascii file from binary file (list100). The major input variables required to run the model include:

1. Monthly average maximum and minimum air temperature
2. Monthly precipitation
3. Lignin content of plant material
4. Plant N, P, and S content
5. Soil texture
6. Atmospheric and soil N inputs
7. Initial soil C, N, P, and S levels

Two major steps need to be done before Century Model can be run to simulate particular events; Parameterization and Scheduling using FILE100 and EVENT100 facilities respectively (Table 1). Assuming you have constructed a schedule file (e.g. CASSAVA.SCH), simulating Forest-Logging-Cassava/ *Imperata* rotation, and also have updated the values of existing options or created new options in the xxx.100 files required by the CASSAVA.SCH, then follow the steps presented in Table 2 to run CASSAVA.SCH.

Table 1. Program utilities and input (options) files in the Century model.

FILE100	Program to update values or create new options in any of the aaa.100 files
EVENT100	Program to establish xxx.sch files (the simulation time and to schedule events to occur during the simulation)
Site.100	Site data input
Crop.100	Crop options file
Tree.100	Tree options file
Cult.100	Cultivation options file
Fert.100	Fertilization options file
Fire.100	Fire options file
Graz.100	Grazing data
Harv.100	Harvest options file
Irr.100	Irrigation options file
Omad.100	Organic matter addition options file
Trem.100	Tree removal options file

Table 2. The steps to run Century Model for Cassava.sch

Steps	Action	Explanation
1. Type	Century -s cassava -n cass (enter) (This results in <i>modeling is running</i> , then wait until <i>Execution success</i> comes out)	Cassava is the program to run and cass in the binary file to save the outputs of program. Remember that -s cassava and -n cass should be in lowercase letters
2. Type	LIST100 (enter) <i>Enter the name of binary input file (no .bin)</i> cass (enter) <i>Enter the name of ASCII output file (no .lis)</i> cass	To run program converting outputs in yyy.bin file to yyy.lis file The name of xxx.bin file The name of yyy.lis (may be others)

<p><i>Enter starting time, <return> for time file begins :</i></p> <p>enter</p> <p><i>Enter ending time, <return> for time file ends :</i></p> <p>enter</p> <p><i>Enter variables, one per line, <return> to quit</i></p> <p>fsysc (enter) firstc (enter) sometc (enter) cproda (enter)</p> <p>enter</p>	<p>Using the starting time set in the model</p> <p>using the ending time set in the model</p> <p>Total C Total live C Total soil organic matter Net primary product</p> <p>finish</p>
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V. Reading materials

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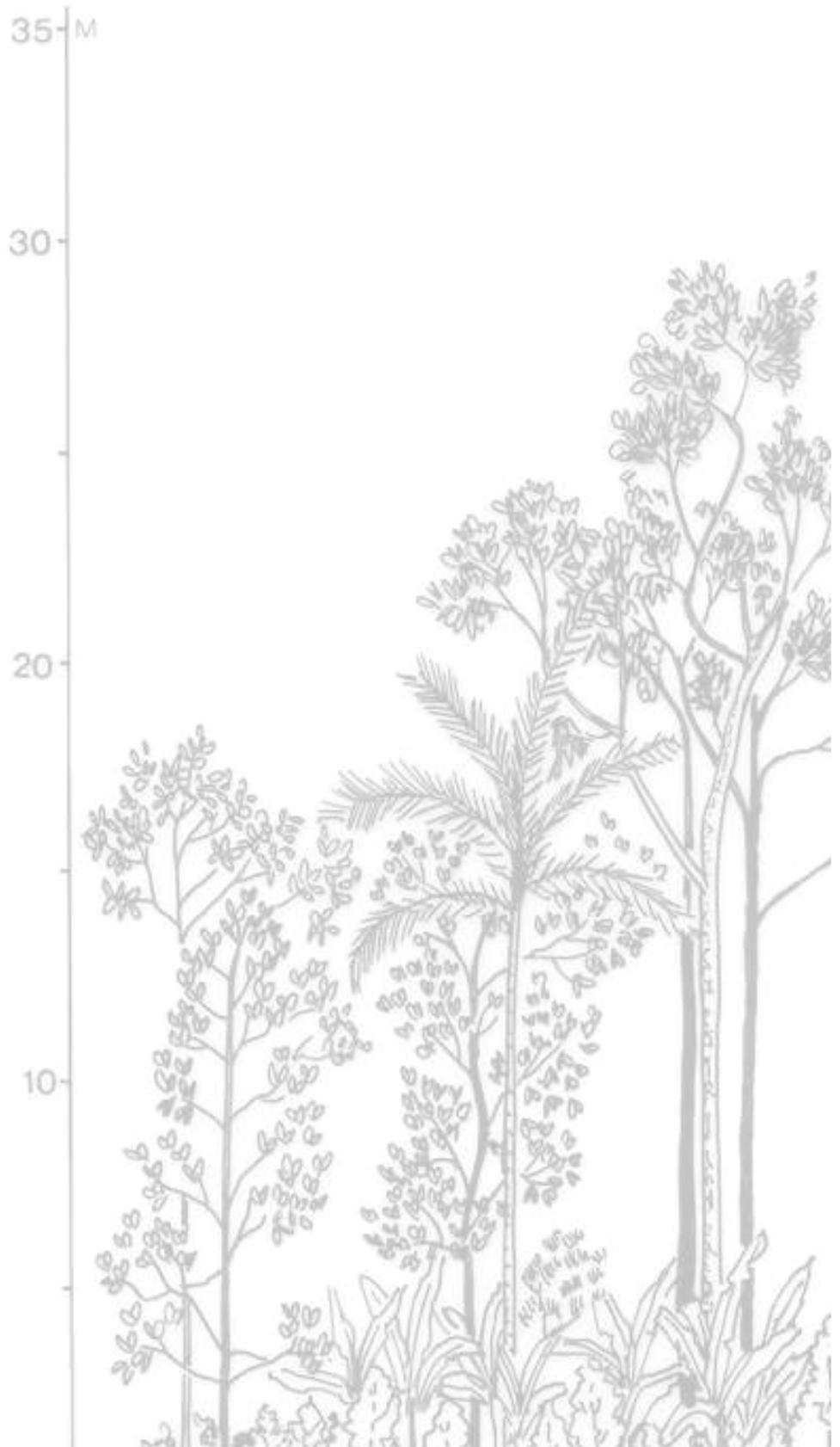
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by: Meine van Noordwijk, Pendo Maro Susswein, Thomas P Tomich, Chimere Diaw and Steve Vosti
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