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FIELD MANUAL
FOR PLOT ESTABLISHMENT AND REMEASUREMENT (RAINFOR)

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Introduction

The tropical forests of Amazonia constitute one of the most important ecosystems of the Earth. They account for 45% of the world's tropical forest, storing about one fifth of the carbon residing in terrestrial vegetation and annually processing about three times as much carbon through photosynthesis and respiration as humans release to the atmosphere through fossil fuel combustion (Malhi *et al.* 1999, Malhi & Grace 2000). Amazonia also accounts for a large portion of global land surface evapotranspiration, and a significant fraction of the world's known species. Relatively small changes in the structure and/or function of these forests could therefore have global consequences for biodiversity, the carbon cycle and the rate of climate change.

RAINFOR is an attempt to utilise long-term permanent sample plots (PSPs) to monitor forest biomass and dynamics, and relate these observation to soil and climate. Many of these plots were established in the past to investigate specific local ecological or forest management questions. However, by compiling and comparing these studies on a *regional* scale a whole new level of information becomes available: information that may provide vital insights into the mechanisms underlying the current responses of Amazonian ecosystems to climate and the possible future of Amazonia under global change scenarios.

The studies associated with RAINFOR have the following objectives:

1. Quantify long term changes in forest biomass and turnover to date.
2. Relate *current* forest structure, biomass and dynamics to local climate and soil properties.

Understand the extent to which climate and soils will constrain *future changes* in forest dynamics and structure.

3. Understand the relationships between productivity, mortality and biomass.
4. Use relationships (i) to (iii) to understand how changes in climate may affect the biomass and productivity of the Amazon forest as a whole, and inform basin-scale carbon balance models.
5. Examine variability of tree biodiversity across Amazonia, and its relationship to soils and climate.

One potential problem with the analysis of data from many different sources is the use of different methodologies at different sites. In addition, the impact of any changes in the methodology over time needs to be assessed before apparent temporal changes in dynamics can be considered robust. An important component of RAINFOR is to encourage discussion of methodological issues and the standardisation of forest inventory protocols. To achieve this objective, this manual sets out the procedures for plot establishment and remeasurement that have been developed over the course of RAINFOR fieldwork in northern Peru, Bolivia and Ecuador 2001/2.

Plot establishment

A. Location

The pan-Amazon strategy within RAINFOR is to maintain sample forest plots across the edaphic range within each climatic zone and regional plot cluster (Malhi *et al.* 2001). New plots should be randomly located within local, geomorphological strata that satisfy certain logistical criteria. New plots should:

- be on homogenous soil parent material and soil type
- have adequate access
- have sufficient long term security from human disturbance
- have sufficient long term institutional support

However, in most Amazonian research sites, accurate habitat maps are lacking, which prohibits complete stratified sampling at large scales. Similarly at local scales, identifying geomorphological strata is difficult because no accurate soil maps exist. Landsat images help in identifying the range of vegetation types that might be found in any one area, but the scale of resolution is too coarse to help identify them in the field. Equally, it is difficult to match up GPS readings in the field with co-ordinates on the images. Information from botanists who know the area is most useful. Logistical constraints are also important: it is impractical to locate a plot greater than 1 hour from the field base, and it can be difficult to fit a 1 hectare plot into a forest that is dissected by tracks.

B. Position

Within strata, plots should be randomly located, to avoid 'majestic forest' bias. If maps are available, plot location should be randomly assigned prior to going to the field. If not, in the field, there may be a tendency to start the plot in particularly 'good' forest. In this case, the position of the plot starting point can be randomised by locating it in a random direction at a random distance >20m (i.e. out of sight), of the original, potentially 'biased' starting point.

C. Timing

To minimise the errors caused by variation in stem water content between successive enumerations, plots should be measured over whole year intervals and at the time of year when there is least interannual variation in soil water availability. For plots in areas that experience severe interannual variation in rainfall due to El Niño events, the best time of year is during the wet season.

D. Orientation

N/S and E/W directions for the principal axes of the plot are the most convenient but the eccentricities of the local strata may prevent this. The bearings of the main axis, and the latitude, longitude and elevation of the centre of the plot should be recorded.

E. Shape

It is important to maintain homogeneity within the plot, so the shape of the geomorphological strata is an important consideration. Square plots have lower edge:area ratio than rectangular plots, so have fewer problems with decisions concerning the presence of trees in or outside the plot at the edges. However, rectangular plots will be less disturbed by cut lines within the plot, less susceptible to 'mature forest' bias and the dynamics they record will be less influenced by single tree fall events. Both shapes are used within the RAINFOR network.

F. Size

The coefficient of variation of basal area increases as sample plot size decreases below 0.4 ha in Costa Rica (Clark and Clark 2000). 1 ha is a standard size, greater than the scale of typical tree fall events, but sufficiently small to sample individual soil types. 20 x 20 m is a convenient subplot size.

G. Topography

New plots within RAINFOR should be set up to sample one hectare of land surface, which requires some flexibility with bearings and distances when closing the final side of the plot. External and internal boundaries of the plot are measured in 20m segments. In some cases, a planar projection of 1 ha of forest has been used (Dallmeier 1992, Condit 1998) and slope corrections applied: the distance to be measured parallel to the ground for each segment is given by:

$$d = 20/\cos\theta$$

where θ is the inclination of slope in degrees. Plots laid out in this way will always tend to include a greater surface area of land surface, and correction factors allowing comparison between plots on the basis of land surface area need to be calculated.

H. Visibility

It must be possible to relocate plots, but any permanent markers used must not attract too much attention! Plastic stakes can be installed in each of the four corners of the plot, driven well into the ground, with approximately 10 cm showing above the ground.

I. Stringing the plot

This works well with 4 people: 1 with compass, 1 to cut line, 1 to measure the distance and 1 to follow behind laying out the string. Stringing the base line of the plot and then carefully stringing each subplot is the most accurate method of delimiting the plot.

J. Tagging trees

Tagging and measuring the trees can be done concurrently by three people. One person should work out the best order in which the trees should be tagged, and tag them, one measure, and one take notes and roughly map the plot.

Trees are included if greater than 50 % of the roots are inside the plot. Trees should be tagged systematically moving round each subplot with the last tree tagged in each subplot close the start point of the next subplot.

Knock in the nail at a slight downward angle, just far enough so that it penetrates the bark and is secure but leaving as much space as possible for the tree to grow without “eating” the tag. Tag at 1.60m, and consistently on the same side of the trees throughout the plot. In square, 100 x 100m plots it is useful to tag each successive line of subplots on a different side of the tree, as this helps identify where the internal lines of the plot are on subsequent occasions. Iron nails are required for the trees with the hardest wood (palms, Fabaceae). Note:

- Newly broken or deciduous trees can be completely leafless so check carefully: they are living and should be tagged as long as the cambium beneath the bark is live.

- Multiple-stemmed trees are tagged only on the largest stem that is ≥10cm diameter at 1.30m height**.** If two stems of the same species are very close together, check the roots carefully to see if the stems in join below ground.

- Fallen trees should be checked carefully to see if they are still alive. They should be tagged 1.60m from the tree base.

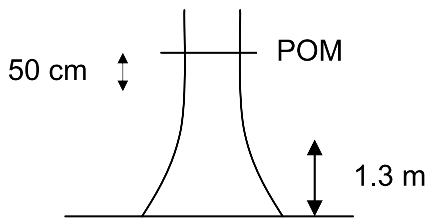
- Tag each liana stem that is ≥10cm diameter at any point within 2.5m of the ground, even if <10cm at 1.30m. CHECK CAREFULLY AS THEY CAN BE EASY TO MISS! Each climbing liana stem that meets this criterion AND is separately rooted counts as one individual plant (but check carefully to see that the point where the stem meets the ground is actually rooted and not simply covered by leaf litter).

K. Tree measurement

Measure at 1.3 m height wherever possible. IF 1.3 m IS NOT USED AS THE POINT OF MEASUREMENT ("POM"), RECORD THE HEIGHT OF THE POM. Use a pole with 1.3 m marked, pushed firmly into the leaf litter to the mineral soil next to the tree, to define POM (Swaine, et al. 1987, Condit 1998). Note that breast height is not the vertical height above the ground, but should be measured as the straight line distance along the trunk, even if it is leaning or bent. In plots where the trees are tagged at 1.6m height, the POM is 30cm below the tag unless noted otherwise.

- **Climbers**: The tape is passed under any vines or roots on the stem and then is moved back and forth to clean the POM of loose bark and debris. Hemiepiphytes, or lianas that closely hug the stem should not be cut. The diameter can be estimated by holding the tape perpendicular to the stem at the POM, or using an optical method (see below).

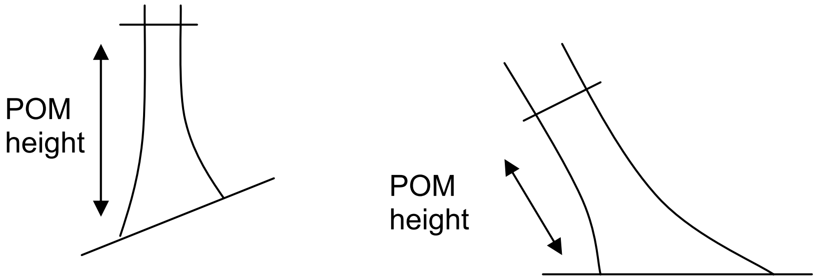
- **Buttresses**: If the tree is buttressed at 1.3 m, measure stem 50 cm above the top of the buttress (Condit 1998). Record height of POM.



- **Deformities**: If the tree has a major stem deformity at 1.3 m height, then measure 2 cm below the deformity (Condit 1998). Record POM height.

- **Fluted trees**: Trees that are fluted for their entire length should be measured at 1.3 m.

- **Slopes, and fallen or leaning trees**: Breast height is always calculated on the downhill side of the tree, and trees that are fallen or leaning are always measured at 1.3m length along the side of the stem closest to the ground. This procedure avoids confusion with the common situation when trees are both on slopes and leaning – trees usually lean downhill and these rules mean there is no confusion regarding the side of the tree used to measure the POM. On fallen trees it is difficult to define the base of the trunk accurately – therefore measure the tree 20 cm below the tag.



- **Stilt-rooted trees**: Stilt rooted individuals should be measured 50 cm above the highest stilt root and the POM recorded.

- **Resprouts:** On standing, but broken trees, or fallen individuals, the main stem and resprouts are measured at 1.3 m from the base of the stem. A resprouting individual is only included if the resprouts are greater than 1.3 m from the stem base.

- **Multiple stems**: All stems greater than 10cm at 1.3 m are measured and recorded.

- **Large trees**: Large trees should be left by the measurement team and done separately later: it typically takes two people one day to measure the large trees in a plot. A ladder is very useful to reach the POM of large trees, and in some cases two ladders are needed to ensure accurate measurement. If the POM cannot be reached, then diameter should be measured using an optical method, using either a digital camera or Relaskop.

For Relaskop measurements:

Record:

- the angle of inclination to the POM,
- the number of Relaskop Units (RU) at the POM,
- the horizontal distance to the centre of the tree (h),
- the angle to the base of the stem,
- the bearing from the viewpoint to the tree,
- diameter estimate at POM.

Diameter at POM = 2 x h x RU.

The diameter estimate should allow you to quickly recognise possibly erroneous Relaskop measures in the field.

A separate fieldsheet is required for Relaskop measured trees.

For digital camera measurements:

A digital camera provides a more accurate method for measuring the diameter of large trees. A photo is taken of a ruler, tape, or straight pole of known dimensions aligned at the POM. From each photo, the diameter can be measured in pixels, and the number of pixels per cm calculated.

Record:

- height of POM
- height of camera
- bearing from camera to tree
- horizontal distance from camera to the centre of the tree
- photo number
- diameter estimate, as a check

Error is minimised if the angle from the camera to the POM is as shallow as possible. To achieve this, if a tripod is available, the camera can be placed at a greater distance and the photo taken with zoom. This method works best if a laptop computer is also available every evening to download the digital data and calculate diameter. This allows for a return visit to the tree the next day in case any uncertainties remain.

For both optical methods, a correction should be applied as both fractionally underestimate diameter (see below).

L. Liana measurement

Lianas present special measurement challenges for long-term plot studies. We have developed a range of protocols to maximise long-term comparability across sites and through time at individual sites. These are being revised in line with current efforts to standardise neotropical liana measurements (Schnitzer et al. in prep. Nov. 2002).

Selecting the point of measurement (POM) for lianas is particularly tricky, and has not been well standardised making comparisons among different research groups difficult***. Our protocol (revised Nov. 2002) now calls for each liana stem to be measured at three different points, to maximise comparability within the site for time-dependent analyses (growth, recruitment, mortality), within the RAINFOR dataset, and with other studies.***

We include any liana or hemi-epiphyte that reaches 10cm diameter at any point along the stem between 0 and 2.5m above the ground. For lianas and hemiepiphytes, record the diameter measurements at three points:

1. at 130cm *along the stem from the roots*,
2. at 130cm *vertically above the ground* (i.e., 30cm below the nail in plots where plants are tagged at 1.6m),
3. and ALSO at the widest point on the stem within 2.5m of the ground ("dmax").

Check carefully for the maximum diameter point – in lianas it is often close to the ground or a branching node where anomalous growth can be most marked. Describe the maximum diameter measurement point precisely in notes (e.g., 'by ground', '10cm above tag' etc.).

Some lianas are 'cabled' (e.g., some Malpighiaceae) with the cables progressively splitting as the liana ages and each cable thickens; in these cases it is difficult to measure the liana in a way to permit long-term estimation of radial growth increments. For these lianas, diameter is estimated by tightening the diameter tape around all adjacent cables originating from the same root base. Other lianas are clearly elliptic in cross-section (reaching extremes in some 'monkey-ladder' *Bauhinia* spp); these stems should be measured in two ways: conventionally (i.e. wrap the tape round the whole stem) and by twice measuring the linear distance of each of the maximum and minimum dimension and taking the geometric mean. Following these conventions, every liana that attains ≥10.0cm dmax should be tagged and measured.

Further difficulties can be presented by deciding where one liana ends and another starts. Thus, lianas are sometimes connected to one another below ground but this can be hard to establish. Therefore, for ease of application we apply the criterion that any climbing stem that fully enters the mineral soil counts as an independent plant (= an "apparent genet"). If unsure, then tag the stem and comment that it may be the same as another stem. In cases where the liana plant branches, each branch that branches within 2.50m vertical distance from the ground and attains ≥10.0cm dmax is measured (as with all trees that branch at ≤1.30m). In practice it is extremely rare for a branching liana to have two or more branches ≥10cm diameter (on average in Amazonia this occurs at a frequency of <0.1 per ha).

For each liana stem (or ascending branch if there are more than one), note the number of the tree in which tree(s) the liana crown is in, record the tree number whose crown is most heavily affected by the liana, and estimate the height of the highest liana leaves. The purpose of this is to generate simple and comparable estimates of liana/tree interactions (e.g., estimate the extent to which liana infestation may enhance the probability of tree death). If the host tree is outside the plot it will not have a number: in these cases the tree diameter should be measured directly (tape) or visually (Relaskop or digital camera method).

M. Data recording

In summary, the following details should be recorded:

Trees:

- subplot number
- estimated X and Y co-ordinates from bottom left-hand corner of plot
- diameter
- POM, if different from 1.3 m
- ladder, or Relaskop/digital camera used.
- bole form: leaning, fluted, forked below 5 m, rotten, multiple stemmed individual, stem broken above/below 1.3 m, stem prostrate, stem resprouting.

The following codes may be used:

Type	Code	Use
Measurement	K	Measured with Relaskop
	A	POM ≠ 1.3m, (buttress, stem deformity etc)
Bole form	L	Tree leaning
	F	Tree fluted
	O	Stem forked (below 5m)
	T	Bole rotten
	M	Multiple stemmed individual
	Q	Stem broken above 1.3m
	X	Main stem broken under 1.3m
	Y	Prostrate stem
	R	Stem resprouting

Measurements of multiply measured buttressed trees should be put in the same row of the data table for ease of converting to stem BA values and individual stem records for mortality rates etc. Measurements of multiple stemmed trees go in separate rows. Relaskop/digital camera measurements go on separate sheet, coded on original fieldsheets.

Lianas:

- Diameter at 1.3 m along the stem
- Diameter at 1.3 m vertical height
- Max. diameter at any point below 2.5 m
- Tree(s) that liana canopy is in
- Tree most heavily affected by the liana canopy
- Max. height of the liana canopy

Sub-plot

- Sketch map of tree locations
- Slopes of subplot boundaries
- Soil texture and drainage

Plot

- Lat./Long
- Elevation
- Bearings of plot boundaries
- Local landmarks to assist plot relocation
- Rooting depth: For fallen trees – evaluate depth of rooting mat, depth of deepest root; record if it has a taproot, and the taproot diameter. Record species and dbh of the downed tree, and topographical position.

N. Tree bole length and total tree height

In addition, tree heights should be measured, to establish plot level diameter/height relationships for accurate modelling of tree-by-tree volumes for each plot, and test whether tree shape differs between stands in different environmental conditions. The aim is to characterise the 'ideal' height/diameter curve as determined by climatic and edaphic conditions and not confused by the influence of damaged trees.

Excluding trees coded as leaning, rotten, broken, forked below 5m, fallen or resprouted, randomly select from the plot fieldsheets:

- 10 individuals, 10-20 cm dbh
- 10 individuals, 20-30 cm dbh
- 10 individuals, 30-50 cm dbh
- 10 individuals greater than 50 cm dbh.

From a suitable viewpoint, (angles of approx. 45^o to the first branch are ideal as they minimise the error from any inaccuracy in measuring the angle):

- the angle to the base of the first main branch (a). A main branch is defined as one greater than 5 cm diameter, with leaves.
- the horizontal distance from this point to the centre of the tree (x)
- the angle to the base of the stem (b).

Bole height = x (tan(a) + tan (b)).

For measurement of total tree height, '(a)' should be substituted by the angle to the top of the crown.

If in the field, a tree is found to be unsuitable (impossible to get a suitable viewpoint, for example), then the nearest stem in the correct size class should be used.

O. Wood density measurements

A rapid approach to assessing stand-level wood density has also been developed. This variable is necessary to achieve greater accuracy in measurements of biomass than those based solely on plot basal area, and can also be used as a functional measure of forest species composition. Measurements of branch wood density in the field provide information on (usually non-timber) species that have not previously been studied.

From branches cut down from the crown for botanical collection or leaf nutrient analysis collect 10 cm long samples of at least 1.5 cm diameter. Dry these samples in air in the field (fungus will grow if they are kept in plastic bags). Density is calculated as dry weight over fresh volume. As measurements are not usually possible directly after sampling, 'fresh' volume is measured following rehydration of the samples in water overnight. Following this, maximum and minimum diameter of each end of the sample is measured to 0.1 mm using calipers. Dry the samples overnight in a herbarium drier. Record sample mass to 0.01 g.

P. Botanical collection

For new plots, all individuals that cannot be identified in the field need to be collected. Samples need to be pressed and transported to the relevant herbarium. Duplicates should be identified in the field to avoid unnecessary collections being made. Botanical collection, identification, and specimen curation are specialised and time-consuming processes. To enable among-site and longitudinal within-site comparisons of floristic pattern and change requires planning, investment, and long-term involvement of botanists. Here we simply flag these issues but do not attempt to cover them in detail

Q. Suggested timing and personnel

Locating and stringing a plot: 3-4 people, 2 days

Tree tagging and plot measurement: 3 people, 4 days

Large trees and tree heights: 2 people, 1 ½ days

Topography: 2 people, ½ day

Botanical collection: 2-3 people, 10 days *[new 1-ha plot, assuming median Amazon alpha-diversity, 150-200 species per ha]*

Plot remeasurement

A. Stringing

For relocating a previously established plot, run string along all the outer edges of the plot, using the bearings and the location of previously tagged trees to help define the plot edge. This is quite straightforward where the understory is clear and most trees still have their tags, but is time-consuming where many trees have lost their tags and/or the plot edge crosses a tree-fall. Using a previous hand-drawn map of the trees, if available, can help. Recorded compass bearings for plot edges are obviously helpful too but beware: small deviations in a bearing can result in incorrect exclusion or inclusion of large numbers of trees growing close to the plot edges. If you do follow a bearing, always check that the string is not excluding any previously tagged trees or including any large trees that obviously have never been tagged. Run string along each subplot edge, to follow the old number sequences.

B. Tree and liana measurement

One person takes notes, using waterproof paper pre-printed with plot tree information. The note-taker should use any existing map of tree positions, if one is available. Hand-drawn maps are not precise but should be good enough to work out where trees should be - and therefore where to search for them if the measurement team does not locate them.

The same measurement protocols should be used as above. When remeasuring trees, if the top of buttress has grown within 30 cm of the marked POM, in addition to measuring at original POM, measure diameter 50 cm above first POM. Discard low POMs as buttress extends over them with time. This procedure ensures that there is always a consistent, non-buttressed measurement of diameter growth.

C. Dealing with buttressed trees

Where plots have been established using different protocols, there can be problems with the measurements of buttressed trees. We have developed various approaches aiming to obtain unbiased, above-buttress, estimates of plot basal area and growth. The approach used depends on whether previous measurements were ‘good’ or ‘bad’, and on subsequent buttress growth.

Previous measurement	What's happened?	Field protocol	Calculating growth
'Good': above buttress & POM recorded	No buttress growth	Measure at original POM	Standard
	Buttress grown over, or close to, POM	2 measurements at original POM, and above buttress	Growth calculated using measurements at original POM. Future measurements made at the new POM and standardised to original POM using the ratios of the diameters at the two heights.
'Poor': around buttress, or POM not recorded, or diameter estimated	Possible to judge location of previous POM and 'reasonable' measurement possible	2 measurements at original POM, and above buttress	Growth calculated at new POM; original measurement standardised to new POM using the ratios of the diameters at the two heights.
	Not possible to locate previous POM	1 measurement above buttress	Growth calculated at new POM either extrapolating previous data (3+ censuses) or using the median growth rate of the appropriate size class (10-20, 20-40 & 40+ cm size classes), following Veillon 1985 p. 23, using size classes with approx. equivalent stem numbers. These growth rates should be derived for an individual plot, using reliable increment data, excluding palms.

D. Mortality and recruitment

For dead trees, the mode of death should be recorded – fallen, broken, standing (i.e. with branches intact), or presumed.

The following codes may be used:

DS	Dead, standing
DF	Dead, fallen
DB	Dead, broken
D?	Presumed dead

Stems that have been broken and are resprouting are only counted as 'alive' if the resprouts occur above 1.3m. If the stem is resprouting at the base, this should be noted on the fieldsheet; however, the stem is counted as dead, and does not need to be remeasured.

When recensusing, two people should do the tree measurements and carry nails, tags, and a hammer, and tag new recruits as they are found. Give them the number of the nearest tagged tree and add A, B etc, to keep the spatial pattern. Mark unidentified new trees (recruits) clearly with bright pink tape for later collecting.

E. Dealing with errors

Think about the measures as you record them: The plot data sheets provide a lot of information about individual trees, i.e. size, taxon, and previous 'traumas' (e.g., 'live, broken') which may explain its disappearance since. The historical measurement progression gives the note-taker further insights which can be very useful (e.g. it helps to flag immediately if the new measurement may be error – can unusually large or negative changes in diameter be explained by recent changes to the trees' local environment or condition?). In the field, if the measure called out shows an increase above the long-term trend, or a decrease, the note-taker should ask the measurer to remeasure immediately to check. The person taking notes should check carefully that no trees have been missed, particularly fallen trees. When recensusing try to follow spatial sequence of old numbers if possible: it makes it easier to work out the old numbers of trees who have lost their tags.

F. Suggested timing and personnel requirements

Locating and stringing a plot: 3-4 people, 1 day

Plot measurement: 3 people, 2 days

Large trees and tree heights: 2 people, 1 ½ days

Topography: 2 people, ½ day

Botanical collection: 2-3 people, 1 day *[recruits into an existing plot, assuming 1 ha, 5 yrs since last census, 2% annual turnover rate, and median Amazon alpha-diversity, 150-200 species per ha]*

G. Data processing

Even with careful field procedures, problems can arise during data processing.

'Unlikely' recruits

Occasionally, relatively large trees of slow-growing species 'appear' in the plot. We assume these were missed in the previous census and calculate their previous dbh using the median growth rate of the appropriate size class (10-20, 20-40 and 40+ cm).

Missing data

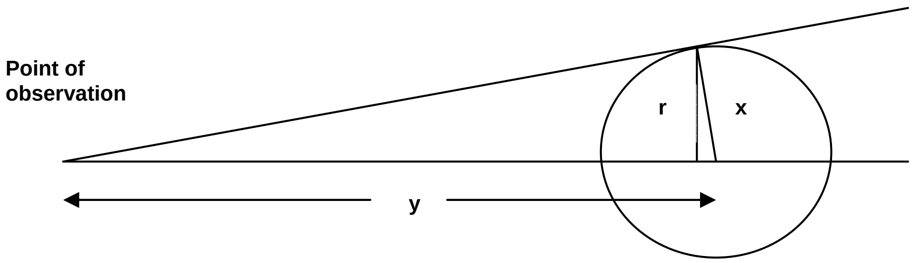
We use linear interpolation to estimate diameters of trees that have been missed during intermediate censuses.

Abnormal growth

We correct obvious typos in previous census data in the field. Often, incorrect measurements show up when a plot has several censuses, as odd measurements in an otherwise steady sequence. In these cases we use interpolated values.

H. Correction for optical measurements of tree diameter

Optical measurements of tree diameter underestimate true diameter:



where x = true radius, r = measured radius and y = distance from point of observation to point of measurement of tree (= a / cosα, where a is the horizontal distance to centre of tree, and α = angle of elevation from observation point, to point of measurement on the tree). Assuming the cross-section of the trunk is circular along the line of sight, the true radius is given by:

$$x = (0.5 * (y^2 - (y^4 - 4r^2y^2)^{1/2}))^{1/2}$$

Typically, the error is approximately 0.5 % of the measured diameter. It increases with tree size and decreases with larger distances between the tree and the point of observation.

Further data organisation and processing issues

Plot data organisation, one Excel file per plot

Worksheets 3 worksheets per file, giving tree, liana and site details

Columns Tree and liana sheets contain information on plot and stem number, taxonomy, all diameter measurements, and point of measurement (POM). Where two diameter measurements were made on a single stem, due to buttress growth above original POM, this data is included in separate columns (dbh 02 (2) and POM (2)). Field notes column includes observations useful in the field (leaning, fluted etc); data notes column includes details of any manipulation of the data for that stem (missing data interpolated etc)

Rows One row per stem. Each stem of multiple stemmed individuals occupies one row.

Buttressed trees

A. Where problems exist in the measurement of buttressed trees we have used various approaches to give 'best estimates', aiming to obtain unbiased, above-buttress, estimates of plot basal area and growth. Various scenarios are possible:

Previous measurement	**What's happened?**	**Field protocol**	**Calculating growth**
Above buttress & POM recorded	No buttress growth	Measure at original POM	Standard
	Buttress grown over, or close to, POM	Two measurements at original POM, and above buttress	Growth calculated using measurements at original POM. Future measurements made at the new POM and standardised to original POM using the ratios of the diameters at the two heights.
Around buttress, or POM not recorded, or diameter estimated	Possible to judge location of previous POM and 'reasonable' measurement possible	Two measurements at original POM, and above buttress	Growth calculated at new POM; original measurement standardised to new POM using the ratios of the diameters at the two heights.

	Not possible to locate previous POM	One measurement above buttress	Growth calculated at new POM either extrapolating previous data (3+ censuses) or using the median growth rate of the appropriate size class (10-20, 20-40 & 40+ cm size classes) (2nd census), following Veillon 1985 p. 23, using size classes with approx. equivalent stem numbers. Over 40 cm dbh, growth rates are approx. constant in two 50 ha plots (Condit et al. 1999). This quantity should be derived at a plot level using reliable increment data, excluding palms, other monocots, lianas, and hemiepiphytes.

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