CFS Methodology

Forest Inventory Guideline

This document is designed to assist project developers in assessing:

- If an area is defined as 'forest'
  in regards to chapter '01 Eligibility'
- How much 'Stem volume' and 'Non-woody biomass' is stored on an area
  in regards to chapter '08 Baseline'
- How much 'Stem volume' is stored on a management unit
  in regards to chapter '06 CO_2-fixation'

The icons ◀ ▼ ▲ ▶ indicate for which parameter the respective text is important:

◀ Eligibility ▼ Baseline - Woody ▲ Baseline - Non-woody ▶ Management Units

For the conversion of the unit 'tons of CO_2', please follow the chapter 'Conversion Procedure' in the CarbonFix Standard.

1. Shape and size of plots

◀▼▶ The plot size should be large enough so that at least 10 trees (ideal is 12 to 15 trees) are measured within the plot boundaries. A common size of plots is 250 to 500 m^2. With a circular sample plot, this corresponds to a radius of 8.92 to 12.61 m. A general rule is that larger plots lead to smaller sampling errors.

▲ To measure the non-woody biomass, the size of the plot should be large enough to contain samples of a minimum of 1 kg of fresh biomass. Therefore, the sample plots are normally about 1 to 2 m^2.

▶ 10 trees are the minimum amount of trees that shall be measured at the end of a rotation / when the forest reaches its sustainable stem volume. Therefore, depending on the thinning regime and the loss of trees, sometimes even more than double the amount are measured in the beginning.

In planted forests the distance from one tree to another is often regular. Here, it is also possible to define the plot area by the number of trees being measured.

Formula to determine the **amount of trees remaining per sample plot**

$n_e = s_r * r_r * n_s$

trees/ha = % * % * trees/ha

n_e = Amount of trees at the end of the rotation / when the forest reaches its equilibrium stand volume
s_r = Estimated survival rate
r_r = Estimated removal rate
n_s = Amount of trees at the project start

An example
The project intends to plant trees with a distance of 3 x 3 meters. This leads to 1 111 trees per hectare.
A survival rate of 80% is expected. Furthermore, it is planned to remove 50% of the trees during thinnings.

$n_e = s_r * r_r * n_s$
= 60% * 50% * 1 111
= 333 trees/ha

333 trees will remain per hectare at the end of a rotation period / when the forest reaches its equilibrium stand volume.

Formula to determine the **size of the sample plots**

A_{min} = 10 000 * n_{min} / n_e
m^2 = m^2/ha * trees / trees/ha

A_{min} = Minimum plot size
n_{min} = Amount of minimum trees required per plot (at least 10)
n_e = Amount of trees at the end of the rotation / when the forest reaches it equilibrium stand volume

An example
When the forest reaches its equilibrium stand volume, it has been calculated that 333 trees/ha will still be on the area. It is known that the minimum amount of trees required per plot are 10.

A_{min} = 10 000 * n_{min} / n_e
= 10 000 * 10 / 333
= 300 m^2

The minimum size of the plot would be 300 m^2 which equals a radius of 9.78 m.

2. Stratification

To facilitate the fieldwork and increase the precision of measuring the existing biomass, it is useful to classify the area to be inventoried into different strata, whereby one stratum consists of an area with homogenous patterns.

The process to form different strata is called stratification. For stratification, the size and spatial distribution of an area is not relevant - meaning that it does not matter if a stratum consists of one large contiguous block of land or many small parcels.

To work efficiently, a pre-stratification is recommended. Hereby 6 sample plots per stratum are implemented to give an indication about the standard deviation within the stratum. Based on this standard deviation, the total amount of sample plots can be determined.

For the stratification of an area, maps from satellite imagery of soil, vegetation or topography shall be used.

◄ Stratification classes for the Eligibility analysis are:

- Forest (non-eligible)
- Wetland (non-eligible)
- Non-forest (eligible)

▼▲ Stratification classes for the Baseline analysis can include the following:

- Different types of vegetation (woodland, bushland, etc.)
- Cropland
- Grassland
- Wetland

Baseline stratification must only take place on the eligible planting area.

► Different strata within the eligible planting area are called management units.

Management Units often distinguish themselves in their homogeneous characteristics by the following patters:

- Site properties (substrate, supply of nutrients, water regime)
- Establishment of the site (tree species, species composition, species arrangement, tree spacing)
- Maintenance of the stand (fertilizer application, pruning, weeding
- Age of the stand
- Rotation period
- Utilization (thinning system, harvesting system)
- Topography

3. Amount of Sample plots

The amount of sample plots determines the precision level of the analysis. Therefore, before field measurements are executed, the first step is to identify the required number of plots to obtain the desired precision.

The following formula shall be used to calculate the necessary amount of sample plots. The assisting document 'Sample Plot Calculation' can also be used.

Formula to determine the **amount of sample plots per stratum.**

$$n = \frac{(N * s)^2}{\frac{N^2 * E^2}{t^2} + N * s^2}$$

E	=	Allowable error
	=	Mean (e.g. Stem volume) * Precision level
		▶ Within a management unit the precision level shall be below 20%. If the precision level is above 20%, the additional difference must be deducted from the mean.
t	=	If a sample size is unknown, it is set to 2
	=	If the sample size is known, the following website assists you to find 't': http://onlinestatbook.com/chapter8/t_distribution.html - the confidence level = 95 %
N	=	Number of sampling plots for one stratum
	=	Area of the stratum (ha) / Area of the sample plot (ha - not m^2)
s	=	Standard deviation of a stratum

An example

Within a project, the ecotype bushland is homogeneous and therefore counts as one stratum. In total it covers 50 ha of the project area.

According to the guideline it has been calculated that a plot size of $250m^2$ (=0.025 ha) will be of sufficient size. The results of a pre-stratification expect standard deviation of 30 m^3/ha and a mean stock of Stem volume of 100 m^3/ha.

The desired precision level is 20%.

E	= Mean stock of stem volume	* Precision level
	= 100	* 0.2
	= 20 m^3/ha	
t	= if unknown take 2	
N	= Area of the stratum	/ Area of the sample plot
	= 50	/ 0.025
	= 2 000	
s	= Standard deviation	
	= 30 m^3/ha	
n	= $(2\,000 * 30)^2$ / $((2\,0002 * 20^2)/2^2) + 2\,000 * 30^2)$	
	= 9 plots	

A minimum of 9 plots must be implemented to determine the accurate Stem volume of this stratum.

4. Location of Plots

To maintain precision, plots must be located without bias. If plots follow a road, trail or straight river they might be biased. In this case, the location of plots should be relocated. The area to be inventoried shall be evenly sampled.

► Plots which are used for the verification of forest growth-models must be established on a permanent base.

▲ It is recommended to use the same location of the plots for non-woody biomass, as used for the plots of the woody biomass (Stem volume).

The location of plots can be random or systematic. However, it is recommended to use a systematic setting, because this approach is easier in its preparation and gives a better impression of the special distribution of the plots.

Random sampling

Systematic sampling

5. Slope Correction

▼ ▶ Because all measurements of a sample plot are reported on a horizontal-projection basis, the establishment of plots on sloping lands must use a correction factor. The slope angle must be measured with a clinometer.

The following table provides the correction factor for horizontal distances, in function of the slope:

Slope %	Slope °	Correction factor
10 – 17	6 – 10	1.01
18 – 22	10 – 13	1.02
23 – 26	13 – 15	1.03
27 – 30	16 – 17	1.04
31 – 33	18 – 19	1.05
34 – 36	20 – 21	1.06
37 – 39	22 – 23	1.07
40 – 42	24 – 25	1.08
43 – 44	25 – 26	1.09
45 – 47	27 – 28	1.10
48 – 49	29 – 29	1.11
50 – 51	30 – 31	1.12
52 – 53	31 – 32	1.13
54 – 55	33 – 33	1.14
56 – 57	34 – 35	1.15
58 – 59	35 – 36	1.16
60 – 61	37 – 38	1.17

Formula to **correct the plot area on slopes over 10%**.

$r_{new} = r_{old} * Cf$

r_{new} = New radius of the sample plot
r_{old} = Normal radius of the sample plot
Cf = Correction factor

An example
A project has planted trees on several mountain slopes to fight erosion. One of the sample plots is placed on a hillside with a slope of 58%. According to the table above the correction factor is 1.16. On flat terrain the project uses circular plots of $250 m^2$ with a radius of 8.92 meters.

$r_{new} = r_{old} * Cf$
$= 8.92 * 1.16$
$= 10.34$ m

This means that the plot will have to be measured with a radius of 10.34 m to represent 250 m^2 on flat terrain.

6. Field Measurements - woody biomass

◄▼► Woody biomass / Stem volume

STEP 1	Accurately locate the plot. Use a GPS and if necessary a compass.
STEP 2	Mark the middle of the plot with a colored PVC tube or a metal pole. If possible the tube or metal pole should be marked with the ID number of the plot.
STEP 3	Mark the first tree to know the starting point.
STEP 4	Use the rope to measure the defined radius. Where sample plots are located on a slope that is >10% the plot radius has to be adapted.
STEP 5	Measure the diameter of the tree at breast height (1.3 m). See infobox 'DBH measurements' for further instructions.
STEP 6	After each tree move clockwise to the next tree. ▼ Number each tree with the colour or aluminium tag. In case of multi-stemmed trees below breast height mark each stem with the same number and a different letter (1a, 1b …).
STEP 7	Record the ◄ ▼ average height and the ◄ crown cover of the trees. See upcoming chapters for further instructions.
STEP 8	Analyse all data in an excel sheet

Boundary Trees

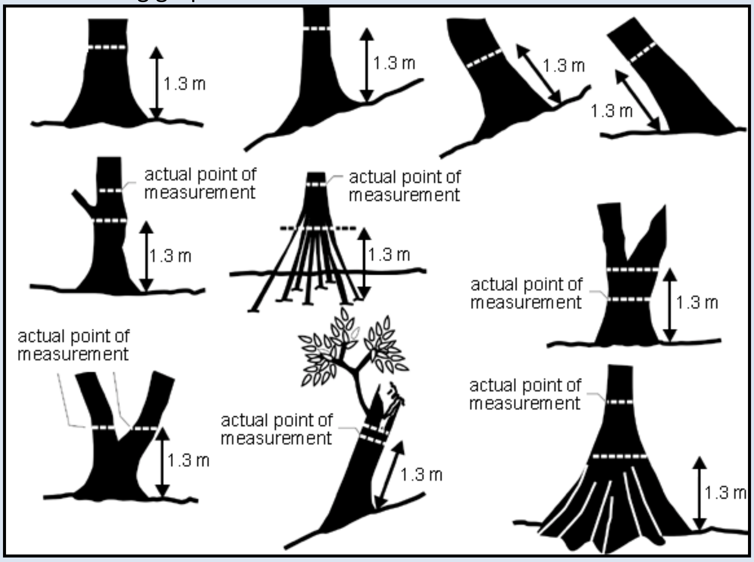
Occasionally trees will be close to the border of the plots. In such a case the following rules shall be applied:

- If more than 50% of the trunk is within the plot boundary, the tree is in.
- If more than 50% of the trunk is outside of the boundary, it is out and should not be measured.
- If it is exactly on the border of the plot, flip a coin to determine if it is in or out.
- If a tree grows into the plot, it should not be measured.

DBH measurements

It is important that a caliper or DBH tape is used properly to insure consistent measurement.

The following graphic show different scenarios of measurement:

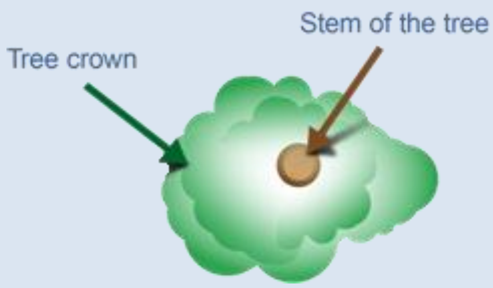


In case of using DBH tapes, be aware that these often measure diameter on one side and circumference on the other. It is important not to mix these!

◄ **Ground cover**

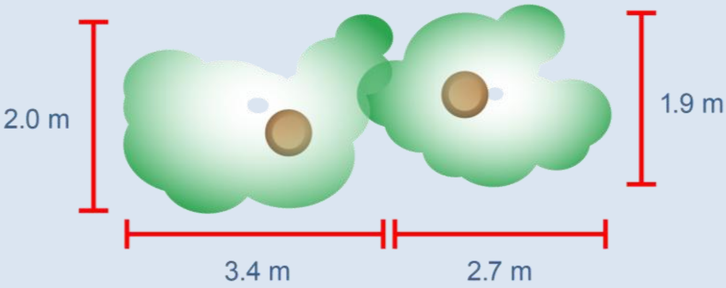
Together with the determination of the baseline, the parameter ‘ground cover’ can be assessed, which might be necessary in order to verify if the area is eligible according to the forest definition of the projects host country. In the following the practical procedure is described:

To determine the ‘ground cover’ within a sample plot, measurements are taken according to the crowns expansion of the individual trees.

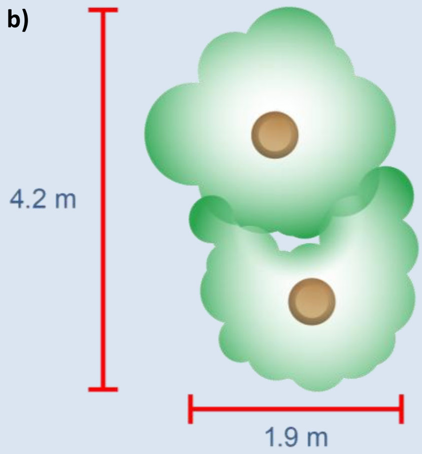


To do so, the perpendicular distances of the crowns edges (see graphic a) are measured. If crowns are merged together (see graphic b), several trees can also be measured at once. With two measurements an approximate rectangular crown area can be calculated.

a)



b)



Crown area = 3.4 * 2.0 + 2.7 * 1.9
= 11.93 m^2

Crown area = 4.2 * 1.9
= 7.98 m^2

◀ ▼ ▶ **Height measurement**

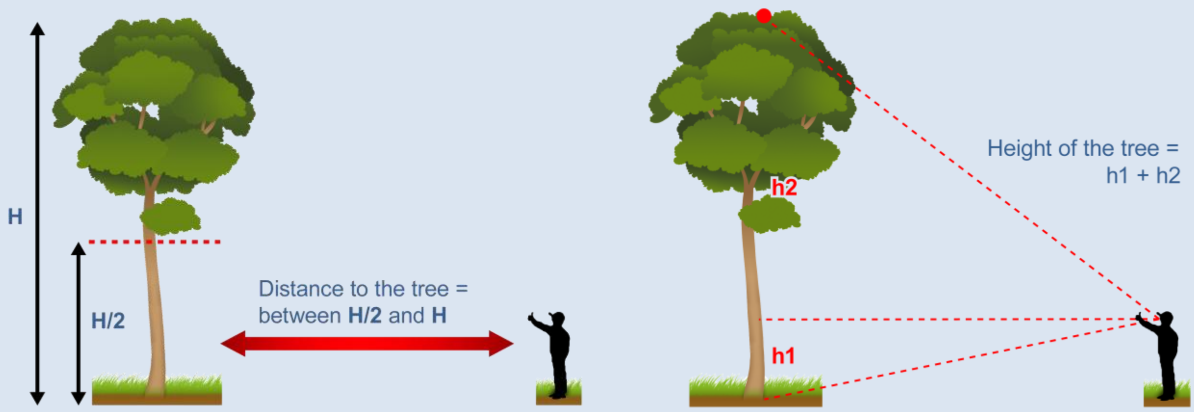
Depending on the scientific model to determine the biomass of an area the height of trees or shrubs might have to be measured. In the following the practical procedure is described how to determine the average height of a sample plot. Note that depending on the scientific model heights other than the 'average' height might be required as a base of calculation.

Height measurements are time consuming compared with DBH measurements. For that reason minimum 3 trees per plot - with an average height ! - shall be measured for each plot. The field crew taking the measurements shall decide together which trees are most representative.

To be most accurate

- trees with a height < 6 m should be measured with a measurement stick
- trees with a height > 6 m should be measured with a height measurement tool

When measuring with a height measurement tool, the horizontal distance between the field crew member and the tree to be measured should be between half of the height and the actual size of the tree. It can also be more than this.



Independent of the slope of the terrain the crew members shall measure two heights and add them. On flat terrain h1 is equal to the height of the crew member.

7. Field Measurements - non-woody biomass

▲ Non-woods biomass

STEP 1	Place the plot eg. 1 meter north of the centre from the 'Woody biomass' plot.
STEP 2	Establish the non-woody plot by sticking 4 nails in the ground (1 x 1 meter) and tie the string around it.
STEP 3	Clip all vegetation within this plot to ground level.
STEP 4	Weigh the sample in the field (= Fresh biomass).
STEP 5	Take exactly 500 grams of the collected biomass with you.
STEP 6	Dry the 500 grams in an oven at ~ 70°C (for around 1 hour). Then weigh again. This will determine the Wet-to-Dry ratio.

8. Equipment

The equipment used for fieldwork should be accurate, rugged, and durable to withstand the rigors of use under adverse conditions. The following list covers the necessary equipment for field measurements.

Rope with the length of the plots radius nodes for slope corrections are useful **or** Optical distance measurement device eg. VERTEX	◀ ▼ ▲ ▶	for measuring the plot radius
GPS and compass if necessary	◀ ▼ ▲ ▶	for locating plots
PVC tube **or** Metal pole	◀ ▼ ▶	for marking the plots centre
White colour and a brush **or** Aluminium nails and numbered tags (◀ ▼)	◀ ▼ ▶	for marking trees
Calliper **or** Tree diameter tape	▼ ▶	for measuring trees
Clinometers eg. SUUNTO, VERTEX	◀ ▼ ▶	for measuring slope
Height measurement stick for trees < 6m	◀ ▼ ▶	for tree height measurement
Height measurement tool for trees > 6m	▼ ▶	for tree height measurement
1.3m (DBH) stick not necessary for trained staff	▼ ▶	for measuring DBH
Tape measure up to 15 meters	◀	for measuring the tree crowns
4m of string + 4 long (20cm) nails	▲	for defining the non-woody plots
1 shear **or** 1 secateurs	▲	for cutting the non-woody biomass
Plastic bags as many as sample plots will be assessed		for collecting the fresh non-woody biomass
Scale precise to 10g, with a max scale of 5kg	▲	for weighing the fresh non-woody biomass

Forest equipments suppliers: www.benmeadows.com, www.forestry-suppliers.com, www.grube.de

◀ Eligibility ▼ Baseline - Woody ▲ Baseline - Non-woody ▶ Management Units

▶ DATA ENTRY FORM

Slope: ____% Plot size: ______ m^2 Planting Date: __________ Date: ____/____/____

Management Unit: _____ Plot ID: _____ GPS (X/Y): __________/__________ Field-Crew Chief: _______________

Tree No.	DBH [cm]	Height [m]	Specie / Comment	Tree No.	DBH [cm]	Height [m]	Specie / Comment
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			

◄ ▼ DATA ENTRY FORM   Slope: _____%   Picture: _______   Plot size: ________m^2 Date: _____/_____/_____

Plot ID: ______   GPS (X/Y): ___________/_________   Field-Crew Chief: __________________

Tree No.	Crown area [m^2]	DBH [cm]	Height [m]	Specie / Comment	Tree No.	Crown area [m^2]	DBH [cm]	Height [m]	Specie / Comment
1					16				
2					17				
3					18				
4					19				
5					20				
6					21				
7					22				
8					23				
9					24				
10					25				
11					26				
12					27				
13					28				
14					29				
15					30				

▲ Plot size: _____ m^2

Weight fresh biomass: ________ grams

Weight fresh biomass sample: _______ grams

Weight dry biomass sample: _______ grams

8. Parameter overview

▶ The following table gives an overview where the different parameters of the monitoring from the 'Net CO_2-fixation' of a management unit have to be documented.

ID	Data variable	Data unit	Measured (m) Calculated (c) Estimated (e) Default (d)	CFS Template
M O N I T O R I N G - CO_2 F I X A T I O N				
Monitoring per sample plot				
M 1	Date of inventory	Date		Forest Inventory XLS
M 2	ID of sample plot			Forest Inventory XLS
M 3	Name of responsible person			Forest Inventory XLS
M 4	Plot location	GPS coordinates	m	Forest Inventory XLS
M 5	Slope	%	m	Forest Inventory XLS
M 6	Picture (optional)			Forest Inventory XLS
M 7	Plot size	m^2		Forest Inventory XLS
M 8	ID of tree			Forest Inventory XLS
M 9	Diameter breast height (DBH)	cm	m	Forest Inventory XLS
M 10	Tree height	m	m	Forest Inventory XLS
M 11	Form factor			Forest Inventory XLS
M 12	Tree specie			Forest Inventory XLS
Analysis I per Management Unit				
M 13	Date of inventory	Date		Forest Inventory
M 14	ID of sample plot			Forest Inventory
M 15	Mean or Dominant tree height	m	c	Forest Inventory
M 16	Mean DBH	cm	c	Forest Inventory
M 17	Mean Form factor		c	Forest Inventory
M 18	Mean Stem volume	m^3/ha	c	Forest Inventory
M 19	Area of stratum	ha	m	Forest Inventory
M 21	Current precision level	%	c	Forest Inventory
M 20	Preset precision level	%	d	Forest Inventory
M 22	Amount of plots required to meet the precision level (n)		c	Forest Inventory
M 23	Current amount of plots		m	Forest Inventory
M 24	t		c or d	Forest Inventory XLS
M 25	Standard deviation within the sample plot (s)	m^3/ha	c or e	Forest Inventory XLS
M 26	Allowable error (E)	m^3/ha	c	Forest Inventory XLS
M 27	Mean plot size	ha	c	Forest Inventory XLS
M 28	Possible amount of sample plots in the stratum (N)		c	Forest Inventory XLS
Analysis II per Management Unit				
M 29	Planting Date	Date		Forest Inventory
M 30	Initial amount of trees	trees/ha	c	Forest Inventory
M 31	Current amount of trees	trees/ha	m	Forest Inventory
M 32	Age	years	c	Forest Inventory
M 33	Radius growth	cm	c	Forest Inventory
M 34	Height growth	m	c	Forest Inventory
M 35	Volume growth	m^3/ha/a	c	Forest Inventory
M 36	Survival rate	%	c	Forest Inventory
Conversion to CO_2				
M 37	Biomass Expansion Factor (BEF)			CO_2-fixation
M 38	Root-to-Shoot ratio (R-t-S)			CO_2-fixation
M 39	Wood density			CO_2-fixation
M 40	Carbon fraction		d = 0.5	CO_2-fixation
M 41	C to CO_2 ratio		d = 3.666	CO_2-fixation