



The
DryFlor

Field Manual for Plot Establishment and
Remeasurement

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Introduction

Dry forests (also known as seasonally dry tropical forest: SDTF) constitute one of the most important yet understudied ecosystems on earth (DRYFLOR, 2016). Dry forests can vary from tall, closed forest with a 25-30 m canopy, to more open, low, thorny and cactus scrub, and are found in areas receiving <1600 mm rainfall a year and with a pronounced dry season. Often occurring on fertile soils, the majority of trees in dry forests are deciduous (Pennington et al., 2000).

Most dry forests are highly fragmented and threatened, but their study and conservation have been neglected in comparison to that of humid tropical forests (DRYFLOR, 2016), and they are often confused with savannas and other kinds of forests (Griffith et al. 2017, Torello-Raventos et al. 2013). Consequently, relatively little is understood about the structure, function, floristics and dynamics of dry forests. Correcting this oversight is of paramount importance in the context of global change, as the majority of forested, tropical regions are likely to become hotter and drier (Corlett, 2016). Understanding dry forests is, therefore, key to planning for and mitigating the effects of climate change (Pennington et al., 2018).

The DRYFLOR (Latin American Seasonally Dry Tropical Forest Floristic Network) Field Manual for Plot Establishment and Remeasurement (referred to herein as the *DRYFLOR Plot Protocol*) provides guidance for monitoring of woody stems (trees and lianas) in long-term permanent dry forests sample plots with a standard protocol to monitor forest biomass, compositional shifts and dynamics, and thus relate these observations to floristics, soil and climate across dry forests.

The *DRYFLOR Plot Protocol* has been developed as part of the NERC-Newton-FAPESP funded NordEste Project, which has set up a permanent monitoring plot network across the Caatinga dry forest region (Prado & Gibbs, 1993; DRYFLOR, 2016; Queiroz et al. 2017) in northeast Brazil. The design of this protocol is a modified and expanded version of the protocol (Phillips et al. 2018) used by RAINFOR (The Amazon Forest Inventory Network), an established plot network in humid forests across the Americas with a particular emphasis on the Amazon Basin. The data collected using the *DRYFLOR Plot Protocol* will enable comparison with existing RAINFOR data, facilitating multi-biome comparisons which may provide insight into how biomes respond to global change, as well as studies aiming to understand how biomes have formed.

The *DRYFLOR Plot Protocol* is designed for studies with, but not limited to, the following objectives:

1. Quantify long term changes in plot floristics, structure, biomass, and turnover.
2. Relate plot *current* floristics, structure, ecophysiology, biomass and dynamics to local climate, soil properties and land-use history.
3. Understand the relationships among floristics, ecosystem function, productivity, mortality and biomass.
4. Use relationships of (1) to (3) to understand how changes in climate may affect the floristics, biomass and productivity of dry forests as a whole, and inform biome-scale models of carbon dynamics.
5. Examine variability of taxonomic, functional and phylogenetic tree diversity across dry forests, and its relationship to soils and climate.
6. Facilitate comparisons of (1) to (5) among dry forests and other biomes.

Furthermore, the standardisation of measurements and data across studies, biomes and continents facilitated by this protocol will aid researchers wishing to address scientific, social, and applied questions beyond the scope of (1) to (6) and the DRYFLOR network.

This is because one potential problem in the analysis of forest plot data from many different sources is the use of different methodologies at different sites. In addition, the impact of any changes over time needs to be assessed before the apparent temporal changes in dynamics can be considered robust. An important component of the *DRYFLOR Plot Protocol* is to encourage discussion of methodological issues and the standardisation of forest inventory protocols for dry forests. To help achieve this, this manual sets out the procedures for plot establishment and remeasurement. It draws heavily on the RAINFOR protocol (Malhi et al., 2002; Phillips et al., 2018) already successfully applied in many tropical moist forest plots in South America and beyond, modified and expanded to address the methodological challenges intrinsic to dry forests. This has been an ongoing process, carried out across three projects awarded by UK Research Councils (NERC and NERC-Newton) in partnership with Brazilian research foundations (FAPESP and FAPERJ). Most of these challenges were identified over the course of fieldwork in Peru, and the refined protocol was tested during fieldwork in the Caatinga region of north-eastern Brazil.

As well as the RAINFOR input, the *DRYFLOR Plot Protocol* also includes features from other protocols previously used in dry forest and savanna studies in Brazil and beyond. While we have not been able to produce a protocol that facilitates direct comparison with data from all alternative protocols (e.g., those that measure stem diameters only at ground level), our protocol is compatible with the majority of widely-used forest monitoring protocols.

The *DRYFLOR Plot Protocol* outlined herein defines a minimum set of procedures that balances the criteria detailed above with the need for ecologically-meaningful, comparable data. Individual projects or investigators may wish to supplement this protocol with optional additional measurements. This is encouraged, and we provide a number of optional extra measurements to facilitate this and expect future changes to this protocol will include further, optional measurements (e.g., quantification of functional traits, herb biomass and diversity, etc).

Plot Establishment

A. Location

The strategy within DRYFLOR is to establish and maintain plots across the edaphic and climatic range found within all major Latin American Seasonally Dry Tropical Forest regions (*sensu* DRYFLOR, 2016). Local plot networks should aim to cover the range of climatic and geomorphological strata. Each new plot should be randomly located within local, geomorphological strata that satisfy certain logistical criteria. Each individual plot should:

- be on reasonably homogenous soil parent type and soil type, with a homogeneous land use history;
- have adequate access;
- have sufficient long-term security from human disturbance, including intensive grazing;
- have sufficient long-term institutional support.

In most dry forest research sites, however, accurate habitat maps are lacking, which prohibits complete stratified sampling at large scales. Similarly, at local scales, identifying geomorphological strata may be difficult as usually no accurate soil maps exist. Satellite images may help in identifying the range of vegetation types that may be found in any one area, but problems with image resolution, the lack of ground-truthing, and images taken at different times of year still limit the ability to accurately predict the exact distribution of vegetation types and floristic formations. This is particularly true of dry forests, which at different times of the year may be indistinguishable from either a wet forest or almost bare ground. Information from and collaboration with local residents, reserve managers and botanists who know the area is always vital. Logistical constraints are also important: it may be impractical to locate a plot more than 1 hour from a field base, and it can be difficult to fit larger plots into a highly fragmented forest matrix.

If several plots are going to be established, it is recommended plots cover the topographic variation of the landscape, including different slope aspects and altitudes (upper, middle and lower) hills, while individual plots should be as homogeneous as possible).

B. Position

Within study sites, plots should be randomly located to avoid bias (e.g., the 'majestic forest' bias, Phillips, 1996). If maps are available, plot location should be randomly assigned prior to going to the field. If not, there may be a tendency to start the plot in particularly 'good' forest or to choose sites with 'attractive' trees when in the field. If maps are not available, the position of the plot starting point can be randomised by locating it in a random direction at a random distance (e.g., >20 m and out of sight) of the original, potentially 'biased' starting point).

If possible, plots should be located far (i.e. >50 m) from the edge of a forest patch or other disturbances such as paths. Many dry forests are, however, reduced to small patches and thus this is not always practical. In such cases, a reasonable compromise should be found to ensure that the plot is as far as possible from disturbances. It may also be necessary to alter the orientation of the plot (see below) to ensure this.

C. Timing

To minimise the errors caused by variation in stem water content between successive plot 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. In dry forests, most trees will be leafless in the dry season with the vital task of collecting vouchers and identifying plants then nearly impossible. As the middle of the rainy season may cause logistical problems due to weather conditions, we recommend the wet/dry season transition as providing the best combination of working conditions in general. To complement the plot census revisiting plots to take herbarium vouchers in a different season may be necessary to identify some species.

D. Orientation

N/S and E/W directions for the principal axes of the plot are the general standard but the eccentricities of the local site may prevent this. The bearings of the main axis, and the latitude, longitude and elevation of the centre of the plot should be recorded. Note if true or magnetic north is used.

E. Shape

Square plots have a 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 may be less disturbed by cut lines within the plot, less susceptible to any “mature forest” bias, and their dynamics will be less influenced by single tree fall events.

It is important to maintain homogeneity within the plot, so the shape of forest patches, rock outcrops, or areas of homogeneous soils are an important consideration. For example, a long, thin forest may require a long and thin plot (e.g., 20 × 500 m).

We suggest a standard half-hectare plot should be 100 × 50 m, and any larger plots should be square (i.e. 100 × 100 m). Other shapes should only be considered in exceptional circumstances.

F. Size

Given that the coefficient of variation of basal area was found to increase rapidly as sample plot size decreased below 0.4 ha in Costa Rica (Clark and Clark, 2000), 0.5 ha is a minimum standard plot size used in dry forests. Half a hectare is also greater than the scale of typical tree fall events and larger than the pixel size of satellite data (Schepascheno et al., 2019), but sufficiently small to handle within a reasonable number of days and sample a representative plant diversity. 10 × 10 m is a convenient subplot size, as it may be difficult to see longer distances within dense dry forests. Also measuring and identifying all individuals >5 cm diameter is easier if subplots are smaller. 100 × 50 m plots are the most common within the DRYFLOR network.

We note that most humid forest and savanna plot networks favour 1 ha (100 × 100 m) plots. Such plots are less susceptible to disturbance, the effects of “outlier” trees, and forest structural variability. They further permit a more direct comparison with other 1 ha plots. If these factors are of particular concern and logistics allow, a 1 ha plot should be considered.

G. Topography

New plots within DRYFLOR should be set up to sample at least 0.5 ha horizontal plane (i.e. a rectangle held horizontally over the plot would equal 0.5 ha). This is most easily achieved by holding all tapes horizontally (see *Stringing the Plot* below), but it is also possible to use a laser range finder to correct for slope. This 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 10 m segments, and the slope of each segment should be recorded.

H. Visibility

It must be possible to relocate plots, but any permanent markers used must not attract attention. Metal or plastic stakes can be installed in each of the four corners of the plot, driven well into the ground, with c.50 cm showing above the ground. Metal stakes are best as dry forests occasionally experience fire events. It may be convenient to also locate stakes every 10 m around the plot edges; this is especially important if there is a meaningful intention to monitor the remeasurement and recensus the plot over long periods to reduce edge-associated measurement errors in tree recruitment.

I. Stringing the Plot

Stringing the baseline of the plot and then carefully stringing each subplot is the most accurate method of delimiting the plot. A perfect right angle can be achieved at the beginning by delimiting a right-angled triangle with sides 3, 4 and 5 m long, with the 4 m side running N/S and the 3 m side running E/W (**Fig. I-A**). This triangle should be perfectly horizontal.

Stringing the baseline of the plot works well with 3 people: 1 with a compass; 1 to cut the line; and 1 to measure the distance. Stringing the subplots works well with 4 people in two teams. Each team delimits, cuts, and strings a 10 m side to the subplot with a tape and the point where their tapes meet in the middle is the new corner to the plot (**Fig. I-B**).

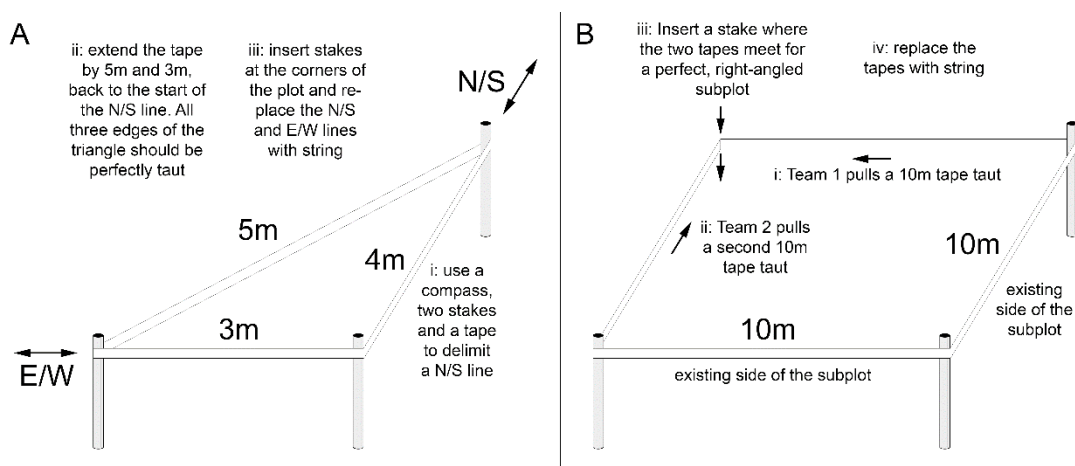


Figure I: Diagrammatic representation of how to string a plot; **A:** setting up a right-angle at the beginning of a plot (note the N/S and E/W lines should be carried on for 100 and 50 m respectively, with a stake inserted every 10 m); **B:** creating square subplots. *Optional: square subplots can be further refined by running a diagonal tape from corner to corner. Opposite corners should be 14.14 m apart.*

J. Tagging trees

Tagging and measuring trees can be done concurrently by 3 people: one to locate the next tree to be tagged and to measure it; one to tag and paint the stems; and one to take notes. For the purpose of this protocol a tree is defined as a free-standing plant (woody or not) that has one or more stem ≥ 5 cm diameter at either 30 cm or 130 cm from the point they leave the ground (i.e. along the stem). All trees fitting these criteria with $>50\%$ of their basal area inside the plot are included in the census. Trees should be tagged systematically moving around each subplot, for example in a clockwise direction (**Fig. J**).

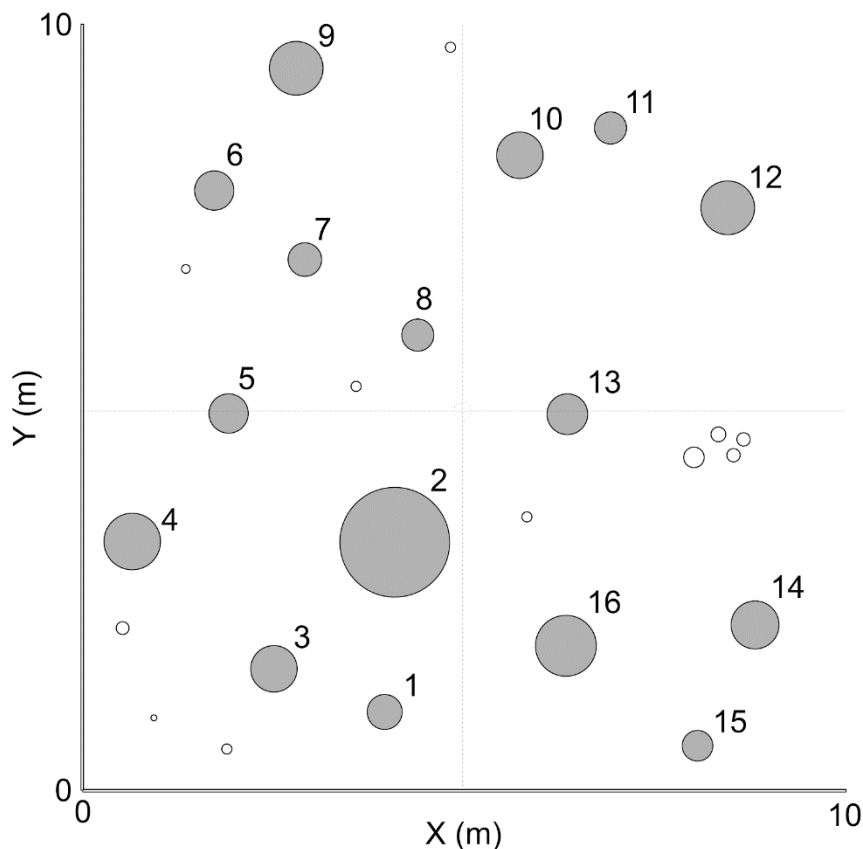


Figure J: Order of measurement for trees in a subplot. Larger circles indicate trees with larger basal areas. Filled circles represent trees meeting the inclusion criteria (≥ 5 cm diameter at either 30 cm or 130 cm POM, see text); non-filled circles represent trees that do not meet the inclusion criteria. Trees are numbered in the order they should be measured and tagged.

The best way to knock in the nail is 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 (i.e. tags should be free to move on the nail as the tree grows). Stems should be tagged at 160 cm height, or exactly 30 cm above the highest point of measurement (POM), consistently above the paint marking the POM (see *Tree Measurement* below). It can be convenient to mark 30 cm on the hammer to ensure consistent placement of the tag, which allows recovery of the POM location in the event the paint does not remain intact.

All trees meeting the above criteria should be tagged: trees with one or more stems that are ≥ 5 cm diameter at either 30 cm or 130 cm (but see section Q below for forests with a dense shrubby layer). Multiple-stemmed trees are tagged only on the largest stem that is ≥ 5 cm at 130 cm:

- Deciduous trees can be completely leafless so check carefully for signs of life. All stems with living cambium at either POM should be measured.
- Cacti meeting the criteria (for trees) should be included. Arborescent cacti often appear dead at the base but living at the top so be aware of cacti that appear as dead.
- Stem succulents (e.g. cacti, bombacoid Malvaceae, tree euphorbias) often have a larger diameter at 130 cm than 30 cm. If this is the case, note this on the field sheet as it may otherwise be flagged as an error during data entry.
- Fallen trees should be checked carefully to see if they are still alive. As with standing trees, they should be tagged 160 cm along the length of the stem from the tree base.
- Liana stems that are ≥ 2.5 cm at any point within 2.5 m from where they root in the ground should be tagged, even if they are < 2.5 cm at 30 cm and 130 cm. Liana stems can be very easy to miss. Each climbing liana stem that meets this criterion and is separately rooted counts as one individual plant (check carefully to ensure the liana is rooted). See detailed section L on liana measurement.

K. Tree measurement

The majority of trees in dry forests have diameters < 10 cm at 130 cm and many stems split below this height. The usual RAINFOR protocol of only measuring trees ≥ 10 cm diameter at 130 cm is therefore insufficient for capturing species diversity, structure and carbon storage in dry forests. We therefore measure all trees with a stem diameter ≥ 5 cm at the usual POM (130 cm) **OR** a stem diameter ≥ 5 cm at an extra POM (30 cm). Measurements are taken for all stems ≥ 5 cm at 130 cm and/or 30 cm.

The POM and extra POM are not the vertical height above the ground; rather, they should be measured as the straight distance along the trunk, even if it is leaning or bent. 30 cm and 130 cm refer to the distance *along the stem from the point the stem leaves the ground*.

Stems should be measured at exactly 130 cm and 30 cm wherever possible. To aid fast yet accurate measurements, it helps to use a pole marked at both heights, pushed firmly into the leaf litter to the mineral soil next to the tree, to define POM (Swaine, et al. 1987; Condit, 1998). **Note:** *If 130 cm OR 30 cm is not used as the POM or Extra POM for any reason, record the height of the POM or Extra POM.*

The exact point of measurement should be marked with chalk by the measurer, and the location then painted with emulsion paint. This enables the relocation of the POM and the accurate remeasurement of the tree. The recommended paint colour depends upon the predominant bark colour in the site. In drier sites, bark is typically pale and red is recommended. In wetter sites, bark is typically darker and yellow paint is recommended. Spray emulsion is quicker to apply than paint applied with a brush but does not last as long. We therefore recommend applying paint with a brush when sites will be recensused.

There are a series of standard codes to record stem and tree condition when alive as well as mode of death. These standard codes must be used and every stem should receive at least one code. Please see the end of this document for details.

1. **Multiple stems:** All stems with a diameter ≥ 5 cm at 130 cm and/or 30 cm are measured, painted, and recorded.
2. **Deformities:** If the tree has a major stem deformity at 130 cm and/or 30 cm, then they should be measured 2 cm below the deformity (Condit 1998). The specific POM height used should be recorded. Deformities include but are not limited to the following:
 - locally thicker stems, supporting side branches.
 - burs/burls (outgrowths associated with anomalous growth).
 - cankers (areas of dead bark).
 - cracks.
 - areas of dead wood (e.g. dead side branches).
3. **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 be lifted but not cut. In rare cases where lianas or stranglers are firmly attached to the tree stem, the diameter can be estimated by holding the tape perpendicular to the stem at the POM, or using an optical method (see below).
4. **Resprouts:** On standing, but broken trees, or fallen individuals, the main stem and resprouts are measured at 130 cm and/or 30 cm POMs from the base of the stem. A resprouting individual is only included if the resprouts are ≥ 5 cm diameter at both/either POMs.
5. **Slopes and fallen or leaning trees:** The height of the 130 and 30 cm POMs are calculated on the downhill side of the tree, and trees that are fallen or leaning are always measured at 130 cm and/or 30 cm POMs 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 often lean downhill and these rules mean there is no confusion regarding the side of the tree used to measure the POM and extra POM. On fallen trees it is difficult to define the base of the trunk accurately – therefore it would be convenient to measure the tree 30 cm below the tag.
6. **Fluted trees and trees with deeply-fissured bark:** Trees that are fluted for their entire length should be measured at 130 cm and/or 30 cm as required. Generally, we try to measure around the fluted stem or deep fissures, not correcting for fissures themselves.
7. **Stilt-rooted trees:** Stilt-rooted trees are absent or rare in dry forests. Stilt rooted individuals should be measured 50 cm above the highest stilt root and at 130 cm if the first measurement is below this. The POM should be recorded.
8. **Buttressed trees:** Large buttressed trees are rare or absent in most dry forests except those dominated by large bombacoid Malvaceae (e.g. *Ceiba* or *Cavanillesia*). Large buttress trees should be left by the measurement team and done separately later: it typically takes two people half a day to measure the large trees in a plot. A single POM should be used above the buttress (unless it finishes < 130 cm). A ladder is essential to reach the POM of some large trees, and in some cases two ladders may be needed to ensure accurate measurement. If the POM cannot be reached, then diameter should be

measured by a climber with a diameter tape; or, if impossible by a climber, then as a last option by digital camera. Measurement by relaskop is not recommended.

- 9. Multistemmed trees:** Multistemmed trees are a common feature of dry forests. For multistemmed trees, all stems with a diameter ≥ 5 cm at 30 cm and 130 cm are measured. If there is clear separation of stems at soil level, two stems are treated as different trees rather than part of the same multistemmed tree even if they likely originated as part of the same tree.

The stem with the largest diameter at 30 cm is the main stem and a tag is placed at 160 cm on this stem. A tag is only placed on the main stem (but see *optional* below). A number of schematic representations of multistemmed trees are shown in Appendix 6 alongside completed field sheets for these trees.

Optional: In some cases, investigators should consider placing a tag on every stem that is separate at 30 cm rather than just the main stem (i.e. one tag per stem rather than one tag per tree). This will significantly increase the time and number of tags required to complete a plot but will allow investigators to track the fates of individual stems with more confidence. We recommend this in plots where turnover of stems is particularly high, where trees routinely have >5 stems, and/or when most trees have multiple stems.

Where multiple tags are used per tree, a continuous number series should be maintained. Do not use a different number or lettered series for secondary stems.

Note 1. *Multiple tags per tree must be used consistently within a plot and ideally across a project. Do not make the decision to use multiple tags per tree on an ad hoc basis, e.g. when particularly complex trees are encountered.*

Note 2. *If multiple tags are used per tree, it is of utmost importance that stems belonging to the same tree are marked clearly and unambiguously on the field sheet. If this is not the case, it will be impossible to distinguish between turnover of stems and trees.*

L. Liana measurement

Lianas present special measurement challenges for long-term plot studies. The RAINFOR protocol includes a range of methods that maximise long-term comparability across sites and through time at individual sites. We reproduce this protocol herein. 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 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), across the whole DRYFLOR and RAINFOR dataset, and with other studies worldwide. This follows the protocol pioneered by Alwyn H. Gentry (Phillips & Miller, 2002).

We include any liana or hemi-epiphyte that reaches 2.5 cm diameter at any point along the stem between 0 and 2.5 m above the ground. 0 is defined as the last rooting point.

For lianas and hemi-epiphytes, record the diameter measurements at three points:

1. at 130 cm along the stem from the principal rooting point (= "d1.3length")
2. at 130 cm vertically above the ground (i.e., 30 cm below the nail in plots where plants are tagged at 1.6 m), (= "d1.3height")

3. and ALSO at the widest point on the stem within 2.5 m of the ground (= "dmax"), including any deformity.

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

Paint all POMs carefully with emulsion paint, just as with trees. Tags should be at a point measured 30 cm above the POM (130 cm vertically above the ground).

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 if not impossible 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 around 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 >2.5 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" or "remet"). 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 2.50 m vertical distance from the ground and attains >2.5 cm dmax is measured (as with all trees that branch at <1.30 m).

For each liana stem (or ascending branch if there are more than one), note the number of tree(s) the liana crown is in and record the tree tag number whose crown is most heavily affected by the liana. 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 data should be recorded:

Trees:

- Subplot number
- Estimated X and Y coordinates from the bottom left-hand corner of the subplot
- Tree tag number
- Identification. To avoid ambiguity this should be recorded **exactly** as recorded on a voucher specimen of the same tree or same species. If known, this should include family, genus and species but in many cases only a morphospecies will be recognised (e.g. "*Cordia* sp. 3"; "Malpighiaceae sp. 2"; "Spiny leaves 3"). In some cases, such as censuses during the dry season this may not be recorded but instead left for a botany team to record later
- Diameter (mm) at 130 cm
- POM, if different from 130 cm
- Extra diameter (mm) at 30 cm
- Extra POM, if different from 30 cm

- Bole form, or descriptive codes of tree form (see Appendix 1 for codes)

Optional measurements of liana canopy infestation of trees and crown illumination are also recommended. Protocol for these are available at <http://www.rainfor.org/en/manuals/in-the-field>, and at the end of this document (see Appendix 3).

Optional estimates or measurements of crown diameter should also be considered:

- Use a 50 m tape. Two people measure the width of the tree crown along its widest axis followed by the axis perpendicular to this (**Fig. M**).
- It may be useful for a third person to shake the tree trunk to help clarify which branches belong to the tree.
- Note: for multi-stemmed trees, take a single measurement for the entire tree (the sum of the canopy of all stems), not a measurement for every stem.
- See Loubata and Feldpausch (2020) and Loubata et al. (in review) for crown diameter protocol.

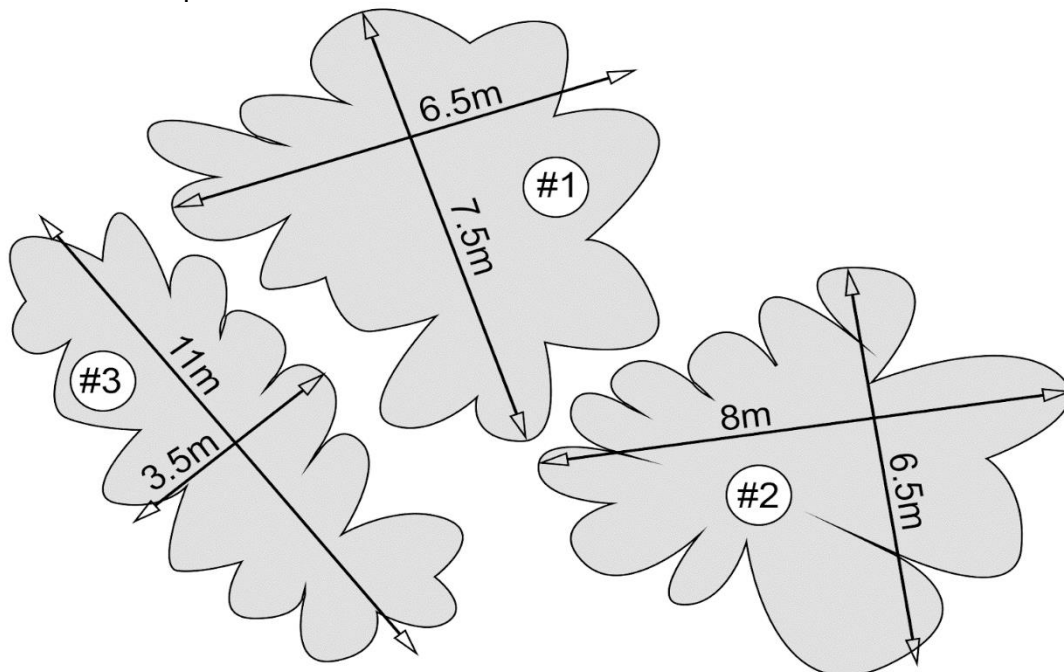


Figure M: *Optional* protocol for estimating tree crowns. Crowns (grey) of individual trees are shown as viewed from above or below the crowns, white circles indicate tree tag numbers, and arrows indicate measurements. Tree #1 has a crown diameter of 7.5 × 6.5 m; #2 has a crown of 8 × 6.5 m; #3 has a crown of 11 × 3.5 m.

Lianas:

- Subplot number
- Estimated X and Y coordinates from the bottom left-hand corner of the subplot
- tag
- Family and species name (in some cases, such as censuses during the dry season this may not be recorded but instead left for a botany team to record later)
- Diameter (mm) at d1.3length
- Point of measurement of d1.3length, if not 130 cm along the branch
- Diameter (mm) at d1.3height
- Point of measurement of d1.3height, if not 130 cm above the ground
- Diameter (mm) at dmax
- Point of measurement of dmax

Sub-plot:

The following measurements are recommended but not essential:

- Sketch of tree locations
- Slope of subplot boundaries
- Soil texture and drainage

Plot:

- Latitude and longitude of all four plot corners
- Elevation of all four plot corners
- Bearings of plot boundaries
- Local landmarks to assist plot relocation

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 (Feldpausch et al., 2011, 2012). 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. Ideally, every tree in the plot should have its height measured. In practice, this may not be possible due to time restrictions. If this is the case the following procedure is recommended:

- Estimate the heights of all trees in the plot. All heights should be estimated by the same person to limit differences of opinion.
- Excluding trees coded as leaning, rotten, broken, forked below 5 m, fallen or resprouted, aim to sample 50 trees at random per plot for height measurement, while including the ten trees with the largest diameter in this sample.

This procedure has been assessed for tropical moist forests and found to provide a practical solution to reduce the uncertainty of height-diameter allometry while not taking more than one day in the field for one person (Sullivan et al., 2018).

The 50 measurements should ideally be made directly (e.g., with 2 m collecting poles linked together to provide a graduated measure), or by laser hypsometer, if not available then manual trigonometric methods are acceptable. Note that all methods have potential limitations or sources of error, for example laser hypsometers rarely function at distances of <10 m. Record the method used.

O. Wood density measurements

A protocol for providing a rapid assessment of stand-level wood density is detailed in the RAINFOR Field Manual for Plot Establishment and Remeasurement (<http://www.rainfor.org/en/manuals/in-the-field>).

P. Voucher collections

Before fieldwork, all relevant permits (e.g. nationwide collection permit; national park permit; genetic permit; export permit) should be secured. DO NOT start fieldwork without the necessary permits! An agreement should be made with a local and/or main project herbarium to ensure they are happy to receive sterile plot vouchers and are sufficiently well-resourced to do so. Ideally, the main project herbarium should be one that can facilitate the inclusion of voucher data and images in an online database.

Vouchers from across the plot network should be compared to ensure identifications are consistent. Ideally, this should be done by expert botanists once all the voucher specimens are collected in the main herbarium.

For new plots, a collection should be made for a **minimum** of one individual per species or morphospecies (more for variable species). All individuals that cannot be identified to species or morphospecies with confidence should also be collected.

Photographs of all characters useful for botanical identification should be taken, and all relevant characters and observations (e.g. presence and colour of exudate; colour of flowers; bark characteristics) should be included in the collection label. Voucher collections should be dried on the day of collection in an air drier. When possible (e.g. if permits allow), a silica gel dried collection should be taken along with each voucher collection. Botanical voucher collection, identification, and specimen curation are specialised and time-consuming processes and a plot cannot be considered complete until these processes are complete. Electronic copies of photographs of collected vouchers should be labelled including the collector last name and collection number in the file name.

Every voucher specimen should be accompanied by a collection label with the following details:

- Name of the principal collector.
- Collection number (preferably a sequential plain number for the collector; avoid complex coding).
- Date of collection. Use a format such as “3 ii 2019” or “3 Feb 2019” rather than 3/2/2019 or 2/3/2019 to clarify which number refers to the days and months.
- Plot name and tree tag number.
- Scientific name, if known.
- Common name, if known.
- The name used in the plot for this species (e.g. “Annonaceae sp. 1” or “spiny palm”). This will aid linking the voucher with all individuals of the species in the plot, which can become complex if the voucher is reidentified.
- A description of the plot locality. This can be the same for all collections made within a plot, and should be a short, unambiguous description of how to reach the plot *assuming anyone reading the label has no further information on the locality of the plot.*
- Altitude and coordinates of the plot.
- A brief description of the predominant habitat at the plot. This can be the same for all collections made within the plot.
- A description of the plant. Characters that will not survive the drying process (e.g. colour, smell, latex) and those too large to collect (e.g. tree height, length of palm leaves) should be noted in the description.
- Indication if a silica sample was made (e.g., Silica: yes/no).
- Indication if a spirit collection was made (e.g., Spirit: yes/no).
- Indication if field photographs were taken (e.g., Photos: yes/no).
- Indication if the voucher was preserved in ethanol during the drying process.

An example of a **minimum collection label** is presented in appendix 5. This appendix includes examples of plot locality and habitat descriptions, and plant descriptions.

For further information, please refer to the RBGE Guide to Collecting Herbarium Specimens in the Field:

<https://rbge-publications.myshopify.com/products/guide-to-collecting-herbarium-specimens-in-the-field>

Optional: If there are no expert botanists present as a part of the field team, or if the field team (which may include expert local ecologists, guides, loggers, or parataxonomists) are not familiar with the local flora, we recommend a collection is made of every individual in the plot. This may also be desirable for specific projects (e.g. to investigate plot-wide population genetic structure). Note however that this will significantly increase the time required to voucher the plot.

Q. Optional Smaller trees protocol

In shrubby dry forest physiognomies (e.g. see Torello Raventos et al., 2013), the standard protocol for larger trees may not capture the majority of tree biodiversity or biomass and misses out on essential structural variation. It is therefore important in many cases to reduce the standard diameter required for stem inclusion from ≥ 5 cm to ≥ 2.5 cm. This will however significantly increase the time required to complete the plot beyond the timings outlined below (**R.**). We present here an optional protocol using subplots that represents a reasonable compromise between extra data and time:

1. *Subplot Selection:* Select 5 subplots across the plot. The subplots chosen should represent a compromise between (i) avoiding the most potentially disturbed parts of the plot (i.e. the 50 m and 100 m baseline); (ii) covering the whole N-S and E-W range of the plot, and (iii) random placement. For example, in a 100 × 50 m plot with 10 × 10 m subplots, we recommend the following design (**Fig. Q**). This plan was designed using the following, pseudo-random protocol: (i) subplots with double borders were excluded, to avoid the baselines; (ii) the remaining subplots were grouped into lines of two; (iii) a subplot was chosen from each group at random; (iv) subplots were rejected if they were placed in the same horizontal line as one more subplot (with the exception of the last, chosen subplot).

Perform steps 2 to 7 below only in the selected subplots

5	6	15	16	25	26	35	36	45	46
4	7	14	17	24	27	34	37	44	47
3	8	13	18	23	28	33	38	43	48
2	9	12	19	22	29	32	39	42	49
1	10	11	20	21	30	31	40	41	50

Figure Q: Suggested plan for intensive subplot sampling in a half-hectare (100 × 50 m) plot with 10 × 10 m subplots. Numbers indicate subplots. Subplots highlighted in light grey are discounted as they run adjacent to the primary axes of the plot (i.e. the plot baselines) and are likely to experience increased disturbance. Subplots highlighted in dark grey are selected for intensive sampling. *Note: if the baselines are not running along the axes highlighted in light grey this design should be altered to avoid disturbed areas of the plot.*

2. *Tagging trees:* All trees with one or more stems that are ≥ 2.5 cm diameter at either 30 cm or 130 cm should be tagged.

Trees not meeting the entry criteria for the main plot census (i.e. those where all stems < 5 cm diameter at 30 cm and 130 cm) should be given a new tag.

Trees that did meet the entry criteria for the main plot census (i.e. one or more stems that are ≥ 5 cm diameter at either 30 cm or 130 cm) should be assessed to determine whether any stems enter at the more inclusive criteria. No new tag should be given to these trees; rather, the existing tag should be noted.

It is essential to ensure trees tagged with this optional protocol cannot be confused with those tagged during the main census (see K: *Tree Measurement* above). We recommend using a different style of tree tag or a number sequence differentiated from those in the main plot by > 100 tags.

3. *Tree measurement:* All stems with a stem diameter ≥ 2.5 cm should be measured at the usual POM (130 cm) **OR** a stem diameter ≥ 2.5 cm at the extra POM (30 cm). Measurements for all stems ≥ 2.5 cm at the POM and extra POM are taken, although all measurements for stems ≥ 5 cm should already have been taken.

For full stem measurement criteria, see above.

4. *Liana measurement:* all lianas ≥ 2.5 cm should already have been measured (see above), and we do not recommend including lianas < 2.5 cm in the census.

5. *Tree bole length and total tree height:* measured as above.

6. *Wood density measurements:* as above.

7. *Voucher collections:* as above.

If the plot structure is in between a dry forest and savanna physiognomy, additional measurements may be desirable. A description for such additional measurements on low vegetation can be found in (Torello Raventos et al., 2013).

R. Suggested timing and personnel for a new 0.5-ha plot

Dry forests are very physiognomically diverse and differ greatly in their canopy height and alpha diversity. These factors have a large effect on the time taken to establish a plot. We present indicative timings for plots of varying levels of plot complexity.

Locating and stringing a 0.5 ha plot with 10 x 10 m subplots:

- A relatively sparse plot (< 500 stems and few shrubs) on flat ground: 3-4 people, 1 day
- A relatively dense plot (> 2000 stems and many shrubs) on undulating ground: 3-4 people, 2 days.

Tree tagging, painting, mapping and measurement:

- A relatively sparse plot (< 500 stems, few multi-stemmed trees): 3 people, 1.5 days.
- A relatively dense plot (> 2000 stems, many multi-stemmed trees): 3 people, 5 days.

Tree height measurements: 2 people, 0.5 days.

Botanical collection:

- A relatively simple plot (canopy <10 m, <20 species): 2 people, 1 day.
- A relatively complex plot (canopy >20 m, 30-60 species): 3 people, preferably including a tree-climber, 3-5 days.

Total: 12 to 40 person-days

Optional ≥ 2.5 cm diameter subplots: 3 people, 0.5-1.5 days.

Optional crown diameter estimates: 2-3 people, 1 days

Additional time may need to be allocated for logistically-complex sites, significant rain delays, unforeseen circumstances, and breaks for field-team rest and recreation. The latter is particularly important for hot or physically demanding sites.

Note: if carrying out the botanical collection separately (for example if the plot was established during the dry season) the timing estimates above are still accurate.

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 and, where available, any edge stakes. This is quite straightforward where the understorey 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 map of the trees (e.g. from the RAINFOR database), if available, can help. Recorded compass bearings for plot edges are obviously helpful too but extremely time consuming and 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.

Note: it may be necessary to replace existing stakes following their loss or removal from a site, degradation, or fire. In the absence of disturbance, metal stakes should last c.1 decade in relatively wet dry forest sites but it is advised to take sufficient stakes to replace all stakes in remote plots, or to budget for their replacement in relatively accessible plots.

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. Maps of trees 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.

C. Dealing with buttressed or deformed trees

Buttresses and other deformities require careful siting of points of measurement (POMs), and owing to tree growth these POMs may need to be changed. We have developed field approaches aiming to help obtain unbiased, above-buttress, estimates of plot basal area and growth. The approach used depends on whether previous measurements were 'good' or 'bad'. ***The field team must make a clear decision and record this on the field sheets.*** 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. When re-measuring 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 to ensure there is always a consistent, non-buttressed measurement of diameter growth.

D. Mortality and recruitment

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

There are a special set of codes for tree status (alive + dead). See Appendix 1.

When remeasuring, two people can 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 or orange 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 indicate a previous 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 re-measure immediately to check. The person taking notes should check carefully that no trees have been missed, particularly fallen trees. When re-censusing, 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

Re-censusing 0.5-ha plot

Locating and stringing the plot: 3 people, 0.5-1 day(s)

Tree tagging, painting and measurement: 3 people, 2-4 days

Botanical collection of new recruits: 1-2 people, 1 day (less in low diversity forests)

Total ~8-17 person-days

Additional time may need to be allocated for significant rain delays, breaks for field-team rest and recreation, and unforeseen circumstances. Botanical collection-times are very variable, being sensitive to the difficulty (number of species), weather conditions, and the physical skills and technical knowledge of the team.

G. Data processing

Data collected during the DRYFLOR field campaigns are uploaded to ForestPlots.net (www.ForestPlots.net; Lopez-Gonzalez et al. 2011). Please follow the protocol described in the "Post-field data handling" section of the ForestPlots.net manual to prepare your data for upload. After the data have been uploaded, follow the quality control protocol. The quality control protocol includes information on how to deal with data processing problems like "unlikely recruits" (large trees that "appear" in the plot), missing census information of trees and "abnormal growth". In all cases, a record should be kept of the original measurement, the presumed error, and the correction made. The ForestPlots.net database includes functionality for recording all such data manipulations (see ForestPlots.net manual).

Floristic presence-absence and abundance data should be uploaded to the DRYFLOR database (www.dryflor.info) following the DRYFLOR data entry protocol (Weintritt & Pullan, 2016). This database currently lacks the functionality to record multiple censuses from a single site and therefore to track floristic dynamics change over time thus it is only necessary to upload these data following the initial survey.

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Appendix 1 - Fieldwork Database Codes for Tree Stems

NOTE: Every stem of a multi-stemmed tree should receive one or more code

FLAG 1: ALIVE STATUS (if the tree is dead, write "0" in this column)

a=	Alive normal, should be used by itself unless a tree is a recruit (n) or multi-stemmed (h).
b=	Alive, broken stem/top & resprouting, or at least live phloem/xylem. Write in the comments column at what height the stem is broken.
c=	Alive, leaning by $\geq 10\%$. The leaning code cannot be used with the fallen code 'd'.
d=	Alive, fallen (e.g. on ground)
e=	Alive, tree fluted or/fenestrated
f=	Alive, hollow
g=	Alive, rotten
h=	Multiple stemmed individual. Each stem of a multi-stemmed individual receives this code. Should be used with other code - e.g. if a tree is broken and with multiple stems use 'bh'.
i=	Alive, no leaves, few leaves
j=	Alive, burnt
k=	Alive, snapped <130 cm (therefore the diameter at 130 cm is 0 mm)
l=	Alive, has liana ≥ 10 cm diameter on stem or in canopy
m=	Alive, covered by lianas. Use where canopy is at least 50 % covered by lianas, even if no individual liana reaches 10 cm diameter.
n=	Alive, new recruit. Always use with another code - e.g. if a tree is normal and new then use the code 'an', if a tree is broken and a new recruit the code is 'bn'.
o=	Alive, lightning damage
p=	Alive, Cut
q=	Alive, Peeling bark (bark loose/flaking)
s=	Alive, has a strangler
w=	Alive, has wound and/or cambium exposed
x=	Alive, elephant damage
y=	Alive, termite damage
z=	Alive, declining productivity (nearing death)

Note: - Tree Alive Status Codes can be used together in any combination. The only exceptions are codes 'a', 'c' and 'd'. Please read the notes when using these codes!
- If 'strangler', write it in the **comments column**.

FLAG 2: MODE OF DEATH (if the tree is alive, write "1" in this column)

All dead trees have two or three letter codes.

1. *Physical mechanism of mortality (how the tree died)*

a=	Standing
b=	Broken (snapped trunk)
c=	Uprooted (root tip-up)
d=	Standing or broken, probably standing (not uprooted)
e=	Standing or broken, probably broken (not uprooted)
f=	Standing or broken (not uprooted)
g=	Broken or uprooted, probably uprooted
h=	Broken or uprooted, probably broken
i=	Broken or uprooted (not standing)
k=	Vanished (found location, tree looked for but not found)
l=	Presumed dead (location of tree not found e.g. problems, poor maps, etc.)
m=	Unknown

2. *Number of trees in Mortality event*

p=	Died alone
q=	One of multiple deaths
r=	Unknown

3. Killed or killer process

- j=** Anthropogenic
- n=** Burnt
- o=** Lightning
- s=** Unknown whether killed or killer
- t=** Killer of at least one other tree >10 cm DBH
- u=** Killed, no more information
- v=** Killed by tree that died broken
- w=** Killed by another tree that uprooted
- x=** Killed by branches from dead standing tree
- y=** Killed by branches fallen from living tree
- z=** Killed by strangler
- 2=** Killed by liana
- 3=** Killed by strangler / liana weight [tree died broken or fallen]
- 4=** Killed by strangler / liana competition [tree died standing]
- 5=** Killed by elephant
- 6=** Killed by termites
- 7=** Killed by wind

Note: Select one code from each category. For example a dead tree that is standing, died alone and was killed by lightning would be 'apo'. For multiple deaths the numbers of trees that died should be recorded and written in the comments column. For broken trees the height at which the breakage occurred should be recorded in the comments column

FLAG 3: MEASUREMENT TECHNIQUE

- 0=** Normal measurement, tape measurement
- 1=** Relascope
- 2=** Digital camera
- 3=** Estimate
- 4=** Ladder, with diameter tape
- 5=** Unknown
- 6=** Dendrometer

FLAG 4: POST-FIELD DATA MANAGEMENT

- 0=** No retrospective modification
- 1=** Extrapolated from previous measurements forwards or final measurement backwards
- 2=** Corrected expected typographical error
- 3=** Interpolated (two good measurements either side of a problem measurement)
- 4=** Estimated using median growth rates
- 6=** The POM was changed because it had to be, good measurement before
- 7=** Zero growth rate assumed
- 8=** Another transformation, see notes/ not clear what was done
- R=** Correction using Ratio between non-affected and affected measurement (i.e. deformation, bark peeling)

FLAG 5: HEIGHT MEASUREMENT TECHNIQUE

Total Tree Height - Height should be recorded in meters and the height measurement code recorded in the Flag 5 column. If height was not measured, leave the height column and Flag 5 empty.

- 1=** Estimated by eye.
- 2=** Manually by trigonometry (clinometer).
- 3=** Manually by trigonometry (clinometer), carefully trained.
- 4=** Laser or ultrasonic distance to tree, electronic tilt sensor for angle.
- 5=** Laser hypsometer from directly below crown, "last return" filter function.
- 6=** Directly (e.g. climbing, cutting, adjacent tower, tape attached to pole).

Note: Only one measurement technique and one data post-field data management (Flag 4) code should be selected for each tree, except when a tree has POM change, then write "6" for POM change together with another code for Data Manipulation, e.g. "60"

Appendix 2 - KEY to the Mode of Tree Death

1A	Trunk standing.....	2
1B	Fallen trunk on the ground without obvious stump.....	6
2A	Standing with fine dead branches (<10 cm), and no resprouts in the main trunk.....	died standing (code: a)
2B	Standing stump without fine dead branches and with main trunk on the ground.....	2
3A	Stump with dead resprout(s) <5 cm.....	died broken (code: b, also note broken height by m)
3B	Stump without resprouts or with dead resprout(s) >5 cm.....	3
4A	Trunks scattered around with no specific coherent direction.....	died standing (then broken afterward) (code: a)
4B	Only with one main trunk on the ground, or a few but with one coherent direction.....	4
5A	Vegetation damage noticeable and the fallen trunk with intact dead fine / crown branches (<10 cm, not resprouts), the trunk on the ground is still hard, and/or the standing stump with jagged end.....	died broken (code: b, also note broken height by m)
5B	Vegetation damage not noticeable and the fallen trunk without fine / crown branches, the fallen trunk with fungi perpendicular to the ground, and/or the end of the stump is somewhat smooth/ soft.....	died standing (then broken afterward) (code: a)
6A	Root bole partially or wholly raised ('tip-up') and with some soil exposed	died uprooted (code c)
6B	Root bole not raised.....	7
7A	Vegetation damage noticeable, with fine branches, and/or with resprout(s)	broken at 0 m (code b, note broken height at 0 m)
7B	Vegetation damage not noticeable, roots in advanced decomposition stage, and/or with fungi perpendicular to the ground.....	died standing, roots decomposed, and then fallen (e.g., palm trees) (code: a)

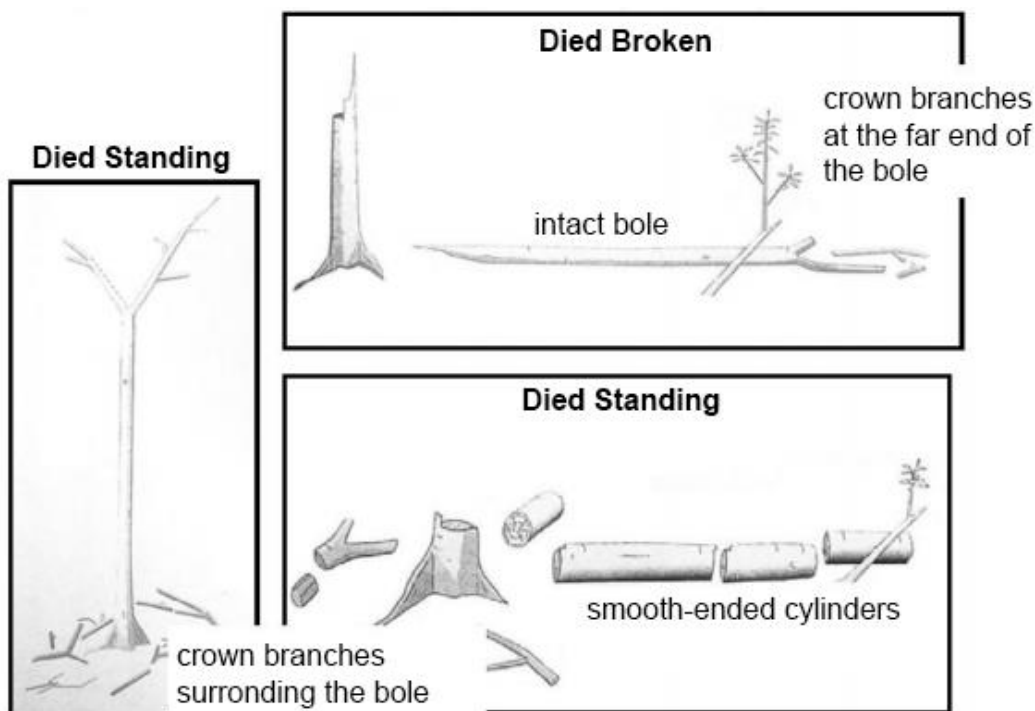
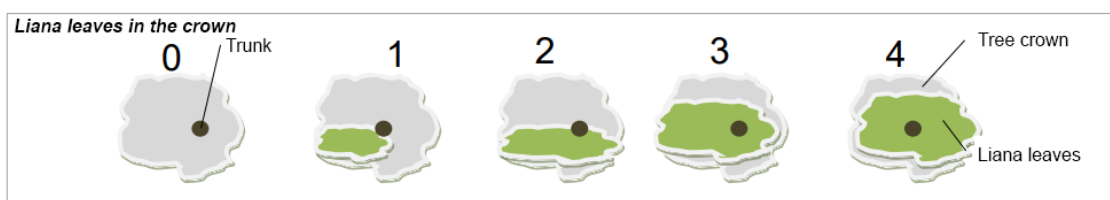


Figure from Gale (1997)

Appendix 3 - DRYFLOR & RAINFOR Fieldwork Database Codes for Liana Infestation (LI), Crown Illumination (CI) and Crown Formation (CF) Index



Liana Infestation:

- 0 No lianas in the crown
- 1 1-25% of the crown covered in liana leaves
- 2 >25-50% of the crown covered
- 3 >50-75% of the crown covered
- 4 >75% of the crown covered

Crown Formation Index

Crown Formation:

- 0 Crown intact, not broken
- 1 1-25% of the crown broken
- 2 > 25-50% of the crown broken
- 3 >50-75% of the crown broken
- 4 >75% of the crown broken

The DRYFLOR and RAINFOR networks use a modified form of the Dawkins index (Dawkins 1958), as in Synnott (1979) and Moravie (1999) (figure modified from Phillips et al. 2018).

Index Definition

- 5** Crown completely exposed to vertical and lateral light in a 45 degree curve, e.g. emergent
- 4** Crown completely exposed to vertical light, but lateral light blocked within some or all of the 90 degree inverted cone encompassing the crown
- 3b** High vertical illumination (>50%)
- 3a** Some vertical light (<50% of the vertical projection of the crown is exposed to vertical light)
- 2c** High lateral light
- 2b** Medium lateral light
- 2a** Low lateral light
- 1** No direct light (crown is not lit directly vertically or laterally)

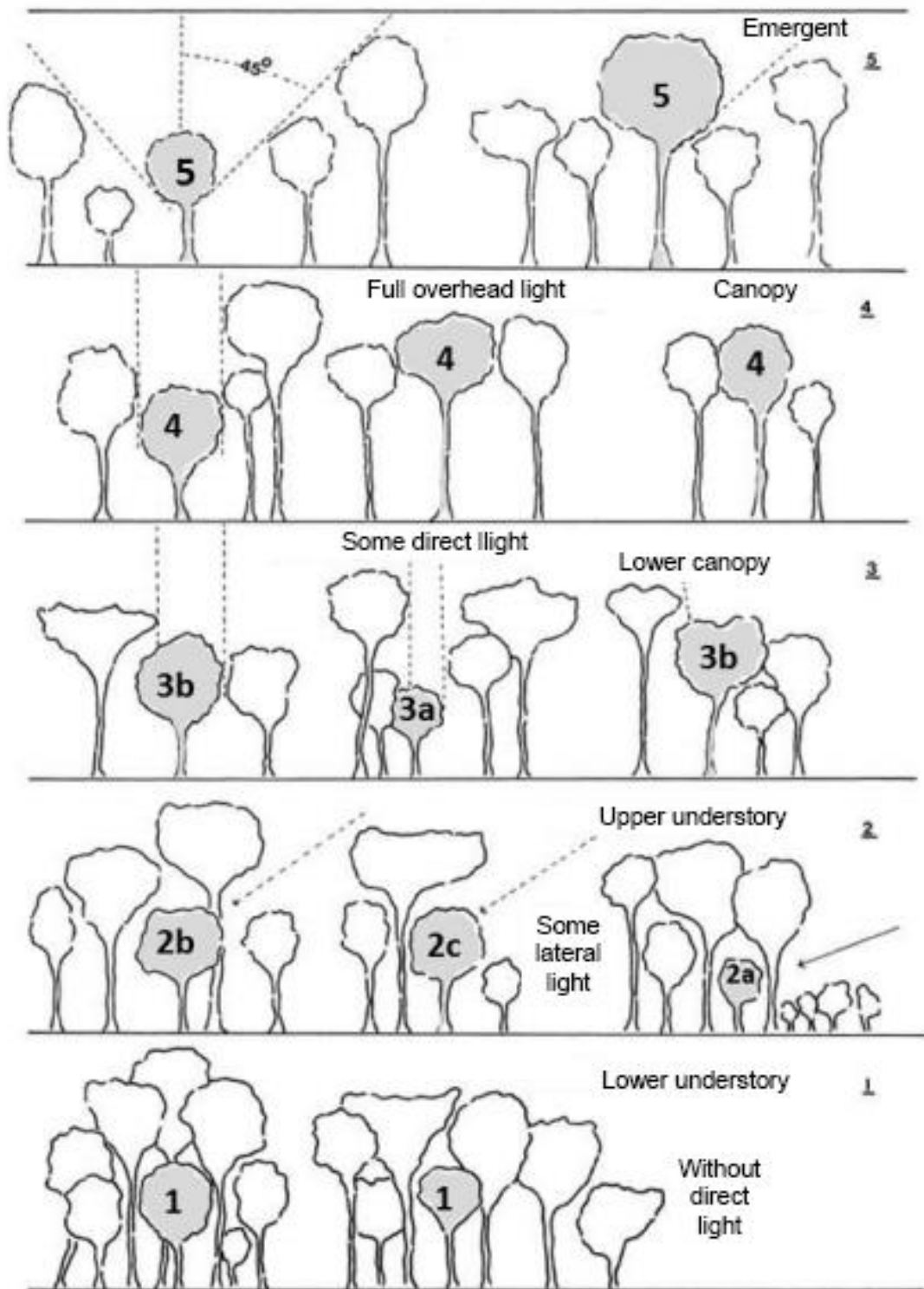


Figure reproduced from Synnott, T.J. (1979). Synnott, T.J. (1979). A manual of permanent plot procedures for tropical rainforests. Tropical Forestry Papers no. 14. 67pp. Department of Forestry Commonwealth Forestry Institute, University of Oxford. UK. ISBN:0 85074 031 2. ISSN:0141-9668.

Appendix 4 - DRYFLOR & RAINFOR Fieldwork Database **Codes for Liana Stems**

NOTE: Every stem of a multi-stemmed liana should receive one or more code

FLAG 1: ALIVE STATUS (if the liana is dead, write "0" in this column)

- a=** Alive normal, should be used by itself unless liana is a recruit.
- b=** Alive, broken stem/top & resprouting, or at least live phloem/xylem. Write in the comments column at what height the stem is broken.
- c=** Alive, leaning by $\geq 10\%$. The leaning code cannot be used with the fallen code 'd'.
- d=** Alive, fallen (e.g. on ground).
- e=** Cabled.
- f=** Alive, hollow.
- g=** Alive, rotten.
- h=** Multiple stemmed individual, i.e. two or more stems $>99\text{mm}$ at maximum diameter, branching $<1.3\text{ m}$ height. Each stem of a multi-stemmed liana receives this code. Should be used with other code - e.g. if a liana is leaning and with multiple stems use 'ch'.
- i=** Alive, no leaves, few leaves
- j=** Alive, burnt
- k=** Alive, snapped $<1.3\text{ m}$ (therefore the diameter at 1.3 m is 0 mm).
- l=** Alive, itself has liana $\geq 10\text{ cm}$ diameter on stem or in canopy.
- m=** Itself covered by lianas. Use where canopy is at least 50% covered by lianas, even if no individual liana reaches 10 cm diameter.
- n=** New recruit. Always use with another code- e.g. if liana is normal and new then use the code 'an', if liana is broken and a new recruit the code is 'bn'.
- o=** Lightning damage
- p=** Cut
- q=** Peeling bark (bark loose/flaking)
- s=** Has a strangler.
- u=** Elliptical.
- z=** Alive, declining productivity (nearing death)

Note: *Liana Alive Status Codes* can be used together in any combination. The only exceptions are codes 'a', 'c' and 'd'. Please read the notes when using these codes!

Main Host Status:

- 1=** Climbs living host in plot
- 2=** Climbs dead host in plot
- 3=** Climbs living host outside plot
- 4=** Climbs dead host outside plot
- 5=** Climbs tree $<10\text{ cm}$ diameter
- 6=** Does not climb any tree Note: Record the "Main Host" Tag Number in the "Main Host" column. If the "Main Host" is outside the plot, record this information in the comments section.

FLAG 2: MODE OF DEATH (if the liana is alive, write "1" in this column)

All dead lianas have two or three letter codes.

1. Physical mechanism of mortality (how the liana died)

- a=** Standing
- b=** Broken (snapped stem)
- c=** Fallen
- d=** Standing or broken, probably standing (not uprooted)
- e=** Standing or broken, probably broken (not uprooted)
- f=** Standing or broken (not uprooted)
- g=** Broken or uprooted, probably uprooted

- h=** Broken or uprooted, probably broken
- i=** Broken or uprooted (not standing)
- k=** Vanished (found location, liana looked for but not found)
- l=** Presumed dead (location of liana not found e.g. problems, poor maps, etc.)
- m=** Unknown

2. *Number of woody stems in Mortality event*

- p=** Died alone
- q=** Died with Host
- r=** Unknown

3. *Killed or killer process*

- j=** Anthropogenic
- n=** Burnt
- o=** Lightning
- s=** Unknown whether killed or killed
- t=** Died with host that the liana killed
- u=** Died with host tree, no more information
- v=** Died with host that died broken
- w=** Died with host tree that died uprooted
- x=** Died due to fallen branches of dead host tree
- y=** Died due to fallen branches of living host tree
- 4=** Killed by strangler / liana competition [liana died standing]
- 5=** Fell from living, undamaged host tree

Note: Select one code from each category. For example a dead liana that is fallen, died alone and was killed by branches from a living host tree would be 'cpy'.

For multiple deaths the numbers of lianas that died should be recorded and written in the comments column.

For broken lianas, the height at which the breakage occurred should be recorded in the comments column

FLAG 3: MEASUREMENT TECHNIQUE

- 0=** Normal measurement, tape measurement
- 3=** Estimate
- 5=** Unknown
- 6=** Caliper
- 7=** Geometric Mean (Max, min dimensions)

FLAG 4: POST-FIELD DATA MANAGEMENT

- 0=** Normal measurement, no retrospective modification
- 1=** Extrapolated from measures of same diameter type
- 2=** Corrected expected typographical error
- 3=** Interpolated from measures of same diameter type
- 4=** Estimated using median growth rates
- 7=** Zero growth rate assumed
- 8=** Another transformation, see notes/ not clear what was done
- 9=** Extrapolated using ratio of diameters from later census
- 10=** Extrapolated using mean ratio of diameters for taxon

Note: Only one measurement technique and one data post-field data management (Flag 4) code should be selected each liana and each diameter should have a measurement technique and diameter type. Comments: Everything else!

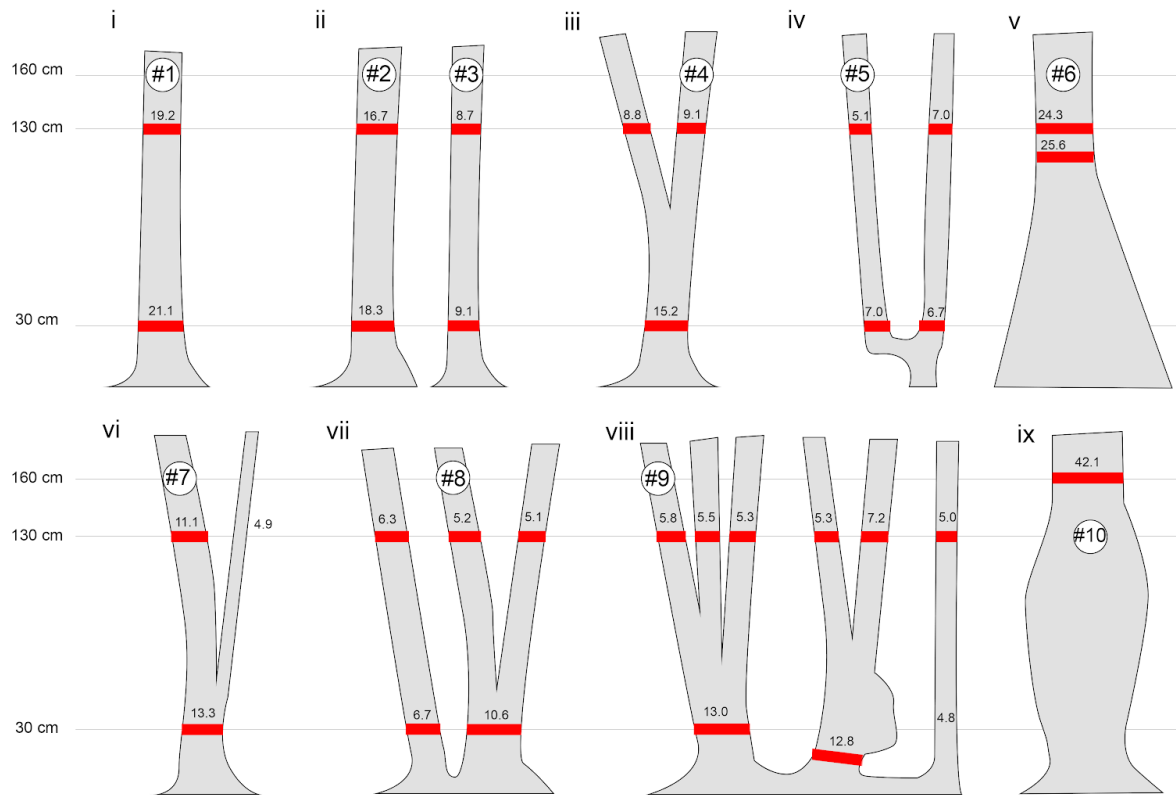
Appendix 5 - Minimum voucher specimen label

FLORA OF BRAZIL	Country displayed prominently
ROYAL BOTANIC GARDEN (E)	Sponsoring institute
_____	Plant family, if known
Family: ANNONACEAE	Genus, species and authority of name, if known
<i>Annona leptopetala</i> (R.E.Fr.) H.Rainer	Country, higher- and lower-order administrative regions
Locality: Brazil, Bahia State, Caetité Municipality	Short, unambiguous description of how to reach the plot, including the name of the nearest settlement
c.2.5 km NW of BA-156 from Caetité to Brejinho das Ametistas, reached via windfarm access road.	GPS coordinates and altitude of the plot
14° 13' 30" S, 42° 31' 37" W (WGS84), 889m.	Unique plot code and tag number of the tree from which the voucher was taken
Plot Code and Tree Number: CAE-01: Tag #302	Name used on the plot field sheets. This serves to link the voucher to all individuals of the same species in the plot. This may be a species, morphospecies, or nickname
Name used in plot: Annonaceae sp. 1	Short habitat description. This allows botanists to rule out possible species during the identification process
Habitat: Semideciduous forest with a canopy >10m. Relatively open at ground level, except in treefall gaps. Some large lianas. No CAM layer but occasional shrubs and terrestrial orchids.	Description of the plant. This should include all characters that may be useful for identification but will not be preserved on a herbarium specimen, including but not limited to: habit, size, colours, smells, latex, bark characters, shapes
Description: Tree to ca. 4m. Bark brown, rough. Young stems with smooth bark, peeling in strips. Leaves with felty texture and medicinal scent when crushed. Sterile.	Details of any associated material collected
Associated material collected: Silica dried material for DNA, photographs.	Name of collector(s) and unique collector number
Collector: Peter W. Moonlight 641	Name of determining botanist, acronym of their herbarium, and determination date
Det by: Peter W. Moonlight (E) 29 xi 2019	Date of collection
Date: 29 iii 2017	

An example of a minimum herbarium label for a plot voucher. Many herbaria will have a preferred shape, size and layout, and labels should be prepared in the format of the herbarium that has agreed to accept the voucher material. The herbarium label shown here is in the layout preferred by the Royal Botanic Gardens Edinburgh, and is provided to show the data that should be included on a herbarium label. Note: the *locality*, *GPS coordinates*, *altitude* and *habitat description* can be the same for every collection made in the plot.

Appendix 6 - Complex Trees

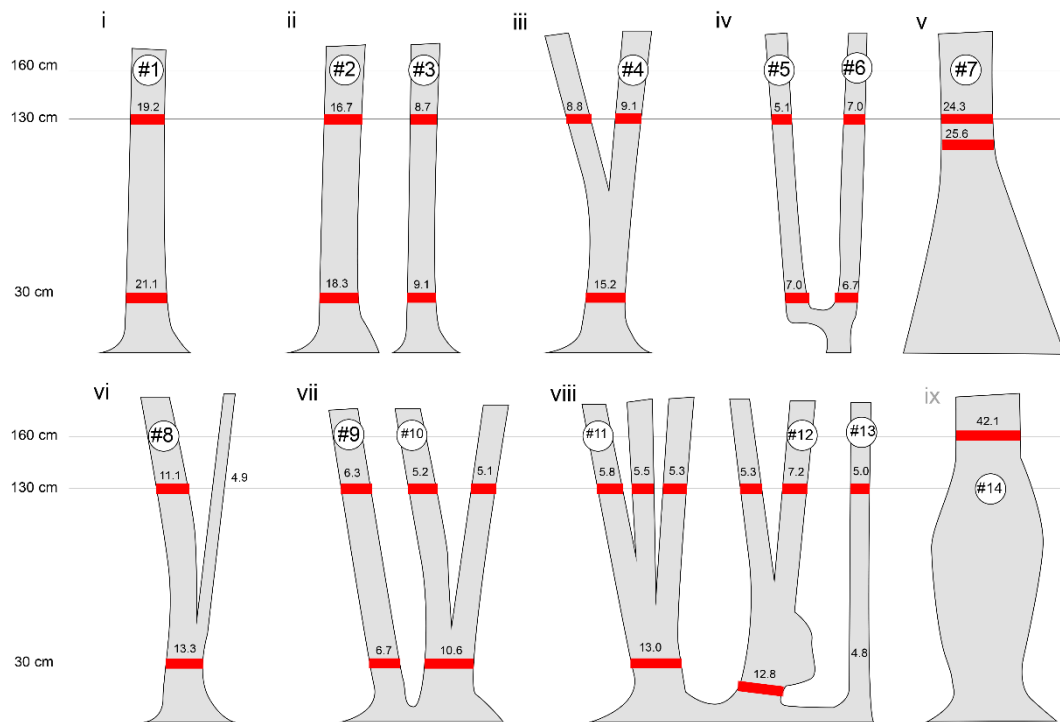
Example 1, using the usual protocol with one tag per tree



Census Date: 2 xii 2019					Field Team: Carlos Rodriguez, Bridgette Morales, John Smith, Sally Jones (Botanist)															
Tag No	Stem	T1	X	Y	Family	plot identification	D	POM1300	Extra D	Extra POM 300	Flag1	Flag2	Flag3	Flag5	Li	Cl	Height	Voucher code	Notes	
1	-	1	3	1	Annonaceae	Annonaceae sp. 1	19.2	-	21.1	-	a	1	0	0	1	0	4	9.5	PWM 1302	
2	-	1	3	2	Annonaceae	Annonaceae sp. 1	16.7	-	18.3	-	b	1	0	0	1	1	3a	5		Broken at 5m
3	-	1	3.2	2	Annonaceae	Annonaceae sp. 1	8.7	-	9.1	-	a	1	0	0	1	1	3b	6		
4	a-i	1	4	3	Annonaceae	Annonaceae sp. 1	9.1	-	15.2	-	h	1	0	0	1	0	1	3.5		
-	a-ii	-	-	-	-	-	8.8	-	-	-	h	-	-	-	-	-	-	-		
5	a	1	5	3	Annonaceae	Annonaceae sp. 1	5.1	-	7	-	h	1	0	0	1	2	2a	5.5		
-	b	-	-	-	-	-	7	-	6.7	-	h	-	-	-	-	-	-	-		Stem diameter larger above
6	-	1	5.5	3	Leguminosae	Dalbergia sp. 1	24.3	-	25.6	115	a	1	0	0	1	1	5	16.5	PWM 1303	
7	-	1	6	3	Annonaceae	Annonaceae sp. 1	11.1	-	13.3	-	a	1	0	0	1	2	2c	7.6		
8	a-i	1	8	2	Annonaceae	Annonaceae sp. 1	5.2	-	10.6	-	h	1	0	0	1	1	4	8		
-	a-ii	-	-	-	-	-	5.1	-	-	-	h	-	-	-	-	-	-	-		
-	b	-	-	-	-	-	6.3	-	6.7	-	h	-	-	-	-	-	-	-		
9	a-i	1	9	1	Combretaceae	Terminalia sp. 1	5.8	-	13	-	h,m	1	0	0	1	4	2b	6.5	PWM 1304	
-	a-ii	-	-	-	-	-	5.5	-	-	-	h,m	-	-	-	-	-	-	-		
-	a-iii	-	-	-	-	-	5.3	-	-	-	h,m	-	-	-	-	-	-	-		
-	b-i	-	-	-	-	-	7.2	-	12.8	20	h,m	-	-	-	-	-	-	-		
-	b-ii	-	-	-	-	-	5.3	-	-	-	h,m	-	-	-	-	-	-	-		
-	c	-	-	-	-	-	5	-	-	-	h,m	-	-	-	-	-	-	-		Stem diameter larger above
10	-	1	10	5	Bombacaceae	Ceiba sp. 1	-	-	42.1	160	a	1	0	0	1	2	5	19	PWM 1305	Stem deformed <155 so only one diameter taken. Tag at 130 cm

Examples of complex trees and a completed field data sheet for those trees (using one tag per tree)

Example 2, using the optional protocol with one tag per stem



Census Date: 2 xii 2019					Field Team: Carlos Rodriguez, Bridgette Morales, John Smith, Sally Jones (Botanist)															
Tree	Stem	T1	X	Y	Family	plot identification	D	POM1300	Extra D	Extra POM 300	Flag1	Flag2	Flag3	Flag4	LI	CI	Height	Voucher code	Notes	
1	1	1	3	1	Annonaceae	Annonaceae sp. 1	19.2	-	21.1	-	a	1	0	0	1	0	4	9.5	PWM 1302	
2	2	1	3	2	Annonaceae	Annonaceae sp. 1	16.7	-	18.3	-	b	1	0	0	1	1	3a	5	-	Broken at 5m
3	3	1	3.2	2	Annonaceae	Annonaceae sp. 1	8.7	-	9.1	-	a	1	0	0	1	1	3b	6	-	
4	4a	1	4	3	Annonaceae	Annonaceae sp. 1	9.1	-	15.2	-	h	1	0	0	1	0	1	3.5	-	
-	4b	-	-	-	-	-	8.8	-	-	-	-	-	-	-	-	-	-	-	-	
5	5	1	5	3	Annonaceae	Annonaceae sp. 1	5.1	-	7	-	h	1	0	0	1	2	2a	5.5	-	
-	6	-	-	-	-	-	7	-	6.7	-	-	-	-	-	-	-	-	-	-	Stem diameter larger above
7	7	1	5.5	3	Leguminosae	Dalbergia sp. 1	24.3	-	25.6	115	a	1	0	0	1	1	5	16.5	PWM 1303	
8	8	1	6	3	Annonaceae	Annonaceae sp. 1	11.1	-	13.3	-	a	1	0	0	1	2	2c	7.6	-	
9	9	1	8	2	Annonaceae	Annonaceae sp. 1	5.2	-	10.6	-	h	1	0	0	1	1	4	8	-	
-	10a	-	-	-	-	-	5.1	-	-	-	-	-	-	-	-	-	-	-	-	
-	10b	-	-	-	-	-	6.3	-	6.7	-	-	-	-	-	-	-	-	-	-	
11	11a	1	9	1	Combretaceae	Terminalia sp. 1	5.8	-	13	-	h,m	1	0	0	1	4	2b	6.5	PWM 1304	
-	11b	-	-	-	-	-	5.5	-	-	-	-	-	-	-	-	-	-	-	-	
-	11c	-	-	-	-	-	5.3	-	-	-	-	-	-	-	-	-	-	-	-	
-	12a	-	-	-	-	-	7.2	-	12.8	20	-	-	-	-	-	-	-	-	-	
-	12b	-	-	-	-	-	5.3	-	-	-	-	-	-	-	-	-	-	-	-	
-	13	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	Stem diameter larger above
14	14	1	10	5	Bombacaceae	Ceiba sp. 1	-	-	42.1	160	a	1	0	0	1	2	5	19	PWM 1305	Stem deformed <155 so only one diameter taken. Tag at 130 cm

Examples of complex trees and a completed field data sheet for those trees (using one tag per stem at 30cm)