ESPA p4ges PROJECT

Work Package Carbon (WP4-Carbon)

Manual for carbon stock quantification within the Ankeniheny-Zahamena Forest Corridor within the Classical Survey framework

(Manual n°1)

Period of work: April 2014 - June 2015

Authors: ***RAZAFINDRAKOTO Mieja, RIANA Hary Andrisoa, ANDRIANIRINA Carole, RAZAFIMBELO Tantely, ANDRIAMANANJARA Andry, SANEHO Haritiana Julio Gabriel, RAMIFEHIARIVO Nandrianina, RANAIVOSON Ntsoa, RAZAFISOAZARA Mihajasoa, RAZAFIMANANTSOA Marie Paule, RAZAKAMANARIVO Herintsitohaina***

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CONTEXT

The p4ges « *Can paying 4 global Ecosystem Services reduce poverty ?* » project in Madagascar aims to influence the development and the implementation of payement for ecosystemic services at intarenational scale in order to alleviate poverty. Among ecosystemic services of interest, the carbon survey in the Ankeniheny Zahamena coridor (CAZ) in eastern Madagascar was carried out by the carbon workpackage (WP4; NE/K008692/1). Carbon stock assessment was performed in different land uses for five (5) pools defined by the IPCC (2006), were assessed 1) Aboveground biomass (AGB), 2) Belowground biomass (BGB), 3) Litter layer, 4) Dead wood (DW), 5) Soil Organic Carbon (SOC).

The present manual is established under the p4ges project "*Can paying 4global ecosystem services reduce poverty ?*" for the carbon survey conducted by WP4. It develops the first step of survey that will be used as a basis of all carbon quantification within a forest ecosystem. It focuses on AGB, litter, deadwood and soil survey. This manual is divided in four (4) main parts. The first part concerns the development of the design sampling, and it is followed by the sampling strategy. The preliminary data handling is detailed after the presentation of the laboratory analysis.

Anyway, all datasets which were generated by methodology process described within this manual have been archived at Environmental Information Data Centre - EIDC (http://eidc.ceh.ac.uk).

COMPOSITION OF THE WP4-CARBON TEAM

Central team

Dr. HDR RAZAKAMANARIVO Herintsitohaina
Pr. RAZAFIMBELO Tantely
Dr. ANDRIAMANANJARA Andry
Dr. RAZAFIMAHATRATRA Hery

Assistants of research

ANDRIANIRINA Carole
RAMBOATIANA Nantenaina
RIANA Hary Andrisoa
SANEHO Haritiana Julio Gabriel
RAZAFINDRAKOTO Mieja Ambina
RAMIFEHIARIVO Nandrianina
HARINIRINA Ando

Field team

RAZAFISOAZARA Mihajasoa Georgine
RANDRIARILALA Tanteliniaina
RANDRIANASOLO Heritiana Michel
ANDRIANOTAHINA Harivony Honoré
RANDRIANARIJAONA Jean Marcel
RAZAFIARISON Justin Théodore

Responsible of laboratory

RAZAFIMANANTSOA Marie Paule

GLOSSARY, ABBREVIATIONS and UNITS

Terms	***Abbreviations and units***	***Description***
Aboveground biomass	**AGB (*kg* at tree level and *MgC.ha*$^{-1}$ at site level)**	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, branches, bark, seeds, and foliage. (IPCC, 2006)
Ankeniheny-Zahamena Forest Corridor	**CAZ**	Remains of the evergreen forest of eastern region in Madagascar
Belowground biomass	**BGB (*kg* at tree level and *MgC.ha*$^{-1}$ at site level)**	All biomass of live roots.
Campsite		Location or village around which, sampling plots were located
Carbon	**C**	Carbon in a defined pool
Carbon content	**(*g.kg*$^{-1}$)**	Quantity of carbon in a defined quantity of soil or biomass
Carbon stock	**(*MgC.ha*$^{-1}$)**	The quantity of carbon in a pool for an unit of area (IPCC, 2003)
Closed canopy	**CC**	Primary forest formation
Conservation International	**CI**	Conservation International
Dead wood	**DW**	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil (IPCC, 2006)
Diameter at breast height	**DBH (*cm*)**	Diameter of the measured tree at 1.3m height
Height	**H (*cm*)**	Height of the measured tree
Indicator species		Species characterizing a determined land use
Intergouvernemental Panel on Climat Change	**IPCC**	
Laboratoire des RadioIsotopes	**LRI**	Laboratory of soil carbon and biomass analysis- Antananarivo University
Land use	**LU**	The type of activity being carried out on a unit of land (IPCC, 2003)
Litter		Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for deadwood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil (IPCC, 2006). In the field, this pool was divided into *litter layer* and *root mat*
Mid Infra-Red Spectroscopy	**MIRS**	Soil analysis method based on soil reflectance of infra-red emissions of defined wavelength spectrum

Can paying for global ecosystem services reduce poverty	**p4ges**	"Can Paying for ecosystem services reduce poverty?" project
Plot		Iindividual site (corresponding to a land use types) which was common for biophysical workpackages in which the survey was done
Pool of carbon		A reservoir of carbon, a component able to accumulate or release carbon (IPCC, 2006)
Sapling		Tree with diameter under 5cm and height above 1.30m
Shrub fallow	**SF**	A land use type corresponding to subsequent fallow cycle after deforestation (Styger *et al.*, 2007)
Site		Unit of sampling (corresponding to a plot) that can either an individual site or included within a transect site
Soil organic carbon	**SOC (*MgC.ha*$^{-1}$)**	Carbon in soil organic matter, up to either 30 cm (*SOC30*) or 100 cm (*SOC100*) depth
Soil organic matter		Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series. Live and dead fine roots within the soil (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically (IPCC, 2006)
Subplot	**S**	Unit of sampling inside the plot
***Tany maty* or Degraded land**	**TM (or DL)**	A land use type corresponding to final stage of deforestation, or land that is abandoned (Styger *et al.*, 2007)
Transect of site	**TR**	4 plots in a landscape including land use and geomorphology variations
Tree fallow	**TF**	A land use type corresponding to first fallows following deforestation
Understorey		Herbaceous vegetation in forests and fallows land use types with height under 1.30 m
Wood Specific Gravity	**WSG**	Density of the wood species which was obtained either by direct measurement (field sampling work in laboratory) or by use of standard value in available national and international wood density databases
WorkPackage	**WP**	Specialized group of researchers and assistants working on the different work packages of the p4ges project
WorkPackage 1	**WP1**	P4ges workpackage in charge of remote sensing and design sampling
WorkPackage 2	**WP2**	P4ges workpackage in charge of hydrology survey
WorkPackage 4	**WP4**	P4ges workpackage in charge of carbon assessment
WorkPackage 5	**WP5**	P4ges workpackage in charge of biodiversity survey
Zone of Interest	**ZOI**	Area of distribution of sampling effort throughout the spatial extent in order to capture the variation in CAZ and limit pseudo replication

TABLE OF CONTENT

1. Development of the design sampling

1.1. Identification of the Zone of Interest

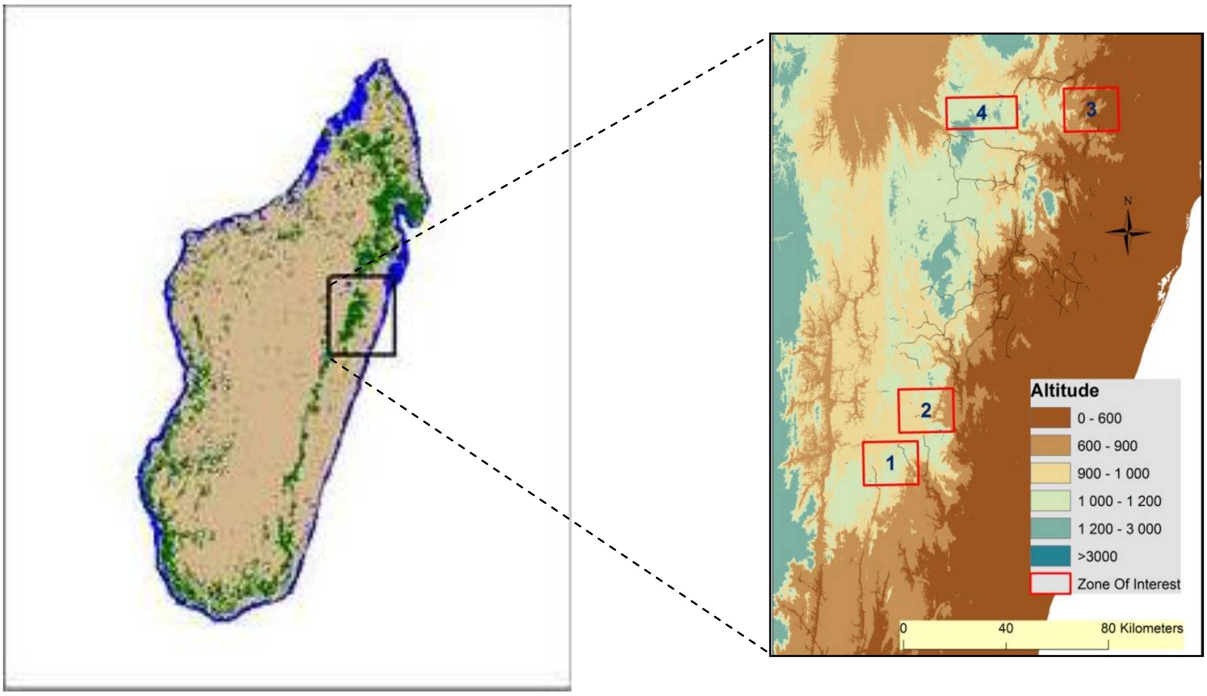
In order to catch the representativeness of the whole studied Ankeniheny-Zahamena Forest Corridor, the biophysical workpackages (Biodiversity, Carbon and Hydrology) contributed to the definition of a sampling design strategy to locate some zones to focus all works.

The zones of interest (ZOI) were then identified after discussion between WPs by taking into account different criterias such as:

- Biophysical criterias : altitude, slope and other biophysical criterias as bioclimate zone, length of dry season, soil type
- The deforestation history
- The access

According to these criterias, four (4) ZOIs considered as representative and including all the principal existing conditions of the CAZ area were selected. (Map 1)

- ZOI1 in Lakato
- ZOI2 in Andasibe
- ZOI3 in Anjahamana/Ambalarondra
- ZOI4 in Didy



Map 1 : location of the four Zones of Interest within the Ankeniheny-Zahamena Forest Corridor

1.2. Sites identification

For the carbon workpackage (WP4) field activities, site was defined as a unit of sampling where field activities were done. The criterias to be considered when selecting the sites are presented as the following.

1.2.1. Land use classification

The land use characterization is based on the study of Styger and al. (2007). Four land uses were identified in different villages:

- Closed canopy
- Tree fallow
- Shrub fallow
- *Tany maty* or Degraded Land

In addition to these land uses, there were another land use type was the reforestation. It was identified by the other workpackages through interviews with Non-government Organizations (NGOs), local communities, and was included among all WP4 sites.

1.2.2. Criteria for the site identification

Each site should fulfill other criteria than LU type defined by biophysical workpackages. As there were some specific requirements for the WP2 (Hydrology workpackage) &WP5 (biodiversity workpackage), the main criteria retained for the site selection was slope threshold (less than 45 degrees). A part from that:

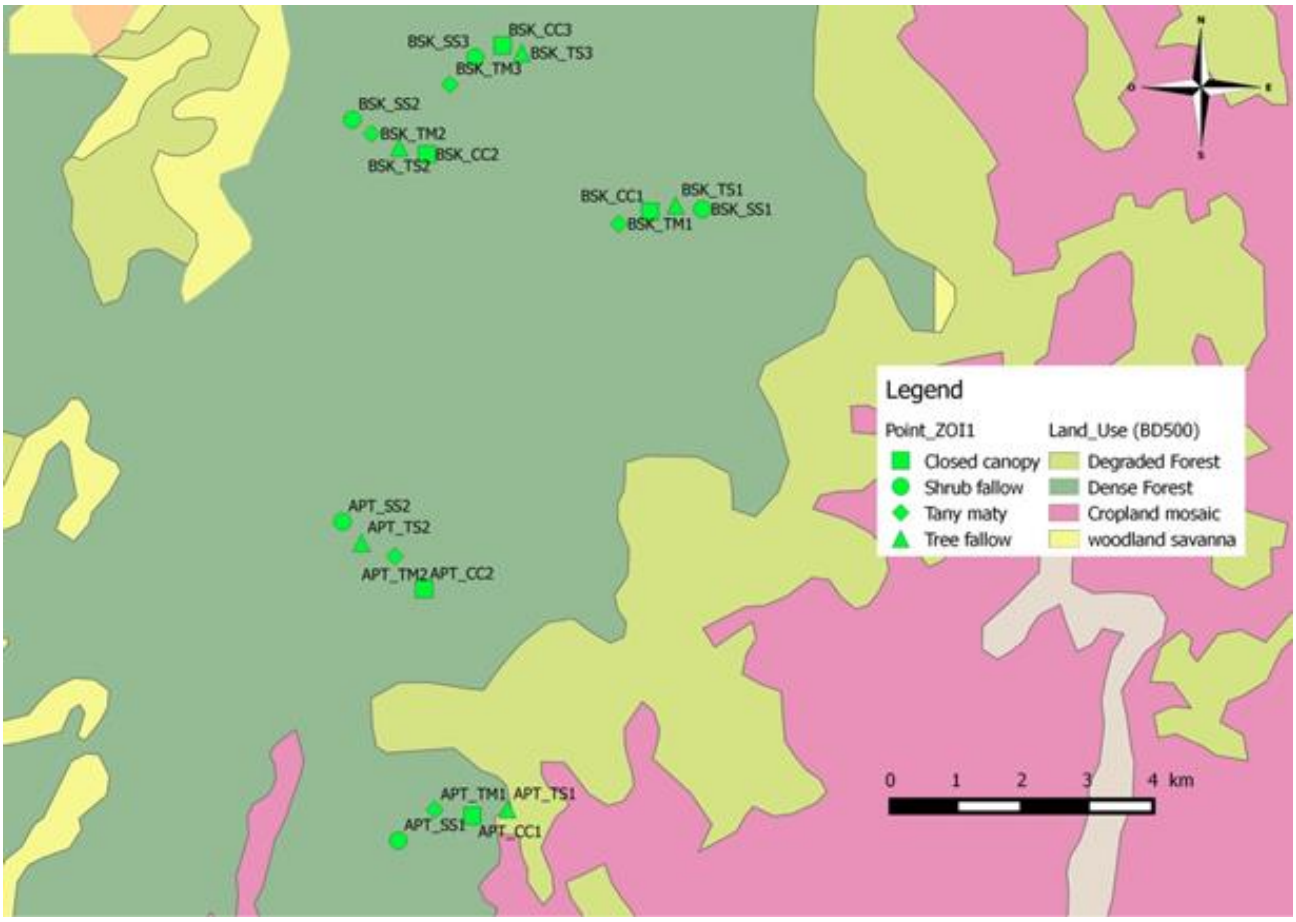
- Transects of sites must be located as near to the centre of a patch of habitat as possible to avoid edge effects
- Each site must be superior or equal to 120m by 120m
- Avoid areas of unusual disturbances, such as mining sites
- Transects should not be laid across or along streams
- Distance between sites are at least 500m each other.

1.2.3. Number and location of sites

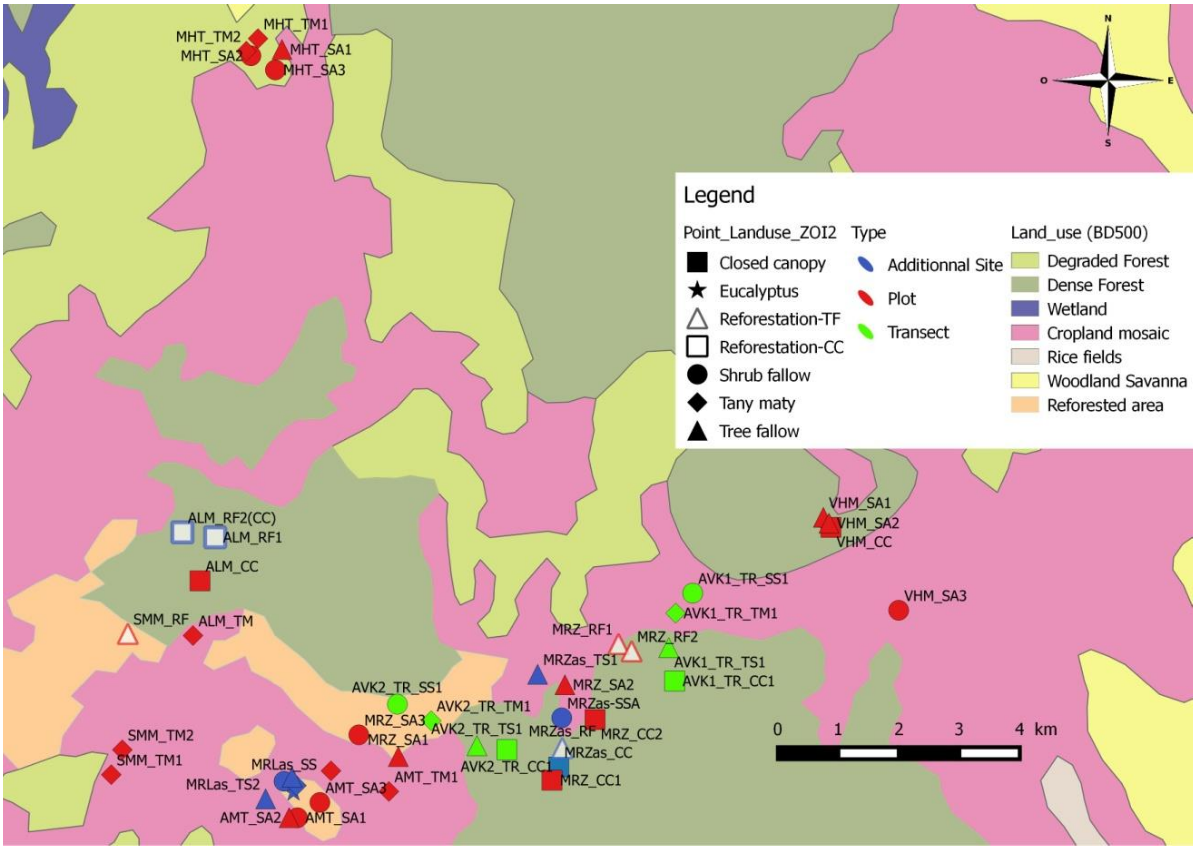
In each ZOI, there were three or four campsites which were formed by some set of sites. For a good sampling, biophysical WPs choose a number of 16 plots to be surveyed in each ZOI. To be more specific, the 16 plots are obtained as follow: 4LU x 4 replicates.

Particularly for WP4, because of the need of apprehending the most C stock variability, some extra plots were surveyed within each ZOI (Maps 2 to 5). In total 28 sites were surveyed in ZOI1 Lakato, 48 sites in ZOI2 Andasibe, 28 sites in ZOI3 Anjahamana, and 28 sites in ZOI4 Didy.

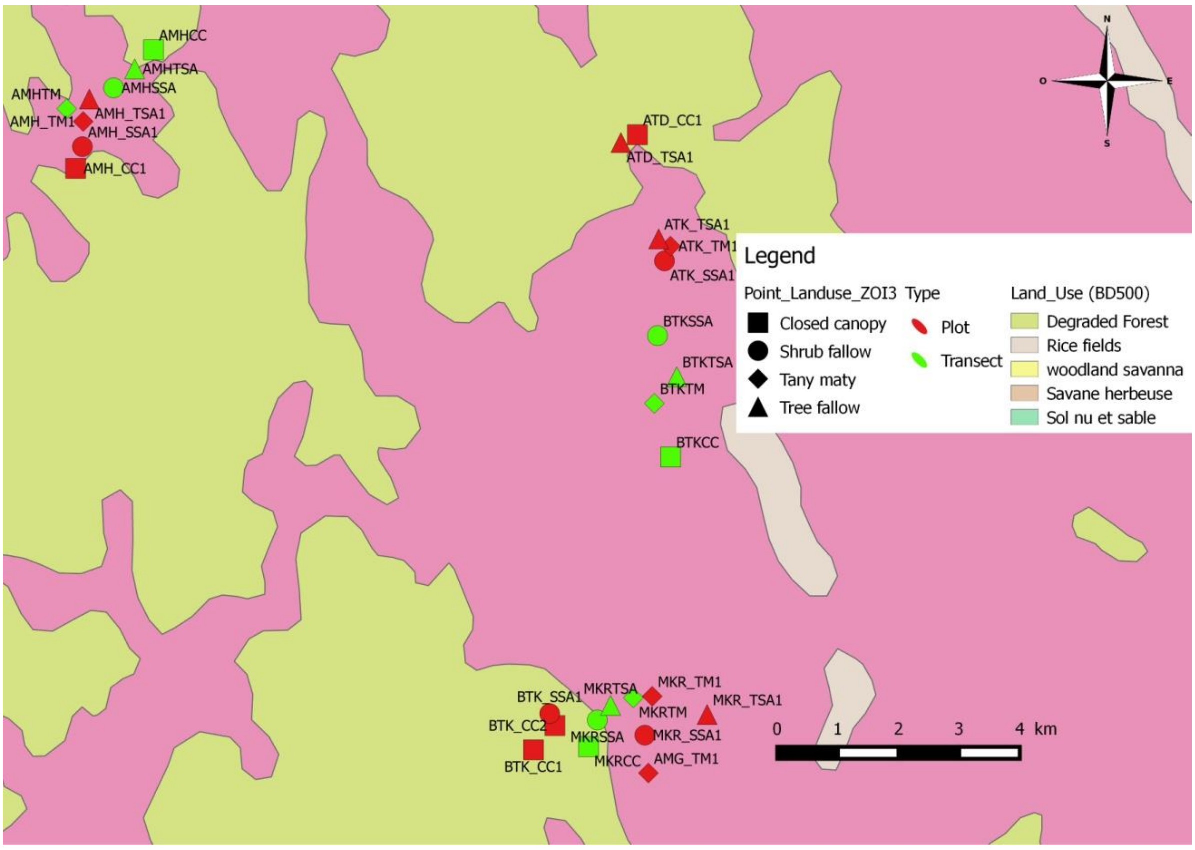
The sites locations are identified by remote sensing carried out by CI team. One site corresponds to one land use. Each site location was described and gathered in specific datasets.



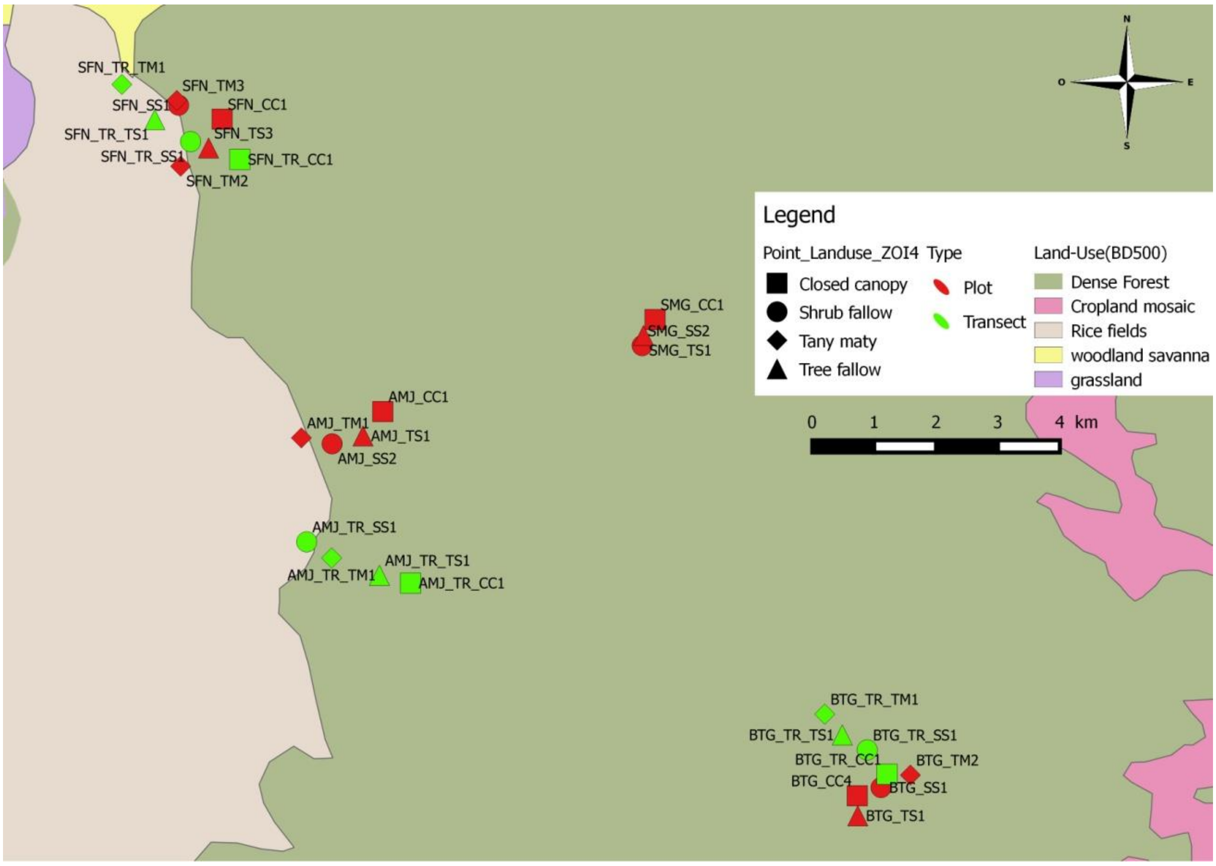
Map2 : surveyed Sites in ZOI 1 Lakato



Map 3 : surveyed Sites in ZOI 2 Andasibe



Map 4 : surveyed Sites in ZOI 3 Anjahamana



Map 5 : surveyed Sites in ZOI 4 Didy

2. Sampling strategy

2.1. Preliminary activities

2.1.1. Field reconnaissance

In order to confirm if the sites identified firstly by remote sensing were suitable for the survey, a field recognition mission has been carried out. Reconnaissance team includes team members from each biophysical WPs (Carbon, Hydrology, Biodiversity) and sometimes with CI team members.

During field reconnaissance, the team verified if each site fulfills the pre-established criteria (cf section 2.2.2.), assessed the botanical *indicator species* and collected data about land use history to confirm the type of land use in the site. The accessibility of each site was also verified by the team.

2.1.2. Minimal area test

The "minimal area" is defined as the minimum representative unit of sampling in order to cover the diversity of the ecosystem. A minimal area test was made on July 2014. To determine this minimal area, inventory of species in a quadrat of 1m x 1m was made. This previous area was doubled and inventory of new species was done. This operation was repeated until no new species appeared.

The results show that the area of $16m^2$ corresponds to the minimal area that will be needed then to be considered during all C stock quantification within the CAZ.

2.2. Before field work

2.2.1. Administrative work

The preliminary step before going to the field is the preparation of administrative papers. These administrative papers concern especially the permits, the mission order and the insurances.

2.2.2. Preparation of forms and documents used in the field

To insure the execution of the activities in the field, there are some elements to be prepared.

a) Data collection sheets

There were five different types of forms (considering some parameters as presented in the appendix) which were used in the field work

- Characteristics of the site
- Inventory including the inventory of natural regeneration, standing dead wood, fallen dead wood, tree inventory
- Coverage percentage (Braun Blanquet)
- Sampling of sapling, litter, roots, under storey vegetation
- Description of the soil profile

b) Materials

- for forest inventory: forester compass, vertex, decameter, flags
- for biomass and soil sampling: cylinders, soil auger, quadrat

c) Samples bags

- labeling
- weighting with a numeric precision (0.01g) scale

2.3. During field work

2.3.1. Design sampling at plot level

For biomass assessment, the general design sampling for all C pools surveys could be presented in Figure 1. There was only one sampling method (plot with 5 m radius) for degraded land. The same sampling method was used in all land use for soil carbon assessment.

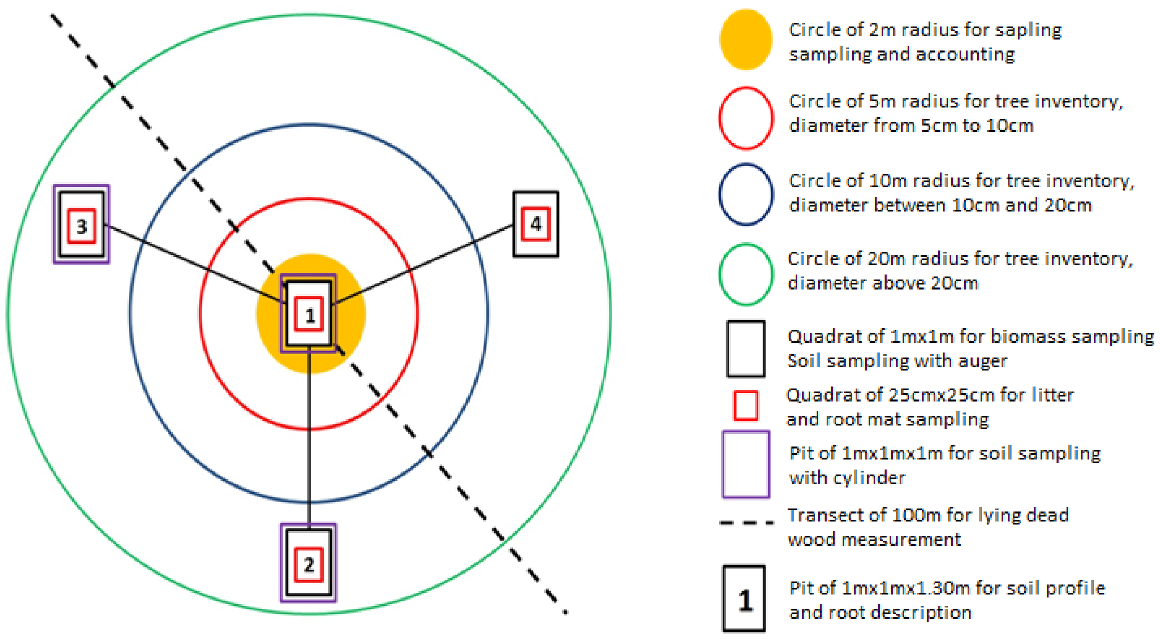


Figure 1: General design sampling for all pools at plot level

2.3.2. Activities for biomass assessment

2.3.2.1. In closed canopy and fallows

a. Forest inventory

For each sampling site, four subplots located in circular area were identified (Figure 1).

- For the first area of 2 m of radius, sapling (DBH<5cm and H>1.30m) were accounted for each species. Then, 5 different species of saplings chosen randomly were weighed and sampled.
- For the second circular area of 5 m of radius, DBH and height of trees (living wood and standing dead wood) from 5 to 10 cm of DBH were measured. Their local name were also recorded
- For the circular area of 10 m radius, DBH and height of trees with DBH between 10 cm and 20 cm were measured. Their local name were also recorded
- For the circular plot of 20 m of radius, DBH, height and local name of trees (living wood and standing dead wood) with DBH above 20 cm were recorded

Only for standing dead wood, diameters at 1,30m and at the top were recorded in addition to DBH and height. In addition to diameters, the observed wood density categoryof each standing dead wood was recorded. The wood density was classified as Sound (S), Intermediate (I) and Rotten (R). The values of each class are those applied by Conservation International Madagascar (CI Madagascar).

Lying dead wood was measured on a transect of 100 m passing through the center of the plot. For each lying dead wood intercepting the transect, the diameter at which the rope passes is recorded. In addition to the diameter, the wood density of each lying dead wood is recorded. The wood density is classified as sound (S), intermediate (I) and rotten (R). The values of each class are those applied by Conservation International (CI).

b. Aboveground biomass by direct measurement

A direct measurement of aboveground biomass was carried out in closed canopy. Indeed, 54 trees from four species were then selected from the forest inventory, on the basis of their relative contribution to tree density (ratio between the number of stems per hectare of the species and total number of stems). Then, in second phase, these trees were felled and weighed after separating trunk, branch and leaves biomass (Picard et al. 2012). The total fresh weight of each component was obtained in the field using electronic balances. After, subsamples were collected from the field for a lab-based humidity analysis. The dendrometric characteristics of these 54 trees were recorded.

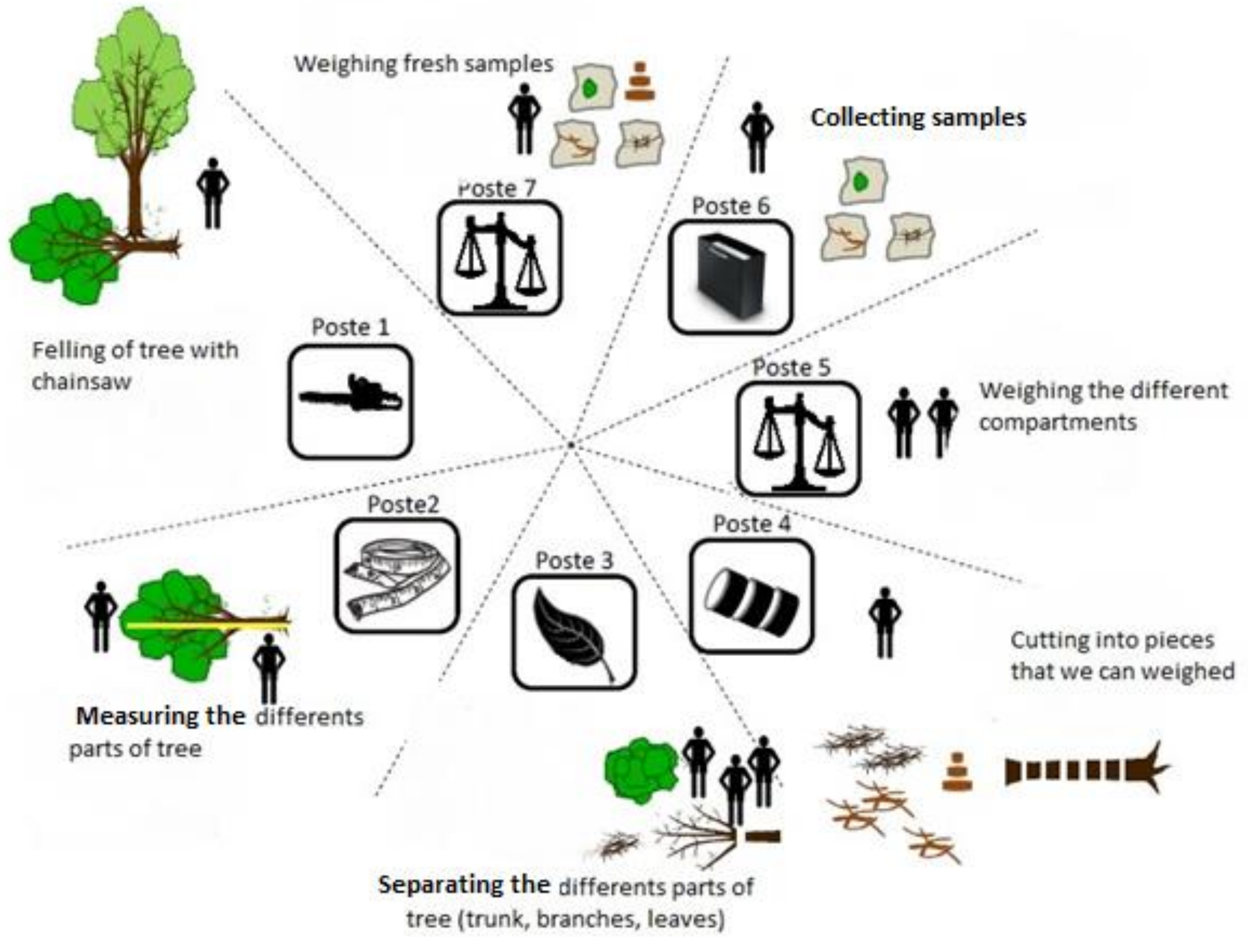


Figure 2: Collection of data for aboveground biomass by direct measurement

c. Understorey vegetation, litter and root mat sampling

Understory vegetation, litter and root mat sampling have been made on the four subplots located in the center of the circle (01) and in 3 points (2,3 and 4) located at 12.5m from the center and forming accordingly to each other an angle of 120° (Figure 1).

Firstly, litter and root mat sampling have been made with a quadrat of 25 cm x 25 cm. All litter and root mat inside the quadrat have been collected. The data concerning the litter and root matt were recorded at EIDC Data center. Secondly, understorey vegetation sampling has been made with a quadrat of 1 m x 1 m. All the biomass inside the quadrat has been weighted with a numeric hanged scale and sampled (Photo 3). Biomass and root samples obtained from each quadrat have been taken for lab works in Antananarivo.

Photo 2 : Litter sampling (25cmx25cm)

Photo 1 : Understorey vegetation sampling (1mx1m)

Photo 3 : Biomass weighting

d. Root description and sampling

In the framework of this classical carbon stock survey, root carbon study was as follow:

In the center of the circle plots, a pit in an area of $1m^2$ was made for root description and sampling. Root collection was made during the pits digging. All roots were classified according to their diameter:

- 2mm < Ø <10 mm (Medium Root, MR)
- And Ø > 10 mm (Coarse Root, CR)

The two categories of root have been washed, weighted and sampled. In addition to this sampling, a root description was made. This process consist onto the description of the distribution all along the soil profile of roots density and root depth in the pit number 1[1].

Photo 4 : Differentiation of the 2 classes of root

Photo 5 : Root description

e. Estimation of percent cover

The estimation of percent cover has been used for the land use type checking process; it consisted on the evaluation of relative surface coverage of one species in a determined surface.

The percent (%) cover was estimated for the indicator species within a circle of 5m radius (area of 78.54 m^2) in which the inventory of trees with DBH of 5 to 10cm has been conducted. For each site, % cover was determined with a local botanist. The team used a visual guide to estimate the % cover. It was recorded by using an 8 category scale known as the Braun-Blanquet scale.

[1] In ZOI3, there were possibility to do the root description was done in the three soil pits

Tableau 1 : Braun Blanquet scale

Scale	Cover
0	Not present
.T	Trace amount< 1%
1	1-5% cover
2	5-25% cover
3	25-50% cover
4	50-75% cover
5	75-95% cover
6	>95% cover

Source: Braun Blanquet, 1964

2.3.2.2. In degraded land or *tany maty*

For this land use, there were no needs to do inventory because there was no tree (Photo 6) with diameter beyond 5cm. Only biomass sampling, root description and estimation of percent cover were made following the same design sampling used in closed canopy and fallows. The data available in degraded land are the understorey carbon stock, litter and root mat, soil carbon stock, root description and braun blaquet data.

Photo 6 : *Tany maty* or degraded land plot

2.3.3. Activities for soil carbon assessment

2.3.3.1. Soil sampling

The soil sampling was done at the same place as the understorey vegetation sampling (points 1, 2, 3 and 4).

Two methods were applied for the soil sampling. One for bulk density samples and the other for soil carbon sampling.

a. Soil sampling by auger for soil carbon content determination

It was done in the 4 subplots every 10 cm depth for 0 to 100 cm; that means 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, 70-80 cm, 80-90 cm and 90-100 cm depth.

Photo 7 : Soil sampling by auger

b. Soil sampling by cylinder for bulk density determination

The metallic cylinder used for this sampling had a diameter of 8.1cm and a height of 10 cm. It was performed in the soil pits located in the 3 subplots (or points 1, 2 and 3 in figure 1), according to the depths: 0-10 cm, 10-20 cm, 20-30 cm, 50-60 cm and 80-90 cm. These samples were used for the bulk density measurement after later lab works. Some samples, to estimate the moisture were also taken in addition to these samples to the cylinder.

Photo 8 : Soil sampling by cylinder

2.3.3.2. Soil profile description

This activity was conducted in the subplot 1 soil pit located in the center of each plot, with a depth of 1.30 m. Its objectives was to determine and describe the different soil horizons, know their colors (by using the soil color of Munsell), their textures and structures and root depth. The abundance of roots and porosity were also observed and recorded.

Photo 9 : Description of soil profile

2.3.4. Other collected data

Except data about biomass and soil, there were other data that have been collected like site characteristics. It included GPS coordinates, Slope and deforestation history. The last one was known after interviews with local land owners.

2.4. After the field work

2.4.1. Data entry and archiving

To save data collected in the field, the following tasks were done.

- Field forms filled during the field work were scanned and stored in the project numeric archive
- Collected data are entered in excel file
- Photos were renamed and classified and stored within the project share space in Bangor University data center.
- Collected data were arranged in data series and sent to the EIDC data repository as ESPA WP4 data for long term storage and valorization.

2.4.2. Samples management and storage

Samples collected in the field were transmitted to the LRI laboratory for analysis. Once they arrived into the laboratory, they were stored at room temperature and air dried. Simultaneously, the correlation between collected and delivered samples is verified. Then they receive lab number defined by the soil provenance, and lab entry number. A list with n° field, n° lab and worksheets corresponding to the requested tests is established before the samples were sent for laboratory analysis.

3. Laboratory analysis

3.1. Biomass analysis

Biomass samples collected in the field were first air dried then oven dried at the laboratory in order to determine the dry biomass. For that, the samples were dried in an oven stove at 75°C and weighted frequently with precision scale until the stabilization of the weight. Generally, the process took around 48 hours but it depends on the size of the sample (if it was too big, the drying takes more time; up to one week). A part from that, there were also all works about wood specific gravity WSG determination (detailed within Manual n° 4).

3.2. Soil analysis

Soil sample were firstly prepared as in section 3.4.1, they were labeled and sent to the sample preparation room, where they undergo the following preparations:

- air drying at least 3 days
- sieving through a sieve with 2 mm size
- sieved sample collected in a plastic bag and weighed again
- coarse soil (rocks) and coarse root fraction > 2 mm were also recovered in another bag and weighed
- for classic soil analysis were done on the soil sample, it was ground to 200 microns

- **Soil drying to determine the moisture content**

To determine the moisture of the soil samples, they were dried in stoves at 105°C during 48 hours. After, they are weighted and the moisture was obtained by the difference between the weight before and after the drying.

Photo 10 : Sample air drying inside the LRI greenhouse

- **Walkley & Black method**

The Walkley-Black titration method is one of the classical methods for rapid analysis of soil organic carbon. The organic material is oxidized without external heating by a sulfuric potassium dichromate solution. It is considered that the heat of solution of H_2SO_4 (120 ° C) is sufficient to oxidize 77% of carbon. The excess dichromate is determined by Mohr's salt $(NH_4)_2 Fe (SO_4)_2$, 6 H_2O. The data on soil C content obtained using these chemical analyses served as calibration reference for further soil analysis using spectrometry.

- **Mid Infra Red Spectroscopy (MIRS) soil analysis**

The MIRS approach appeared to be a relatively recent soil analysis method. The principle is based on the absorption of infrared radiation by the organic matter. This absorption is related to the chemical composition of the samples. The measure of the light intensity absorbed at each wavelength leads to a characteristic spectrum of the studied product. Subsequently, based on reference data from the Walkley & Black method, MIRS could predict the soil C content by use of each soil spectra.

- **Carbon stable isotope analysis using $\delta^{13}C$**

A few soil samples were selected according to land use type and carbon content along the soil profiles in the whole four ZOIs. These samples were sent to the *Laboratoire de Biochimie et Physiologie Moléculaire des Plantes (LBMP in Montpellier, France)* for C stable isotope analysis. The values and distribution of the $\boldsymbol{\delta^{13}C}$ within each soil profile was determined. The corresponding dataset was also archived at the EIDC datacentre and will be used for land use type determination and carbon dynamic survey along the soil profile and across the different land uses.

In sum, different types of analysis were used for the quantification of the soil organic carbon. Details of this soil analysis process are presented in Manual n°3.

4. Data handling

Data collected in the field and from the laboratory were used for data mining with the objective of carbon stock calculation in all pools for all sites.

4.1. For aboveground biomass

Analysis of data from forest inventory was done by the study of the Braun Blanquet and floristic structure (richness and diversity) and the study of the spatial structure which or the abundance of each biomass element.

This first step will be the basis of all biomass direct measurement presented in the Manual 2 which focuses on below ground survey. Anyway, biomass has been studied along the different levels or strata inside the plot:

- At tree level, allometry equations have been used to assess biomass and C stock (*kg.tree*$^{-1}$). This step used either indirectly with different allometry equations developed by several authors (Chave *et al.*, 2005; Vielledent *et al.*, 2012; Chave *et al*, 2014) or directly with empiric allometry equations based on direct tree measurements. To be noted that allometry equations correspond to regression that relates the amount of biomass of a compartment with an easily measurable dendrometric variable (Razakamanarivo, 2009).

The existing following allometry equations were used for the biomass estimation:

*CHAVE 2005: AGB = Exp (-2,977+ln (WSG*DBH*DBH*H))* *(Equation 1)*

*MADA I.1: AGB= Exp (-1,948+ (1,969*ln (DBH))+(0,66*ln(H))+(0,828*ln(WSG))* *(Equation 2)*

MADA II.1: AGB= Exp ((-1,159+2,297 ln (DBH) +0,830ln (WSG)) *(Equation 3)*

CHAVE 2014: AGB= 0.0673 (WSG*DBH*DBH*H) 0.976* *(Equation 4)*

with:

- AGB: Above ground biomass (dry weight in *kg.tree*$^{-1}$)
- Ln: Neperian Logarithm
- DBH: Diameter at Breast Height (1.3m above ground, in *cm*)
- H : height (in *cm*)
- WSG : Wood Specific Gravity (no unit, obtained from literature)

After estimating the biomass per tree, biomass per plot *(Mg.ha*$^{-1}$) was evaluated by applying allometry equations on data of each tree recorded during from forest inventory (sum of biomass densities of all trees present at the plot according to its inventoried area, scaled up to 1 hectare afterwards). Carbon stock at tree or plot level was obtained by multiplying the biomass density per 0.5 (Brown, 2002).

- Floristic analyses and sampling conducted to the lower strata biomass assessment, such as understorey vegetation.

4.2. For litter, understorey vegetation and root

Dry weights of biomass samples on these strata (which were obtained through oven-dry) were reported on the total fresh weight recorded in the field in the measured area. Total biomass for plot level was then calculated in upscaling these biomass densities to 1 hectare.

The same coefficient of 0.5 (Brown, 2002) was used to get C stock at the sampled area and plot levels.

4.3. For dead wood

a. Lying dead wood

The biomass of lying dead wood was obtained by using the formula (Pearson & Brown, 2005)

Biomass (kg tree^{-1}) = volume x density

With:

density: density of each piece of dead wood according to its category (Sound (S), Intermediate (I) and Rotten (R)

Volume (m^3) = $\pi^2 * ((d_1^2 + d_2^2 + \ldots + d_n^2)/8 * L)$;

Within which d= diameter of intersecting pieces of dead wood (*cm*); d_i = diameter (*cm*) of the lying dead wood intercepting the transect and L = length of the transect (100 m)

Biomass and C stock of lying deadwood at plot level was obtained by summing Biomass and C density per deadwood tree.

b. Standing dead wood

The biomass of standing dead wood was obtained by using the formula (Walker et al, 2012)

Biomass (kg tree^{-1}) = volume x density

density: density of each piece of dead wood according to its category (Sound (S), Intermediate (I) and Rotten (R)

Volume = $1/3 * \pi * H * (r_1^2 + r_2^2 + r_1 * r_2)$ within which H= total height (*m*), r_1= radius (*cm*) at the base and r_2= radius (*cm*) at the top

Biomass and C stock of lying deadwood at plot level was obtained by summing Biomass and C density per deadwood tree.

The sum of all C stocks in all these aboveground pools led to the total aboveground *(Mg ha^{-1})* per plot.

4.4. For soil

Bulk density calculations were done using the following equation:

BD (g.cm^{-3}) = Dry mass (g) / Soil volume (cm^{-3}) *(Equation 5)*

After the acquisition of the organic carbon content, the bulk density and the percentage of coarse elements, organic carbon stock was calculated using the equation 6.

The Soil Organic Carbon SOC (*Mg.ha^{-1}*) was calculated for each soil layer using the equation defined by Parras-Alcàntara *et al.* (2013):

$$SOC = \sum (BD_i * C_i * (1 - CF_i) * t_i * 0.1) \quad \text{(Equation 6)}$$

Where SOC (*Mg.ha*$^{-1}$) is the C stock in soil to 30 or 100 cm depth; BD_i (*g.cm*$^{-3}$) is the bulk density in soil layer at the depth i (0 to 30 cm or 0 to 100 cm); C_i (*g.kg-1* of soil) is the soil carbon content for the layer at depth i; and CF_i (%) is the percentage of coarse fraction > 2 mm in the soil profile; t_i (*cm*) is the thickness of the corresponding layer.

To consider for soil differences in terms of density from different land use types, the *equivalent mass method* was also considered to estimate the SOC stock. The two depth of soil, 0-30 cm (SOC30) and 0-100cm (SOC100) were considered because of their carbon stock importance and their sensibility to land management.

5. Data publication

Obtained data were published or in process for publication. Main scientific papers (a part from oral and poster presentations in different international and national events) could be cited as following:

- Ramifehiarivo N., Brossard M., Grinand C., Andriamananjara A., Razafimbelo T., Rasolohery A., Razafimahatratra H., Seyler F., Ranaivoson N., Rabenarivo M., Albrecht A., Razafindrabe F., Razakamanarivo H.. (2016). Mapping soil organic carbon on a national scale: towards an improved and updated map of Madagascar. Geoderma Regional ISSN 2352-094, In press

- Ramifehiarivo N., Brossard M., Razakamanarivo H.. (2016). Challenges in establishing digital maps of soil organic carbon in Madagascar. Pedometron 39, 26-31

- Andriamananjara A., Hewson J., Razakamanarivo H., Andrisoa R.H., Ranaivoson N., Ramboatiana N., Razafindrakoto M., Ramifehiarivo N., Razafimanantsoa M.P., Rabeharisoa L., Ramananantoandro T., Rasolohery A., Rabetokotany N., Razafimbelo T.. (2016). Impact of land use changes on aboveground and soil carbon stocks in a humid tropical forest of Madagascar. Agriculture, Ecosystems and Environment. 233: 1–15

- Ranaivoson N., Andriamananjara A., Razafimbelo T., Hewson J., Rasolohery A., Andrisoa R. H., Razafindrakoto M., Ramifehiarivo N., Razafimanantsoa M. P., Rabetokotany N., Razakamanarivo H. (2016). Toward a better understanding of soil organic carbon variability in eastern humid region of Madagascar. *Under review in European Journal of Soil Science.*

- Razafindrakoto M., Andriamananjara A., Razafimbelo T., Hewson J., Andrisoa R.H., Jones J., Ilja van Meerveld H.J., Cameron A., Ranaivoson N., Ramifehiarivo N., Ramboatiana N., Razafinarivo R.N.G., Ramananantoandro T., Rasolohery A., Razafimanantsoa M.P., Jourdan C., Saint-André L., Rajoelison G., Razakamanarivo H. (2016). Organic carbon stocks in all pools following land cover change in rainforest of Madagascar. In: Munoz M.A., Zornoza R., *Editors. Soil Management and Climate Change: Effects on Organic Carbon, Nitrogen Dynamics, and Greenhouse Gas Emissions, Elsevier. Under review.*

6. References

1. Braun-Blanquet, J. 1964. Pflanzensociologie: Grundzuge der Vegetationskunde.3Te aufl. Springer-Verlag, Wein. 865 pp.
2. Brown, S. 2002. Measuring carbon in forests: current status and future challenges. *Environment and Pollution* 116, 363-372.
3. IPCC 2003, Good Practice Guidance for LULUCF. Institute for global environmental strategies (IGES). Hayama, Japan. ISBN 4-88788-003-0.
4. IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Institute for global environmental strategies (IGES). Hayama, Japan. ISBN 92-9169-220-4.
5. Razakamanarivo, H. 2009. Potentialités de stockage du carbone dans le système plante-sol des plantations d'eucalyptus des hautes terres malgaches. Ecole Supérieure des Sciences Agronomiques. Thèse en co-tutelle : Université Montpellier 2 et Université d'Antananarivo. Doctorat en science du sol. 193 p.
6. Styger E., Rakotondramasy H., Pfeffer M., Fernandes E., Bates D. 2007. Influence of slash and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. *Agriculture, Ecosystems Environment* 119, 257–269. doi:10.1016/j.agee.2006.07.012
7. Pearson T., Brown S., 2005. Guide de Mesure et de Suivi du Carbone dans les Forêts et Prairies Herbeuses. Winrock International. 39p
8. Walker S., Pearson T., Casarim F., Harris N., Petrova S., Grais A., Swails E., Netzer M., Goslee K. and Brown S. 2012. Standard Operating Procedures for Terrestrial Carbon Measurement. Winrock International. 96p.
9. Parras-Alcàntara, L., Martin-Carrillo, M, Lozano-Garcia, B. 2013. Impacts of land use change in soil carbon and nitrogen in a Mediterranean agricultural area (Southern Spain). Solid Earth.4: 167–177.

APPENDIX

Parameter collected in the field

For tree inventory

Local name, DBH and height of trees inside circles of 5m, 10m and 20m radius

Local name and number of sapling

Categories (Solid, Intermediary and rotten), Diameter in the base, DBH, Diameter at the top and Height of standing dead wood.

Diameter of lying dead wood along a transect of 100m

Biomass sampling

Thickness, weight of total biomass and weight of the samples for litter, root mat in the 4 subplots

Thickness, weight of total biomass and weight of the samples for sapling

Local name of species inside quadrat, weight of total biomass and weight of the samples of understorey vegetation

Soil sampling

Weight of soil samples

Description of the soil profile

Name of the horizons

Depth, color, texture, structure, abundance of roots, porosity, particularity of each horizon

Scheme of the soil profile

Root description

Distance from the pit, local name, number, diameter and height of the neighbor trees

Weight of all medium and coarse roots inside pit of $1m^3$

Weight of samples of medium and coarse roots

Abundance of roots (coarse and medium) in 5 layers (0-10cm, 10-20cm, 20-30cm, 50-60cm and 80-90cm)

Scheme of the profile

Indicator species

Percentage cover of indicator species and the Braun Blanquet scale