PV CLIMATE MODULE

PU007

Module for Performing Adaptive Pre-project Woody Biomass Baseline for Small-scale Agroforestry

Version 1.0

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Contents

1 Summary

This *Module* provides a method for defining an adaptive baseline for change in *woody biomass* present within the *Project Area*, prior to the start of the *Project Intervention*.

Using a sigmoid-based growth curve, the *Module* provides an approach for determining the expected *biomass* growth of the pre-project and newly planted trees in the *Project.* The output of the model is used within *Methodology* **PM002** to determine the adjustment factor that needs to be applied.

The input parameters for the sigmoid-based growth curve are derived from a subset of *sample plots*, also referred to as *monitoring plots*. These parameters include but are not limited to *Aboveground Biomass* of trees with a height above 1.3 meters, species names, and year of planting.

There are two possible types of sigmoid-based growth curves. A species-specific growth curve is developed for each tree species for which the required parameters are available. If one of the criteria described in Section 5.2.1 is not met, a generic growth curve is developed, based on available data that meet the criteria of *ground truth data* collection (see **PT006** Section 5.1.1).

For each *monitoring plot*, the *biomass* change is estimated for each year of the *Project* based on the species growth curves (or general growth curve if no specific curve could be constructed). *Monitoring plots* are measured every year, and a new adjustment factor is calculated.

Based on the year of planting, trees are separated into pre-project trees (planted before the *Project Intervention*) and additional trees (planted during the *Project Period*). The pre-project trees are used for establishing an adaptive baseline while the additional trees are used to establish the percentage contribution of pre-project *vs*. newly planted trees. Combined they are used to estimate an adjustment factor.

2 Sources

This *Module* applies the following *Methodology*, *Module, and Tool*:

- **PM002** Methodology for Quantifying Carbon Benefits from Small-scale Agroforestry v1.0
- **PT006** Tool for Ground Truth Sampling v1.0
- **PU008** Module for Estimating Uncertainty of Carbon Benefits from Small-scale Agroforestry v1.0

3 Definitions

All terms in this document follow the PV Climate Glossary and **PM002**, with the addition of the following definitions:

Monitoring plot

A *monitoring plot* is a designated area used to measure and compare carbon storage against the *Project Area*. It serves as a reference to determine the *baseline scenario*, helping to quantify the additional *carbon sequestration* achieved by the *Project*.

Stratum

A group into which members of a population/*Project Area(s)* are divided into stratified sampling based on specific characteristics. In this *Module* an *ecoregion* is considered a *stratum*. Where necessary, further stratification can be done through, for example, a variety of *pre-project tree biomass* or *Project* activities.

4 Applicability Conditions

The method described in this *Module* is globally applicable, as the implemented features are available for every *ecoregion* and are applied to a specific *Project*. For this *Module*, the applicability conditions of *Methodology* **PM002** should be met.

5 Procedures

The method of the pre-project tree adjustment model is based on three parts:

1. Selection of *monitoring plots* following a representative stratified systematic sampling strategy.
2. Modeling the *Aboveground Biomass (AGB)* growth of individual trees within a *Project*, based on *monitoring plot* data (tree species, year of planting), by generating growth curves of the tree species.
3. Using the growth curve models determined in (2) to estimate *pre-project tree biomass* growth as a percentage of total tree *biomass* growth.

5.1 Input data

5.1.1 Sample plots (tree species biomass)

Tree species information is derived from the *ground truth measurements* collected for each *Project* (see **PT006**). The *ground truth data* is subject to quality assurance and preparation.
The tree *biomass* dataset should contain information about all trees that are detected and measured through the *ground truth measurement* procedures.

5.1.2 Sub-selection of monitoring plots

From the full set of *ground truth data*, a minimum of 30 *sample plots* per *Project* are selected as *monitoring plots*. The same approach described in **PT006** is followed for selecting a representative sample, however for *biomass* model calibration, all classes have to be equally represented to avoid bias towards low or high *biomass*, here the proportion of *monitoring plots* in each class has to be representative of the *biomass* range of *Project Areas* in each class.

5.2 Generate AGB growth curves

The type of function used to model all tree growth curves is sigmoid. This 's-shaped' growth curve is a well-established representation of plant species growth (Pödör et.al., 2014; Seo et al., 2023; Weiner & Thomas 2001; Yix et.al., 2003; Zeide 1993). The key features of real-world tree growth that are well captured by the sigmoid function are 1) an initial slow growth; 2) a strong increase in growth rate (with maximum growth at the sigmoid mid-point); 3) a later strong decrease in growth rate, resulting in a maximum *biomass* reached (long before the tree dies) as presented in Figure 1.

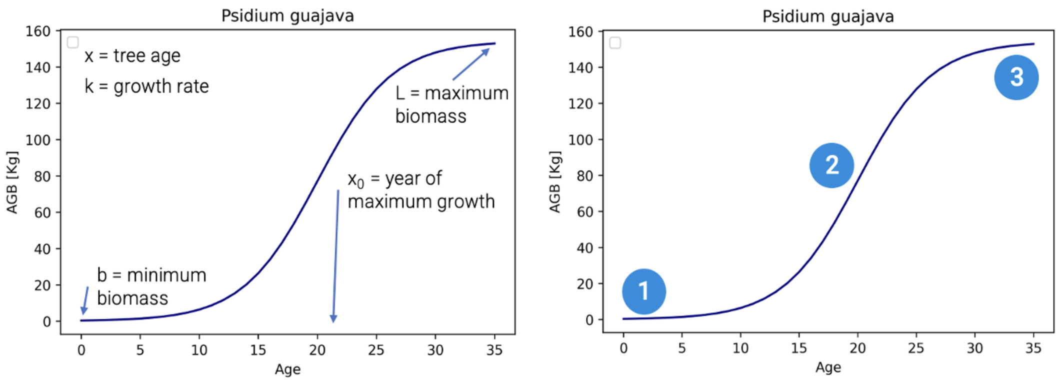

Figure 1: Tree growth features by the sigmoid

Equation 1 is used to calculate the Sigmoid *AGB* growth curves.

$$j = \frac{L}{1+\exp(-k(x-x0))} + b$$

Equation 1

Where:

j = *Aboveground Biomass* of an individual tree (tonne)

L = The maximum *biomass* that a tree species can reach (tonne)

k = The growth rate of a tree species (% per year)

x = The tree age (years)

$x0$ = The year of maximum growth (relative) of a tree species (year)

b = The minimum *biomass* that a tree species can reach (tonne)

The input data that is used to generate the growth curves per tree species derived from *ground truth data* are:

- *Aboveground Biomass* of all trees from all species
- Age of all trees from all species

To construct the growth curves per species follow the next steps:

1. Group all trees of a species based on the tree age.
2. Extract the median value (50% quantile) of the *Aboveground Biomass* of all trees that belong to each tree age group.
3. Sigmoid curve fit–generate curve by finding the best sigmoid fit to the series of the given data points by using non-linear least squares and construct the growth curve. Evaluation is performed by multiple iterations to select the precise value within the range of the optimal parameters of the best fit by using the RSS (residuals sum of squares) as a metric, which

describes the variance of the residuals. The parameters that produce the lowest RSS are the ones that are selected as the optimal parameters.

The parameters that are used in the curve fitting method are the following:

- Maximum number of evaluations for optimal parameters: 1000
- Algorithm to minimize influence of outliers, for example trust region reflective.
- Boundaries for the optimal parameters:
    - Maximum *Aboveground Biomass* a species can reach (L): 0-10 tonne.
    - Age when the maximum growth (or maximum curve steepness) can be observed ($x0$): 5-30.
    - Steepness of the growth curve (k): 0-2.
    - Minimum *Aboveground Biomass* a species can reach at the baseline (b): 0-0.005 tonne.

The output must contain:

- Name: species name for species specific curve.
- Maximum age of the trees that are used to generate the growth curves.
- Optimal parameters.
    - Maximum *Aboveground Biomass* a species can reach (L)
    - Age when the maximum growth (or maximum curve steepness) can be observed ($x0$)
    - Steepness of the growth curve (k)
    - Minimum *Aboveground Biomass* a species can reach at the baseline (b)
- Number of tree-age groups used for each species.

The section below describes the two different tree *AGB* growth curves types (species specific and generic curves), when they are selected and how they are generated to model the tree *AGB* growth.

5.2.1 Species specific AGB growth curve

To generate a species specific *AGB* growth curve, a set of criteria from the tree *biomass* file should be met. The tree species that do not meet all criteria qualify for a generic *AGB* growth curve. The set of criteria for the generation of a species specific *AGB* growth curve are the following:

- Tree species data availability within tree age (years) groups: Tree age 0-40 years, split into 8 groups of 5 years each. For every tree species, a minimum of one point to at least 4 of these groups.
- The minimum number of data points required for a tree species is 8: There should be at least 8 trees detected of a certain species, which is considered sufficient (Chave et.al., 2014; Pödör et.al., 2014; Seo et al., 2023).
- The minimum age of the oldest tree for a tree species is 15 years and the maximum age of the youngest tree for a tree species is 5 years.
- The maximum tree age (years) of a tree is 40 years.

Example: A sigmoid fit example is shown in Figure 2. In this example, there are a few hundreds of *Cordia africana* trees (grey dots) with 32 different tree ages. The blue dots below represent the median *AGB* value of the 32 tree age groups. These median values are used to generate the fit. The R^2 value is determined by comparing the data of the *Cordia africana* species with its best-fit sigmoid curve and it gives an indication of how accurate the data of this species resemble a true sigmoid. This R^2 is later used as another metric to determine whether a tree species gives a reasonable species-specific fit or whether a generic curve needs to be generated instead.

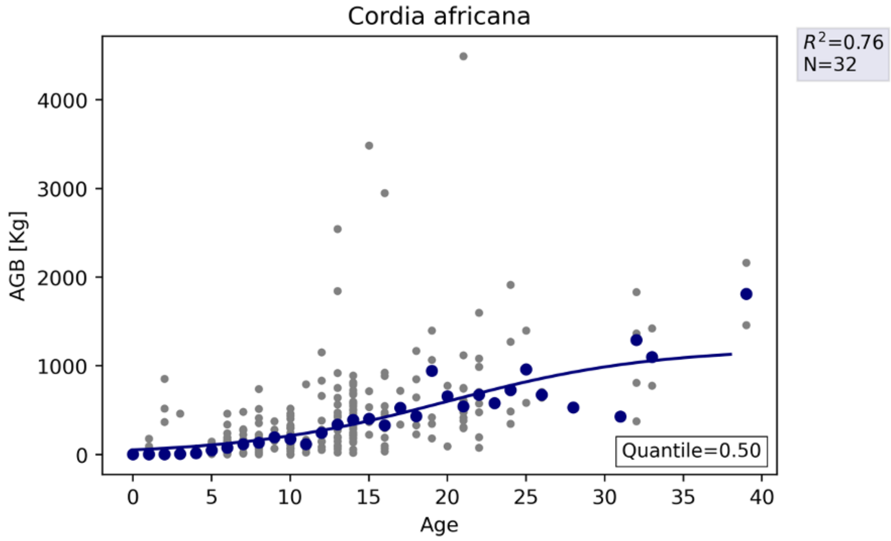

Figure 2: Example of sigmoid fit for Cordia Africana trees for a Project. Blue dots indicate the median (50th quantile) per year of age that are used as input to the sigmoid fit.

When the species-specific sigmoid is generated, the following criteria need to be met in order to accept the sigmoid:

- Slope of the sigmoid fit is positive.
- Fitting curve starts at *Aboveground Biomass* smaller than 5 (tonne/ha). Median *biomass* of trees in the oldest age class is within 30% of maximum sigmoid *biomass*.
- R^2 of sigmoid fit is greater than 0.25.

All criteria need to be met. If one of the criteria above is not met for a certain tree species, a generic curve is generated instead.

Note that the thresholds do not indicate well-fitted model. They are used to differentiate between species-specific and generic sigmoid growth curves. In all cases, *uncertainty* is corrected for.

5.2.2 Generic AGB growth curve

The tree species that do not qualify for a species-specific *AGB* growth curve are considered as separate tree species. Data points (tree age and *AGB*) are taken from all trees belonging to this category in order to construct a *AGB* growth curves for these species as a group. This growth curve is called Generic *AGB* growth curve and the steps for its generation are the same as the species specific *AGB* curve, described in Section 5.2.

5.3 Model total AGB growth (pre project plus additional) after project intervention

The modelling of the tree *AGB* growth of all trees from the *monitoring plots* is done by using the species-specific and the generic *AGB* growth curves. This includes both pre-project trees and trees planted after the start of the *Project Intervention*.

The *pre-project AGB* per *monitoring plot* is calculated following Equation 2.

$$ETB_{mp,t} = \sum_{i=1}^{n} (g)i$$

Equation 2

Where:

$ETB_{mp,t}$ = Estimated *pre-project AGB* in *monitoring plot mp* at time *t* of the *Project* (tonne/ha)

g = *Aboveground Biomass* of a pre-project tree (tonne)

The total *biomass* $TB_{mp,t}$ is calculated for each *monitoring plot.* The parameter combines both *AGB* derived from sigmoid growth curves, summing the $ETB_{mp,t}$ of pre-project trees and $ETB_{mp,t}$ of trees planted after *Start Date* following Equation 3.

$$TB_{mp,t} = \sum_{i=1}^{n} (j)i$$

Equation 3

Where:

$TB_{mp,t}$ = Total *AGB* in *monitoring plot mp* at time *t* of the *Project* (tonne/ha)

j = *Aboveground Biomass* of an individual tree (tonne)

5.4 Estimate percentage of pre-project tree AGB growth (EETB)

When the expected total tree *AGB* growth is estimated per *monitoring plot*, the *pre-project tree AGB* is separated from the additional tree *AGB* (by *Project Intervention*), based on the year of planting and the start year of the *Project Intervention*. Figure 3 shows the pre-project, additional, and total *AGB* growth for a *Project* after the *Project Intervention* starts and identifies the $EETB$ in different periods. This percentage of *pre-project tree AGB* growth ($EETB$) is estimated by considering all *monitoring plots* from a *Project* location, by using Equation 4. $EETB$ is recalculated at least every 3 years or every time new *monitoring plots* are measured, for example during *validation* and *verification*.

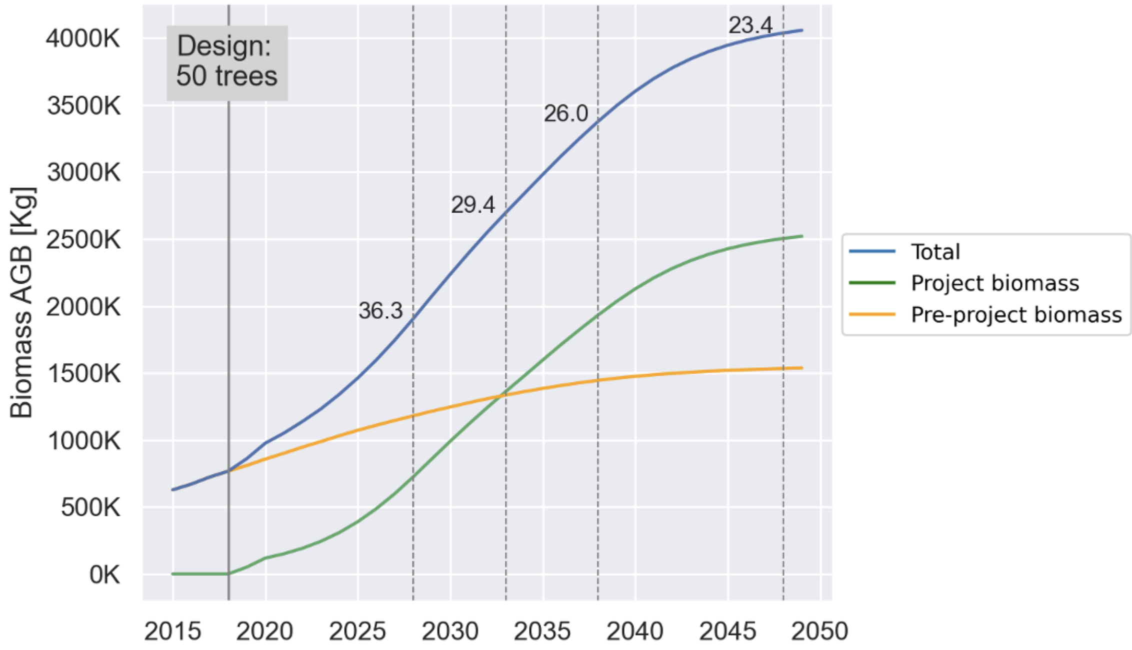

Figure 3. Example of the pre-project AGB and the Project AGB growth over the years, when planting 50 trees in 2018.

$$EETB_{s,t} = \frac{\sum_{i=1}^{n} \left(\frac{(ETB_{mp,t} - ETB_{mp,t=0})}{(TB_{mp,t} - ETB_{mp,t=0})} \cdot 100 \right) i}{n}$$

Equation 4

Where:

$EETB_{s,t}$	= Estimated pre-project *AGB* in *stratum s* at time *t*
$ETB_{mp,t}$	= Pre-project *AGB* in *monitoring plot mp* at time *t* of the *Project* (tonne/ha)
$ETB_{mp,t=0}$	= Pre-project *AGB* in *monitoring plot mp* at the start of *Project Intervention t=0* (tonne/ha)
$TB_{mp,t}$	= Total *AGB* in *monitoring plot mp* at time *t* (tonne/ha)
n	= Number of *monitoring plots* in *stratum s*

5.5 Calculate adjustment factor

1. Estimate the percentage model *uncertainty* of $EETB_{s,t}$ at 90% confidence level, by following the procedure listed in *Module* **PU008**. The parameters are adapted as follows to correspond to the parameters used in the current *Module*.

a. The calculation of the residual value (Equation 5 in *Module* **PU008**) is based on $AGB_{validation(m)}$ derived from *ground truth data*, and $TB_{mp,t}$ which is used to replace $AGB_{validation(p)}$.
b. For calculation of $U_{s,y}$ per *stratum* follow *Module* **PU008**. $U_{s,y}$ equals to U in **PU008** Equation 1.

2. Estimate the percentage sampling *uncertainty* of the set of *monitoring plots* by following Equation 5.

$$U_{sample} = \frac{1.645 \cdot std(EETB_{s,t})}{\sqrt{n}} \cdot \frac{1}{\overline{EETB_{s,t}}}$$

Equation 5

Where:

$std(EETB_{s,t})$	= Standard deviation of measured *Aboveground Biomass* of ground truth *plots* (tonne/ha)
$\overline{EETB_{s,t}}$	= Mean estimated pre-project *AGB* in *stratum s* at time *t* (tonne/ha)
$EETB_{s,t}$	= Estimated pre-project *AGB* in *stratum s* at time *t* (tonne/ha)
U_{sample}	= *Uncertainty* of the ground truth sampling at 90% confidence level

3. Estimate propagated error $U_{s,t}$ following Equation 6.

$$U_{s,t} = \sqrt{{U_{sample}}^2 + {U_{s,y}}^2}$$

Equation 6

Where:

$U_{s,t}$	= Propagated *uncertainty* at 90% confidence level
U_{sample}	= *Uncertainty* of the ground truth sampling at 90% confidence level
$U_{s,y}$	= *Uncertainty* of sigmoid-based model (see **PU008**)

4. Adjust for the *uncertainty* of $EETB_{s,t}$ by using Equation 7.

$$AdjU_{EETB_{s,t}} = 0.25 \cdot (U_{s,t} - 0.5)$$

Equation 7

Where:

$AdjU_{EETB_{s,t}}$ = Adjustment for *uncertainty* of $EETB_{s,t}$ in *stratum s* in time *t*

$U_{s,t}$ = Propagated *uncertainty* at 90% confidence level

5. Calculate adjustment factor $AdjB_{s,t}$ following Equation 8.

$$AdjB_{s,t} = EETB_{s,t} + AdjU_{EETB_{s,t}}$$

Equation 8

Where:

$AdjB_{s,t}$ = Adjustment for *pre-project tree biomass* in *stratum s* in time *t*

$EETB_{s,t}$ = Estimated pre-project *AGB* in *stratum s* at time *t*

$AdjU_{EETB_{s,t}}$ = Adjustment for *uncertainty* of $EETB_{s,t}$ in *stratum s* in time *t*

5.8 Model Assumptions

Category	Assumption	Explanation
General – *Monitoring plot* data	*Monitoring plots* tree data is reliable (except for obvious outliers, which are removed) [*Methodology* **PM002**]	The accuracy of the modelling and projections relies on the accuracy of the *monitoring plot* data, especially tree age (year of planting) and input values for *Aboveground Biomass* calculation (height, DBH, etc.).
Tree models - theory	Allometric equations describe *Aboveground Biomass* per tree species well.	[*Methodology* **PM002**]
Tree models - sigmoid	Growth of all tree species is represented by a sigmoid.	Sigmoid functions represent tree growth well (see above). However, some trees might not grow exactly as a sigmoid, or at least not for the entire growth period. Trees with growth curves that deviate from the sigmoid shape will affect the accuracy of the model.
Projections - sampling	*Monitoring plot* data for visited *Project Areas* is representative of all *Project Areas*.	[*Methodology* **PM002**]
Projections – *ecoregion*	Growing conditions within an *ecoregion* are similar.	The models are generated per *ecoregion* (based on WWF classification) as per *Methodology* **PM002**. This implies that conditions are stable within the *ecoregion*.

Projections	Current *Project* conditions (e.g. climate, soil quality, tree density, pruning practices, etc.) for the already collected *Project Areas* within the *Project* are assumed to be constant throughout the projected period and overall *Project Areas* within the *Project*.	While the data-driven approach implies that *Project* conditions are by definition built into the models, potential changes in these conditions are not accounted for. Therefore, if conditions change significantly during the projected period, then the true *biomass* growth over time may deviate from the predicted values (because the parameters of the sigmoid may change).
Projections	For the already collected *Project Areas* within the *Project*, singular events such as disease outbreaks or fires are not accounted for by the modelling.	One-off events cannot be taken into account. The *buffer pool* is set up for this purpose.

6 Parameters

Data/Parameter	b
Units	Tonne
Description	Minimum *biomass* (t CO_2e close to zero)
Equations	Equation 1
Source	Derived from peer-reviewed literature sources cited in bibliography for each species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Use to build the growth curve
Comments	N/A

Data/Parameter	k
Units	% per year
Description	Growth rate
Equations	Equation 1
Source	Derived from peer-reviewed literature for each tree species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Used to build the tree-specific growth curve
Comments	N/A

Data/Parameter	L

Units	Tonne
Description	Maximum *biomass*
Equations	Equation 1
Source	Derived from peer-reviewed literature for each tree species
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required in order to build a representative model
Purpose of Data	Used to build the tree-specific growth curve
Comments	N/A

Data/Parameter	n
Units	No unit
Description	Total number of *monitoring plots*
Equations	Equation 2
Source	**PT006**
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Total number of *monitoring plots*
Purpose of Data	Development and performance assessment of model for estimating *biomass* from satellite imagery
Comments	N/A

Data/Parameter	g
Units	Tonne
Description	*Aboveground Biomass* of a pre-project tree (tonne)
Equations	Equation 2
Source	Calculated based on results of sigmoid growth curves
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	The parameter is required to estimate the amount of *biomass* per tree
Purpose of Data	Use to build the estimate Pre-project tree adjustment factor
Comments	N/A

Data/Parameter	$U_{s,y}$
Units	No unit
Description	*Uncertainty* of sigmoid-based model
Equations	Equation 6
Source	**PU008**
Value	N/A
Justification of choice of data or description of	The parameter is required to estimate the *uncertainty* of sigmoid-based model. $U_{s,y}$ per *stratum* equals to U in **PU008** Equation 1.

measurement methods and procedures applied	
Purpose of Data	Use to build the estimate Pre-project tree adjustment factor
Comments	N/A

Data/Parameter	x
Units	Year(s)
Description	Tree age
Equations	Equation 1
Source	Derived from *monitoring plot* data. *Project Participants* are asked about the tree age(s) when collecting *monitoring plot* data. If age is unknown, *Project Participant* together with the data collector estimates the tree age.
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	Used to build growth-curves
Purpose of Data	Predict *biomass* growth
Comments	N/A

Data/Parameter	x_0
Units	Year
Description	The year of max growth
Equations	Equation 1
Source	Modelled based on tree species type and *monitoring plot* data
Value	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Predict *biomass* growth
Comments	N/A

7 References

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