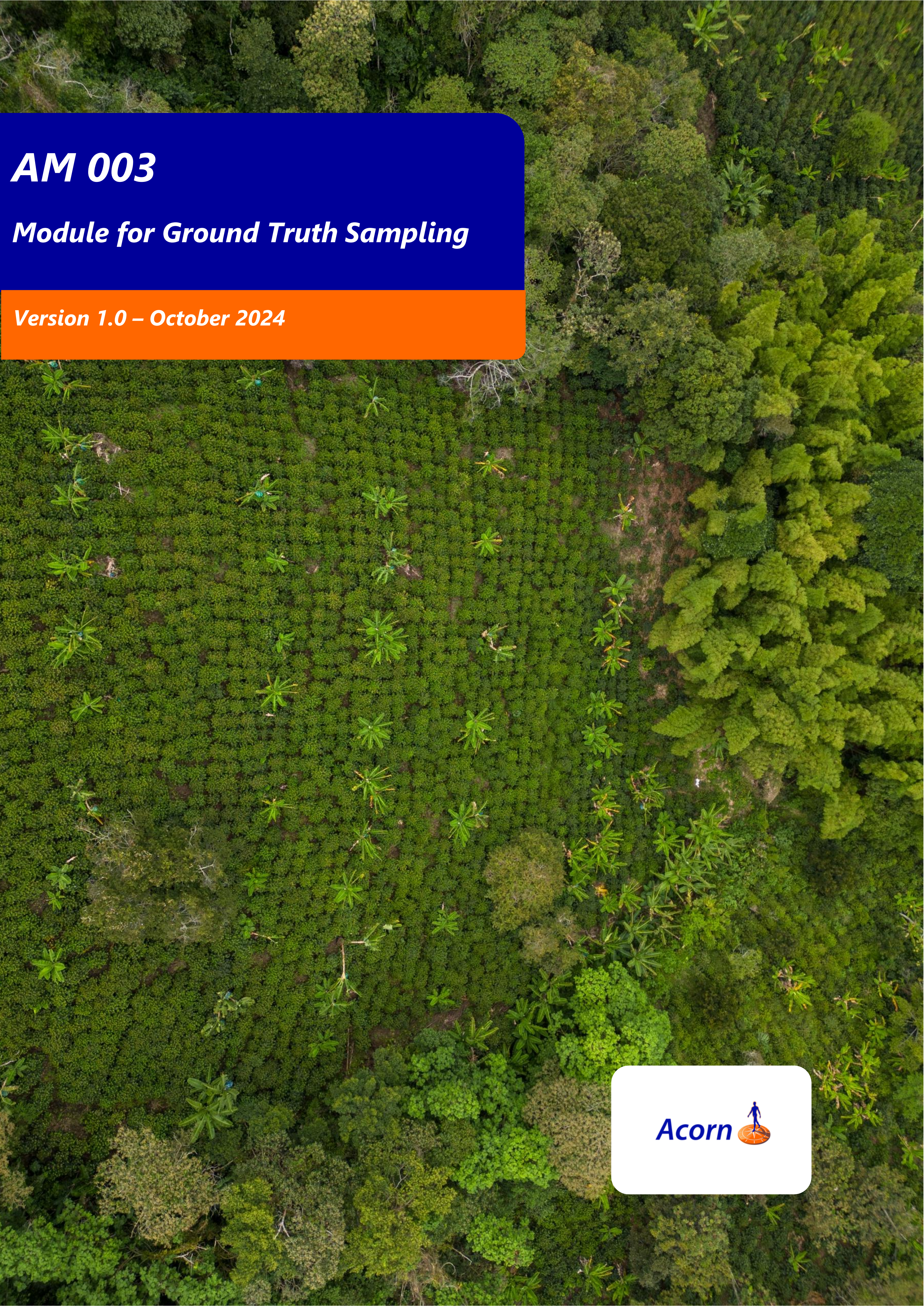
AM 003

Module for Ground Truth Sampling

Version 1.0 – October 2024



Acorn

Contents

1 Summary

This module describes the approach to select representative *ground truth data* collection locations, per *ecoregion* (*stratum*). In addition, it provides the standard operating procedure (SOP) for *ground truth data* collection and a method to transform it for use as input to *biomass* modelling. *Ground truth* data is used to develop, train, and validate the *biomass* model described in Acorn Methodology and Acorn Module **AM-004**, as well as to estimate the *pre-existing biomass* on a *plot level*. The *ground truth data* is also used to determine the contributions of *pre-existing biomass* described in Acorn Methodology and Module **AM-005**.

The data is subdivided per *ecoregion* to incorporate differences in growth rates of tree species due to environmental conditions.

To assure we cover the full range of *biomass* within the *ground truth data*, both environmental conditions and an indication of *pre-existing biomass* are considered to determine a representative selection of ground truth locations within an *ecoregion*. Features used related to environmental conditions include altitude, slope, rainfall, temperature, and soil type. The average NDVI (Normalized Difference Vegetation Index) and the average EVI (Enhanced Vegetation Index) of the previous year are used as an indicator of existing *biomass*. These features are calculated and categorized for all *plots* within the *Acorn project* with at least 1 ha. If there aren't enough *plots* with a minimum size of 1 ha, neighbouring *plots* can be combined to create an area of more than 1 ha which can be used for *ground truth data* collection.

2 Sources

This module supports the following methodology:

- **AM-004** Module for Model Development, Calibration, Validation and Application
- **AM-005** Module for Pre-project Woody Biomass Modelling for Small-scale Agroforestry

3 Definitions

Definitions used in this module follow the latest version of the Acorn Glossary available on the Acorn website.

4 Applicability Conditions

The method described in this module is globally applicable, as the implemented features are available for every *ecoregion* and are applied to a specific *Acorn project*. For this module, the applicability conditions of the Acorn Methodology **AM-001 v2.0** should be met.

5 Procedures

5.1 Procedure for selection of location of ground truth data

5.1.1 Data sources and requirements:

The data sources needed for the selection of representative *plots* for *ground truth data* collection are summarized in Table 1. Required data sources for the selection of representative ground truth plots – including all data parameters, sources, and resolution.

Table 1. Required data sources for the selection of representative ground truth plots – including all data parameters, sources, and resolution.

Parameter	Example Source*	Minimum required resolution	Data Type
Soil type	SoilGrids (Poggio, L, et al., 2021)	250 m	Categorical (nominal; with 30 classes)
Elevation	Copernicus DEM (ESA, 2023)	30 m	Numerical (continuous)
Precipitation	CHIRPS (Funk et al., 2015)	5 km Yearly Sum	Numerical (continuous)
Temperature	ERA5 (Muñoz Sabater, J., 2019)	11 km Yearly minimum and maximum	Numerical (continuous)
Temperature anomalies	ERA5 (Muñoz Sabater, J., 2019)	11 km (5-year count in months)	Numerical (discrete)
Land cover	ESA (WorldCover, 2021; Zanaga et al., 2021)	30 m	Categorical (nominal; with 11 classes)
NDVI (mean)	Sentinel-2 (Rouse et al., 1973; Sentinel Hub, 2023; Drusch et al., 2012)	10 m	Numerical (continuous)
EVI (mean)	Sentinel-2 (Pandey et al., 2019; Malhi et al., 2021; Sentinel Hub, 2023)	10m	(Numerical (continuous)

**The source might differ from the one listed in the table. If an alternative source is needed, the resolution requirement should be met.*

In addition to these parameters, the following criteria need to be met for a location to be suitable for *ground truth data* collection:

- The measured area must be at least 1 ha of land (comprising of 1 or multiple adjacent *agroforestry plots*).
- All parameters listed in Table 1 should be available for download. If the listed source is not available, an alternative, globally available, open-source data with similar or better resolution should be used.
- All parameters should be in raster format.
- All parameters should be in the same coordinate systems.
- All parameters should be in the same grid resolution. The parameter with the highest available resolution is used as the standard to follow for the lower-resolution parameters. E.g., if the highest resolution is 10x10 m, a lower-resolution parameter of 30x30 m is up sampled to 10x10 m.
- The *project area* containing all *plots* that belong to the *Acorn project* must be defined.
- The number of desired ground truth locations should be pre-defined based on criteria described in AM-001 Section 11.1.

5.1.2 Method:

1. Pre-process data.
    a. Rasterize vector-based data sets to facilitate processing performance.
    b. Transform data to the same coordinate reference system to make the data spatially compatible.
    c. Resample the different datasets to the same grid to align pixels in the various raster data.
    d. Collect *sample plots* that belong to the *Acorn project*. If *plots* are smaller than 1ha, combine adjacent *plots* to cover a 1 ha area.
    e. Exclude plots smaller than 1ha with no adjacent plot.
    f. Extract all data per *plot*.

2. Categorise data.

The goal of this step is to establish whether there are enough *plots* in each category that can be used as *ground truth data*. If categories are insufficiently represented, more *plots* must be collected from the underrepresented category. If the number of *plots* available is higher than the desired number of ground truth locations, we follow a stratified systematic sampling approach, to make the most appropriate selection. The creation of the categories is described as follows.

a. All *plots* larger than 1 hectare for each *ecoregion* within the *project area* are classified based on both the numerical and the categorical data sets, separately. Each class should contain an equal number of pixels of the same size.

The numerical parameters are classified in 5 classes. The 5 classes are defined based on the distribution of the pixels. They are binned into 5 classes so that each class contains an equal number of pixels. First, we gather all the pixel values from the area and sort them based on the values of the variables. Then we divided the sorted pixel values into 5 equal parts. Each part will contain the same number of pixels. The plots are then allocated to each class based on the class they fall into, following their numerical value.

Similarly, the categorical parameters are also classified in 5 categories. The *plots* are allocated to the class they fall into, following their categorical value. Each class and category should contain the same number of *plots*.

All possible combinations between the continuous and categorical parameters are assessed. Since ecoregions have similar temperature, elevation, and soil type (less than 100 combinations are often possible). *Plots* for *ground truth data* collection are selected to represent each combination.

b. Decrease the number of categories for the parameter with the lowest coefficient of variation (CV)-score.

   The higher the CV, the greater the dispersion (spread in values) of that parameter. Therefore, the aim is to have a higher number of categories for parameters with the largest variation. If a parameter has a low variation (e.g., the temperature varies little between all *plots*), the parameter is categorized in less categories to reduce the number of unique combinations of categories.

c. Repeat the previous step until the unique combination count is below or equal to the desired ground truth location sample size. For each iteration over parameters, the next parameter in the CV-ranking (2nd smallest variation, 3rd smallest variation, etc.) is selected for decreasing the number of categories.

After the ground truth locations have been selected following the steps above, the collection of *ground truth data* in these *plots* can start. This is described in the segment below.

5.2 *Standard operating procedure for ground truth data collection*

Starting with definitions & materials:

Figure 1. Graphical representation of a Smallholder Farmer's land property, incl. relevant definitions

1. Land-property: entire land-property of the *Smallholder Farmer* (excluding roads, houses, timber lots, etc.).
2. *Plot* (GPS Polygon): A simplified figure, typically a polygon delineated by GPS coordinates that define the boundaries of a land property.
3. *Sample plot*: 1 ha *plot* within the total land property of the *Smallholder Farmer*.
4. Subplot: a 25x25m subplot that is located within the main *plot*.
5. 1 hectare (ha): total size of a sample plot

All materials advised for collect ground truth data:

- A **smartphone with internet** connection and access to the **SurveyCTO**
  Alternative: Garmin eTrex 10, writing pads
- **Tree list** provided by the Local Partner, both the scientific and local names as a drop-down menu.
- 100m **measuring tape** (preferably two for easier definition of plots).
- 4x 25m of **pre-measured rope**.
- **Chalk** or spray to mark measured trees.
- **Nikon Forestry Pro Rangefinder** (preferably, similar systems are accepted like Suunto hypsometer), or **straight stick**/ruler to measure height.
- **Compass** (on smartphone)

The next steps define the *ground truth data* collection protocol:

5.2.1 Define sample plot

The first step is to determine, a *sample plot* on the entire land property of the *Smallholder Farmer*. Ideally a sample is a 1ha square of 100m by 100m. If that not possible in the assigned farmer plot a different shape but 1 ha is allowed.

After establishing the polygon of the entire land property, the outlines of the *sample plot* (a 1 ha area on the entire land property) can be pinpointed to provide at least 4 GPS coordinates per corner. Placing demarcation poles and/or flags at these corner points ensures that trees are measured within the right area.

5.2.2 Define subplots within the *sample plot*.

Each sample plot is divided into 16 subplots, square-shaped *plots* of 25x25 meters, using measuring tape and a compass. Each subplot is numbered and added to a simple sketch that lays out the entire *sample plot*, an example is shown in Figure 4 below. Corner points are demarcated using poles and/or flags at the corner points. Of every corner of each subplot at least one coordinate pair with an accuracy of maximum 5 meter needs to be recorded.

Per *sample plot* the following data should be collected:

- GPS coordinates (preferably in DD (Decimal Degree) format)
- Name of collector
- Name of farm/*Smallholder Farmer*
- Date, location

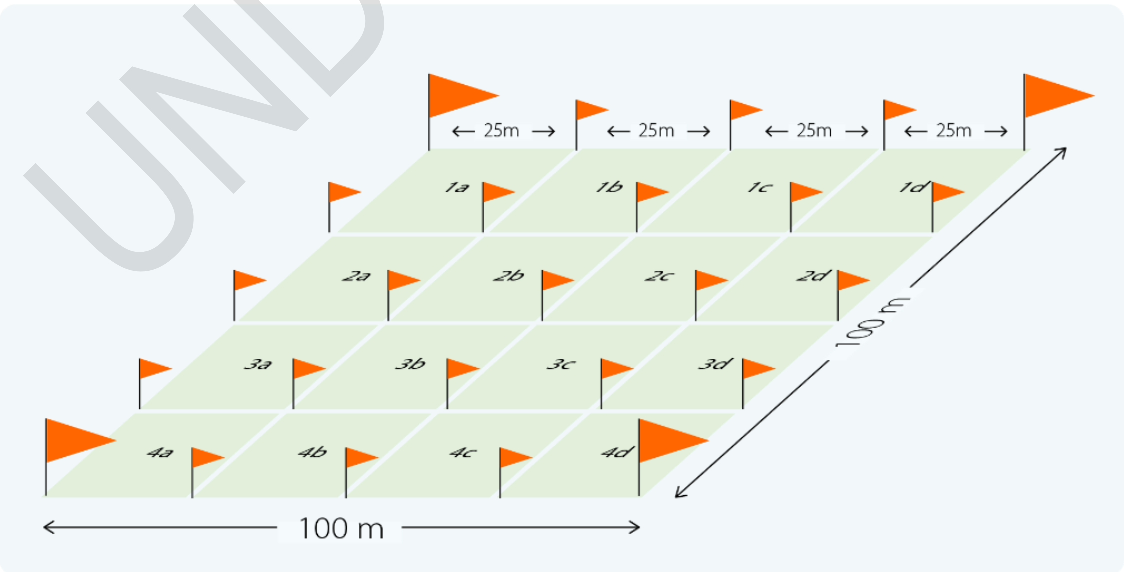


Figure 2. Example of a sample plot

5.2.3 Measuring *biomass* per subplot

After the subplots are demarcated, measurements are taken of the vegetation for the purpose of model calibration. If a plant is located on the plot border, determine whether most of the stem is inside or outside the subplot– if within, the tree will be counted and if outside, the tree will not be counted.

The measurement methods depend on the vegetation characteristics. Trees with a DBH larger than 10 cm are measured separately, grouping is accepted for plants with a DBH smaller than 10 cm and primary crops/woody vegetation if they meet certain criteria.

The method for grouping vegetation is derived from (Heiskanen et al., 2013). Per group, all the plants are counted. Plants can be grouped when they are from the same species, same plant age, similar DBH and similar height. The smallest, median, and largest plants of a group are measured for DBH and for height.

The following measurements need to be taken per subplot. See Table 2 for examples per vegetation type:

Table 2. Examples per vegetation type.

Vegetation type	Example species
Primary woody vegetation	Coffee, cacao, tea, fruit trees (if primary crop)
Vegetation > 1.3 m & woody/tree-like	Ceder, Inga, Baobab, fruit trees (non primary crops), palms
Vegetation < 1.3m & woody/tree-like	Newly planted trees/saplings of woody tree-like species
Non-woody vegetation	Maize, rice, sorghum, sugarcane, grass

1. Primary crops/woody vegetation

Define the primary woody, tree-like crop is above 1.3 m height. If there are multiple primary crops (e.g., mixed coffee and cocoa plantation with shade trees in between) make separate groups per crop (i.e., one for coffee and one for cocoa).

Per group record:

- Scientific Species (if not available: genus or common name);
- Planting year;

- Plant count;
- Of the smallest, median and largest plant report:
    - Height (see 8.1);
    - Pruning height (when pruned);
    - Number of stems;
    - DBH (see 8.2).

2. Vegetation > 1.3m woody/tree-like

For every individual plant record:

- Scientific Species (if not available: genus or common name);
- Planting year;
- Height (see 8.1);
- Pruning height (when pruned);
- Number of stems;
- DBH see 8.2).;
- Tree location (at least one coordinate pair).

3. Vegetation < 1.3m woody/tree-like

Identify all woody, tree-like plants lower than 1.3 m. These plants can be grouped based on *identical* species and planting year, and *similar* dimensions. Otherwise, they must be measured as different groups. Per group the following characteristics must be measured

Per group record:

- Scientific Species (if not available: genus or common name);
- Planting year;
- Plant count;
- Of the smallest, median and largest plant report:
    - Height (see 8.1);
    - Pruning height (when pruned);
    - Number of stems;
    - DBH (see 8.2).

4. Non woody vegetation

These plants can be grouped based on *identical* species and planting year, and *similar* dimensions. Otherwise, they must be measured as different groups. Per group the following characteristics must be measured for the smallest, median and largest plant within the group:

- Scientific Species (if not available: genus or common name);
- Plant count or coverage percentage;
- Height (see 8.1)

5.3 Translate tree measurement into Aboveground Biomass

The field data is combined into individual plant level and subplot level datasets for further processing. Both datasets are preprocessed to remove or correct invalid data. After pre-processing both datasets, *biomass* is calculated per plant and aggregated on a subplot *level (Equation 1)*. If the acceptance criteria per subplot from both the individual plant level dataset and subplot *level* dataset are met, the subplots will be used for further modeling.

$$AGB_{subplot} = \sum AGB_{plant} \in subplot$$

Equation 1

Where:

$AGB_{subplot}$	= Aboveground biomass of one subplot (kg)
AGB_{plant}	= Aboveground biomass of one plant (kg)
$subplot$	= Selected subplot to calculate biomass

5.3.1 Pre-processing subplot level data

The collected subplots are checked for geometrical accuracy, whether they are in the right country, length-width ratio, protrusion, size, number of vertices, and duplicate subplot-IDs.

5.3.2 Pre-processing tree data

The data will be pre-processed to translate species names, enforce data quality checks, standardize value formats, format qualitative variables, and detect and correct abnormal and data.

Species names are corrected for grammar, spelling, and other typographical errors. The collected species names are translated to scientific species names. If no translation can be found for a species name, the translated species name is set to "UNKNOWN_species".

Values above the threshold for DBH and height values are flagged. The standard threshold for DBH is 1590 cm, which is the DBH of a baobab tree (*Adansonia digitata*), currently the largest agroforestry tree in the world (South African Government, 2022). The threshold for height is 70 meters, since trees higher than 70m are rare and cannot be found within regions Acorn is active (Tng et al. 2012).

Where possible, species-specific thresholds for DBH and height are researched from literature. If one of the parameters of height or DBH exceeds the threshold, equation 2 is used to calculate the correct value according to the correct parameter. If both height and DBH exceed the threshold, the maximum DBH is used to calculate the height. Of these variables, DBH measurements and wood density values are generally the most reliable inputs.

The standard method of correcting woody plant dimensions is by done following formula from Chave et al. (2014), see Equation 2. This equation calculates height from DBH, based on an environmental stress factor. The environmental stress factor was calculated by Chave et al. (2014) with equation 3 and processed into a global gridded layer. The environmental stress factor is retrieved based on the location of the subplot of the trees.

$$\ln(H) = 0.893 - E + 0.760 * \ln(DBH) - 0.0340 * \ln(DBH)^2$$

Equation 2

Where:

H	=	Tree height (m)
DBH	=	Diameter at breast height (cm)
E	=	Environmental stress variable based on geographical location

$$E = (0.178 * TS - 0.938 * CWD - 6.61 * PS) * 10^{-3}$$

Equation 3

Where:

E E	=	Environmental stress variable based on geographical location
TS	=	Temperature seasonality
CWD	=	Climate Water Deficit
PS	=	Precipitation seasonality

5.3.3 *Biomass calculation*

After pre-processing, plant *biomass* is calculated for each measured plant with an appropriate allometric *biomass* equation. The rank-order method of the Quality Assessment of REDD+ Carbon Credit Projects by Berkeley Carbon Trading Project will be used (Haya et al., 2023) to select the most appropriate biomass equation.

The allometric equation to estimate *Aboveground Biomass* of tropical trees by Chave et al. (2014) will be used as the default biomass equation, if no more appropriate biomass equation is available. This equation calculates *biomass* for pantropical tree species based on DBH, height and wood density. See Equation 4 below.

$$AGB = 0.0673 * (\,\mathrm{p} * DBH^2 * H)^{0.976}$$

Equation 4

Where:

AGB	= *Aboveground Biomass* (kg)
p	= Wood density (g/cm^3)
DBH	= Diameter at breast height (cm)
H	= Tree height (m)

5.3.4 Wood density selection

Depending on the biomass equation, a wood density value is needed as a parameter. Wood density values are matched for each woody plant within the data collection. The wood density values are first extracted from the ICRAF wood density database (Orwa et al., 2009). Wood density is selected based on the region and species or genus level. If no wood density can be found for a plant on a genus level, a literature search is done.

Wood densities values from literature are added to a larger wood density database with values from literature, compiled by Acorn. If multiple values are found on the same species, genus or regional level, the average wood density value is used for the biomass calculations.

If no information is available for the wood density values of a woody species within the ICRAF database and literature, the average wood density value of all woody species within the data collection is used for the biomass calculations.

The order of selection can be found in Figure 3 below.

Figure 3. Wood density selection process

5.3.5 *Plot biomass*

After the plant *biomass* calculations, total *biomass* per subplot is calculated by summing *biomass* from all measured plants (samples) over 1.3 meters in height of the subplot. Biomass density per subplot is calculated with Equation 5.

$$AGBsubplot\ per\ hectare = \frac{AGBsubplot}{1000} \cdot \left(\frac{10000}{area_{subplot}}\right)$$

Equation 5

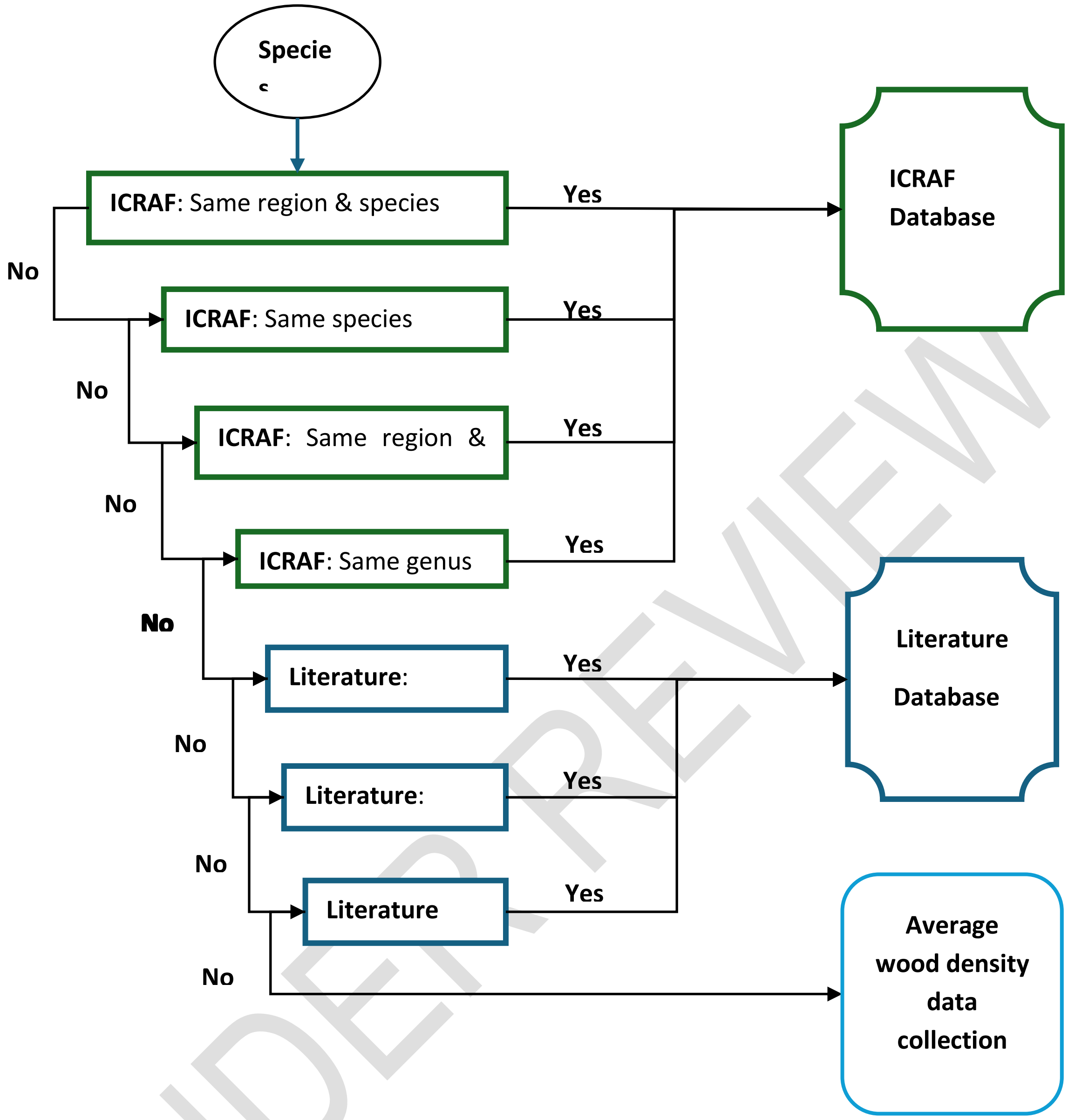
Where:

$AGBsubplot\ per\ hectare$ = Aboveground biomass density subplot (tonne/h)

$AGBsubplot$ = Aboveground biomass per subplot (kg)

$area_{subplot}$ = subplot area (m^2)

The total plot biomass is calculated by aggregating biomass from all subplots of the plot.


Specie
s
ICRAF: Same region & species
ICRAF: Same species
ICRAF: Same region &
ICRAF: Same genus
Literature:
Literature:
Literature
Yes
Yes
Yes
Yes
Yes
Yes
Yes
No
No
No
No
No
No
No
ICRAF Database
Literature Database
Average wood density data collection

6 Parameters

Data/Parameter	AGB_{plant}
Units	Kg
Description	Aboveground biomass of one plant (kg)
Equations	Equation 1
Source	Chave et al., (2014)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Commonly used in literature
Purpose of Data	It is the plant biomass to measure total plot biomass
Comments	N/A

Data/Parameter	$AGBsubplot$
Units	Kg
Description	Aboveground biomass per subplot (kg)
Equations	Equation 5
Source	n/a
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Calculated for model input
Purpose of Data	Subplot biomass of one subplot to determine biomass density
Comments	N/A

Data/Parameter	$area_{subplot}$
Units	m^2
Description	subplot area (m^2)
Equations	Equation 5
Source	Ground truth data
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Size is needed for correctness

Purpose of Data	Subplot size is needed to determine biomass density of a sub plot
Comments	N/A

Data/Parameter	CWD
Units	mm / Month
Description	Climate Water Deficit
Equations	Equation 2
Source	Chave et al., (2014)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	The maximum climatological water deficit (CWD) is computed by summing the difference between monthly rainfall Pi and monthly evapotranspiration ETi
Purpose of Data	Applied to predict *biomass* growth
Comments	N/A

Data/Parameter	DBH
Units	Centimeter (cm)
Description	Diameter breast height
Equations	Equation 1
Source	*Ground truth data* collection
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Common practice for determining *biomass*
Purpose of Data	Collected to predict *biomass* growth
Comments	N/A

Data/Parameter	E
Units	No unit
Description	Environmental stress variable based on geographical location
Equations	Equation 1 and Equation 2
Source	Chave et al., (2014)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Commonly used stress factor

Purpose of Data	Applied for correcting abnormal height measures
Comments	N/A

Data/Parameter	Elevation
Units	Meters (m)
Description	The Digital Elevation Model that represents the surface of the Earth globally
Equations	Not applicable
Source	Copernicus DEM (Digital Elevation Model)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Altitude is an important indicator of *biomass* growth
Purpose of Data	Select a representative sample of *ground truth data*
Comments	N/A

Data/Parameter	H
Units	Meters (m)
Description	Tree height
Equations	Equation 3
Source	*Ground truth data* collection
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Common practice to determine *biomass*
Purpose of Data	Collected to predict *biomass* growth
Comments	N/A

Data/Parameter	NDVI
Units	No unit
Description	The normalized difference vegetation index is simple and effective for measuring the density of vegetation
Equations	Not applicable
Source	ESA
Value	N/A
Justification of choice of data or description of	A simple indication of *biomass* is used to cover the full range of *biomass* present in the *Acorn project*

measurement methods and procedures applied	
Purpose of Data	Select a representative sample of *ground truth data*
Comments	N/A

Data/Parameter	PS
Units	Mm/month
Description	Precipitation seasonality
Equations	Equation 2
Source	Chave et al., (2014)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Precipitation seasonality is the coefficient of variation in monthly rainfall values, or the SD expressed in percent of the mean value
Purpose of Data	Applied to predict *biomass* growth
Comments	N/A

Data/Parameter	Soil type
Units	Soil categories
Description	Spatial distribution of soil properties across the globe
Equations	Not applicable
Source	ISRIC
Value	Name
Justification of choice of data or description of measurement methods and procedures applied	Soil type is an important indicator of *biomass* growth
Purpose of Data	Select a representative sample of *ground truth data*
Comments	N/A

Data/Parameter	Temperature
Units	Degrees Celsius
Description	Used as one of the input layers
Equations	Not applicable
Source	ERA5
Value	Number
Justification of choice of data or description of	Temperature is an important indicator of *biomass* growth.

measurement methods and procedures applied	
Purpose of Data	Use maximum, minimum and anomalies of the *plots* as features
Comments	N/A

Data/Parameter	TS
Units	Degrees Celsius * 100
Description	Temperature seasonality (TS), is the standard deviation (SD) of the monthly mean temperature over a year, expressed in degrees Celsius multiplied by 100.
Equations	Equation 2
Source	Chave et al., (2014)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	Temperature seasonality is a parameter in the calculation of the environmental stress value, as defined by Chave (2014).
Purpose of Data	Applied to predict *biomass* growth
Comments	N/A

Data/Parameter	p
Units	g/cm^3
Description	Wood density (kg/m^3)
Equations	Equation 3
Source	ICRAF wood density database (Orwa et al., 2009)
Value	Number
Justification of choice of data or description of measurement methods and procedures applied	It is a parameter that integrates species-specific characteristics for the *biomass* calculation or adjusts the *biomass* equation to be representative of different species
Purpose of Data	Calculate *biomass* for pantropical tree species
Comments	N/A

7 References

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8 Appendix

8.1 Measuring tree height without a tool

If there is not tool available to measure the height of the three, following these steps:

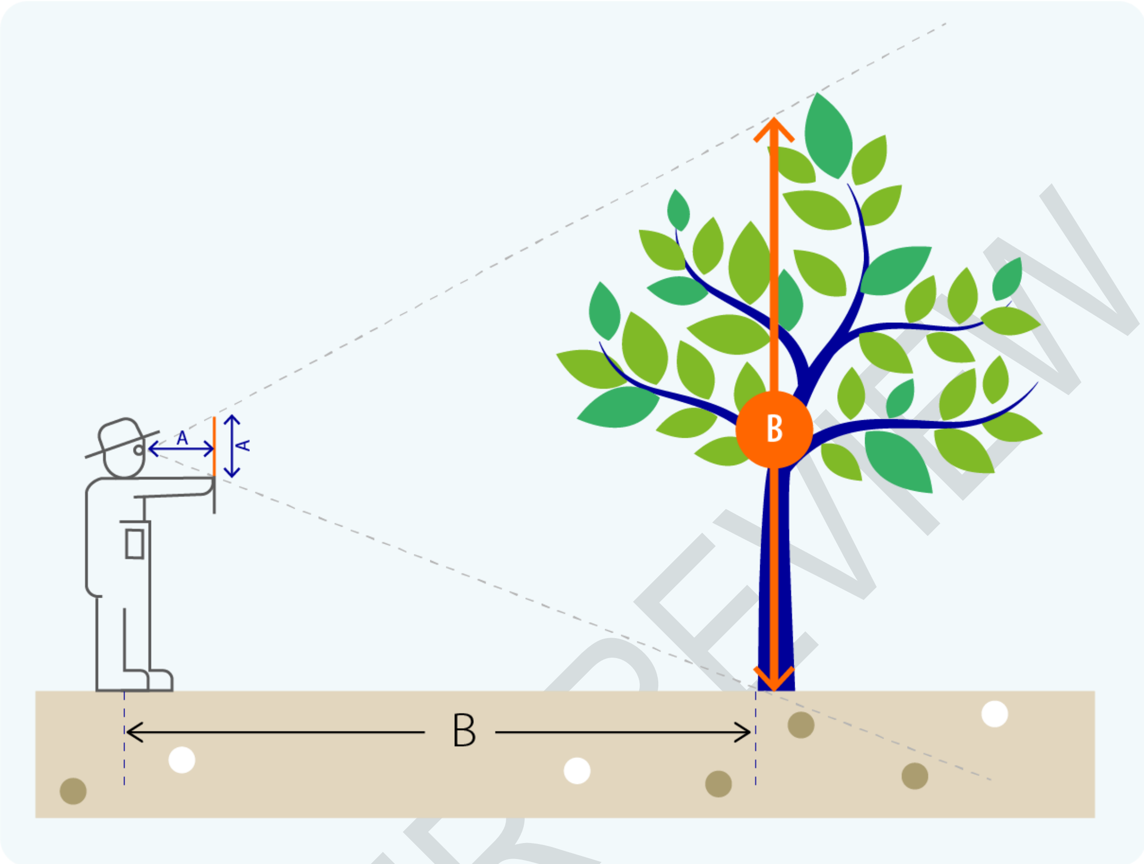

Figure 4. How to measure the height of a tree without a laser measuring tool

1. Measure the horizontal distance from your eye to the hand of your outstretched arm (a).
2. Hold the ruler vertically in front of you. The distance from the top of the ruler to where you hold it must be the same length as the distance from your eye to your hand (a).
3. Walk towards or away from the tree until the tree is visually the same length as the length between the top of the ruler to your hand (a).
4. Mark the location where you are standing and measure the distance from there to the trunk of the tree (b). This distance is the height of the tree (b).

8.2 Measuring DBH

Depending on the measurement materials used, either the circumference or diameter of the tree should be recorded at breast height (DBH) (1.3 meters) for plants larger than 1.3 meters. Preference is given to measuring stem circumference. Examples of measurement materials and their related stem dimensions used are diameter calliper (DBH), measuring tape (circumference), or diameter tape (DBH). The stem dimension, either DBH or circumference, is noted by the data collector.

Measuring DHB per tree brings challenges related to different tree shapes and orientations in the field. See Figures 5 below, based on Martin (2022), for guidance on how to measure DBH. Please note these instructions should be merely considered for guidance and may be suggested to change if more accurate techniques are found.

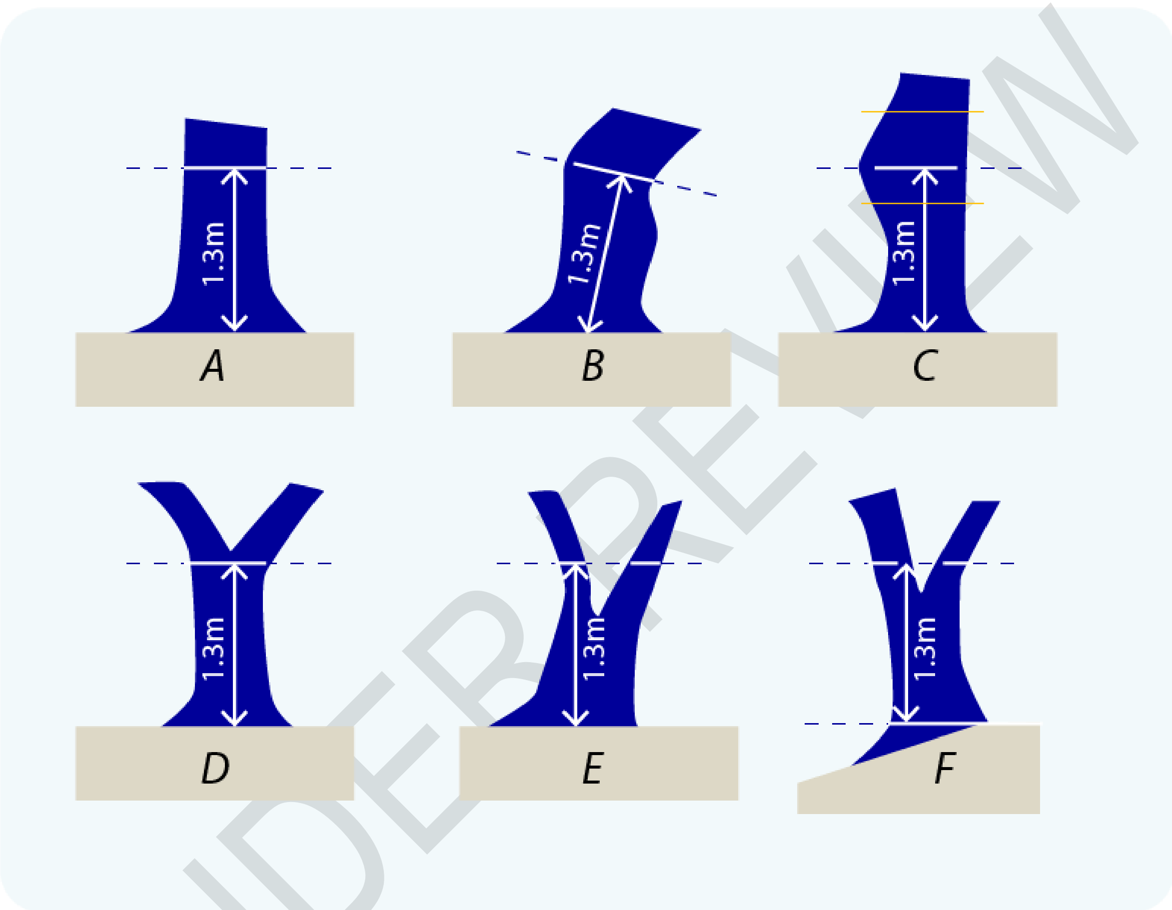

Figure 5. Where to measure DBH on different shapes of trees

a. Normal tree: Wrap the measuring tape horizontally around the tree.
b. Bent tree: Wrap the measuring tape around the tree in the shortest way, which is often not horizontal.
c. Tree with an irregular diameter at 1.3 m: Measure DBH below and above the irregularity and report the average value.
d. Tree forked above 1.3 m: Measure as a normal tree.
e. Tree forked below 1.3 m: Measure all stems and average the DBH,
   Tree located on a hill: Measure at 1.3 m height from the highest point of the soil.