TECHNICAL GUIDELINES FOR CARBON QUANTIFICATION IN AFOLU PROJECTS

– DC.CER.003 –

VERSION 1.2

CERTIFICATION PROGRAM

TERO CARBON AVALIAÇÕES E CERTIFICAÇÕES S.A.

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LIST OF ACRONYMS

AFOLU	Agriculture, Forestry and Other Land Uses
AGB	Above-Ground Biomass
ALM	Agricultural Land Management
ANOVA	Analysis of Variance
APD	Avoided Planned Deforestation
ARR	Afforestation, Reforestation, and Revegetation
BD	Bulk Density
BGB	Below-Ground Biomass
BMR	Minimum Claimable Benefit (*Benefício Mínimo Reivindicável*)
CF	Carbon Fraction
CI	Confidence Interval
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRVE	Verified Emission Reduction or Removal Certificate (*Certificado de Redução ou Remoção Verificada de Emissões - SBCE*)
DAB	Diameter at Base
DBH	Diameter at Breast Height
DDW	Down Dead Wood
FI	Forest Inventory
GHG	Greenhouse gas
GWP	Global Warming Potential
HI	Harvest Index
ICROA	International Carbon Reduction and Offsetting Alliance
INPA	National Institute of Amazonian Research (*Instituto Nacional de Pesquisas da Amazônia*)

IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LIS	Line Intersect Sampling
LTCS	Long-Term Cyclical Carbon Stock
MRV	Measurement, Reporting, and Verification
NBS	Nature-based Solutions
PDD	Project Design Document
QA/QC	Quality Assurance / Quality Control
REDD+	Reducing Emissions from Deforestation and Forest Degradation, including the conservation and enhancement of carbon stocks
SBCE	Brazilian Greenhouse Gas Emissions Trading System (*Sistema Brasileiro de Comércio de Emissões de Gases de Efeito Estufa*)
SOC	Soil Organic Carbon
TBS	Technology-Based Solutions
VCSU	Verified Carbon Stock Unit - Carbon Stock Asset
VCU	Verified Carbon Unit - Carbon Credit Asset
VVB	Validation/Verification Body

LIST OF PROGRAMS

ID	NAME
DC.CER.001	Certification Program
DC.MET.001	Methodologies Program
DC.REG.001	Asset Program

LIST OF SUPPORTING DOCUMENTS

ID	NAME	SOLUTION
DC.COM.001	Definitions	All
DC.GOV.001	Tero Carbon Governance Structure	All
Law n° 15.042/2024	Establishes the Brazilian Greenhouse Gas Emissions Trading System (SBCE)	All

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1. INTRODUCTION AND OBJECTIVE

This document, "Technical Guidelines for Carbon Quantification in AFOLU Projects (DC.CER.003)", is a fundamental component of the Tero Carbon Certification Program. Its main objective is to establish the Tero Carbon-approved guidelines, procedures, and methods for quantifying carbon stocks and, by inference, the changes in these stocks (fluxes), in projects within the Agriculture, Forestry, and Other Land Use (AFOLU) sector. This document operates under the principles of the "Tero Carbon Governance Structure (DC.GOV.001)".

The accurate and consistent quantification of carbon stocks is crucial for the environmental integrity of the Verified Carbon Units (VCUs) and Verified Carbon Stock Units (VCSUs) generated under Tero methodologies. This document aims to provide a robust technical reference, aligned with international best practices, such as the guidelines of the Intergovernmental Panel on Climate Change (IPCC), and adapted to the realities and needs of projects in Brazil and, potentially, in other regions.

Tero Carbon seeks to democratize access to the carbon market, especially for small-scale projects that may face technical and financial challenges. To this end, this document presents different levels of approach (Tiers), allowing for methodological flexibility without compromising the conservatism and credibility of the results. Although Tero Carbon encourages the use of higher precision methods (Tier 3), simplified methods (Tier 2) are accepted, including the use of remote sensing software and models, provided they are duly calibrated and homologated by Tero Carbon.

This document is mandatory for Project Developers who use Tero Carbon's AFOLU methodologies (such as ALM, APD, ARR, REDD+, among others) and serves as a guide for Validation/Verification Bodies (VVBs) in auditing the quantification aspects. It is structured to receive updates and inclusions of new crops and methods as scientific knowledge and technologies evolve.

Tero Carbon is in the process of preparing to seek future accreditations with international bodies such as ICROA and CORSIA (ICAO), and this document reflects the commitment to the highest standards of quality and integrity, also aiming for future alignment with the quantification requirements of the Brazilian Greenhouse Gas Emissions Trading System (SBCE), as per Law No. 15,042/2024. Project Developers may propose alternative or complementary quantification methods in the Project Design Document (PDD), provided they demonstrate their scientific validity, robustness, conservatism, and equivalence or superiority to the methods established herein, subject to the approval of Tero Carbon and the VVB.

2. SCOPE OF APPLICATION

This document applies to all project activities submitted to the Tero Carbon Certification Program that involve the quantification of carbon stocks and/or changes in these stocks (fluxes) in the following contexts:

- **Sector:** Agriculture, Forestry, and Other Land Use (AFOLU).
- **Solutions:** Primarily Nature-Based Solutions (NBS), but may be referenced by Technology-Based Solutions (TBS) if there is an AFOLU component.
- **Tero Methodologies:** All AFOLU methodologies approved by Tero Carbon.
- **Carbon Pools:** As detailed in Section 3.1.
- **Project Scale:** Applicable to Small and Large-Scale projects.
- **Asset Types:** Quantification for the generation of Verified Carbon Units (VCU) and Verified Carbon Stock Units (VCSU).

This document describes the quantification methods homologated by Tero Carbon. Alternative methods may be proposed by the Project Developer in the PDD, accompanied by robust technical justification, and will be subject to analysis and approval by Tero Carbon and the VVB.

This document has been structured to meet the quantification needs of both **forest projects** and **agricultural management projects**. Project Developers are recommended to consult the sections according to their applicability:

- **For forest projects:** Section 5 details the methods for estimating biomass and carbon in forest vegetation.
- **For agricultural management projects:** Section 6 details the methods for estimating biomass, soil organic carbon (SOC), long-term cyclical carbon stocks (LTCS), and emission reductions (EMIS) in agricultural systems.

The remaining sections (Sampling, Uncertainty, MRV, etc.) contain general guidelines applicable to both project types, with specific notes where necessary.

3. FUNDAMENTAL CONCEPTS

3.1. Carbon Pools

According to the IPCC, the main carbon reservoirs (pools) in AFOLU projects are:

- **Above-Ground Biomass (AGB):** All living biomass of vegetation above the soil level, including trunks, branches, bark, seeds, and foliage.

- **Below-Ground Biomass (BGB):** All living biomass of roots. Fine roots (< 2 mm in diameter) are often difficult to measure and may be excluded if conservatively justified, or estimated by standard ratios.
- **Deadwood (DW):** Includes standing dead wood (dead trees, snags) and down dead wood (logs, coarse and fine branches on the forest floor).
- **Litter:** All non-decomposed dead biomass, with a diameter smaller than that of down dead wood (generally <10 cm or as per IPCC definition), on the soil surface, including leaves, fine branches, bark, and fruits.
- **Soil Organic Carbon (SOC):** Organic carbon in mineral and organic soils, including living organic matter (microorganisms) and dead matter (detritus) in the soil. Generally measured to a standard depth (e.g., 0-30 cm).
- **Harvested Wood Products (HWP):** (Not extensively detailed in this document, but recognized as a pool).

The selection of pools to be included in the project's accounting depends on the specific Tero methodology, the project activity, and the significance of the pool. Mandatory pools are defined in the specific methodologies. The exclusion of a potentially significant pool must be justified, demonstrating that its omission is conservative or that the pool is not impacted by the project activity.

3.2. IPCC Approach Levels (Tiers)

The IPCC defines three levels (Tiers) for the quantification of GHG emissions and removals, reflecting different levels of precision and specificity:

- **Tier 1:** Uses standard emission/removal factors and activity data provided by the IPCC or global sources. It is the simplest method, with greater uncertainty.
- **Tier 2:** Uses emission/removal factors and activity data specific to the country or region of the project, derived from national/regional studies or local measurements. It offers greater precision than Tier 1.
- **Tier 3:** Uses more complex models, project-specific inventory data, continuous direct measurements of GHG fluxes, and/or high-resolution remote sensing data calibrated with field data. It is the most precise method, but also the most demanding in terms of data and resources.

Tero Carbon encourages the use of Tier 3 approaches whenever feasible. However, to promote inclusion, especially for small-scale projects, Tier 2 approaches, including the use of software and models homologated by Tero Carbon (see Section 7.3), are acceptable, provided the methodology is robust, transparent, verifiable, and conservative. The Developer must justify the choice of Tier in the PDD.

3.3. General Principles of Quantification

- **Conservatism:** In the absence of certainty or when multiple approaches are possible, the option that is least likely to overestimate net removals or underestimate net emissions should be chosen.
- **Consistency:** Quantification methods must be applied consistently over time and between the baseline and project scenarios.
- Transparency: All methodologies, data, assumptions, and calculations must be clearly documented and made available for verification.
- **Accuracy:** Estimates should be as accurate as possible, given data and resource limitations, and uncertainties must be quantified and reported.
- **Comparability:** Estimates should be comparable between different projects and periods, whenever possible.
- **Completeness:** All significant pools and emission sources within the project boundaries must be accounted for, unless their exclusion is conservative and justified.

Additionally, the quantification must seek alignment with the good practices and rigor levels that may be required for methodologies accredited under the Brazilian Greenhouse Gas Emissions Trading System (SBCE), as per Law No. 15,042/2024, for projects aiming to generate Verified Emission Reduction or Removal Certificates (CRVEs).

4. SAMPLING STRATEGIES AND DATA COLLECTION

4.1. Sampling Design

A well-designed sampling plan is essential to obtain representative estimates with acceptable uncertainty. The plan must:

- Clearly define the target population (e.g., all trees above a certain DBH in the project area).
- Specify the sampling method (e.g., simple random, systematic, stratified).
- Determine the sample size (number of plots or individuals) to achieve the desired level of precision.
- Describe the design of the sample units (plots).
- Define the parameters to be measured.

The sampling plan **MUST** be developed in conjunction with the statistical analysis approach that will be used to estimate average stocks and their uncertainties. The statistical approaches accepted by Tero Carbon, including the general (frequentist) approach and the Bayesian approach (recommended for

agricultural management projects), are detailed in Section 8. The choice of sampling method, stratification, and sample size will directly influence the precision and robustness of the results obtained through these approaches.

4.2. Stratification

Stratifying the project area into more homogeneous subpopulations (strata) can increase the precision of estimates and optimize sampling effort. Strata can be defined based on:

- Vegetation or crop type.
- Age class.
- Soil type.
- Topography.
- Historical management or current practices.
- Biomass density classes (derived from preliminary remote sensing).

Sampling must be conducted independently within each stratum. Statistical validation of the stratification (e.g., ANOVA) is recommended.

4.3. Sample Plots

- **Shape and Size:** Plots can be circular, square, or rectangular. The size should be sufficient to capture local variability and minimize edge effects, but practical for measurement.
    - **Forests:** 0.1 ha (e.g., 20x50m, 25x40m) to 1 ha is common.
    - **Agricultural crops:** Can be smaller (e.g., 1m² for dense annual crops, or a defined number of plants for perennial crops).
- **Location:** Plots must be georeferenced with precision (good quality GPS).
- **Permanence:** Permanent plots are preferable for monitoring changes over time. If temporary, they must be allocated in a way that allows for comparison between periods.

4.4. Quality Assurance and Quality Control (QA/QC) of Field Data

QA/QC procedures are crucial and should include:

- Training of the field team.
- Use of calibrated equipment.
- Standardized measurement protocols.
- Clear and verifiable data records (field forms, electronic spreadsheets).

- Cross-verification of a percentage of measurements by a second measurer or supervisor.
- Identification and treatment of outliers.

5. METHODS FOR ESTIMATING BIOMASS AND CARBON IN FOREST VEGETATION

5.1. Above-Ground Biomass (AGB) in Forests

5.1.1. Direct Measurement (Destructive Method) – For Calibration

Consists of cutting, separating components (trunk, branches, leaves), and weighing trees in sample plots. Samples are taken to the laboratory to determine moisture content and convert to dry biomass.

- **Use:** Mainly to develop or validate local or regional allometric equations. It is not practical for large-scale inventories.
- **Reference:** Follow good practices, such as those described in INPA studies (e.g., Silva, 2007; Araújo *et al*., 1999).

5.1.2. Indirect Measurement (Non-Destructive Method)

5.1.2.1. Use of Allometric Equations

Allometric equations relate easily measurable variables (DBH, height, wood density) to biomass.

- **Selection of Equations:**
  - Preference for local or regional equations validated for the project's forest type.
  - In the absence, pantropical equations (e.g., Chave *et al*., 2014) can be used with caution, ideally with local-specific wood density data.
  - This equation, developed for the ZF2 region (Manaus) by INPA, is an example of how above-ground biomass can be estimated:
    - $AGB_{ZF2} = 2.2737 \times DBH^{1.9156} \times 0.584 \times h_{CF}$

      $(R^2=0.85$ and Syx% $= 4.20)$

      Where:

      AGB_{ZF2} = Estimated dry Above-Ground Biomass from the ZF2 equation (kg/tree).

`DBH` = Diameter at Breast Height (cm), measured at 1.30 m from the ground.

`h_CF` = Height correction factor, calculated as `H_dom_local / H_dom_ZF2`.

Note: The Developer must justify the choice of any allometric equation, present its parameters, the standard error of the estimate (`Syx%`), and the coefficient of determination (`R²`), if available in the original source.

- **Input Variables:**
  - **DBH:** Measured at 1.30 m from the ground.
  - **Height (H):** Can be total height (`Ht`) or stem height (`Hs`). The inclusion of H can improve precision but increases costs and potential for measurement error. Some robust equations for the Amazon do not require H.
  - **Wood Density (ρ):** Specific values by species or averages for the forest community.
    Sources: Global Wood Density Database, local literature.
- **Requirements:** The Developer must justify the choice of the equation, present its parameters, the standard error of the estimate (`Syx%`), and the coefficient of determination (`R²`).

5.1.2.2. Estimation by Volume and Wood Density (Cubage)

When the biomass estimate is based on the volume of the stem (or other tree components) and wood density:

- `B_stem = V_stem * D_b_wood`

Where:

`B_stem` = Biomass of the tree stem (kg or t, the unit must be consistent with `V_stem` and `D_b_wood`).

`V_stem` = Volume of the tree stem (m^3).

`D_b_wood` = Basic wood density (kg/m^3 or t/m^3).

The application of this method will imply the estimation of the stem biomass only:

`AGB_total = B_stem * FEB_canopy_roots`

Where:

`AGB_total`	=	Estimated total Above-Ground Biomass (kg or t).
`FEB_canopy_roots`	=	Biomass Expansion Factor for canopy and, if included in the factor, roots (dimensionless). This factor must be justified and derived from appropriate sources for the forest type. *Note: It is more common to use separate expansion factors for canopy and roots (BGB).*

- **Rigorous Cubage:** The volumetric determination of each log/tree (rigorous cubage) is mandatory **ONLY** if the chosen method for estimating biomass and carbon is based on volume (i.e., `Volume of the log/tree x Basic wood density x Carbon Fraction`). In this case, all field data and protocols of the cubage **MUST** be presented, validated, and verified.
- If the project opts for the use of validated allometric equations (which estimate biomass directly from `DBH`, height, and/or wood density), the rigorous cubage of each tree is not required, as it is sufficient to detail the equations, their parameters, and the field measurements used as input for these equations.

5.2. Below-Ground Biomass (BGB) in Forests

Below-ground biomass (BGB) is commonly estimated from above-ground biomass (AGB) using a Root-to-Shoot Ratio (`R:S ratio`):

- **Root-to-Shoot Ratios (`R:S ratio`):**
  - `BGB = AGB * R_S_ratio`

Where:

`BGB`	=	Below-Ground Biomass (unit consistent with `AGB`, e.g., kg or t).
`AGB`	=	Above-Ground Biomass (unit consistent with `BGB`, e.g., kg or t).

`R_S_ratio` = Root-to-Shoot Ratio (dimensionless). The values should be obtained from sources like the IPCC (e.g., Table 4.4, Vol 4, Chap 4, 2006 IPCC Guidelines) or specific scientific literature for the forest type and region.

- **Specific Allometric Equations for BGB:** If available and validated for the region.
  - **Example of Allometric Equation for BGB in the Amazon (ZF2 - INPA):**
    - $BGB_{ZF2} = 0.0469 \times DBH^{2.4757} \times 0.533 \times h_{CF}$
      `(R² = 0.95 and Syx% = 5.12)`

      Where:

      `BGB_ZF2` = Dry Below-Ground Biomass, estimated by the ZF2 equation (kg/tree).

      `DBH` = Diameter at Breast Height (cm).

      `h_CF` = Height correction factor applicable to `BGB`, if specified by the original source (can be different from the `h_CF` for `AGB` or can be 1 if there is no height correction for `BGB`).
  - **Example of Allometric Equation for Total Biomass (AGB + BGB) in the Amazon (ZF2 - INPA):**
    - $BS_{total\ ZF2} = 2.7179 \times DBH^{1.8774} \times 0.584 \times h_{CF}$
      `(R²=0.94 e Syx% = 3.91)`

      Where:

      `BS_total_ZF2` = Total Dry Biomass (AGB + BGB) estimated by the ZF2 equation (kg/tree).

      `DBH` = Diameter at Breast Height (cm).

      `h_CF` = Height correction factor applicable to total biomass (may be the same `h_CF` as for `AGB` or a specific factor).

5.3. Deadwood (DW)

5.3.1. Standing Dead Wood/Tree (Snags)

Inventory similarly to live trees (DBH, height, and decomposition class, if possible). Good practices described by the IPCC suggest that all dead matter (trees) should be considered as total emissions, regardless of their state of decomposition. To estimate the "carbon stock in dead wood," the same allometric equations already described are adopted.

5.3.2. Down Dead Wood (DDW)

The base of the individual must be within the limits of the fixed area sample unit to be counted/sampled. All fallen trees found within the plot must be sampled and their independent variables recorded (DBH, heights, etc.). The estimation of biomass/carbon of these individuals follows the same protocol as for live trees.

5.4. Litter

5.4. Litter

A component of litter biomass, according to Silva (2007), in a tropical Amazonian forest area, approximately 2.9% (± 1.5) is dead matter. This includes trees and litter. Thus, the litter can be (conservatively) omitted in any project.

If the proponent wishes to include this component, it is recommended:

Installation of at least 30 (thirty) sample units (plots), per project stratum, of fixed area, where the minimum size is 1 m², preferably square-shaped. Collect all litter material in small plots (e.g., 1m²), dry, and weigh. Extrapolate to the area.

All plots must be georeferenced and identified in the field.

5.5. Carbon Quantification in Forest Biomass

The conversion of dry biomass to carbon stock is done using a Carbon Fraction (CF):

```
CS_biomass = BS_dry * CF_biomass
```

Where:

`CS_biomass` = Carbon stock in biomass (t C).

`BS_dry`	=	Total dry biomass (AGB + BGB + other pools if included, such as dead wood and litter) (`t DM` - tonnes of dry matter).
`CF_biomass`	=	Carbon Fraction in dry biomass (`t C / t DM`, dimensionless). The IPCC default value is `0.47` for total forest biomass, but specific values per component (AGB, BGB) or forest type should be used if available and justified (e.g., `0.485` for `AGB` and `0.383` for `BGB` in ZF2).

The conversion of carbon stock to carbon dioxide equivalent (CO_2e) is

```
CO2e_biomass = CS_biomass * (44 / 12)
```

Where:

`CO2e_biomass`	=	Carbon dioxide equivalent stored in biomass (t CO_2e).
`CS_biomass`	=	Carbon stock in biomass (t C).
`(44 / 12)`	=	Ratio between the molecular mass of CO_2 (44 g/mol) and the atomic mass of Carbon (12 g/mol).

6. METHODS FOR ESTIMATING BIOMASS AND CARBON IN AGRICULTURAL SYSTEMS

6.1. Soil Organic Carbon (SOC) in Agricultural and Forest Areas

According to IPCC 2006 Guidelines, Vol 4, Chap 2 and ALM methodologies:

6.1.1. Soil Sampling

- **Depth:** Standard 0-30 cm. Incremental layers (e.g., 0-10, 10-20, 20-30 cm) are recommended. Greater depths can be considered if justified.
- **Sampling Design:** Stratified (by soil type, use, relief) or random. A minimum number of composite samples per sub-samples is necessary per stratum/area for representativeness. E.g., At least 5-10 composite samples per stratum, each with 10-20 sub-samples.
- **Tools:** Augers and volumetric rings for collecting undisturbed samples (for density) and disturbed samples (for `C` analysis).

6.1.2. Laboratory Analysis

- **Soil Density (Bulk Density - BD):** g/cm³, determined in undisturbed samples dried in an oven.
- **Organic Carbon Concentration (%C):** Determined by dry combustion (e.g., CHN elemental analyzer) or wet oxidation (Walkley-Black, with correction caveats).
- **Coarse Fragments (>2mm):** Percentage in volume or mass, for correction of the fine soil volume.

6.1.3. SOC Stock Calculation

The Soil Organic Carbon (SOC) stock per unit area for a given soil layer "`i`" is calculated as:

```
SOC_i = C_frac_i * BD_i * D_i * (1 - FG_frac_i) * F_conv
```

Where:

`SOC_i`	=	Soil Organic Carbon stock for layer "`i`" (t C/ha).
`C_frac_i`	=	Organic carbon concentration in soil layer "`i`", expressed as a decimal fraction (e.g., for 2%, use 0.02).
`BD_i`	=	Soil density (Bulk Density) for soil layer "`i`" (g/cm³ or t/m³).
`D_i`	=	Depth (thickness) of soil layer "`i`" (cm or m).
`FG_frac_i`	=	Volumetric fraction of coarse fragments (>2mm) in soil layer "i", expressed as a decimal fraction (e.g., for 10%, use 0.10).
`F_conv`	=	Unit conversion factor to result (tC/ha).

- If `BD_i` is in g/cm³ and `D_i` is in cm, then `F_conv = 100`.
- If `BD_i` is in t/m³ and `D_i` is in m, then `F_conv = 10,000`.

Note: The choice of the conversion factor must be consistent with the units of BD and D.

The total SOC stock to a certain depth is the sum of the stocks of the individual layers:

```
SOC_total = Σ SOC_i
```

Technical Note: The `SOC_total` value calculated for each sampling point represents the input data for the statistical analysis models described in Section 8. In the context of the Bayesian approach nomenclature (Section 8.2), the SOC stock measured at a point i at time t (e.g., baseline) corresponds to the variable `Eit`.

6.1.4. Use of Models for SOC (Optional and under Conditions)

- Models like RothC, Century, or DayCent can be used to estimate changes in SOC, especially for Tier 3.
- Requires calibration and validation with local data (initial SOC measurements, climatic, soil, and management data).
- Transparency in the model parameters and data sources is crucial.
- Must be approved by Tero Carbon and VVB.

6.2. Biomass in Perennial/Semi-perennial Agricultural Crops

(E.g.: Coffee, Cocoa, Fruit trees, Palm)

6.2.1. Above-Ground Biomass (AGB_perennial)

- **Destructive Method (for calibration):** Similar to forestry, but adapted to the plant scale.
- **Allometric Equations:** Preferably specific to the crop, age, and region.
    - Common input variables: base diameter (BD), canopy diameter, plant height.
- **Carbon Fraction (CF):** Specific to the crop, or IPCC default for woody crops (~0.50).

6.2.2. Below-Ground Biomass (`BGB_perennial`)

- **Root-to-Shoot Ratios (R:S):** Specific to the crop or IPCC defaults.
- **Allometric Equations for BGB:** If available.

6.2.3. Example: Allometry for Coffee (Coffea arabica and Coffea canephora)

- **Recommended Equation (Rezende, 2023 for Monte Carmelo-MG, 4-6 year old coffee):**
    - `BS_tot_coffee = 0.1754 * (DAB_coffee)^2.0845`

      Where:

`BS_tot_coffee`	=	Total Dry Biomass (AGB + BGB) of the coffee plant (kg/plant).
`DAB_coffee`	=	Diameter at Base of the main coffee stem (cm).

- **Carbon Fraction (CF) for Coffee (Rezende, 2023):**
  - 4 years: 42.79% (0.4279)
  - 6 years: 44.73% (0.4473)
- **Calculation of carbon in the total biomass of coffee:**
  - `CS_tot_coffee = BS_tot_coffee * CF_coffee_age`

Where:

`CS_tot_coffee`	=	Carbon stock in the total biomass of the coffee plant (kg C/plant).
`CF_coffee_age`	=	Specific Carbon Fraction for the age of the coffee plant (dimensionless, e.g., 0.4279 for 4 years, 0.4473 for 6 years, according to Rezende, 2023).

6.2.4. Structure for Future Perennial/Semi-perennial Crops (e.g., Cocoa)

This section will be expanded to include validated allometric equations for other perennial/semi-perennial crops (e.g., Cocoa) as they are homologated by Tero Carbon. Developers can propose equations in the PDD, with due justification and validation data.

6.3. Biomass in Annual/Cyclical Agricultural Crops – Long-Term Cyclical Carbon Stock (LTCS)

(E.g.: Soybean, Millet, Corn etc)

6.3.1. Definition and Delimitation of LTCS

The LTCS represents the average carbon stock maintained in the living biomass (`AGB_cyclical` and `BGB_cyclical`) of annual or short-cycle crops over multiple cultivation cycles, under a sustainable and continuous agricultural management regime. It is distinct from SOC, which is the carbon in the soil. The LTCS recognizes that, although the biomass of cyclical crops is harvested, a certain average amount of carbon is present in the agricultural system over time due to crop rotation and succession.

6.3.2. Sampling Strategies for Peak Biomass

To estimate the LTCS, it is crucial to determine the peak biomass of the crop(s) in the system.

- **Frequency:** Sampling at the time of maximum accumulated biomass (generally at physiological maturity, before senescence and harvest).
- **Number and Size of Samples:** Defined by statistical analysis to achieve the desired precision, considering the variability of the crop and the plot. Use sampling subplots (e.g., 1m² for grains, or a specific number of plants). For populations with normal distribution, a minimum of 3 (three) samples per stratum is recommended. For populations that do not have a normal distribution, a minimum of 30 (thirty) samples per stratum is recommended.
- **Sampling Over Cycles:** To calculate a robust average, the peak biomass should be sampled over multiple cycles (e.g., 3-5 representative years of the rotation).

6.3.3. Methods for Estimating Peak Biomass (`AGB_cyclical`)

6.3.3.1. Estimation by Volume and Wood Density (Cubage)

- Collect all the AGB of the crops within the sampling subplots at peak biomass.
- Weigh the total fresh biomass.
- Collect representative sub-samples, weigh them fresh, dry them in an oven (e.g., 65-70°C to constant weight), and weigh them dry to determine the dry matter content.
- `AGB_cyclical_dry = (M_fresh_AGB_subplot / A_subplot) * (Perc_DM_AGB / 100) * F_conv_AGB_cyclical`

  Where:

`AGB_cyclical_dry`	=	Dry Above-Ground Biomass of the cyclical crop (t DM/ha).
`M_fresh_AGB_subplot`	=	Total fresh mass of the AGB collected in the sampling subplot (kg).
`A_subplot`	=	Area of the sampling subplot (m²).
`Perc_DM_AGB`	=	Percentage of Dry Matter of the AGB (%), determined in the laboratory.

`F_conv_AGB_cyclical`	=	Conversion factor for t/ha (if the units above are used, `F_conv_AGB_cyclical = 10`).

6.3.3.2. Use of Specific Allometric Equations

If robust and validated allometric equations are available for the specific crop, relating easily measurable variables (e.g., plant height, planting density, leaf area index) to AGB, they can be used. They must be duly referenced and their applicability justified.

6.3.3.3. Harvest Indices and Conversion Factors

- **Harvest Index (`HI`):**

```
HI = M_dry_harvested_product / M_dry_AGB_total
```

Where:

`HI`	=	Harvest Index (dimensionless).
`M_dry_harvested_product`	=	Dry mass of the marketable harvested product (e.g., grains) (t DM/ha or kg DM/ha).
`M_dry_AGB_total`	=	Total dry mass of the Above-Ground Biomass of the crop (t DM/ha or kg DM/ha, unit consistent with the numerator).

- **Estimation of AGB from productivity and `HI`:**

```
AGB_cyclical_dry = Prod_grains_dry / HI
```

Where:

`AGB_cyclical_dry`	=	Dry Above-Ground Biomass of the cyclical crop (t DM/ha).
`Prod_grains_dry`	=	Productivity of grains (or other product) in dry mass (t DM/ha).
`HI`	=	Harvest Index (dimensionless).

6.3.4. Estimation of Below-Ground Biomass (`BGB_cyclical`)

```
BGB_cyclical_dry = AGB_cyclical_dry * R:S_ratio_cyclical
```

Where:

`BGB_cyclical_dry`	=	Dry Below-Ground Biomass of the cyclical crop (t DM/ha).
`AGB_cyclical_dry`	=	Dry Above-Ground Biomass of the cyclical crop (t DM/ha).
`S_ratio_cyclical`	=	Specific Root-to-Shoot Ratio for the cyclical crop (dimensionless).

6.3.5. Calculation of LTCS (Long-Term Cyclical Carbon Stock)

- **Total Peak Cyclical Biomass (or cycle average):**

```
BS_cyclical_total_peak = AGB_cyclical_dry + BGB_cyclical_dry
```

Where:

`BS_cyclical_total_peak`	=	Total Peak Dry Cyclical Biomass (or cycle average) (t DM/ha)

- **Carbon in Peak Cyclical Biomass (or cycle average):**

```
CS_cyclical_total_peak = BS_cyclical_total_peak *
CF_crop_cyclical
```

Where:

`CS_cyclical_total_peak`	=	Carbon Stock in the Total Peak Cyclical Biomass (or cycle average) (t C/ha).
`CF_crop_cyclical`	=	Specific Carbon Fraction for the cyclical crop (dimensionless).

- **Calculation of LTCS (average over N_years or rotation cycles):**

```
LTCS = ( Σ CS_cyclical_total_peak,year_i ) / N_years
```

Where:

`LTCS`	=	Long-Term Cyclical Carbon Stock (t C/ha).
`CS_cyclical_total_peak,year_i`	=	Carbon Stock in the Total Peak Cyclical Biomass for the year (or cycle) "`i`" (t C/ha).
`N_years`	=	Number of representative years (or cycles) considered in the average.

6.3.6. Treatment of Agricultural Residues

The fraction of `AGB` residues that is left in the field (e.g., straw) and returns to the soil contributes to the SOC. Double counting must be avoided:

- The LTCS represents the carbon in the average living biomass.
- The carbon from residues that decompose and enter the SOC must be accounted for separately in the SOC dynamics.
- Estimate the amount of residues left (`Residues_AGB_dry = AGB_cyclical_dry - AGB_harvested_dry`), the fraction that effectively becomes SOC (`f_residue_to_SOC`), and its carbon content.

6.3.7. Example 1: Carbon Quantification in Soybean (Glycine max)

(Based on the INPA booklet: Souza et al., 2022. "The production of soybean at São Wustro Farm (Bahia) – 2020-2021 harvest.")

- **Peak Biomass Method:** Direct cutting and weighing.
- **Reference Data (São Wustro Farm, 2020-2021 Harvest, R5 Phase - peak biomass):**
  - Total Dry Mass (`AGB+BGB`) of Soybean: 10.66 ± 0.63 t/ha. (This is already the total biomass, `AGB+BGB`).
  - Total Carbon Stock in Soybean (`AGB+BGB`): 4.48 ± 0.27 tC/ha.
    (Implies a Carbon Fraction (CF) of approximately 4.48/10.66 = 0.42)
- **`LTCS` Calculation for Soybean (Simplified Example):**
  - If soybean were cultivated continuously and this peak value (4.48 tC/ha) were representative of each cycle, the `LTCS_soybean` would be close to this value.
  - If there is rotation, the `C_cyclical_total_peak` of each crop in the rotation would be calculated and the weighted average by frequency in the rotation would form the system's LTCS.

- **Observation:** The INPA booklet focuses on a single cycle. For the `LTCS`, the Project Developer must apply this method of quantifying peak biomass over several cycles and calculate the average, as described in Section 6.3.5.

6.3.8. Example 2: Carbon Quantification in Millet (Pennisetum glaucum)

(Based on the INPA booklet: Souza *et al*., 2022)

- **Peak Biomass Method:** Direct cutting and weighing.
- **Reference Data (São Wustro Farm, 2020-2021 Harvest):**
  - Total Dry Mass (`AGB+BGB`) of Millet: 6.24 ± 0.86 t/ha.
  - Total Carbon Stock in Millet (AGB+BGB): 2.87 ± 0.40 tC/ha. (Implies a Carbon Fraction (CF) of approximately 2.87/6.24 = 0.46)
- **`LTCS` Calculation for Millet (Simplified Example):**
  - Similar to soybean, if millet is the main crop in a system and this peak value (2.87 tC/ha) is representative, the `LTCS_millet` would be close to it.
  - If it is a cover crop or part of a rotation, its `C_cyclical_total_peak` would contribute to the system's LTCS.

6.3.9. Structure for Future Annual/Cyclical Crops

This section will be expanded to include parameters (`HI`, `R:S`, `CF`) and quantification methods for other annual/cyclical crops (e.g., corn, cotton, bean, specific cover crops) as they are proposed by projects and validated by Tero Carbon.

6.4. Carbon Quantification in Agricultural Biomass

```
CS_agricultural = BS_agricultural_dry * CF_crop
```

Where:

`CS_agricultural`	=	Carbon stock in the agricultural biomass (e.g., per plant or per hectare) (t C or kg C).
`BS_agricultura`	=	Dry agricultural biomass (AGB or AGB+BGB, according to the scope) (t DM or kg DM).

`l_dry`

`CF_crop` = Specific Carbon Fraction for the crop (dimensionless).

6.5. Quantification of GHG Emission Reductions from Agricultural Management (EMIS)

Agricultural Land Management (ALM) projects often include activities aimed at reducing greenhouse gas (GHG) emissions directly from management practices, in addition to promoting carbon sequestration. This section describes the guidelines for quantifying these emission reductions.

6.5.1. Emission Sources and Relevant Gases

The main emission sources and GHGs associated with agricultural management that may be targeted for reduction include:

- **N_2O (Nitrous Oxide) from the Soil:**
  - Direct emissions from the application of synthetic and organic nitrogen fertilizers.
  - Direct emissions from the decomposition of crop residues left in the soil.
  - Direct emissions from the cultivation of organic soils.
  - Indirect emissions due to nitrogen volatilization (as NH_3 and NOx) and subsequent deposition.
  - Indirect emissions due to leaching and surface runoff of nitrogen.
- **CH_4 (Methane):**
  - Emissions from the anaerobic decomposition of organic matter in flooded soils (e.g., irrigated rice cultivation).
  - Emissions from manure management (if integrated into the agricultural system and altered by the project).
- **CO_2 (Carbon Dioxide):**
  - Emissions from urea use as a fertilizer.
  - Emissions from the application of lime and other carbonates to correct soil acidity.
  - Emissions from the consumption of fossil fuels in agricultural machinery and equipment.
  - Loss of Soil Organic Carbon (SOC) due to intensive soil preparation practices (this source is generally treated as a change in the SOC stock, but its reduction can be considered an emission reduction if the baseline involved continuous loss of SOC).

The Project Developer must identify and justify which sources and gases are relevant to the baseline scenario and the project activities, according to the ALM methodology or other applicable one.

6.5.2. Calculation Methodology (Activity Data x Emission Factors)

- **Calculation of GHG Emissions:**

  `E_GHG_source = AD_source * EF_GHG_source`

  Where:

`E_GHG_source`	=	Emissions of a specific GHG (e.g., N_2O, CH_4, CO_2) from a given source (e.g., fertilizer, burning) (t GHG or t CO_2e, if the EF is already in CO_2e).
`AD_source`	=	Activity Data for the source (specific unit, e.g., kg N of applied fertilizer, ha of burned area, liters of consumed fuel).
`EF_GHG_source`	=	Emission Factor for the GHG and the specific source (t GHG/unit of AD, or t CO_2e/unit of AD).

- **Activity Data (AD):** Refers to the magnitude of the human activity that results in emissions or removals. Examples:
  - Quantity of applied nitrogen fertilizer (kg N/ha).
  - Area of irrigated rice cultivation (ha).
  - Quantity of applied lime (t/ha).
  - Fuel consumption (liters/ha or liters/operation).
  - Area under a certain type of soil management (ha).

The AD must be collected following good measurement and verification practices. The method must be replicable and auditable, in addition to being technically and scientifically based, using property records, fiscal notes, field notebooks, or direct measurements.

- **Emission Factors (EF):** Represent the quantity of GHG emitted per unit of activity data.
  - They must be selected based on the appropriate approach level (Tier) (see Section 6.5.3).
  - Primary sources: IPCC Guidelines (2006 IPCC Guidelines and 2019 Refinement), National Emissions Inventory, or peer-reviewed scientific studies specific to the region and practice.

The emission reduction is calculated as the difference between the emissions in the baseline scenario and the emissions in the project scenario:

$$RR\_EMIS = E\_GHG\_BSL - E\_GHG\_PROJ$$

Where:

RR_EMIS	=	Reduction of GHG Emissions (t CO_2e).
E_GHG_BSL	=	Total GHG emissions in the Baseline scenario (t CO_2e).
E_GHG_PROJ	=	Total GHG emissions in the Project scenario (t CO_2e).

Note: Both E_GHG_BSL and E_GHG_PROJ are the sum of the emissions of all relevant sources ($\Sigma\ E\_GHG\_source$) converted to tCO_2e using the appropriate GWPs, using the Global Warming Potentials (GWP) from the most recent IPCC assessment report formally adopted by the UNFCCC for the reporting period.

6.5.3. Approach Levels (Tiers) for EMIS

- **Tier 1:** Uses IPCC default emission factors. It is the simplest approach and may be suitable for small-scale projects or when local data is scarce. Uncertainty is generally higher.
- **Tier 2:** Uses emission factors specific to the country or region, or for specific management practices, derived from national/regional studies or local measurements. Requires more data, but offers greater precision. Simple country-specific models also fit here.
- **Tier 3:** Uses more complex models and local-specific data, or direct measurements of GHG fluxes (e.g., static or dynamic chambers for N_2O from the soil). It is the most precise, but also the most intensive in data and resources.

Tero Carbon encourages the use of the highest Tier that is technically and financially feasible for the project. The choice of Tier must be justified in the PDD.

6.5.4. IPCC References and Tools

Project Developers **MUST** consult and reference the following IPCC publications for the quantification of EMIS:

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use.

- 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use.*
- IPCC software tools (such as the IPCC Inventory Software) can be useful for applying the methodologies.

The project documentation must detail the sources of AD, the EFs used (and their justification/source), the applied equations, and any assumptions made.

Developers should also be aware that, for the purpose of generating CRVEs under the SBCE, the system's managing body may establish or endorse specific emission or removal factors for Brazil, or quantification methodologies that become a national reference, as per Art. 8, II and XVII of Law No. 15,042/2024.

7. USE OF REMOTE SENSING AND MODELING

7.1. Tier 2: Methods Based Predominantly on Remote Sensing

For projects where extensive field data collection is unfeasible (especially small-scale), Tero Carbon accepts the use of methods based on remote sensing (satellite, LiDAR, radar, drones) to estimate biomass and carbon.

- **Requirements:**
  - The software or model must be calibrated with field data representative of the region and vegetation/crop type.
  - It must be submitted for homologation by Tero Carbon (see Section 7.3).
  - It must provide uncertainty estimates.
  - The methodology must be transparent.
- **Verification:** The results of Tier 2 models will be mandatorily field-verified by a VVB, which will perform sampling to validate the model's estimates.

7.2. Tier 3: Integration of Field Data with Remote Sensing

This is the preferred approach, combining the precision of field measurements with the extrapolation and monitoring capacity of remote sensing.

- Field data (inventory plots) are used to train and validate models based on remote sensing variables (e.g., vegetation indices, canopy height, texture).
- The calibrated models are then used to map carbon stocks across the entire project area and monitor changes over time.

7.3. Homologation of Software and Models by Tero Carbon

Tero Carbon recognizes the potential of using software and models based on remote sensing and/or simulation algorithms to optimize the quantification of carbon stocks and changes in these stocks, especially for Tier 2 approaches or as a support tool in Tier 3. To ensure the robustness and credibility of the results, software or models proposed by Project Developers for use in the quantification of Tero Carbon assets **MUST** undergo a homologation process.

The Developer wishing to use a specific software or model **MUST**:

1. **Submit to Tero Carbon a Request for Homologation**, accompanied by detailed technical documentation, which includes, at a minimum:
    - **Model/Software Description:** Name, version, developer, scope of application (types of vegetation/crop, regions, carbon pools).
    - **Scientific Basis and Algorithms:** Detailing of the scientific principles and the mathematical/statistical algorithms employed.
    - **Input Data:** Specification of the types of input data required (e.g., satellite images, climatic data, soil parameters, field data).
    - **Calibration Process:** Description of how the model/software was calibrated, including the sources of ground truth data used for calibration, their geographic and temporal representativeness, and the statistical methods employed.
    - **Independent Validation:** Presentation of results of the model/software validation against independent field data sets (not used in calibration), demonstrating the accuracy and precision of the estimates (e.g., R^2, RMSE, bias). The validation must be representative of the conditions where the project will be applied.
    - **Sensitivity and Uncertainty Analysis:** Demonstration of how the model/software treats and quantifies the uncertainties associated with its estimates, including sensitivity to input parameters.
    - **Carbon Compartments:** Clear identification of which carbon pools (AGB, BGB, SOC, etc.) are estimated by the model/software.
    - Limitations: Explicit recognition of the model/software's limitations.
    - **QA/QC Protocols:** Internal quality assurance and control procedures for the development and application of the model/software.
2. **Provide Access (if requested):** Allow the Tero Carbon technical team, or specialists designated by it (under a confidentiality agreement, if necessary), to test or audit the functioning of the software/model.
3. **Provide a Public Technical Summary:** Prepare a concise document, in Portuguese and English, that describes the general methodology of the software/model, its main uses and limitations, in a transparent manner,

without necessarily exposing critical intellectual property. This summary will be made publicly available by Tero Carbon if homologation is granted.

Indicative Evaluation Criteria for Homologation:

- Scientific and methodological robustness.
- Quality and representativeness of calibration and validation data.
- Proven performance in terms of accuracy and precision.
- Adequate approach for quantifying and propagating uncertainties.
- Transparency and clarity of documentation.
- Applicability to Tero Carbon's methodologies and project types.
- Compliance with the principles of conservatism.

Tero Carbon may maintain a public list of homologated software and models. The homologation of a software/model does not exempt the project from field verification by a VVB, which may include sampling to validate the specific estimates of the project. Tero Carbon reserves the right to request additional information or require specific validations for different biomes or conditions before granting homologation. A detailed procedure on the software homologation process will be made available by Tero Carbon.

8. UNCERTAINTY ANALYSIS AND STATISTICAL APPROACHES

The quantification of uncertainty is a requirement for all estimates of carbon stock and GHG fluxes. The following guidelines should be followed:

- Identify the sources of uncertainty (measurement errors, sampling errors, model errors, uncertainty in parameters like Carbon Fractions (CF) and Root-to-Shoot Ratios ($R:S$))
- Quantify the uncertainty for each relevant carbon pool and emission source, and propagate these uncertainties to the final estimate of net reductions/removals, using appropriate statistical methods.
- Report the estimates as a mean value accompanied by a confidence interval (e.g., 90% or 95% CI, as specified by the applicable Tero methodology or, in the absence of specification, the Developer must justify the choice).
- The acceptable level of uncertainty for the final VCU estimates may vary according to the Tero methodology and the project scale.

This section presents two approaches for the statistical analysis of sample data and the treatment of uncertainty. The choice of approach must be justified in the PDD.

8.1. General Approach (Frequentist)

This approach is based on classical statistics and is applicable to all types of AFOLU projects, being common in forest inventories. Uncertainty propagation should be performed using methods such as error propagation as per the IPCC 2006 guidelines (Annex 1 of Volume 1) or Monte Carlo simulation.

8.1.1. Conservative Application of the Confidence Interval in Final Estimates for Crediting

To ensure the principle of conservatism in the final quantification of Verified Carbon Units (VCUs) to be issued, the margin of uncertainty (derived from the confidence interval) must be applied unilaterally, resulting in the most conservative estimate of the climate benefit. The Project Design Document (PDD) and the Monitoring Reports must clearly detail how the uncertainty was propagated and how the conservative limit was applied.

The following guidelines should be followed:

1. **For Estimates of Climate Benefits (Reductions/Removals):**
    - When calculating a net GHG removal (e.g., increase in carbon stock in soil or biomass) or a net emission reduction (e.g., avoided emissions in APD, reduction of emissions from agricultural management), the margin of uncertainty must be subtracted from the mean estimate. The creditable value will be the lower limit of the confidence interval.
    - Example: If the estimated net removal is 100 tCO_2e with a margin of uncertainty of ±10 tCO_2e (for a 90% CI), the value to be considered for crediting (before other adjustments like leakage and permanence) will be 100 - 10 = 90 tCO_2e. The project must present the calculation that leads to the unilateral margin of 10 tCO_2e (e.g., Z * SE, where Z is the critical value for the unilateral confidence level desired).
2. **For Estimates of Baseline Stocks or Emissions that Reduce the Project's Benefit:**
    - If a carbon stock in the baseline (e.g., `CS_BSL_NAT_n` in ARR projects, representing the carbon that would accumulate naturally) is subtracted from the project's removals, or if baseline emissions are considered as a benefit (e.g., `E_BSL_APD_n` in APD, which are avoided by the project), the conservative application of the CI depends on the net effect:

- If `CS_BSL_NAT_n` (natural baseline stock) is subtracted from the project's removals, the uncertainty margin of `CS_BSL_NAT_n` should be added to its mean estimate. This increases the baseline value, making the project's net benefit more conservative.
- For `E_BSL_APD_n` (avoided baseline emissions), which is a benefit, the uncertainty margin should be subtracted from the mean estimate, as per item 1.

3. **For Estimates of Project Emissions (PE or E_PROJ):**

- When calculating GHG emissions that occur as a result of project activities (e.g., `E_PROJ_n`, `FE_n`, or `EMIS_PROJ_n`), the uncertainty margin must be added to the mean estimate of these emissions. This increases the emissions attributed to the project, making the net benefit more conservative.

4. **Non-Negative Final Result:**

- After the conservative application of the confidence interval, if the resulting value for a net removal or net reduction is negative, it must be considered zero for crediting purposes.

The Project Developer must justify in the PDD the chosen confidence level (e.g., 90% or 95%) and transparently present the calculations of the uncertainty propagation and the derivation of the unilateral margin applied for each component of the GHG quantification, as per the IPCC guidelines (2006 IPCC Guidelines, Vol. 1, Chap. 3 and Annex 1). The specific Tero methodology may provide additional guidance on the required confidence and precision levels.

8.2. Bayesian Approach (Recommended for Agricultural Land Management - ALM Projects)

For projects involving the quantification of changes in carbon stocks with high variability, such as Soil Organic Carbon (SOC) in agricultural systems, Tero Carbon recommends the use of Bayesian inference. This approach allows for a more complete quantification of uncertainty and a transparent, conservative decision-making process.

8.2.1. Objective

To estimate average and total carbon stocks (soil and/or biomass) and their changes associated with the implementation of sustainable management practices, with uncertainty quantified through Bayesian inference.

8.2.2. Data Structure

For each plot/sample unit $i = 1, ..., n$:

- E_{it}: stock (Mg C ha^{-1}) at time t (baseline).
- $E_{i,t+1}$: stock (Mg C ha^{-1}) at time $t+1$ (post-intervention).
- Δ_i: change per sample unit (Mg C ha^{-1}).

$$\Delta_i = E_{i,t+1} - E_{it}$$

The average change per hectare in the sample is the mean (or weighted mean by strata) of the Δ_i.

$$\Delta = (1/n) * \Sigma \Delta_i$$

8.2.3. Bayesian Statistical Model

The objective is to estimate the true mean stock (μ) of the area and its uncertainty.

$$E_i \sim Normal (\mu, \sigma^2)$$

Where:

- μ: mean stock (Mg C ha^{-1}).
- σ: variability between points + measurement error.

a) Simple Paired Model (without covariates):

When there are measurements at two time points (preferably at the same locations), the change (Δi) is modeled directly:

$$\Delta_i \sim Normal (\mu\Delta, \sigma\Delta^2)$$

Where:

- $\mu\Delta$: mean change (Mg C ha^{-1}).
- $\sigma\Delta$: variability of the point-to-point change.
- Priors: Weakly informative priors should be specified, for example: $\mu\Delta \sim Normal (0, 10^2)$, $\sigma\Delta \sim Half\text{-}Cauchy (0, 5)$.

b) Extension with Measurement Error and Unit Effects (Recommended):

This model separates spatial variability (between points) from analytical error:

- E_{ijt} (observed) ~ Normal (E_{it}, σ^2means)
- E_{it} ~ Normal ($\mu_t + u_i$, σ^2site)
- u_i ~ Normal (0, τ^2)
- $\Delta_i = E_{i,t+1} - E_{it}$, with Δ_i ~ Normal ($\mu\Delta$, $\sigma\Delta^2$).

c) With Covariates/Strata:

If there are strata s (soil, landscape, management), the model for the change is:

- Δ_i ~ Normal ($\mu\Delta_{s[i]}$, $\sigma\Delta_{s[i]}^2$)
- with a hierarchical structure: $\mu\Delta_s$ ~ Normal ($\mu\Delta$, $\tau\Delta^2$)

The mean change for the area is the weighted average by the areas of the strata.

8.2.4. Uncertainty and Conservative Value (Certification)

The posterior distribution of $\mu\Delta$, resulting from the Bayesian analysis, provides the complete probability of carbon gain/loss. For a conservative decision, Tero Carbon requires the use of the Minimum Claimable Benefit (BMR), which corresponds to the lower bound of the 95% Credibility Interval (5th percentile) of the posterior distribution of $\mu\Delta$.

$$BMR = q0.05\ (\mu\Delta \mid data)$$

Rule:

- If $BMR > 0$, there is a ≥ 95% probability of carbon gain per hectare. Only positive BMR values are eligible for crediting.
- The BMR may also be required to exceed a technical threshold, if specified by the methodology.

Application Example:

Suppose that after the Bayesian analysis of SOC data from an ALM project, the posterior distribution for the mean change per hectare (μΔ) has the following characteristics:

- Posterior mean = +1.5 Mg C ha^{-1}
- 95% Credibility Interval for $\mu\Delta$ (CrI95%) = [-0.2 Mg C ha^{-1}, +3.2 Mg C ha^{-1}]

In this case, the BMR is the lower bound of the CrI95%, which is -0.2 Mg C ha^{-1}.

According to the decision rule, since BMR is not greater than zero, the result is considered inconclusive. Although the mean indicates a gain, the uncertainty is too high to be 95% confident in the gain. Therefore, no carbon credits for SOC removal would be issued for this monitoring period.

8.2.5. Total Stock/Change in the Area

For an area A (ha):

$$\Delta total = A \times \mu\Delta$$

If A or $\mu\Delta$ have uncertainty, it must be propagated by sampling from the posterior distribution:

$$\Delta total(m) = A(m) \times \mu\Delta(m) \text{ , for } m = 1, \ldots, M$$

The final report must present the 95% CrI of Δtotal and the total BMR (5th percentile of Δtotal).

8.2.6. Sampling Design and Weights

- Stratify (by soil/topo/management) to reduce $\sigma\Delta$.
- Perform optimal allocation of samples, proportional to the expected variance per stratum.
- Apply weights ws in the stratified weighted mean by area:
  - $ws = As / \Sigma As$ (where As is the area of stratum s).

8.2.7. Reporting Requirements and Decision Rule

When using the Bayesian approach, the PDD and Monitoring Reports **MUST** present:

- **Per hectare:** the posterior mean of $\mu\Delta$, its 95% CrI, and the BMR (in Mg C ha^{-1} and tCO_2e ha^{-1})[1].
- **Total:** The estimate of Δtotal, its 95% CrI, and the total BMR.
- **Certification:** The project is approved for credit generation if $BMR \geq threshold$ (where the minimum threshold is zero). Otherwise, the result is classified as 'inconclusive' for that monitoring period.

[1] The conversion from Mg C to tCO_2e is performed by multiplying the carbon value by the molecular mass ratio (44/12), as detailed in Section 5.5.

- **Transparency:** The priors used, model diagnostics (e.g., R-hat, ESS), and sensitivity analyses to priors must be declared.

9. MONITORING, REPORTING, AND VERIFICATION (MRV) OF CARBON STOCKS

- **Monitoring:** The Monitoring Plan in the PDD must detail the frequency and methods for reassessing carbon stocks throughout the project's crediting period.
    - For LTCS, reassessment every X years (e.g., 5 years) or with significant changes in practices.
- **Reporting:** The Monitoring Reports must present the updated estimates of carbon stocks, the changes since the previous period, the methods used, and the uncertainty analysis.
- **Verification:** An independent VVB will audit the data, calculations, and compliance with this document and the specific Tero methodology.

10. REVIEW OF THIS DOCUMENT

This document: "Technical Guidelines for Carbon Quantification in AFOLU Projects (DC.CER.003)" will be reviewed periodically by Tero Carbon, at least every 3 (three) years, or as necessary to:

- Incorporate scientific and technological advances in carbon quantification.
- Add methods for new crops or vegetation types.
- Reflect changes in IPCC guidelines or relevant international standards (ICROA, CORSIA).
- Incorporate feedback from Project Developers, VVBs, and other stakeholders.
- Correct any inconsistencies or ambiguities.
- Meet specific quantification, measurement, reporting, and verification requirements that may be established by the regulation of the Brazilian Greenhouse Gas Emissions Trading System (SBCE), as per Law No. 15,042/2024.

11. CONSULTED LITERATURE AND THEORETICAL BASIS

ACHARD, F.; EVA, H. D.; STIBIG, H-J.; MAYAUX, P.; GALLEGO, J.; RICHARDS, T.; MALINGREAU, J-P. 2002. Determination of deforestation rates of the world's humid tropical forests. Science. Vol. 297, p. 999-1002.

AKINDELE, S. O.; LEMAY M.V. 2006. Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. Forest Ecology and Management. N° 226. Pp 41 - 48.

ALDER, D. 1980. Forest Volume Estimation and Yield Prediction. Yield Prediction. FAO Forestry Paper 22/2. v. 2. 194 p.

AMADON, D. 1973. Birds of the Congo and Amazon Forest: A comparison. In: Tropical Forest Ecosystems in Africa and South America: A Comparative Review. Ed. By Institution Press. Washington, D. C. p. 267-277.

AMARAL, I. L. do; MATOS, F. D. A.; LIMA, J. 2000. Composição florística e parâmetros estruturais de um hectare de floresta densa de terra firme no rio Uatumã, Amazônia, Brasil. Acta Amazonica. 30 (3): 377-392.

ANDERSON, L. O.; MALHI, Y.; LADLE, R. J.; ARAGÃO, L. E. O. C.; SHIMABUKURO, Y.; PHILLIPS, O. L.; BAKER, T.; COSTA, A. C. L.; ESPEJO, J. S.; HIGUCHI, N.; LAURANCE, W. F.; LÓPEZ-GONZÁLEZ, G.; MONTEAGUDO, A.; NÚÑEZ-VARGAS, P.; PEACOCK, J.; QUESADA, C. A.; ALMEIDA, S.; VÁSQUEZ, R. 2009. Influence of landscape heterogeneity on spatial patterns of wood productivity, wood specific density and above ground biomass in Amazonia. Biogeosciences. 6, 2039–2083.

ANGELSEN, A.; BROCKHAUS, M.; SUNDERLIN, W. D.; VERCHOT, L. V. (eds) 2013 Analysing REDD+: Challenges and choices. CIFOR, Bogor, Indonesia. V. 1. 488 p.

ARAGÃO, L. E. O. C.; MALHI, Y.; METCALFE, D. B.; SILVA-ESPEJO, J. E.; JIMÉNEZ, E.; NAVARRETE, D.; ALMEIDA, S. COSTA, A. C. L.; SALINAS, N.; PHILLIPS, O. L.; ANDERSON, L. O.; ALVAREZ, E.; BAKER, T. R.; GONÇALVEZ, P. H.; HUAMÁN-OVALLE, J.; MAMANI-SOLÓRZANO, M.; MEIR, P.; MONTEAGUDO, A.; PATIÑO, S.; PEÑUELA, M. C.; PRIETO, A.; QUESADA, C. A.; ROZAS-D´AVILA, A.; RUDAS, A.; SILVA JR., J. A.; VÁSQUEZ, R. 2009. Above- and below-ground net primary productivity across tem Amazonian forests on contrasting soils. Biogeosciences, 6, 2759–2778.

ARAÚJO, T. M.; HIGUCHI, N.; CARVALHO JR., J. A. 1999. Comparison of formulae for biomass content determination in a tropical rain forest in the state of Pará, Brazil. Forest Ecology and Management, v.117, p.43-52.

ASNER, G. P.; KNAPP, D. E.; BROADBENT, E. N.; OLIVEIRA, P. J. C.; KELLER, M.; SILVA, J. N. 2005. Selective logging in the Brazilian Amazon. Science. Vol. 310: 480-482.

AYRES, J.M e BEST, R. 1979. Estratégias para a conservação da fauna amazônica. Supl. Acta Amazonica 9(4): 81-101.

AZEVEDO, C. P. de.; SANQUETTA, C. R.; SILVA, J. N. M.; CARVALHO, J. O. P. de.; LOPES, J. C. A.; SOUZA, C. R. de. 2008. Efeito de diferentes níveis de exploração e tratamentos silviculturais sobre a dinâmica do povoamento florestal remanescente. Anais: Seminário Dinâmica de Florestas Tropicais. Belém, PA.

BACCINI, A.; GOETZ, S. J.; WALKER, W. S.; LAPORTE, N. T.; SUN, M.; SULLA-MENASHE, D.; HACKLER, J.; BECK, P. S. A.; DUBAYAH, R.; SAMANTHA, S.; HOUGHTON, R. A. 2012. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. Nature Climate Change. Vol. 2. DOI: 10.1038/NCLIMATE1354. p. 182-185.

BAKER, T. R.; PHILLIPS, O. L.; MALHI, Y.; ALMEIDA, S.; ARROYO, L.; Di FIORI, A.; ERWIN, T.; KILLEEN, T. J.; LAURANCE, S. G.; LAURANCE, W. F.; LEWIS, S. L.; LLOYD, J.; MONTEAGUDO, A.; NEILL, D. A.; PATIÑO, S.; PITMAN, N. C. A.; SILVA, J. N. M.; VÁSQUEZ MARTÍNEZ, R. 2004a. Variation in wood density determines spatial patterns in Amazonian forest biomass. Global Change Biology. 10, 545-562.

BAKER, T. R.; PHILLIPS, O. L.; MALHI, Y.; ALMEIDA, S.; ARROYO, L.; Di FIORE, A.; ERWIN, T.; HIGUCHI, N. KILLEEN, T. J.; LAURANCE, S. G.; LAURANCE, W. F.; LEWIS, S. L.; MONTEAGUDO, A.; NEILL, D. A.; VARGAS, P. N.; PITMAN, N. C. A.; SILVA, J. N. M.; MARTINEZ, R. V. 2004b. Increasing biomass in Amazonian forest plots. The Royal Society, 359:353-365.

BARROS, P. L. C.; SILVA JÚNIOR, A. T. 2009. Equação de volume para árvores de uma floresta tropical densa no município de Anapu, Oeste do estado do Pará, Amazônia Oriental. Revista de Ciências Agrárias. Belém, n. 51, p. 115-126.

BATISTA, J. L. F.; MARQUESINI, M.; VIANA, V. M. 2004. Equações de volume para árvores de caxeta (Tabebuia cassinoides) no estado de São Paulo e sul do Rio de Janeiro. Scientia Florestalis. N. 65. 162-175.

BORGES, C. P. I. Equações alométricas para estimar biomassa de campinaranas florestadas na região de Manaus, Amazônia Central. Dissertação de mestrado, Instituto Nacional de Pesquisas da Amazônia. Manaus, X p. 2010.

BRAGA, P.I.S. 1979. Subdivisão fitogeográfica, tipos de vegetação, conservação e inventário florístico da Floresta Amazônica. Acta Amazonica. Supl., Manaus, v. 9, n. 4, p. 53-80.

BRANDEIS, T. J.; DELANEY, M.; PARRESOL, B. R.; ROYER, L. 2006. Development of equations for predicting Puerto Rican subtropical dry forest biomass and volume. Forest Ecology and Management. 233. 133–142.

BRASIL. Constituição da República Federativa do Brasil, de 1988. Disponível em: http://www.planalto.gov.br/ccivil_03/constituicao/ConstituicaoCompilado.htm.
BRASIL. Constituição do Estado do Amazonas, de 1989. Disponível em: http://www.camara.gov.br/internet/interacao/constituicoes/constituicao_amazonas.pdf.

BRASIL. Lei n. 5.449 de 4 de junho de 1968. Declara de interesse da segurança nacional. Disponível em: http://www.planalto.gov.br/ccivil_03/leis/1950-1969/L5449.htm.

BRASIL. Lei n. 9.985 de 18 de julho de 2000. Institui o Sistema Nacional de Unidades de Conservação da Natureza. Disponível em: http://www.planalto.gov.br/ccivil_03/leis/l9985.htm.

BRASIL. Lei n. 12.651 de 25 de maio de 2012. Institui o Novo Código Florestal Brasileiro. Disponível em: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm.

BROWN, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: a Primer. FAO Forestry Paper 134, Rome, Italy, p. 55.

CAMPOS, J. C. C.; LEITE, H. G. Mensuração Florestal: perguntas e respostas. Viçosa, MG: UFV. 2002. 407 p.

CARNEIRO, V. M. C. Composição florística e análise estrutural da floresta primária de terra firme na bacia do rio Cueiras, Manaus – AM. Dissertação de mestrado, Instituto Nacional de Pesquisas da Amazônia. Manaus, p. 77, 2004.

CARVALHO, J. O. P.; SILVA, J. N. M.; LOPES, J. C. A. 2004. Growth rate of a terra firme rain forest in brazilian amazonia over an eight-year period in response to logging. Acta amazonica. Vol. 34(2): 209 – 217.

CELES, C. H.; HIGUCHI, F. G.; AMARAL, M. R.; SANTOS, J.; LIMA, A. J. N.; COBELLO, L. O.; HIGUCHI, N. Garantia e controle de qualidade (QA/QC) do georreferenciamento em inventários florestais na Amazônia. 2016. Anais do III Mensuflor, Volume 1, Número 1, pg. 424-428

CHAMBERS, J. Q.; HIGUCHI, N.; SCHIMEL, J. P. 1998. Ancient Trees in Amazonia. Nature, 391:135-136.

CHAMBERS, J. Q.; SANTOS, J. dos.; RIBEIRO, R. J.; HIGUCHI, N. 2000. Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. Forest Ecology and Management. 5348. 1-12.

CHAMBERS, J. Q.; HIGUCHI, N.; TRIBUZY, E. S.; TRUMBONE, S. E. 2001. Carbon sink for a century. Nature. Vol. 410. p. 429.

CHAMBERS, J. Q.; HIGUCHI, N.; TEIXEIRA, L. M.; SANTOS, J. dos.; LAURANCE, S. G.; TRUMBONE, S. E. 2004. Response of tree biomass and wood litter to disturbance in a Central Amazon forest. Oecologia. 141: 596–614

CHATTERJEE, S.; HADI, A. S.; PRICE, B. 2000. Regression analysis by example. John Wiley and Sons, New York, New York, USA. V. 5. 424 p.

CHAVE, J.; ANDALO, C.; BROWN, S.; CAIRNS, M. A.; CHAMBERS, J. Q.; EAMUS, D.; FOLSTER, H.; FROMARD, F.; HIGUCHI, N.; KIRA, T.; LESCURE, J. P.; NELSON, B. W.; OGAWA, H.; PUIG, H.; RIERA, B.; YAMAKURA, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145: 85-99.
CLUTTER, J. L.; FORTSON, J. C.; PIENAAR, L. V.; BRISTER, G. H.; BAILEY, R. L. Timber Management: A Quantitative Approach. John Wiley and Sons, Inc. New York. 1983. V. 1. 333p.

COHEN, J.; P. COHEN. Applied multiple regression/correlation analysis for the behavioral sciences. Lawrence Erlbaum, Mahwah, New Jersey, USA. 1983. V. 1. 545 p.

COLPINI, C.; TRAVAGIN, D. P.; SOARES, T. S.; SILVA, V. S. M. 2009. Determinação do volume, do fator de forma e da porcentagem de casa de árvores individuais em uma florestal ombrófila aberta na região noroeste de Mato Grosso. Acta Amazonica. Vol. 39 (1), 97-104.

CONDÉ, T. M.; HIGUCHI, N.; LIMA, A. J. N. 2019. Illegal Selective Logging and Forest Fires in the Northern Brazilian Amazon. Forest, v. 10, p. 61.

COUTO, H. T. Z. do.; BASTOS, N. L. M. 1987. Modelos de equações de volume e relações hipsométricas para plantações de eucalyptus no estado de São Paulo. IPEF, n.37, p.33-44.

D'OLIVEIRA, M. V. N.; BRAZ, E. M. 2006. Estudo da dinâmica da floresta manejada no projeto de manejo florestal comunitário do PC Pedro Peixoto na Amazônia Ocidental. Acta amazonia. Vol. 36(2): 177 – 182.

DRAPER, N. R.; SMITH. H. Applied regression analysis. John Wiley and Sons, New York, New York, USA. 1998. 3rd edition. 706 p.

ELDIK, van T.; LIMA, J. P.; PINTO, A. C.; ESTUMANO, D.; REIS, Q. 2008. Relatório Final do Inventário Florestal Diagnóstico da FLONA de Saracá-Taquera, estado do Pará. Serviço Florestal Brasileiro. 49 p.

EVA, H.D.; ACHARD, F.; STIBIG, H-J.; MAYAUX, P. 2003. Response to comment on "Determination of deforestation rates of the world's humid tropical forests". Science, 299, 1015b.

FEARNSIDE, P. M. 1996. Amazonian deforestation and global warming: carbon stocks in vegetation replacing Brazil's Amazon forest. Forest Ecology and Management. 80, 21–34.

FEARNSIDE, P. M. Desmatamento na Amazônia: Dinâmica, impactos e controles. Acta Amazonia. Manaus, v. 36, n. 3, p. 395-400, 2006.

FEARNSIDE, P. M.; LAURANCE, W. F. 2003. Comment on determination of deforestation rates of the world's humid tropical forests. Science, 299, 1015a.

FELDPAUSCH, T. R.; BANIN, L.; PHILLIPS, O. L.; BAKER, T. R.; LEWIS, S. L.; QUESADA, C. A.; AFFUM-BAFFOE, K.; ARETS, E. J. M. M.; BERRY, N. J.; BIRD, M.; BRONDIZIO, E. S.; CAMARGO, P. de.; CHAVE, J.; DJAGBLETEY, G.; DOMINGUES, T. F.; DRESCHER, M.; FEARNSIDE, P. M.; FRANÇA, M. B.; FYLLAS, N. M.; HIGUCHI, N.; HUNTER, M. O.; IIDA, Y.; SALIM, K. A.; KASSIM, A. R.; KELLER, M.; KEMP, J.; KING, D. A.; LOVETT, J. C.; MARIMON, B. H.; MARIMON-JUNIOR, B. H.; LENZA, E.; MARSHALL, A. R.; METCALFE, D. J.; MITCHARD, E. T. A.; MORAN, E. F.; NELSON, B. W.; NILUS, R.; NOGUEIRA, E. M.; PALACE, M.; PATIÑO, S.; PEH, K. S. –H.; RAVENTOS, M. T.; REITSMAN, J. M.; SAIZ, G.; SCHRODT, F.; SONK, B.; TAEDOUNG, H. E.; TAN, S.;

WHITE, L.; WOLL, H.; LLOYD, J. 2011. Height-diameter allometry of tropical forest trees. Biogeosciences, 8, 1081–1106.

FELDPAUSCH, T. R.; LLOYD, J.; LEWIS, S. L.; BRIENEN, R. J. W.; GLOOR, M.; MONTEAGUDO MENDOZA, A.; GONZALEZ-LOPEZ, G.; BANIN, L.; SALIM, K. A.; AFFUM-BAFFOE, K.; ALEXIADES, M.; ALMEIDA, S.; AMARAL, I.; ANDRADE, A.; ARAGAO, L. E. O. C.; MURAKAMI, A. A.; ARETS, E. J. M. M.; ARROYO, L.; AYMARD, G. A. C.; BAKER, T. R.; BÁNKI, O. S.; BERRY, N. J.; CARDOZO, N.; CHAVE, J.; COMISKEY, J. A.; ALVAREZ, E. OLIVEIRA, A.; DiFIORE, A.; DJAGBLETEY, G.; DOMINGUES, T. F.; ERWIN, T. L.; FEARNSIDE, P. M.; FRANÇA, M. B.; FREITAS, M. A.; HIGUCHI, N.; HONORIO, E.; IIDA, Y.; JIMÉNEZ, E.; KASSIM, A. R.; KILLEEN, T. J.; LAURANCE, W. F.; LOVETT, J. C.; MALHI, Y.; MARIMON, B. S.; MARIMON-JUNIOR, B. H.; LENZA, E.; MARSHALL, A. R.; MENDOZA, C.; METCALFE, D. J.; MITCHARD, E. T. A.; NEILL, D. A.; NELSON, B. W.; NILUS, R.; NOGUEIRA, E. M.; PARADA, A.; PEH, K. S.-H.; PENA CRUZ, A.; PEÑUELA, M. C.; PITMAN, N. C. A.; PRIETTO, A.; QUESADA, C. A.; RAMÍREZ, F.; RAMÍREZ-ANGULO, H.; REITSMA, .J. M.; RUDAS, A.; SAIZ, G.; SALOMÃO, R. P.; SCHWARZ, .; SILVA, N.; SILVA-ESPEJO, J. E.; SILVEIRA, M.; SONKÉ, B.; STROPP, J.; TAEDOUMG, H. E.; TAN, S.; STEEGE, H.; TERBORGH, J.; TORELLO-RAVENTOS, M.; van der HEIJDEN, G. M. F.; VÁSQUEZ, R.; VILANOVA, E.; VOS, V. A.; WHITE, L.; WILLCOCK, S.; WOELL, H.; PHILLIPS, O. L. 2012. Tree height integrated into pantropical forest biomass estimates. Biogeoscience. Vol. 9. 3381-3403.

FENG, Y.; LU, D.; CHEN, Q.; KELLER, M.; MORAN, E.; SANTOS, M. N.; BOLFE, E. L.; BATISTELLA, M. Examining effetive use of data sources and modeling algorithms for improving biomass estimation in a moist tropical forest of the Brazilian Amazon. International Journal of Digital Earth, v. 0., n. 0, p. 1-21, 2017.

FERGUSON, L. S.; LEECH, J. W. 1978. Generalized Least Squares Estimation of Yield Functions. Forest Science. 24:27-42.

FERNANDES, N. P.; JARDIM, F. C. S.; HIGUCHI, N. 1984. Tabelas de volume para floresta tropical de terra firme da Estação Experimental de Silvicultura Tropical do INPA. Acta Amazonica.

FITTKAU, E. J.; IRMLER, U.; JUNK, W. J.; REISS, F.; SCHMIDT, G. W. 1975. Productivity, biomass, and population dynamics in Amazonian water bodies. In: F.B. Golley and E. Medina (Editors), Tropical Ecological Systems -- Trends in Terrestrial and Aquatic Research. Springer, New York, N.Y., pp. 289-311.

FOSTER BROWN, I.; MARTINELLI, L. A.; THOMAS, W. W.; MOREIRA, M. Z.; FERREIRA, C. C. A.; VICTORIA, R. A. 1995. Uncertainty in the biomass of Amazonian

forests: Na example from Rondônia, Brazil. Forest Ecology and Management. 75, p. 175-189.

GAMA, J. R. V.; BOTELHO, S. A.; GAMA-BENTES, M. M. 2002. Composição florística e estrutura da regeneração natural de floresta secundária de várzea baixa no estuário amazônico. Revista Árvore. V. 26, n. 5, p. 559-566.

GRACE, J.; LLOYD, J.; McINTYRE, J.; MIRANDA, A. C.; MEIR, P.; MIRANDA, H. S.; NOBRE, C.; MONCRIEFF, J.; MASSHEDER, J.; MALHI, Y.; WRIGHT, I.; GASH, J. 1995. Carbon dioxide uptake by na undisturbed tropical rain forest in Southwest Amazonia, 1992 to 1993. Science. Vol. 270, p. 778-780.

GRAHAM, M. H. 2003. Confronting multicollinearity in ecological multiple regression. Ecology. 84(11). 2809-2815.

HEDGES, J. I.; CLARK, W. A.; QUAY, P. D.; RICHEY, J. E.; DEVOL, A. H.; SANTOS, U. M. 1986. Compositions and fluxes of particulate organic material in the Amazon River. Limnology and Oceanography. Vol. 31, n. 4, 717-738.

HIGUCHI, N. 1986-87. Amostragem sistemática versus amostragem aleatória em floresta tropical úmida de terra-firme na região de Manaus. Acta Amazonica, 16/17 (único): 393-400.

HIGUCHI, N. Short-term growth of an undisturbed tropical moist forest in the brazilian Amazon. Tese de Doutor, Michigan State University. East Lansing, p. 129, 1987.

HIGUCHI, N. Usando o método “jackknife” para estimar volume de madeira da floresta amazônica. Em: Atas da 24ª Reunião Regional da Associação Brasileira de Estatística e 12ª Semana do Estatístico. Manaus, AM, 22-24 de abril de 1992. pp. 42-56.

HIGUCHI, N. O desmatamento insustentável na Amazônia. Ciência Hoje. v. 39, p. 67-71, Ed. Novembro – 2006.

HIGUCHI, N.; RAMM, W. 1985. Developing bole wood volume equations for a group of tree species of Central Amazon (Brazil). Commonw. For. Rev. 64(1). 33-41.

HIGUCHI, N.; SANTOS, J. dos; JARDIM, F. C. S. 1982. Tamanho de parcela amostral para inventários florestais. Acta Amazonica, Manaus, v. 12, n. 1, p. 91-103.

HIGUCHI, N; SANTOS, J. M.; IMANAGA, M.; YOSHIDA, S. 1994. Aboveground biomass estimate for Amazonian dense tropical moist forest. Memoirs of the Faculty of Agricultura, Kagoshima University (Journal). 30, p. 43-54.

HIGUCHI, N.; SANTOS, J. dos; RIBEIRO, R. J.; FREITAS, J. V.; VIEIRA, G.; CÖIC, A.; MINETTE, L. J. 1997. Crescimento e Incremento de uma Floresta Amazônica de Terra-Firme Manejada Experimentalmente In: Biomassa de Nutrientes Florestais. INPA/DFID, Manaus, p. 89-132.

HIGUCHI, N.; SANTOS, J.; RIBEIRO, R. J.; MINETTE, L.; BIOT, Y. 1998. Biomassa da parte aérea da vegetação da floresta tropical úmida de terra-firme da Amazônia brasileira. Acta Amazonica, 28(2):153-166.

HIGUCHI, N.; CHAMBERS, J. Q.; SANTOS, J.; RIBEIRO, R. J.; PINTO, A. C. M.; SILVA, R. P.; ROCHA, R. M.;TRIBUZI, E. S. 2004. Dinâmica e balanço do carbono da vegetação primária da Amazônia Central. Floresta. 34(3) 295-304.

HIGUCHI, N.; SANTOS, J. dos; LIMA, A. J. N.; TEIXEIRA, L. M.; CARNEIRO, V. M. C.; TRIBUZY, E. S. Manejo florestal sustentável na Amazônia brasileira. Manaus, p. 140-155, 2006.

HIGUCHI, M. I. G.; HIGUCHI, N. (eds). A floresta amazônica e suas múltiplas dimensões: uma proposta de educação ambiental - 2a. edição revisada e ampliada. Manaus: INPA/FAPEAM/CNPq/INCT, 2012. 424p.

HIGUCHI, F. G. DINÂMICA DE VOLUME E BIOMASSA DA FLORESTA DE TERRA FIRME DO AMAZONAS. Tese doutorado. 2015.

HOCKING, R. R. Methods and applications of linear models: regression and the analysis of variance. John Wiley and Sons, New York, New York, USA. 3rd edition. 1996. 720 p.

HOUGHTON, R. A. 1997. Terrestrial carbon storage: global lessons for Amazonian research. Ciencia e Cultura Sao Paulo, 49, 58–72.

HOUGHTON, R.A; SKOLE, D. L; NOBRE, C. A; HACKLER, J.L; LAWRENCE, K. T.; CHOMENTOWSKI, W. H. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature, 403, 301–304.

HOUGHTON, R. A.; LAWRENCE, K. T.; HACKLER, J. L.; BROWN, S. 2001. The spatial distribution of forest biomass in the Brazilian Amazon: a comparison of estimates. Global Change Biology. 7, 731-746.

HOUGHTON, R. A. 2005. Aboveground forest biomass and the global carbon balance. Global Change Biology. 11, 945-958.

HUMMEL, A. C.; ALVES, M. V. S.; PEREIRA, D.; VERÍSSIMO, A.; SANTOS, D. 2010. A atividade madeireira na Amazônia brasileira: produção, receita e mercados. Serviço Florestal Brasileiro, Instituto do Homem e Meio Ambiente da Amazônia. Belém-PA. 32 p.

HUNTER, M. O.; KELLER, M.; VICTORIA, D.; MORTON, D. C. 2013. Tree height and tropical forest biomass estimation. Biogeosciences. 10. 8385-8399.

HUSCH, B.; MILLER, C. I.; BEERS, T. W. Forest mensuration. New York. Ronald Press. 1971.

HUSCH, B.; MILLER, C. I.; BEERS, T. W. Forest Mensuration. New York: John Wiley & Sons. 2nd ed., 1972. 402 p.

IBGE. 2012. Manual técnico da vegetação brasileira. IBGE. Rio de Janeiro. 271 p.

IPCC (Intergovernmental Panel on Climate Change). 1990. Climate Change – The IPCC Scientific Assessment. Edited by: Houghton, J. T.; Jenkins, G. J.; Ephraums, J. J. Cambridge University Press. New York. 414 p.

IPCC. 1990. Climate Change – The IPCC Impact Assessment. Edited by: Tegart, W. J. McG.; Sheldon, G. W.; Griffiths, D. C. Australian Government Publishing Service. Canberra. 296 p.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Disponível em http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

ITTO, 2012: Annual review and assessment of the world timber situation. International Tropical Timber Organization. Yokohama, Japan. Prepared by the Division of Economic Information and Market Intelligence, ITTO. ISBN 978-4-86507-007-1.

JARDIM, F. C. S.; HOSOKAWA, R. T. 1986/87. Estrutura da floresta equatorial úmida da estação experimental de silvicultura tropical do INPA. Acta Amazonica, Manaus, v. 16/17, n. único, p. 411-507.

JIANG, L.; BROOKS, J. R.; WANG, J. 2005. Compatible taper and volume equations for yeloow-poplar in West Virginia. Forest Ecology and Management. 213. 399-409.
JUN, J.; GUENSLER, R.; OGLE, J. H. Smoothing methods to minimize impact of global positioning system random error on travel distance, speed, and acceleration. Profile Estimates. n. 1972, p. 141-150, 2006.

JUNK, W.J. Wetlands of tropical South América. In: Whigham, D.H & Dykyjova, D. (eds.): Wetlands of the world I. Kluwer Academic Publishers. p. 679-739, 1993.

KOCH, G. W.; SILLETT; S. C.; JENNINGS, G. M.; DAVIS, S. D. 2004. The limits to tree height. Nature. Vol. 428. 851-854.

KONHAUSER, K. O.; FYFE, W. S.; KRONBERG, B. I. 1994. Multi-element chemistry of some Amazonian Waters and soils. Chemical Geology. 111. 155-175.

KOSSOY, A.; GUIDON, P. State and trens of the carbono Market 2012. World Bank report. 138 p. 2012.

KRONBERG, B. I.; FYFE, W. S.; LEONARDOS, O. H.; SANTOS, A. M. 1979. The chemistry of some Brazilian soils: elemento mobility during intense weathering. Chemical Geology. 24. 211-229.

LENTINI, M.; VERÍSSIMO, A.; PEREIRA, D. 2005. A expansão madeireira na Amazônia. O Estado da Amazônia, 2:1-4.

LI, M.; IM, J.; QUACKENBUSH, L. J.; LIU, T. Forest biomass and carbon stock quantification using airborne LiDAR Data: A case study over Huntington Wildlife Forest in the Adirondack Park. IEEE Journal of Selected Topics in Applied Earth Observation and Remote Sensing, v. 7, n. 7, p. 3143-3156, 2014.

LIMA, J. A. N. Avaliação de um sistema de inventário florestal contínuo em áreas manejadas e não manejadas do estado do Amazonas (AM). 183 p. Tese (Doutorado em Ciências de Florestas Tropicais). Inst. Nac. de Pesq. Amazônia (INPA). Manaus, 2010.

LIMA, A. J. N.; SUWA, R.; RIBEIRO, G. H. P. M., KAJIMOTO, T.; SANTOS, J. dos; SILVA, R. P. dos; SOUZA, C. A. S. de; BARROS, P. C.; NOGUCHI, H.; ISHIZUKA, M.; HIGUCHI, N. 2012. Allometric models for estimating above- and below-ground biomass in

Amazonian forests at São Gabriel da Cachoeira in the upper Rio Negro, Brazil. Forest Ecology and Management. 277, 163–172.

LOETSCH, F.; ZÖHRER, F.; HALLER, K. E. Forest Inventory. Munich, BLV Verlagsgesellschaft. 2nd edition. Vol. II. 1973. 469 p.

LOPES, U. B. Aspectos Físicos, Químicos e Ecológicos das misturas naturais de águas físico-quimicamente diferentes, na Amazônia. 49 p. Tese de doutorado. INPA–Pós-graduação em Ciências Biológicas. Manaus, 1992.

LU, D. Review Article. The Potential and challenge of remote sensing-based biomass estimation. International Journal of Remote Sensing. v. 27, n. 7, p. 1297-1328, 2006.

LU, D.; CHEN, Q.; WANG, G.; MORAN, E.; BATISTELLA, M.; ZHANG, M.; LAURIN, G. V.; SAAH, D. Aboveground forest biomass estimation with LandSat and LiDAR Data and uncertainty analysis of the estimates. International Journal of Forestry Research, v. 2012, n. 1, p. 1-16, 2012.

LU, D.; CHEN, Q.; WANG, G.; LIU, L.; LI, G.; MORAN, E. A survey of remote sensing-based aboveground biomass estimation methods in forest ecosystems. International Journal of Digital Earth, n. December, p. 37-41, 2014.

MACHADO, S. A.; FIGUEIREDO FILHO, A. Dendrometria. 2nda edição. Guarapuava: Editora Unicentro, 2006. v. 1-2ed. 316p.

MACHADO, S. A.; FIGURA, M. A.; SILVA, L. C. R.; TÉO, S. J.; STOLLE, L.; URBANO, E. 2008. Modelagem volumétrica para bracatinga (Mimosa scabrella) em povoamentos da Região Metropolitana de Curitiba. Pesquisa Florestal Brasileira. Colombo, n. 56. 17-29.

MALHI, Y.; NOBRE, A. D.; GRACE, J.; KRUIJT, B.; PEREIRA, M. G. P.; CULF, A.; SCOTT, S. 1998 Carbon dioxide transfer over a central Amazonian rain forest. Journal of Geophysical Research. Vol. 103, No. D 24, p. 31.593–31.612.

MALHI, Y. R.; WOOD, D.; BAKER, T. R.; WRIGHT, J.; PHILLIPS, O. L.; COCHRANE, T.; MEIR, P.; CHAVE, J.; ALMEIDA, S.; ARROYO, L.; HIGUCHI, N.; KILLEEN, T. J.; LAURANCE, S. G.; LAURANCE, W. F.; LEWIS, S. L.; MONTEAGUDO, A.; NEILL, D. A.; NÚÑEZ-VARGAS, P.; PITTMAN, N. C. A.; QUESADA, C. A.; SALOMÃO, R.; SILVA, J. N.; LEZAMA, A. T.; TERBORGH, J.; VÁSQUEZ-MARTÍNEZ, R.; VINCETI, B. 2006. The regional variation of aboveground live biomass in old-growth Amazonian forests. Global Change Biology. 12, 1107-1138.

MARQUET, P.A.; QUIÑONES, R.A.; ABADES, S.; LABRA, F.; TOGNELLI, M.; ARIM, M.; RIVADENEIRA, M. 2005. Scaling and power-laws in ecological systems. The Journal of Experimental Biology. 208, 1749–1769.

MATOS, F. D. de A.; AMARAL, I. L. 1999. Análise ecológica de um hectare em floresta Ombrófila Densa de terra firme, estrada da várzea, Amazonas, Brasil. Acta amazonica. 29(3): 365-379.

MAZZEI, L.; SIST, P.; RUSCHEL, A.; PUTZ, F. E.; MARCO, P.; PENA, W.; FERREIRA, J. E. R. 2010. Above-ground biomass dynamics after reduced-impact logging in the Eastern Amazon. Forest Ecology and Management. 259, p. 367-373.

MELLO, A. A.; NUTTO, L.; WEBER, K. S. SANQUETTA, C. R.; MATOS, J. L. M.; BECKER, G. 2012. Individual Biomass and Carbon Equations for Mimosa scabrella Benth. (Bracatinga) in southern Brazil. Silva Fennica. v. 46, p. 333-343.

MEYER DE SCHAUENSEE, R. 1966. Species of birds of South America and their distribution. Publ. Acad. Nat. Science, 18: 1-578.

MITCHARD, E. T. A.; FELDPAUSCH, T. R.; BRIENEN, R. J. W.; LOPEZ-GONZALEZ, G.; MONTEAGUDO, A.; BAKER, T. R.; LEWIS, S. L.; LLOYD, J.; QUESADA, C. A.; GLOOR, M.; ter STEEGE, H.; MEIR, P.; ALVAREZ, E.; ARAUJO-MURAKAMI, A.; ARAGÃO, L. E. O. C.; ARROYO. L.; AYMARD, G.; BANKI, O.; BONAL, D.; BROWN, S.; BROWN, F. I.; CERÓN, C. E.; CHAMA MOSCOSO, V.; CHAVE, J.; COMISKEY, J. A.; CORNEJO, F.; CORRALES MEDINA, M.; Da COSTA, L.; COSTA, F. R. C.; Di FIORE, A.; DOMINGUES, T. F.; ERWIN, T. L.; FREDERICKSON, T.; HIGUCHI, N.; HONORIO CORONADO, E. N.; KILLEEN, T. J.; LAURANCE, W. F.; LEVIS, C.; MAGNUSSON, W. E.; MARIMON, B. S.; MARIMON JUNIOR, B. H.; MENDOZA POLO, I.; MISHRA, P.; NASCIMENTO, M. T.; NEILL, D.; NÚÑEZ VARGAS, M. P.; PALACIOS, W. A.; PARADA, A.; PARDO MOLINA, G.; PEÑA-CLAROS, M.; PITMAN, N.; PERES, C. A.; POORTER, L.; PRIETO, A.; RAMIREZ- NGULO, H.; RESTREPO CORREA, Z.; ROOPSIND, A.; ROUCOUX, K. H.; RUDAS, A.; SALOMÃO, R. P.; SCHIETTI, J.; SILVEIRA, M.; de SOUZA, P. F.; STEININGER, M. K.; STROPP, J.; TERBORGH, J.; THOMAS, R.; TOLEDO, M.; TORRES-LEZAMA, A.; van ANDEL, T. R.; van der HEIJDEN, G. M. F.; VIEIRA, I. C. G.; VIEIRA, S.; VILANOVA-TORRE, E.; VOS, V. A.; WANG, O.; ZARTMAN, C.E.; MALHI, Y.; PHILLIPS, O. L. 2014. Markedly divergent estimates of Amazon forest carbon density from ground plots and satellites. Global Ecology and Biogeography. DOI: 10.1111/geb. 12168, p. 1-12.

MORI, S. A.; CUNHA, N. L. The Lecythidaceae of a Central Amazonian Moist Forest.The New York Botanical Garden, Bronx, New York, 60 p. 1995.

MOSS, R.H.; SCHNEIDER, S.H., 2000: Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In: Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC [eds. R. Pachauri, T. Taniguchi and K. Tanaka], World Meteorological Organization, Geneva, pp. 33-51.

NEGRÓN-JUAREZ, R. I.; CHAMBERS, J.; GUIMARÃES, G.; ZENG, H.; RAUPP, C. F. M.; MARRA, D. M.; RIBEIRO, G. H. P. M.; SAATCHI, S. S.; NELSON, B.; HIGUCHI, N. 2010. Widespread Amazon forest tree mortality from a single cross-basin line event. Geophysical Research Letters. Vol. 37, L16701.

NEPSTAD, D.C.; VERÍSSIMO, A.; ALENCAR, A.; NOBRE, C.; LIMA, E.; LEFEBVRE, P.; SCHLESINGER, P.; POTTER, C.; MOUTINHO, P.; MENDONZA, E.; COCHRANE, M.; BROOKS, V. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. Nature. London, v. 398, p. 505-508.

NETER, J.; KUTNER, M. H.; NACHTSHEIM, C. J.; WASSERMAN, W. Applied linear statistical models. Irwin, Chicago, Illinois, USA. 1408 p. 1996.

NIKLAS, K. J. Plant Allometry: The Scaling of Form and Process. The University of Chicago Press. Chicago
. 395p. 1994.

NOGUEIRA, E. M.; FEARNSIDE, P. M.; NELSON, B. W.; BARBOSA, R. I.; KEIZER, E. W. H. 2008. Estimates of forest biomass in the Brazilian Amazon: New allometric equations and adjustments to biomass from wood-volume inventories. Forest Ecology and Management. 256, 1853-1867.

OHASHI, S.; OKADA, N.; NOBUCHI, T.; SIRIPATANADILOK, S.; VEENIN, T. 2009. Detecting invisible growth rings of trees in seasonally dry forests in Thailand: isotopic and wood anatomical approaches. Trees. 23: 813-822.

OHASHI, S.; OKADA, N.; AZIM, A. A. A.; YAHYA, A. Z.; NOBUCHI, T. 2011. Estimation of tree age in the humid tropics by vessel measurement: A preliminary study. Tropics. Vol. 19 (3). 107-112.

OLIVEIRA, A. A. 2000. Inventários quantitativos de árvores em matas de terra firme: Histórico com enfoque na Amazônia Brasileira. Acta amazonica. 30(4): 543-567.

OLIVEIRA, A. N.; AMARAL, I. L. 2004. Florística e fitossociologia de uma floresta de vertente na Amazônia Central, Amazonas, Brasil. Acta Amazonica. Manaus, v. 34, n. 1, p. 21-34.

OLIVEIRA, L. C.; COUTO, H. T. Z.; SILVA, J. N.; CARVALHO, J. O. P. 2005. Efeito da exploração de madeira e tratamentos silviculturais na composição florística e diversidade de espécies em uma área de 136ha na Floresta Nacional do Tapajós, Belterra, Pará. Scientia Forestalis. N. 69, p. 62-76.

OLIVEIRA, A. N.; AMARAL, I. L.; RAMOS, M. B. P.; NOBRE, A. D.; COUTO, L. B.; SAHDO, R. M. Composição e diversidade florístico-estrutural de um hectare de floresta densa de terra firme na Amazônia Central, Amazonas, Brasil. Acta amazonica. 2008. Vol. 38(4): 627-642.

OLIVEIRA, M. M.; HIGUCHI, N.; CELES, C. H.; HIGUCHI, F. G. 2014. Tamanho e formas de parcelas para inventários florestais de espécies arbóreas na Amazônia Central. Ciência Florestal. Santa Maria, v. 24, n. 3, p. 645-653.

OVERMAN, J. P. M.; WITTE, H. J. L.; SALDARRIGA, J.G. 1994. Evaluation of Regression Models for Above-ground Biomass Determination in Amazonia Rainforest. Journal of Tropical Ecology, v.10, p.207-218.

PÉLLICO NETTO, S.; BRENA, D. A. Inventário florestal. Curitiba: Editorado pelos autores, p. 316, 1997.

PETERS-STANLEY, M.; GONZALEZ, G.; YIN, D. Covering New Ground: State of forest carbon markets 2013. Washington, DC. 101 p. 2013.

PHILLIPS, O.L.; HALL, P.; GENTRY, A.H.; SAWYER, S.A. e VÁSQUEZ, M. 1994. Dynamics and species richness of tropical rainforests. Proceedings of the National Academy of Sciences of the United States of America. 91: 2805 – 22809.

PHILLIPS, O. L.; MALHI, Y. HIGUCHI, N.; LAURANCE, W. F.; NÚÑEZ, P. V.; VÁSQUEZ, R. M.; LAURANCE, S. G.; FERREIRA, L. V.; STERN, M.; BROWN, S.; GRACE, J. 1998. Changes in the carbon balance of tropical forests: evidence from long-term plots. Science, 282(5388):439-442.

PHILLIPS, O. L.; LEWIS, S. L.; BAKER, T. R.; CHAO, K. –J.; HIGUCHI, N. 2008. The changing Amazon forest. Philosophical Transactions of The Royal Society. 363, 1819-1827.

PILLI, R., ANFODILLO, T.; CARRER, M. 2006. Towards a functional and simplified allometry for estimating forest biomass. Forest Ecology and Management, 237: 583-593.

PIRES, J. M.; PRANCE, G. T. The vegetation types of the Brazilian Amazon. In: Prance, G.T & Lovejoy, T.E., eds. Amazônia: key environment. London, Pergamon Press, p. 109-145, 1985.

PORTO, M. L.; LONGHI, H. M.; CITADINI, V.; RAMOS, R. F.; MARIATH, J. E. A. 1976. Levantamento fitossociológico em área de "mata-de-baixio" na Estação Experimental de Silvicultura Tropical – INPA – Manaus – Amazonas. Acta amazonica. 6(3): 301-318.

PRANCE, G. T.; RODRIGUES, W. A.; SILVA, M. F. 1976. Inventário florestal de um hectare de mata de terra firme km 30 da Estrada Manaus – Itacoatiara. Acta amazonica. 6(1): 9-35.

QUEIROZ, W. T. Técnicas de amostragem em inventário florestal nos Trópicos. Belém: FCAP. Serviço de Documentação e Informação. 1998. 147 p.

RADAMBRASIL. Programa de Integração Nacional. Levantamento de Recursos Naturais. 1978. V. 14 (Alto Solimões) – RADAM (projeto) DNPM, Ministério de Minas e Energia. Brasil. 626p.

RANKIN-DE-MÉRONA, J. M.; PRANCE, G. T.; HUTCHINGS, R. W.; SILVA, M. F.; RODRIGUES, W. A.; UEHLING, M. E. 1992. Preliminary results of a large-scale tree inventory of upland Rain Forest in the Central Amazon. Acta Amazonia. 22(4): 493-534.

RAYOL, B. P.; ALVINO-RAYOL, F. O.; SILVA, M. F. F. 2011. Similaridade florística entre o estrato arbóreo e a regeneração natural de uma floresta secundária, no município de Bragança, nordeste do estado do Pará. Revista Brasileira de Agroecologia. 6 (3): 107-114.

REES, M.; CONDIT, R.; CRAWLEY, M.; PACALA, S.; TILMAN, D. 2001. Long-term studies of vegetation dynamics. Science. Vol. 293, 650-658.

RENNIE, J. C. 1979. Comparison of Height-Measurement Techniques in a Dense Loblolly Pine Plantation. Southern Journal of Applied Forestry. 3, n. 4, 146–148.
REZENDE, A. V. Diversidade, estrutura, dinâmica e prognose do crescimento de um cerrado sensu stricto submetido a diferentes distúrbios por desmatamento. Tese de doutorado, Universidade Federal do Paraná. 269 p. 2002.

RIBEIRO, J. E. L da S.; HOPKINS, M. J. G.; VICENTINI, A.; SOTHERS, C. A.; COSTA, M. A. da S.; BRITO, J. M. de; SOUZA, M. A. D. de; MARTINS, L. H. P.; LOHMANN, L. G.; ASSUNÇÃO, P. A. C. L.; PEREIRA, E. da C.; SILVA, C. F. da; MESQUITA, M. R.; PROCÓPIO, L. C. Flora da Reserva Ducke: guia de identificação das plantas vasculares de uma floresta de terra-firme na Amazônia Central. Manaus: INPA. p. 816, 1999.

ROBERTS, T. R. 1972. Ecology of fishes in the Amazon and Congo basins. Bull. Mus. Comp. Zool., 143 (2): 117-147.

ROCHA, J. de A. Madeira caída como oportunidade para o manejo florestal comunitário em unidades de conservação no Amazonas, Brasil. Dissertação de mestrado, Instituto Nacional de Pesquisas da Amazônia. Manaus. X p. 2010.

RODRÍGUEZ-PÉREZ, J. R.; ÁLVAREZ, M. F.; SANZ-ABLANEDO, E. Assessment of low-cost GPS receiver accuracy and precision in forest environments. v. 133, n. Nov., p. 159-167, 2007.

ROLIM, S. G.; COUTO, H. T. Z.; JESUS, R. M.; FRANÇA, J. T. Modelos volumétricos para a Floresta Nacional do Tapirapé-Aquirí, Serra dos Carajás (PA). Acta Amazonica, vol. 36(1) 2006: 107–114, 2006.

SAATCHI, S. S.; HOUGHTON, R. A.; SANTOS ALVALÁ, R. C.; SOARES, J. V.; YU, Y. 2007. Distribution of aboveground live biomass in the Amazon. Global Change Biology. 13, 816-837.

SAATCHI, S. S.; HARRIS, N. L.; BROWN, S.; LEFSKY, M.; MITCHARD, E. T. A.; SALAS, W.; ZUTTA, B. R.; BUERMANN, W.; LEWIS, S. L.; HAGEN, S.; PETROVA, S.; WHITE, L.; SILMAN, M.; MOREL, A. 2011. Benchmark map of forest carbon stocks in tropical region across three continents. PNAS. Vol. 108, n. 24. 9899-9904.

SANQUETTA, C. R.; CORTE, A. P. D.; SILVA, F. 2011. Biomass expansion factor and root-to-shoot ratio for Pinus in Brazil. Carbon Balance and Management. v. 6, p. 1-22.

SANTANA, A. C.; SANTOS, M. A. S.; SANTANA, A. L.; YARED, J. A. G. 2012. O valor econômico da extração manejada de madeira no Baixo Amazonas, estado do Pará. Revista Árvore. Vol. 36, n. 3, p. 527-536.

SANTOS, H. M; RIBEIRO, M. N. G. 1988. A hidroquímica do rio Solimões – Amazonas. Acta amazonica. 18(3-4): 145-172.

SANTOS, J. dos. Análise de modelos de regressão para estimar a fitomassa da floresta tropical úmida de terra-firme da Amazônia Brasileira. 121 p. Tese de Doutorado - Universidade Federal de Viçosa, Minas Gerais. 1996.

SICK, H. 1972. A ameaça da Avifauna Brasileira. In: Espécies da Fauna Brasileira Ameaçadas de Extinção. Ed. Pela Academia Brasileira de Ciências / CNPq / FNDCT. P. 99-153.

SIGRIST, P.; COPPIN, P.; HERMY, M. Impact of forest canopy on quality and accuracy of GPS measurements. International Journal of Remote Sensing, v. 20, n. 18, p. 2595-3610, 1999.SILESHI, G. W. 2014. A critical review of forest biomass estimation models, common mistakes and corrective measures. Frest Ecology and Management. 329. 237-254.

SILVA, J. N. M.; LOPES, J. C. A.; OLIVEIRA, L. C.; SILVA, S. M. A.; CARVALHO, J. O. P.; COSTA, D. H. M.; MELO, M. S.; TAVARES, M. J. M. Diretrizes para instalação e medição de parcelas permanentes em florestas naturais da Amazônia Brasileira. Belém, PA: Embrapa Amazônia Oriental: il., 2005. 69 p.

SILVA, R. P. da. Alometria, estoque e dinâmica da biomassa de florestas primárias e secundárias na região de Manaus (AM). 152 p. Tese de Doutorado. Programa Integrado de Pós-graduação em Biologia Tropical e Recursos Naturais (INPA), Manaus, 2007.

SILVA, E. N.; SANTANA, A. C.; QUEIROZ, W. T.; SOUSA, R. J. 2011. Estimação de equações volumétricas para árvores de valor comercial em Paragominas, estado do Pará. Amazônia: Ciência e Desenvolvimento. Belém, v. 7, b. 13. p. 7-18.

SKOLE, D.; TUCKER, C. 1993. Tropical deforestation and habitat fragmentation in the Amazon. Satellite data from 1978 to 1988. Forest Science, Lawrence, v. 260, p. 1905-1910.

SMITH, V. G. 1983. Compatible Basal Area Growth and Yield Models Consistent with Forest Growth Theory. Forest Science. Vol. 29, no. 2. 279-288.

SOARES-FILHO, B. S.; NEPSTAD, D. C.; CURRAN, L.; CERQUEIRA, G. C.; GARCIA, R. A.; RAMOS, C. A.; VOLI, E.; MCDONALD, A.; LEFEBVRE, O.; SCHLEISINGER, P.; MCGRATH, D. 2005. Cenários de desmatamento para a Amazônia. Estudos Avançados. 19 (54). 137-152.

SOARES-FILHO, B. S.; NEPSTAD, D. C.; CURRAN, L. M.; CERQUEIRA, G. C.; GARCIA, R. A.; RAMOS, C. A.; VOLL, E.; McDONALD, A.; LEFEBVRE, P.; SCHLESINGER, P. 2006. Modelling conservation in the Amazon basin. Nature. Vol. 440, n 23. 520-523.

STALLARD, R. F.; EDMOND, J. M., 1983. Geochemistry of the Amazon, 2. The influence of geology and weathering environment on the dissolved load. Journal of Geophysical Research. Vol. 88: 9671-9688.

STEENKAMP, C. J.; VOGEL, J. C.; FULS, A. van ROOYEN, N.; van ROOYEN, M. W. 2008. Age determination of Acacia erioloba trees in the Kalahari. Journal of Arid Environments, vol.72, issue 4, pp. 302-313.

STUIVER, M; REIMER, P. J.; BARD, E.; BECK, J. W.; BURR, G. S.; HUGHEN, K. A.; KROMER, B.; McCORMAC, G.; VAN DER PLICHT, J.; SPURK, M. 1998. INTCALL98 Radiocarbon age calibration, 24,000-0 cal BP. Radiocarbon. Vol. 40, no. 3. 1041-1083.

SULLIVAN, A. D.; CLUTTER, J. L. 1972. A Simultaneous Growth and Yield Model for loblolly Pine. Forest Science. 18:76-86.

SWAINE, M. D.; LIEBERMAN, D.; HALL, J. B. 1990. Structure and dynamics of a tropical dry forest in Ghana. Vegetatio. V. 88: 31-51.

TABACHNICK, B. G.; L. S. FIDELL. 1996. Using multivariate statistics. Harper Collins, New York, New York, USA. 1996. 4th edition. 58 p.

TCA (Tratado de Cooperação Amazônica). Amazonia Without Miths. Comission on Development and Environment for Amazônia. Quito - Equador, p. 99, 1992.

TER STEEGE, H.; PITMAN, N. C. A.; SABATIER, D.; BARALOTO, C; SALOMÃO, R. P.; GUEVARA, J. E.; PHILLIPS, O. L.; CASTILHO, C. V.; MAGNUSSON, W. E.; MOLINO, J-F.; MONTEAGUDO, A.; VARGAS, P. N.; MONTERO, J. C.; FELDPAUSCH, T. R.; CORONADO, E. N. H.; KILLEEN, T. J.; MOSTACEDO, B.; VASQUEZ, R.; ASSIS, R. L.; TERBORGH, J.; WITTMANN, F.; ANDRADE, A.; LAURANCE, W. F.; LAURANCE, S. G. W.; MARIMON, B. S.; MARIMON Jr., B-H.; VIEIRA, I. C. G.; AMARAL, I. L.; BRIENEN, R.; CASTELLANOS, H.; LÓPEZ, D. C.; DUIVENVOORDEN, J. F.; MOGOLLÓN, H. F.; MATOS, F. D. de A.; DÁVILA, N.; GARCÍA-VILLACORTA, R.; DIAZ, P. R. S.; COSTA, F.; EMILIO, T.; LEVIS, C.; SCHIETTI, J.; SOUZA, P.; ALONSO, A.; DALLMEIER, F.; MONTOYA, A. J. D.; PIEDADE, M. T. F.; ARAUJO-MURAKAMI, A.; ARROYO, L; GRIBEL, R. FINE, P. V. A.; PERES, C. A.; TOLEDO, M.; AYMARD, G. A. C.; BAKER, T. R.; CERÓN, C.; ENGEL, J.; HENKEL, T. W.; MAAS, P.; PETRONELLI, P.; STROPP, J.; ZARTMAN, C. E.; DALY, D.; NEILL, D.; SILVEIRA, M.; PAREDES, M. R.; CHAVE, J.; LIMA FILHO, D. de

A.; JØRGENSEN, P. M.; FUENTES, A.; SCHÖNGART, J.; VALVERDE, F. C.; FIORE, A. Di.; JIMENEZ, E. M.; MORA, M. C. P.; PHILLIPS, J. F.; RIVAS, G.; ANDEL, T. R. van; HILDEBRAND, P. von; HOFFMAN, B.; ZENT, E. L.; MALHI, Y.; PRIETO, A.; RUDAS, A.; RUSCHELL, A. R.; SILVA, N.; VOS, V.; ZENT, S.; OLIVEIRA, A. A.; SCHUTZ, A. C.; GONZALES, T.; NASCIMENTO, M. T.; RAMIREZ-ANGULO, H.; SIERRA, R.; TIRADO, M.; MEDINA, M. N. U.; HEIJDEN, G. van DER; VELA, C. I. A.; TORRE, E. V.; VRIESENDORP, C.; WANG, O.; YOUNG, K. R.; BAIDER, C.; BALSLEV, H.; FERREIRA, C.; MESONES, I.; TORRES-LEZAMA, A.; GIRALDO, L. E. U.; ZAGT, R.; ALEXIADES, M. N.; HERNANDEZ, L.; HUAMANTUPA-CHUQUIMACO, I.; MILLIKEN, W.; CUENCA, W. P.; PAULETTO, D.; SANDOVAL, E. V.; GAMARRA, L. V.; DEXTER, K. G.; FEELEY, K.; LOPEZ-GONZALEZ, G.; SILMAN, M. R. 2013. Hyperdominance in the Amazonian tree flora. Science. New York, Vol. 342, 324-343.

THAINES, F.; BRAZ, E. M.; MATTOS, P. P.; THAINES, A. A. R. Equações para estimative de volume de madeira para a região da bacia do Rio Ituxi, Lábrea, AM. Pesquisa Florestal Brasileira. Colombo, v. 30, n. 64, p. 283-289.

THERRELL, M. D.; STAHLE, D. W.; MUKELABAI, M. M.; SHUGART, H. H. 2007. Age, and radial growth of Pterocarpus angolensis in southern Africa. Forest Ecology and Management. 244, p. 24-31.

TRUMBORE, S.; BRANDO, P.; HARTMANN, H. Forest health and global change. Science, v. 349, n. 6250, 2015.

WEISS, N.; HASSETT, M. Introductory Statistics. 1982. Arizona State University. 650 p.

WEST, G. B., BROWN, J. H.; ENQUIST, B. J. 1999. A general model for the structure and allometry of plant vascular systems. Nature, 400: 664-667.

WIEMANN, M. C.; WILLIAMSON, G. B. 2014. Wood specific gravity variation with height and its implications for biomass estimation. Research Paper FPL-RP-677. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 9 p.

WILLIAMS, M. S.; BECHTOLD, W. A.; LABAU, V. J. 1994. Five instruments for measuring tree height: An evaluation. Southern Journal of Applied Forestry., Vol. 18 (2): 76–82.

WOODHOUSE, I. H.; MITCHARD, E. T. A.; BROLLY, M.; MANIATIS, D.; RYAN, C. M. 2012. Radar backscatter is not a 'direct measure' of forest biomass. Nature Climate Change. 2, p. 556-557.

WORBES, M. 2002. One hundred years of tree-ring research in the tropics – a brief history and na outlook to future challenges. Dendrochronologia. 20/1. 217-231.

ZHANG, G.; GANGULY, S.; NEMANI, R. R.; WHITE, M. A.; MILESI, C.; HASHIMOTO, H.; WANG, W.; SAATCHI, S.; YU, Y.; MYNENI, R. B. Estimation of forest aboveground biomass in California using canopy height and leaf area index estimated from satellite data. Remote Sensing of Environment, n. August, 2014.

IBGE. Divisão regional do Brasil em regiões geográficas. Rio de Janeiro, 2017. Disponível em: https://www.ibge.gov.br/apps/regioes_geograficas/#/home.
Araújo, T. M.; Higuchi, N.; Carvalho Jr., J. A. 1999. Comparison of formulae for biomass content determination in a tropical rain forest in the state of Pará, Brazil. Forest Ecology and Management, v.117, p.43-52.

Souza, D.C., Sampaio Filho, I.J., Simonetti, A., Souza, C.A.S., Oliveira, L.R. e Freitas, S.F. A produção de soja na Fazenda São Wustro (Bahia) – safra 2020-2021 - e a mudança do clima ocorrida depois da segunda etapa da Revolução Industrial. Ed. Niro Higuchi – ISBN nº 978-65-00-42466-9, Manaus – AM, 44p.

Araujo, R. F., Chambers, J. Q., Celes, C. H. S., Muller-Landau, H. C., Santos, A. P. F. D., Emmert, F., ... & Higuchi, N. (2020). Integrating high resolution drone imagery and forest inventory to distinguish canopy and understory trees and quantify their contributions to forest structure and dynamics. PloS one, 15(12), e0243079.

Carvalho, J. O. P. de. 1997. Dinâmica de florestas naturais e sua implicação para o manejo florestal. (Embrapa-CNPF. Documentos, 34). Belém: p.41-55.

Ecke, S., Dempewolf, J., Frey, J., Schwaller, A., Endres, E., Klemmt, H. J., ... & Seifert, T. (2022). UAV-based forest health monitoring: a systematic review. Remote Sensing, 14(13), 3205.

Favarin, J. L., Dourado Neto, D., García y García, A., Villa Nova, N. A., & Favarin, M. D. G. G. V. (2002). Equações para a estimativa do índice de área foliar do cafeeiro. Pesquisa agropecuária brasileira, 37, 769-773.

Higuchi, N. 2001. A Inserção do Amazonas no contexto da convenção do clima e Protocolo de Quioto. Apontamentos Didáticos.

Higuchi, N.; Carvalho Jr., J. A. 1994. Fitomassa e conteúdo de carbono de espécies arbóreas da Amazônia.In: Companhia Vale do Rio Doce (ed.). Emissão e seqüestro de CO2: uma nova oportunidade de negócios para o Brasil, Rio de Janeiro: 125-153.

Iglhaut, J., Cabo, C., Puliti, S., Piermattei, L., O'Connor, J., & Rosette, J. (2019). Structure from motion photogrammetry in forestry: A review. Current Forestry Reports, 5(3), 155-168.

IPCC (Intergovernmental Panel on Climate Change). 2004. Good practice guidance for land use, land-use changes and forestry. Kanagawa, Japan, Institute for Global Environmental Strategies.

Lowe, G. (2004). Sift-the scale invariant feature transform. Int. J, 2(91-110), 2.
Niklas, K.J. 1994. Plant Allometry: The Scaling of Form and Process. The University of Chicago Press. Chicago. 395p.

Peixoto, A. S. L. (2021). Distribuição e geometria de clareiras em floresta da Amazônia central combinando imagens de aeronave remotamente pilotada (ARP) e dados de campo. Dissertação de mestrado pelo Programa de Pós-graduação em Ciências de Florestas Tropicais/INPA.

Pilli, R., Anfodillo, T. e Carrer, M. 2006. Towards a functional and simplified allometry for estimating forest biomass. Forest Ecology and Management, 237: 583-593.

Silva, R.P. da. 2007. Alometria, estoque e dinâmica da biomassa de florestas primárias e secundárias na região de Manaus (AM). Tese de Doutorado em Ciências de Florestas Tropicais/ INPA. 152p.

West, G.B., Brown, J.H. e Enquist, B.J. 1999. A general model for the structure and allometry of plant vascular systems. Nature, 400: 664-667.

Zianis, D. e Mencuccini, M. 2004. On simplifying allometric analyses of forest biomass. Forest Ecology and Management, 187: 311-332.

VERSION HISTORY

VERSION	DATE	NOTES
1.2	11/06/2025	Technical review of the statistical approach. Complete restructuring of Section 8 to detail and integrate the Bayesian Analysis methodology as the recommended approach for agricultural management (ALM) projects, preserving the structure and formulas of the reference document. The general (frequentist) approach was maintained with its original text for didactic purposes. Connecting points were added in Sections 2 and 4 to improve clarity and guidance for developers of both forest and agricultural projects.
1.1	06/16/2025	Detailed inclusion of methods for LTCS (Long-Term Cyclical Carbon Stock) for annual/cyclical crops, with an example for Soybean and Millet based on the INPA booklet. Structure for future perennial (Cocoa) and cyclical crops. Clarification on rigorous cubage. Alignment with all AFOLU Tero methodologies. Reinforcement on Tiers and preparation for ICROA/CORSIA. Inclusion of considerations for alignment with the SBCE (Law No. 15,042/2024).
1.0	04/01/2025	Initial version approved by the Directorate and launched for public consultation.