

# PARTICIPATORY FOREST CARBON MEASUREMENT

## MANUALS FOR TECHNICAL STAFF



2010

## Abbreviation

AGB: Above-ground biomass

BGB: Below-ground biomass

DBH: Diameter at breast height

FAO: Food Agriculture Organization

GIS: Geographic Information System

GPS: Global Positioning System

IPCC: Intergovernmental Panel on Climate Change

PCM: Participatory Carbon Measurement

REDD: Reducing Emissions from Deforestation and Forest Degradation

SOC: Soil Organic Carbon

UN- REDD: United Nations – REDD

## List of Tables

Table 1: Statistics of forest blocks in homogeneous status.....	16
Table 2: Identify management objective for the forest block .....	16
Table 3: Plot radius for carbon inventory plots .....	32

## List of Charts

Figure 1: Process of data collection at the local level for monitoring carbon stocks.....	7
Figure 2: Forest status map referenced to Vn2000 in Village 14, Hòa Bắc – Hòa Nam commune (Hòa Bắc – Hòa Nam protective forest management board, Di Linh district).....	13
Figure 3: Map located random sample plots belong to forest startum in Village 14, Hòa Bắc – Hòa Nam commune (Hòa Bắc – Hòa Nam protective forest management board, Di Linh district).....	27
Figure 4: Sampling design of circular plot with 1000m <sup>2</sup> of plot size .....	32
Figure 5: Location of 4 sub-plots 50x50 cm for measuring biomass of LHG and soil .....	35
Figure 6: Measuring DBH tree (Source: Bhishma et al, 2010) .....	38

## TABLE OF CONTENTS

<b>Abbreviation</b>	<b>2</b>
<b>List of Tables</b>	<b>3</b>
<b>List of Charts</b>	<b>3</b>
<b>Part I : Introduction on the Manuals</b>	<b>5</b>
1.1 Objective of the forest biomass and carbon measurement .....	5
1.2 Objective of manuals and target groups who use .....	5
1.3 Structure of the manuals .....	6
1.4 Principles of measurement of forest biomass for predicting carbon stock at the local level .....	7
1.4.1. Approach methods with the participation of communities, local people, and stakeholders are applied in the process of forest carbon measurements at the grassroots level	7
1.4.2. Principles of forest carbon inventory at the local level	9
<b>Part II: Procedure of Participatory Carbon Measurement at local level</b>	<b>10</b>
Step 1: Delineation of Boundaries, Stratification of the forest areas, and relevant issues of forest status block management .....	10
Step 2: Pilot inventory for variation estimation and identification of number of permanent sample plots. Design the random sample plots system .....	17
Step 3: Permanent Pilot Measurement.....	30
<b>References</b>	<b>42</b>
<b>Part III : Annex</b>	<b>43</b>
Annex 1: Tools, equipment needed for PCM.....	43
Annex 2: Guide to set up GPS for Vn2000 Coordination Projection.....	45
Annex 3: Slope correction for the radius of the circle .....	47
Annex 4: Data Sheet forms for pilot inventory .....	48

## Part I : Introduction on the Manuals

### 1.1 Objective of the forest biomass and carbon measurement

Program "Reducing emissions from Deforestation and Forest Degradation - REDD" is being launched in Vietnam as well as around the world. The program aims at reducing deforestation which is cause of loss of biodiversity, reduction of the protective function of forests, and cause of gas emissions including CO<sub>2</sub>. Reduction of CO<sub>2</sub> emissions from forest degradation and deforestation will be compensated through the protection and sustainable forest management. This will help to store carbon well as to increas CO<sub>2</sub> absorpted by forests thank to biomass growth.

For selling carbon credits forest owners, community, and local people should have database of information on forest resources, biomass, stored carbon, and CO<sub>2</sub> absorpted by their forests over time. Therefore it is necessary to build a method of inventory and measurement. The method should be simple and suitable for community, forest owners and other stakeholders so that they can carry out by themself along with support of foresters from forestry institutions such as FIPI. However the establishment of carbon credits have to be accepted by relevant international organizations and volunteer organizations which will buy carbon credits.

Approaches of biomass and carbon stock inventory and monitoring in national REDD programs will be divided into two main levels: i) inventory in local by forest management units, forest owners, households, and community is considered as the first; and ii) the another is synthesizing data on error calculation, estimates of biomass, changes in carbon stocks for each ecological zone, forest type and status; this level is conducted at provincial or national level.

This manual refers to the technical issues to survey at local level, including of monitoring changes in forested areas, and setting up sample plots. Collection of baseline data aims to provide data that is able to convert to cabin stock at the second level. This level requests participation of local people and forest owners. Therefore, it should be more simple for them to regularly inventory and monitor further.

### 1.2 Objective of manuals and target groups who use

#### Objective of the manuals:

- ◆ Providing methods and skills to local foresters who can support communities and forest owners in surveying forest resources and forest biomass

- ◆ Providing the relevant techniques for surveying biomass in the field in order to sufficiently provide reliable data information for periodical estimating carbon stocks.

### **Target groups using the manuals:**

Agencies, organizations, and individuals that are related to forestry management, forest resources management are the target groups using this guidelines. They will facilitate processes of REDD implementation. They are including:

- ◆ Government managers related to forestry at different levels to monitor implementation progress of REDD projects and to make decisions supporting the activities to be taken place.
- ◆ Forestry staffs of the Department of Agriculture and Rural Development, Forest Protection Department, Forestry Department and relevant departments at district and commune such as extension, ranger, foresters in forestry company officials, commune forestry board, extension in commune, and so on.

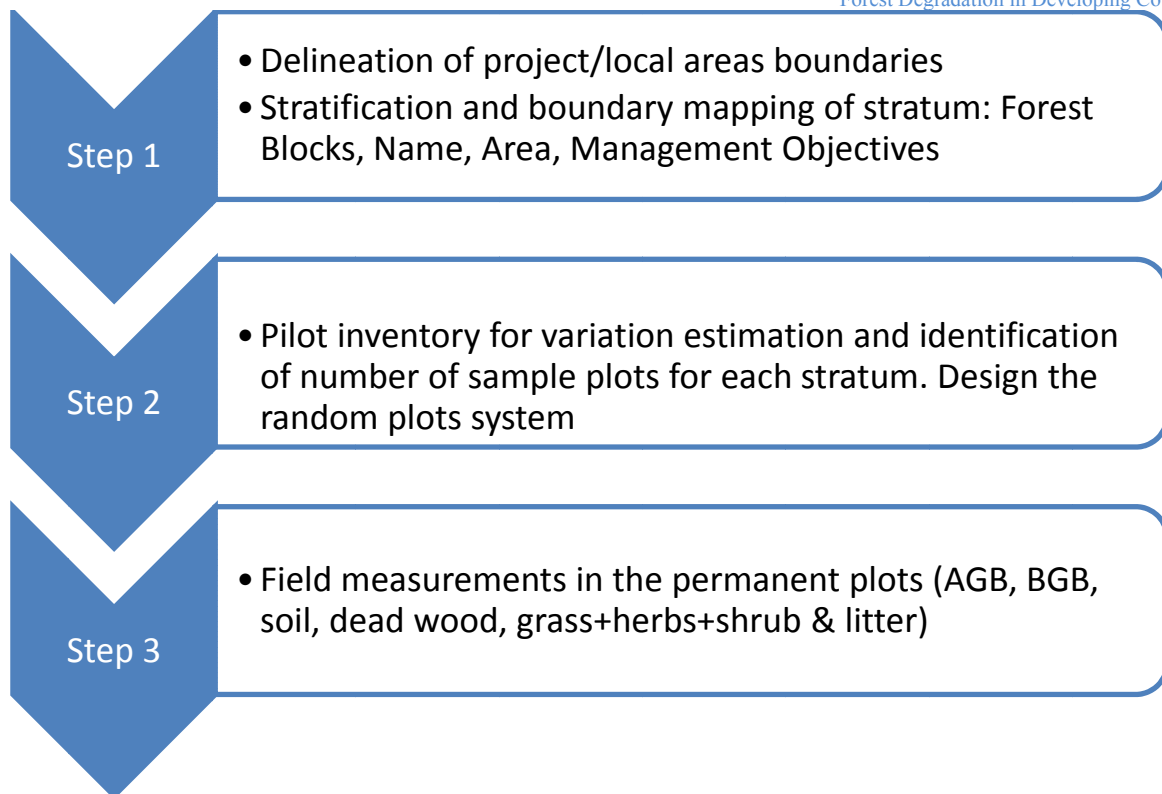
This document can also be used for teaching and training process of implementing REDD at universities, forestry colleges, and technical staffs who promote this program at the local levels in further.

### **1.3 Structure of the manuals**

The methodology and procedures to be used to estimate carbon stocks and their changes over time in forests are simple step-by-step procedures using standard carbon inventory principles and techniques (Bhishma et al, 2010).

The procedures used emphasize the training, capacity building of forest technicians and local resource persons. Procedures are based on data collection and analysis of biomass and carbon accumulating in the above-ground biomass; below-ground biomass, shrubs, herbs, litter, dead wood and soil carbon of forests using verifiable state-of-the-art methods.

Accordingly, forest carbon is calculated with participation of community (PCM). This procedure provides only basic data such as area changes of forest status, forest owners, households. Additionally, data of simple calculation of carbon for monitoring forest carbon changes in the sinks is involved.



*Figure 1: Process of data collection at the local level for monitoring carbon stocks*

## 1.4 Principles of measurement of forest biomass for predicting carbon stock at the local level

### 1.4.1. Approach methods with the participation of communities, local people, and stakeholders are applied in the process of forest carbon measurements at the grassroots level

#### **Participation of local people and capacity building of communities living near forests in forest management and forest carbon monitoring is encouraged:**

Attraction of the participation of local people at the villages in the investigation and evaluation process of carbon stocks will help the community in management of their forest resources and to better understand the environmental values of forests in the global climate changes. Besides they will be helped to regularly monitor and report on forest area and carbon stocks as the requirements of REDD project in participating REDD implementation. Since professional agencies and organizations of inventory are not be sufficient resources, the participation of household and community who have being managed the forest will be a basic for providing regularly updated data and cost effectiveness.

The participation of the local people and the community means that everyone is involved in all activities of management and assessment of forest resources and



carbon stored. This does not mean the local people have to do everything. In forest management and protection of households, communities and REDD projects, the local people will not be able to formulate and implement forest management plans as well as determine their carbon credits without the assistance of technical staff. On the other hand, only the technical staff and inventory agencies could not have sufficient resources to survey and monitor natural resources and forest carbon. Thus, both the community and technical staff are all important in this process. They all must be linked and joined together.

Through the process of inventory and monitoring of forest resources and forest carbon measurements, community and local people capacity will be improved in the management of forest resources as well as helped to better understand the environmental values of forests in global climate change context.

### **The role of technicians**

Technical staff will promote and support community, local people, and forest owners during the monitoring of forest resource changes and carbon measurements. Additionally, they will provide necessary information on policies, new legislation, guidance of silvicultural techniques, and market trading carbon credits for the community and forest owners.

The mission of the technicians is to establish a communication method to generate mutual trust, share information, learn experiences and cooperate among community members, forest owners and outsiders. Consequently, facilitators should be well equipped with the principles of training for elder people, participatory approaches, and facilitation skills in rural development.

### **The role of members in community, household, and forest owners who manage and protect the forest and participate REDD**

Communities, households, and forest owners should be considered as the people who have active role in the decisions of forest management and protection process, and REDD project implementation, of which each group of community members, forest owners is the specific role:

- ◆ The community forest management board, the autonomous board of villages, boards of protective forest, and forestry companies are responsible for operating the monitoring of forest resources, and determining the amount of carbon stored in the forests which are managed by themselves.
- ◆ Household representative and community members participate in the assessment of forest resources, forest management planning as well as determination of the carbon value of their forest plots.



## 1.4.2. Principles of forest carbon inventory at the local level

### Simple Method and Tools

In the context of the implementation of REDD in Vietnam, forest inventory methods, carbon storage estimate must be simple so that communities, households, and forest owners can implement. Other research institutions, management agencies, and technical forestry staff should provide input information for the forest owners and communities such as forest map based on satellite image interpretation/classification, number of necessary sample plots for each area, forest stratum/type. The models of volume estimate, biomass, and forest carbon should be beforehand constructed. Normally, the models are sophisticated but they should be turned into simple tools and straightforward like spreadsheets and diagram which can be easily used by the community and forest owners.

If the method is too complex, forest users will be unable to fully participate in the inventory and analysis of forest resources, and assessment of carbon storage. This may make they are not responsible for the results, therefore, unwilling to comply with plan of long-term forest carbon may happen.

### Appropriate relevance

Process of monitoring and managing data to participate in REDD carbon forests should be based on community resources and forest owners. Therefore apart from simplicity, collection and syntheses of specific and necessary information should be required. These help the monitoring of forest resources, biomass and forest carbon stocks as requirements to be able to participate in REDD.

Ambition, which is to manage too much information and data in complex with insufficient resources of the communities and forest owners for inventory and monitoring or accessing forest/carbon forest, should not be done.

### Cost effectiveness

Less costly and time consumption of communities, forest owners and other stakeholders is a key principle in forest management and implementation of REDD. This will help to long and regularly perform in poor communities with lack of resources. The simple and suitable rule will support for this.

Besides, inventory of forest carbon at local level will help to decrease expenses compared to the inventory carried out by professional forestry agencies.

### Reliability

Forest carbon measurement with participatory of local people, communities, and forest owners will provide a full and long-term database system of forest resources is not only participating REDD but also supporting forest management practices at the local.

In addition it must meet the requirements and criteria of the IPCC and the reliability of the voluntary organizations to be able to sell carbon credits on the market.

## Part II: Procedure of Participatory Carbon Measurement at local level

### Step 1: Delineation of Boundaries, Stratification of the forest areas, and relevant issues of forest status block management

#### Objectives

- ◆ To monitor deforestation and degradation at forest management units.
- ◆ To stratify the forests into homogeneous forest blocks (stratum) in order to easily inventory and assess forest resources, carbon, and to plan forest management.

#### Results

- ◆ Forest of forest owners are assessed boundary and reflected on map
- ◆ The homogeneous forest blocks of status (stratum) is given local name, determined status, area of each block and unified objectives of management

#### Preparation, materials

- Topographic map at scale 1:10,000 – 1:25,000
- Topographic map and forest maps are interpreted/classified at scale 1:10,000 - 1:25,000 using satellite imagery or air photos. In Vietnam, the last status maps is the planning maps of three forest categories produced in 2008. These are projected to VN2000 coordinates and interpreted from SPOT 5 image. In reality, there have changed in forest area so far, thus, a new forest maps provided at the national/regional level is necessary. These maps should be produced based on high resolution satellite images to obtain acceptable accuracy. These maps will be provided to forest owners and community. Pending forest status maps with more accurate are provided, available forest maps can be employed. However, validation of forest area and forest status should be performed.
- GPS for checking boundary of forest boundary of the forest owners
- Transparency paper (enough to cover maps) with pin
- Pen writing table to write on transparency paper and permanent marker to delineate map; alcohol and cotton to wipe the wrong markings.
- Compass to orient the map

#### Implementation

Spatial boundaries of the particular area need to be clearly defined to facilitate accurate measuring, monitoring, accounting, and verification.

Individual forest blocks within the area of forest management unit are mapped jointly by GIS experts, forest technicians, and key farmers of community in a participatory way. High-resolution satellite images printed on a large scale are used to find the different land-covers and natural boundaries and to trace individual forest blocks easily. GPS tracking is carried out to delineate forests in confusing areas, i.e., where the natural boundary cannot be clearly observed. If high-resolution satellite images are unavailable, GPS tracking is the most accurate and efficient alternative method for boundary delineation, even if the process is time consuming.

Each forest block should be traced on to base maps first and then digitized on Mapinfo or ArcGIS software for data input. The data tracking from the GPS receiver is downloaded as a shape file, e.g., DNR Garmin software can be used. The areas of individual forest blocks are estimated after digitizing and editing the data downloaded.

Specific steps:

**i) Divide forest status based on biomass**

Divide into status strata of forest. Once the project area has been delineated, it is essential to collect basic information on features such as land use and land cover as well as data on the vegetation and topography. Data for the project area (e.g., watershed area) can be geo-referenced and traced on to a base map. A base map specifies the details of the project area by indicating the different land-use categories (forest, water bodies, open land, agricultural land, and so forth) and is developed with high-resolution satellite images preferably. Strata are areas distinctly different from each other in forest types, density, and species; and as such they will have different amounts of carbon stored.

To make strata as homogeneous as possible, a forest within the project area is divided into different layers or blocks. Remote-sensing software is used for land-cover classification and forest stratification.

A preliminary field visit is organized within the entire study area to improve the accuracy and precision of the representation. Strata and sub-strata are identified using the expert knowledge of local foresters. The entire project area can be stratified into approximately homogeneous units on the basis of the following parameters:

- ✓ Forest types: Broadleaved evergreen forest, deciduous forest, mixed broadleaved and conifer, mixed woody forest and bamboo, bamboo, dipterocarp forest, pine forest, mangrove forest...
- ✓ Forest status: degradation levels of forest due to human impacts which induce changes of volume and biomass to become rich, medium, poor, and young forest
- ✓ Dominant tree species: Sites containing a dominant tree species are regarded as one-stratum types.
- ✓ Stocking density of trees: Within a dominant type, sites are separated further if they differ substantially in stocking density. Remote-sensing

analysis is used to identify forest areas which differ in tree density. 'Sparse' and 'dense' can, for example, be major types of forests.

- ✓ Age of trees - Sites with distinct age classes are stratified further, as carbon sequestration differs markedly with the age of the stand.
- ✓ Aspect and position of hill slopes: Within a dominant forest type, sites differing in aspect and position on a hill slope are also stratified further because the rate of carbon sequestration varies in relation to these factors. For example, a stand on the south aspect would have far greater productivity than one on the north aspect.
- ✓ Altitude: Forest blocks are selected within altitudinal ranges above mean sea level as vegetation types differ according to altitudinal variation. It is sensible to design elevation strata that represent forests within a 300-500m range in altitude.
- ✓ Physical boundary: The boundary of the forest block is determined on the basis of easily visualized boundaries (i.e., rivers, roads, ridges, and so on).
- ✓ Site quality: Site quality tells us how much timber a forest can potentially produce. The productivity of forest land is defined in terms of the maximum amount of volume that the land can produce over a given amount of time. Site quality is measured as an index related to this timber productivity.

This step should be conducted at provincial, region, and national level in order to provide status map and forest classification for the local people to use and monitor forest area change.

## ii) Check and delineate forest boundaries of owners and forest status

The forest boundaries of owners, forest status, and forest blocks are shown on the forest status map. However, in REDD program, the monitoring of forest area changes should be periodically performed by forest owners, local community who manage and protect the forests. The steps are detailed as following:

- Establish a key group of farmers along with member of management board of community forests, protective forest management board, and forestry companies with about 7-10 people
- Introduce to forest owners and stakeholders on existing status maps or maps produced from high resolution satellite images. These maps and topographic maps should be printed at large scale. Place name and forest boundaries of the forest owners should be introduced.

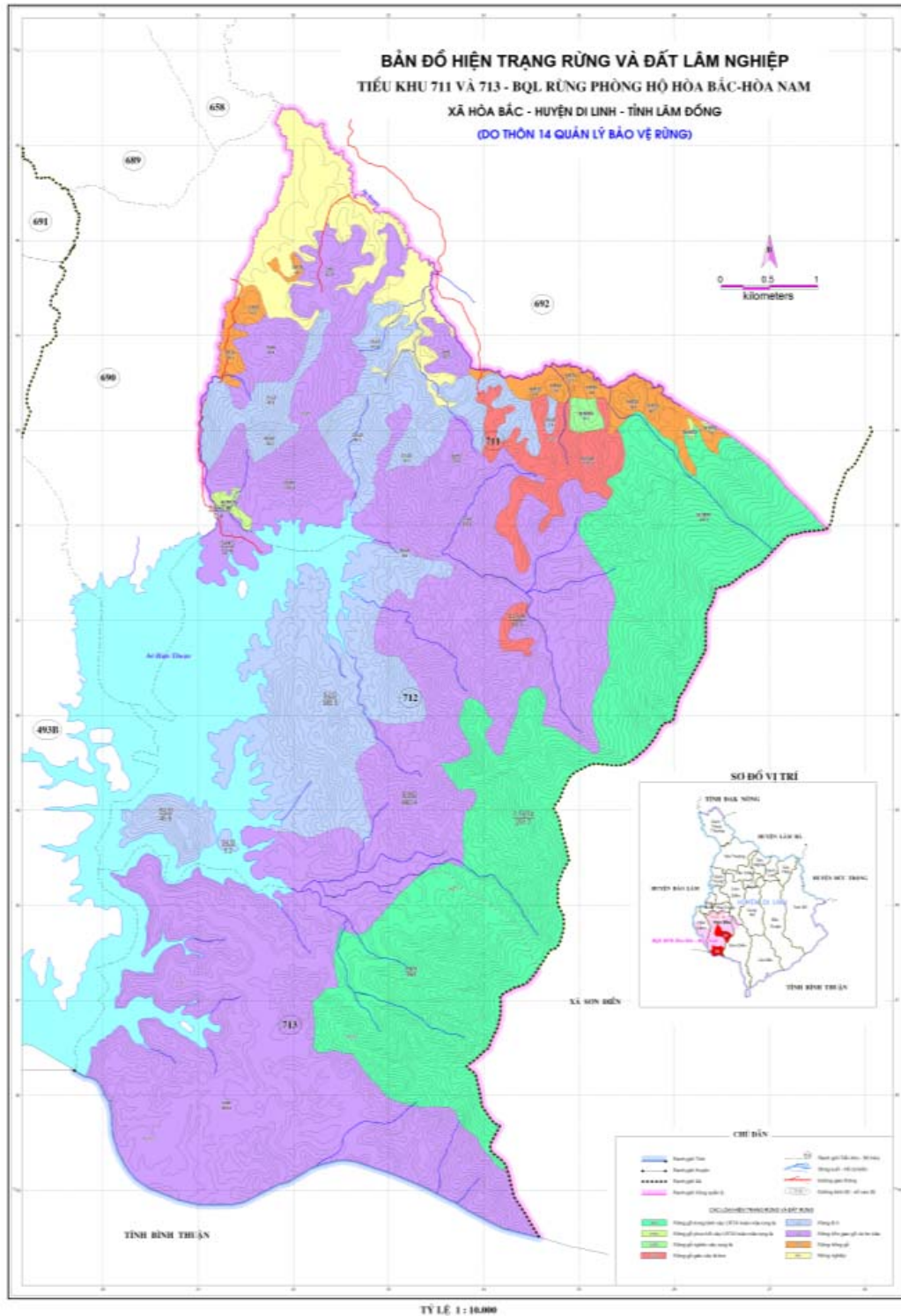


Figure 2: Forest status map referenced to Vn2000 in Village 14, Hòa Bắc – Hòa Nam commune (Hòa Bắc – Hòa Nam protective forest management board, Di Linh district)

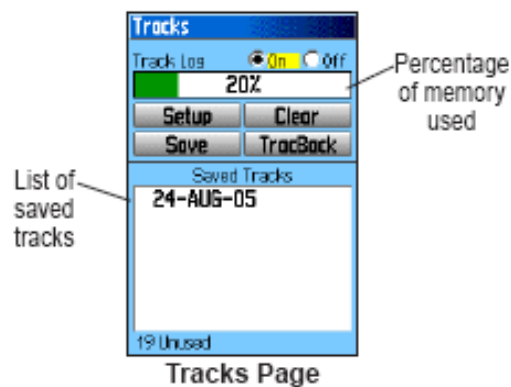


- Map oriented to north is asked. Place cellophane over the map and use pins to temporarily hold on a flat surface. Using the temporary marker pen redrawn roads, stream/river and forest boundaries of forest owners. The forest owner and local people are encouraged to delineate. They also are shown that their errors markings can be removed.
- Forest boundaries of owners are checked then. Forest status is defined based on experience of local people. If the forest boundaries of owners or forest status are different from the forest map, the delineation of the different areas is necessary. In this case, track function in GPS is used while DNR Garmin is employed for transferring data from GPS to GIS map. The forest areas which changed digitized afterward.

The following is introduction of GPSmap 60CSx for use of area delineation



GPSmap 60CSx



Track function of GPS

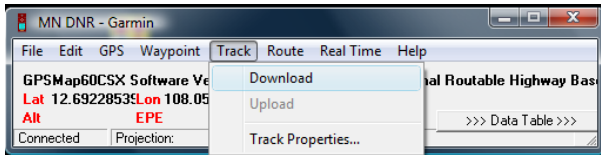
- Press Menu twice to access Tracks and press Enter
- Using Clear button to delete all existing old tracks
- Record the path by travelling with GPS around the area which needs to delineate
- Press Save button to store the result, to name the delineated area



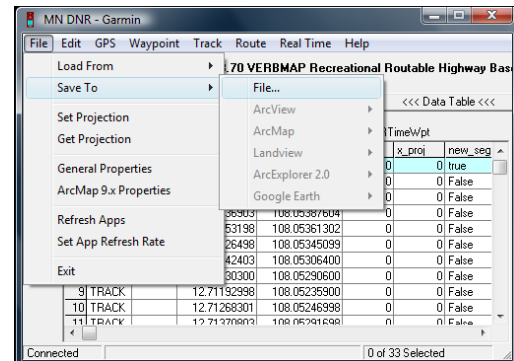
Using **DNR Garmin** to download track data from GPS in GIS map (possible for both coordinates of UTM and Vn2000)

- Connect GPS and GIS through DNR Garmin: GPS/Auto Connect to GPS
- Download Track (Delineate variable areas in GIS): Track/Download

- Save in shape file format to be compatible with GIS software like Mapinfo, ArcGIS: File/Save to (select type of file in \*.shape file). This file is opened in GIS to modify the changes of forest area.



*Download tracks from GPS through DNR*



*Save the tracks in shape file in DNR*

In this step: local people, forest owners delineate changed areas of forest status. They then transfer the data to management level for updating.

**iii) Determine objectives of management, issues in management of forest blocks in the location, and statistic of area of forest blocks**

REDD is not only calculating and monitoring area and sinks of carbon stocks but also showing risks of forest degradation and disappearance along with specific solutions from the local level. Thus prior to inventory and monitor in each forest block, discussion should be done so that the community and forest owners can perceive and co-agreement within the community and owners on solutions in coming time to better manage and protect the forest.

- Based on delineations of forest boundaries and blocks are completed, the forest owners and local people are asked to name their forest blocks on the maps map of the line drawing, line the entire forest and the forest plot; ask people, forest owners to discuss the naming of each lot up on the map. Use of place names familiar to local people as names of rivers, streams, mountains, hills, common local names are encouraged. Since then the forest blocks in management and monitoring areas of carbon stock are calculated.
- On the basis of each block with its name, status, area, position on the map, discussion of key famers and forest owners is taken place to descript and specify their management objectives of the forest blocks such as: for timber?, firewood?, NTFPs?, shoot bamboo?, protection of water? or Sacred Forest? and so forth. The problems, orportunity, and solution for their forest blocks should be discussed.



**Table 1: Statistics of forest blocks in homogeneous status**

No.	Sun-zone	Sub-sub-zone	Block name		Forest status		Area (ha)	Objective management of forest owner
			Technicians	Local	Technicians	Local		
<b>Total</b>	<b>Number of sub-area</b>	<b>Number of sub-subarea</b>	<b>Number of blocks</b>				<b>Area</b>	

**Table 2: Identify management objective for the forest block**

Block name/Block code			
Management objective			
Problem/difficulty			
Opportunity			
Solution			

## **Step 2: Pilot inventory for variation estimation and identification of number of permanent sample plots. Design the random sample plots system**

### **Objectives**

- Set up a system of random sample plots and locate the sample plot for periodic inventory of carbon

### **Results**

- Specify number of necessary sample plots for each forest status within each forest type, and ecological area with allowable error of 5%
- Design random sample plot network for each forest owner, forest management unit on map for inventory and monitoring forest carbon

### **Preparation, materials:**

- Forest status map (interpreted from satellite imageries or forest status map which checked/updated)
- Tools for sample inventory, tree and biomass measurement (as step 3 – permanent sample plot inventory)
- ArcGIS software
- Plotter

### **Implementing**

#### **i) Identification of number of permanent sample plots**

A preliminary inventory then needs to be completed to estimate the variance of the carbon stock in each forest stratum and to provide a basis for calculating the number of permanent plots required for the inventory. It is carried out by laying 10 to 15 plots circular randomly in each forest block and/or stratum within the project boundary. Random selection is important in order to cover the natural variability present within the different forest blocks and /or stratum. The plot size is dependent on tree density (MacDicken 1997).

Accuracy refers to how close a measured quantity is to its actual value, whereas precision expresses how reproducible a measurement is. Ideally, measuring biomass is both accurate and precise. One can imagine, however, a measurement technique that yields very different values every time a measurement is taken, but which provides accurate measurements when large numbers of individual measurements are averaged. Such a technique would be accurate but not precise. In contrast, a

technique that continuously reproduces values within a narrow range but which are far from the actual values will be precise but not accurate. The measured values will be characterized by a systematic bias.

For forest inventories, the reference measurement could be carried out by a team of truly experienced foresters, and the precision of a field crew can be tested by comparing the biomass values from the experienced foresters with that of the field crew. The precision of a forest inventory can be tested by performing multiple forest biomass inventories within the same forest stratum.

In other words, measurements that are 'good enough' are both accurate – meaning that measurements should be identical to measurements carried out by a team of truly experienced foresters – and precise – meaning that the width of the confidence interval around the mean should be sufficiently small. As a rule of thumb, one half of the width of the 95% confidence interval around the mean divided by the mean should be less than 10% within a stratum. If it is greater than that, more samples should be taken within that stratum, or the stratum should be split into two more homogeneous strata. The problem with this approach is that one needs to know the standard deviation of the measurements to know how many samples one needs, and, to know the standard deviation, one has to have carried out the measurements. In practice, it is best to adapt the sampling design and number of samples iteratively. In these guidelines, sample plots are established on a permanent basis to estimate changes in the forest carbon stock, as using permanent plots is more accurate statistically for recording tree growth than resampling the forest blocks or strata every time. Permanent plots that are known to local managers, however, have the potential to be managed differently and may end up with more carbon stock than their surroundings. The existence of this possible bias can be checked by conducting comparative measurements in the surrounding area in subsequent evaluation. Permanent plots are also labelled inconspicuously to minimize the risk.

It is important to note that, by dividing the project area into relatively homogeneous strata, one can increase the accuracy and precision of measuring and estimating carbon. A stratified sampling design decreases the costs of monitoring because it diminishes the number of sampling plots required to acquire a set precision compared to a non-stratified sampling design. A stratified sampling design will allocate a greater number of plots in strata that have greater variability and, therefore, focus the sampling efforts in areas in which more accuracy is needed. Please note that a sampling design in which a single-stratum approach is used for every stratum will yield a greater number of plots than the multiple-strata sampling design described below. This is because a single-stratum sampling design for every stratum will result in the required precision on every stratum. On the other hand, the multiple stratum approach will result in the required precision only in the full area, which is a less stringent requirement.

The following procedure is carried out to calculate the sampling intensity (number of permanent sample plots) required for an above-ground forest biomass inventory.

**Step 1.** Identify the required precision level. A required precision with a value of 10% of the mean, calculated as the half-width of the 95% confidence interval, is frequently used.

**Step 2.** Select the location of the 10-15 preliminary sampling plots per forest stratum – the selection can be either completely random, or can be a random selection from a pre-set rectangular grid of sampling plots. Plots can be laid out or distributed randomly within each stratum using a standard sampling method or software like Hawth's tool of ArcGIS.

**Step 3.** Estimate carbon stock per tree, per plot, per ha, and mean carbon stock per ha for each of the preliminary sampling plots.

**Step 4.** Calculate the standard deviation of carbon [Mg C ha<sup>-1</sup>] for all the plots.

**Step 5.** Calculate the number of plots required using the following statistical for multiple strata:

$$N = \frac{A}{AP}; N_i = \frac{A_i}{AP}$$

where,

- $N$  = maximum possible number of sample plots in the project area [dimensionless];
- $A$  = total size of all strata, e.g. the total project area [ha];
- $AP$  = sample plot size (constant for all strata) [ha];
- $N_i$  = maximum possible number of sample plots in stratum  $i$  [dimensionless];
- $i$  = index for stratum [dimensionless]; and
- $A_i$  = the size of each stratum  $i$  [ha].

$$n = \frac{(\sum_{i=1}^L N_i \cdot s_i)^2}{\frac{N^2 \cdot E^2}{t^2} + (\sum_{i=1}^L N_i \cdot s_i^2)} \quad \text{(ii)}$$

where,

- $n$  = total number of sample plots (total number of sample plots required) in the project area [dimensionless];
- $i$  = project strata number from 1 until  $L$  [dimensionless];
- $L$  = total number of strata [dimensionless];
- $N_i$  = maximum possible number of sample plots in stratum  $i$  [dimensionless];
- $s_i$  = standard deviation for each stratum  $i$  [dimensionless];
- $N$  = maximum possible number of sample plots in the project area [dimensionless];
- $E$  = desired level of precision;
- $t$  = sample statistic from the  $t$ -distribution for the 95% confidence level:  $t$  is usually set at 2 since sample size is unknown [dimensionless]; and
- $s$  = standard deviation for each stratum  $i$  [dimensionless].

$$n_i = n \cdot \frac{N_i \cdot s_i}{\sum_{i=1}^L N_i \cdot s_i}$$

where,

- $n_i$  = number of sample plots for stratum  $i$  [dimensionless];
- $i$  = project strata number from 1 until  $L$  [dimensionless];
- $n$  = total number of sample plots (total number of sample plots required) in the project area [dimensionless];
- $N_i$  = maximum possible number of sample plots in stratum  $i$  [dimensionless];
- $s_i$  = standard deviation for each stratum  $i$  [dimensionless]; and
- $L$  = the total number of strata [dimensionless].

**Step 6.** Visit the field to measure the biomass on the number of sample plots derived in step 5.

**Step 7.** Calculate the true relative half-width of the confidence interval around the mean for each stratum and compare these to the required values of 10%. If the required precision of 10% is not attained, either split or merge the strata or update the number of samples required to get the required precision based on the standard deviation from all the sampling plots.

Repeat steps 5-7 until the required precision is attained or by following the adaptive sampling design as described in Section 2.6. UNFCCC (2009) provides an alternative

method for calculating the number of sample plots for carbon measurement activities.

### **Adaptive sampling design**

Adaptive sampling is a strategy for maximizing the value of biomass inventory samples by continuously adapting the number of samples taken in each forest stratum. Adaptive sampling design works well when sampling individuals are spatially clustered, elusive, or hard to detect. Additionally, adaptive sampling is robust in situations where variability is difficult to estimate before sampling, and it is, therefore, an ideal sampling strategy for forest biomass inventories.

Adaptive sampling contrasts with conventional sampling techniques, such as stratified random sampling, in which all of the sample units are selected prior to the actual inventory. In adaptive sampling, an initial set of sampling units (plots) is selected, either randomly or through a systematic approach, but plot distribution over individual strata is continuously optimized.

Plots are added repeatedly until the desired precision is attained. The basic steps for an adaptive sampling strategy are as follows.

1. Stratify the forest based on elevation classes, forest types, visible stocking (i.e., trees per ha), and aspect. Select 3 to 5 forest strata.
2. Obtain information on variability. When no previous data from biomass inventories are available, the variability of the biomass stock density must be obtained from the literature or from a preliminary survey. When part of the inventory has been carried out already, however, all plots sampled in previous iterations should be used for calculating the number of sample plots required.
3. Use the procedure mentioned in these guidelines to obtain the number of plots required per stratum.
4. In one iteration step, measure about 25% of the total plots required by the sampling design, evenly distributed over each stratum.
5. Estimate biomass stock, variability, and precision for the entire forest and for each individual stratum. Sampling precision can be obtained using the following formula:

$$\text{Precision level} = \frac{SE_{ST} t_{0.95, n-1}}{X_{ST}} \%$$

where,  $SE_{ST}$  is the standard error of the stratified mean,  $X_{ST}$  is the stratified mean, and  $n$  is the number of sample plots.

6. If the desired precision is met (10%), sampling can be finalized
7. If the precision is relatively large in at least one stratum (e.g., precisions greater than 30%), revision of the stratification by splitting forest strata into more homogeneous sub-strata, or merging smaller strata to attain more samples within a stratum should be considered. Re-calculate the biomass stock, variability, and precision for the new strata as explained in step 4.
8. Re-calculate the plots required based on the empirically measured precision levels and the newest stratification following the procedures mentioned in these guidelines.

Repeat steps 2 through 6 until the desired precision over every stratum is attained. It is possible that steps 7 and 8 may result in either more, less, or the same number of plots allocated for one or more strata.

Currently, the rate of sampling is 2% out of the whole forest area in forest inventories in Vietnam. This rate has not reflected the bias (desired level of precision is 10%) and no standard deviation on biomass / carbon for individual forest status in specific area. Hence in every area of individual forest owners, foresters should sample for trial (preliminary survey) to calculate the number of sample plots for each forest status and to check the division of forest status with number of plots sampled at the 95.0% confidence level or less (desired level of precision is 10%) or at the 5% significance level. On that basis, information on the division of forest status, the number of necessary sample plots should be provided to forest owners and community, so that they can design random sample plots network which is permanent plots in the field.

## ii) Design random sample plots system on the stratum forest map

To ensure objectivity in the monitoring of carbon storage, sample plots in each forest status should be randomly arranged on a map with coordinates of every known plot. They are considered as a basis for determining positions in the field where forest tree and biomass are measured to estimate and monitor changes of forest carbon. The random sample plots designed for each area should be carried out in function of “create random point” in ArcGIS.

The number of permanent sample plots is dependent on the size and types of forest stratum. Plots used must be of the same size as those used in the pilot survey. A base map is used to produce locations of random sample plots. Plots are laid out or



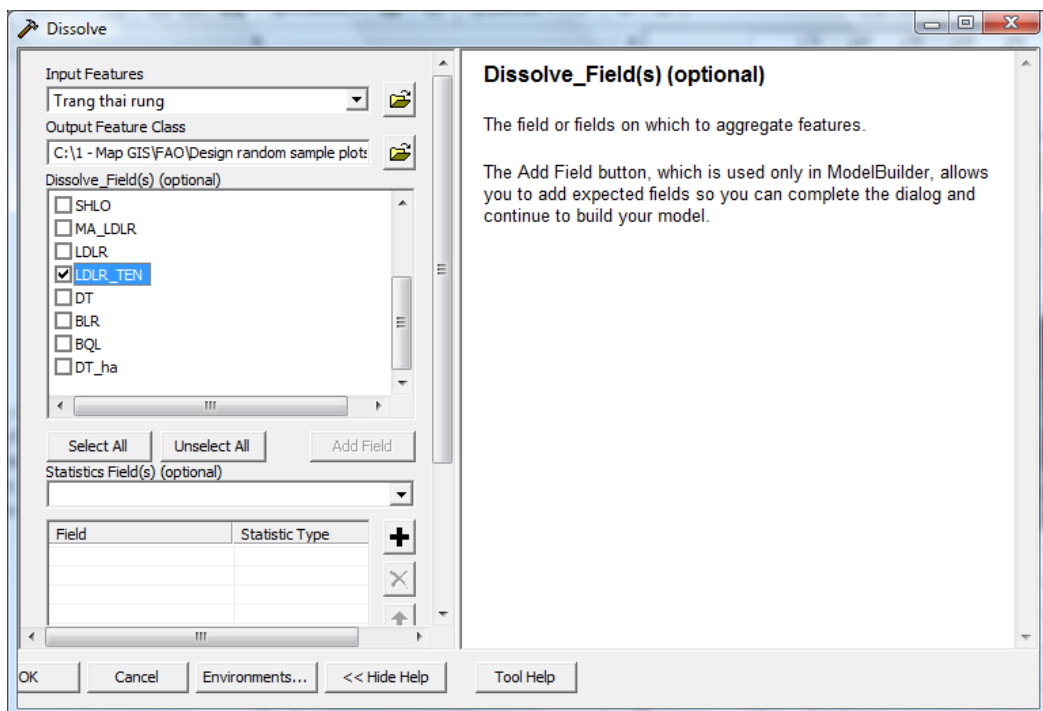
distributed randomly within each stratum using standard sampling methods or software (e.g., Hawth's tool of Arc GIS). Map showing the distribution of permanent plots of each plot are also generated.

**Including following steps:**

**a) Combine forest status blocks into general block for random arrangement of sample plots**

Form homogeneous blocks of state. The same forest status in various polygons is combined to define the location of the sample plots of each status block. Using function of "Dissolve" in ArcGIS for combining

- Select data layer which contains polygons of forest status blocks
- Use Dissolve to combine all polygons having the same status into one: Dissolve; Input Features: Select data layer containing forest status (Trang thai rung); Dissolve Field: Select field of forest status (LDLR\_TEN)



In case of sample plot arrangement for household or status block, layers of status blocks or households are persevered.

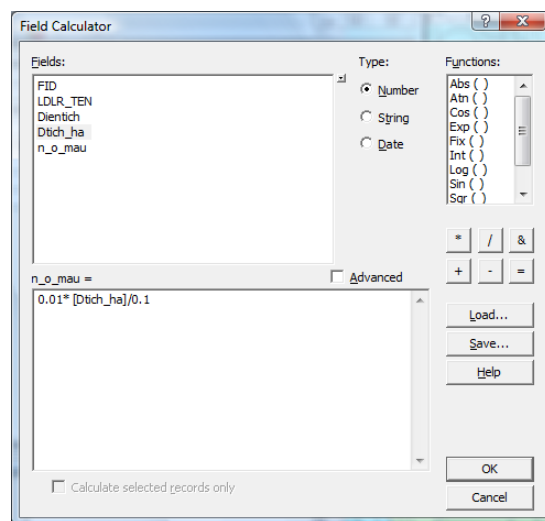
**b) Design random sample plots:**

From results of Dissolve of the status blocks, a random sample network is set up.

- A field of the number of sample plots of each blocks is formed. Number sample plots according to the number of samples for status block of each forest type and ecological zone are calculated as the following equation:

$$n_i = n \cdot \frac{Ni \cdot Si}{\sum_{i=1}^L Ni \cdot Si}$$

Additionally, there are cases that the sample plots are determined by sample withdrawal rate in percent by area. In this example, the rate of sampling is 1% of the area of forest status. The area of sample plot is of 0.1ha. Thence number of sample plot for each block is calculated:  $n_i = 1\% \times \text{area of status block} / \text{Sample plot area (0.1ha)}$ . Calculation function for field is used to define number of sample plots  $n_i$  for each status block.

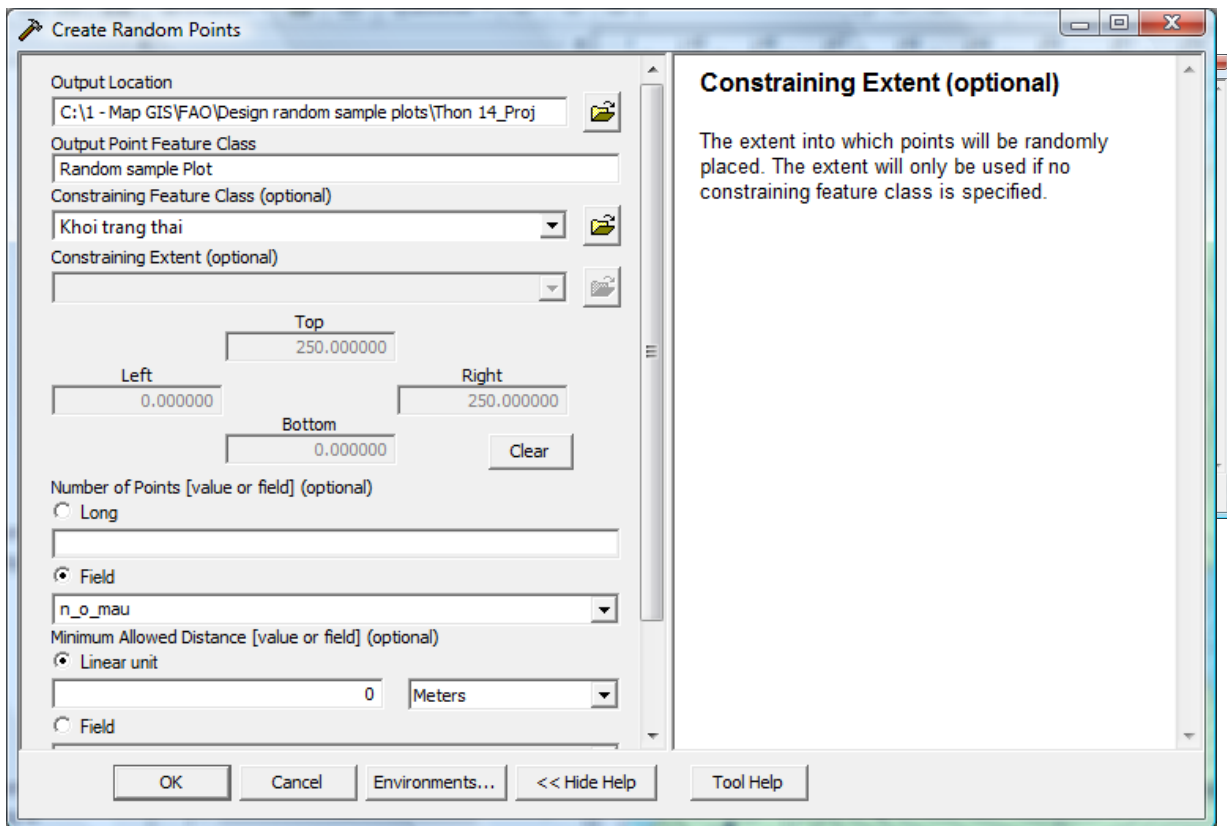


Attributes of Khoi trang thai

FID	Shape *	LDLR_TEN	Dientich	Dtich_ha	n_o_mau
0	Polygon	Nong nghiep	1984410	198.44	0
1	Polygon	Rung go giao cay la kim	1215370	121.54	12
2	Polygon	Rung go phuc hoi cay LRTX hoac nua rung la	95593.797	9.56	1
3	Polygon	Rung go sau khai thac kiet cay rung la	110429	11.04	1
4	Polygon	Rung go trung binh cay LRTX hoac nua rung la	10776900	1077.69	108
5	Polygon	Rung hon giao go va tre nua	20095500	2009.55	201
6	Polygon	Rung lo o	6898300	689.83	69
7	Polygon	Rung trong go	1035610	103.56	10

Record: 2 Show: All Selected Records (0 out of 8 Selected) Options

Set system of random sample plot according to the number of plots for each block status which is identified in ArcGIS: Create Random Points: Number of Points. Select field and select data field to determine number of plots for each block (if Long option is specified, each status will have the same number of randomly placed plots. This is rare in reality since number of sample plots depend on area, standard deviation and its variation). Minimum Allowed Distance: The smallest distance allowed between any two random placed plots. The result is a network of plots on maps with number of random plot in blocks determined.



- Assign coordinates for the location box and switch to a random sample GPS:

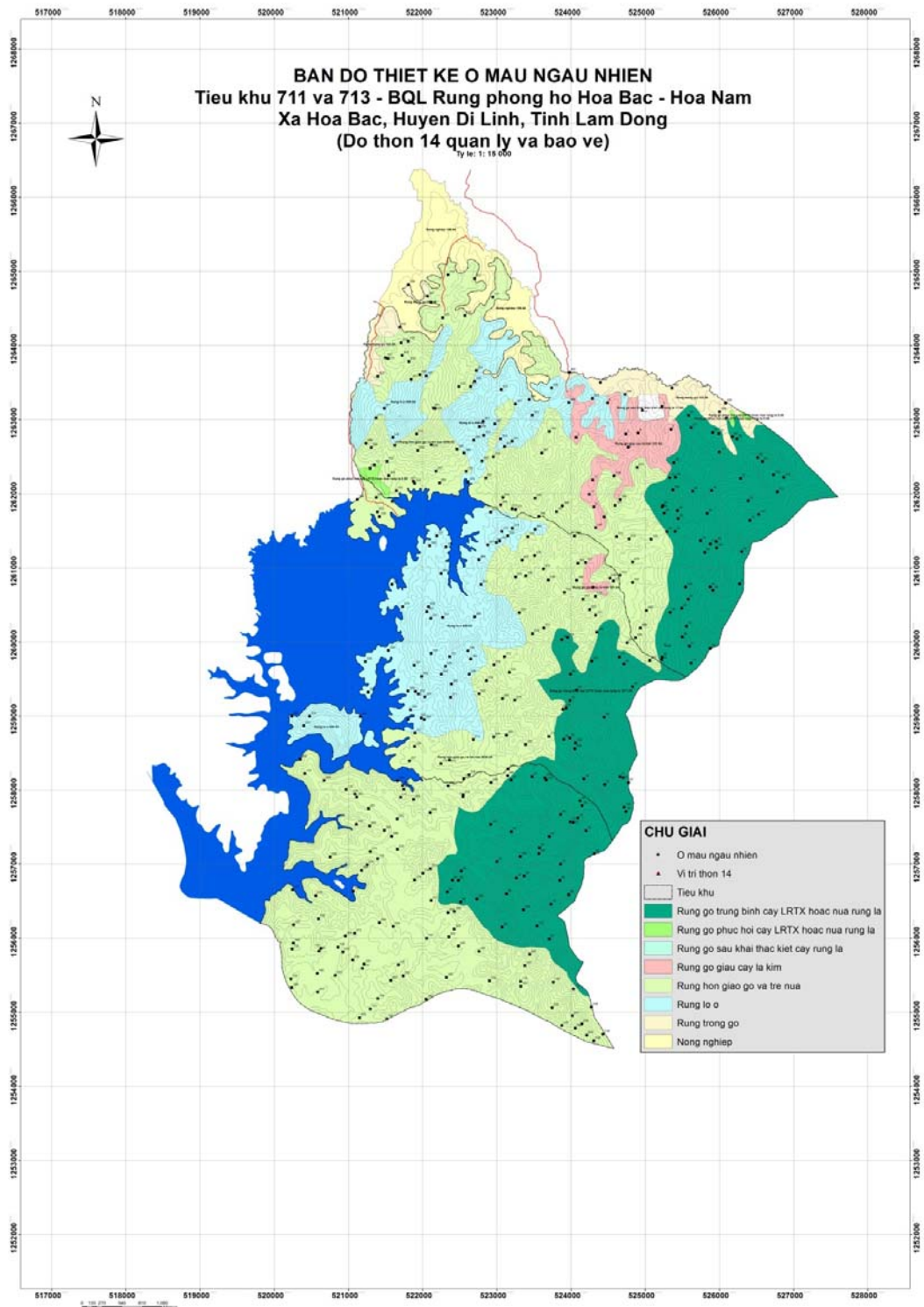
## Use of ArcGIS for data layer is a random sample plots established: Add XY Coordinates

FID	Shape	CID	POINT_X	POINT_Y
0	Point	1	524449.285074	1261684.32025
1	Point	1	525349.470495	1262866.43532
2	Point	1	524070.528416	1262757.47458
3	Point	1	524769.531447	1262624.19545
4	Point	1	524740.012971	1262802.18004
5	Point	1	524494.609521	1263223.52577
6	Point	1	525227.354617	1263174.75494
7	Point	1	524904.987619	1262817.95875
8	Point	1	524311.838026	1261822.54978
9	Point	1	524298.116124	1260735.51158
10	Point	1	524294.13666	1262184.81284
11	Point	1	524246.284969	1261993.1484
12	Point	2	521351.94811	1262390.3633
13	Point	3	524964.164553	1263121.98471
14	Point	4	523987.500389	1259208.83952
15	Point	4	523731.926787	1256459.66146
16	Point	4	524654.495667	1259795.67211
17	Point	4	525914.674794	1260698.2084
18	Point	4	525878.65148	1259910.30381
19	Point	4	523903.582455	1258682.29778
20	Point	4	526274.316065	1260783.22584
21	Point	4	525558.907285	1260212.03964
22	Point	4	524714.685258	1259701.7598
23	Point	4	525257.380468	1261738.67359
24	Point	4	526518.238395	1262489.20488
25	Point	4	524093.598079	1257622.08512
26	Point	4	524454.956944	1258073.2208
27	Point	4	523372.026925	1256838.52982

- Create a field with sign of sample plots assigned:  $So\_hieuo = FID + 1$

FID	Shape	CID	So_hieuo_o	POINT_X	POINT_Y
0	Point	1	1	524449.285074	1261684.32025
1	Point	1	2	525349.470495	1262866.43532
2	Point	1	3	524070.528416	1262757.47458
3	Point	1	4	524769.531447	1262624.19545
4	Point	1	5	524740.012971	1262802.18004
5	Point	1	6	524494.609521	1263223.52577
6	Point	1	7	525227.354617	1263174.75494
7	Point	1	8	524904.987619	1262817.95875
8	Point	1	9	524311.838026	1261822.54978
9	Point	1	10	524298.116124	1260735.51158
10	Point	1	11	524294.13666	1262184.81284
11	Point	1	12	524246.284969	1261993.1484
12	Point	2	13	521351.94811	1262390.3633
13	Point	3	14	524964.164553	1263121.98471
14	Point	4	15	523987.500389	1259208.83952
15	Point	4	16	523731.926787	1256459.66146
16	Point	4	17	524654.495667	1259795.67211
17	Point	4	18	525914.674794	1260698.2084
18	Point	4	19	525878.65148	1259910.30381
19	Point	4	20	523903.582455	1258682.29778
20	Point	4	21	526274.316065	1260783.22584
21	Point	4	22	525558.907285	1260212.03964
22	Point	4	23	524714.685258	1259701.7598
23	Point	4	24	525257.380468	1261738.67359
24	Point	4	25	526518.238395	1262489.20488
25	Point	4	26	524093.598079	1257622.08512
26	Point	4	27	524454.956944	1258073.2208
27	Point	4	28	523372.026925	1256838.52982

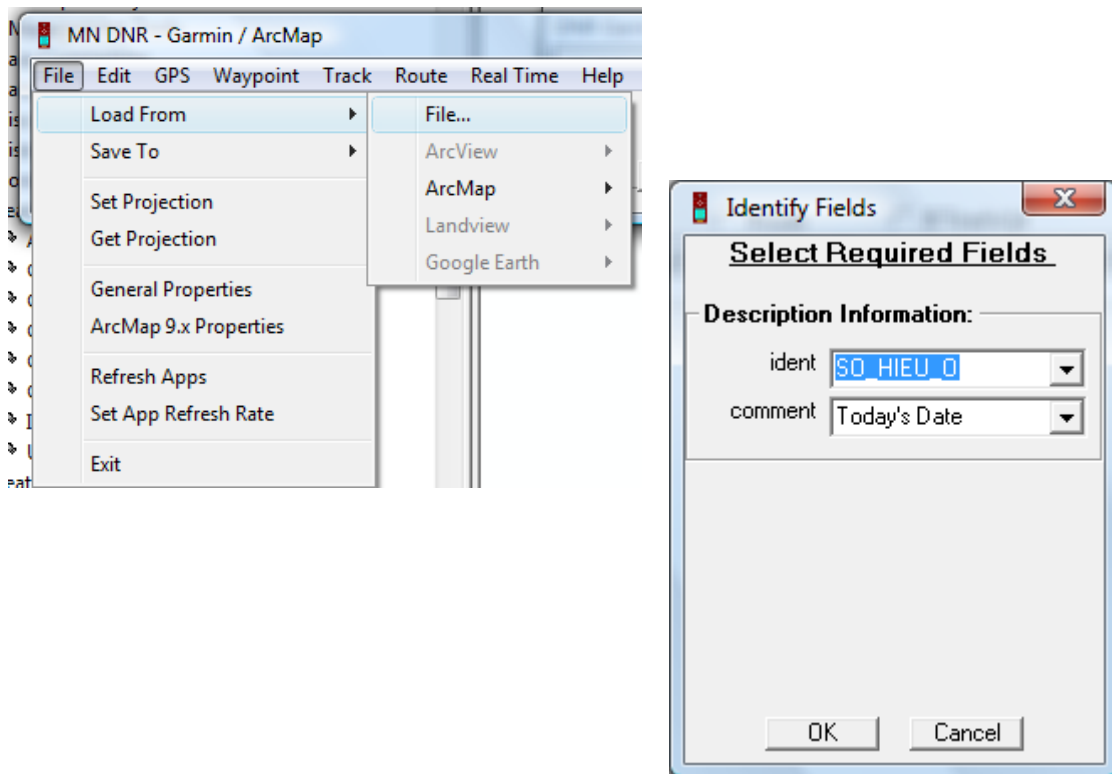
The result is a network of plots and number sign of random sample plots on map



*Figure 3: Map located random sample plots belong to forest startum in Village 14, Hòa Bắc – Hòa Nam commune (Hòa Bắc – Hòa Nam protective forest management board, Di Linh district)*

**c) Upload the coordinates of the random sample plots into the GPS to determine them in the field**

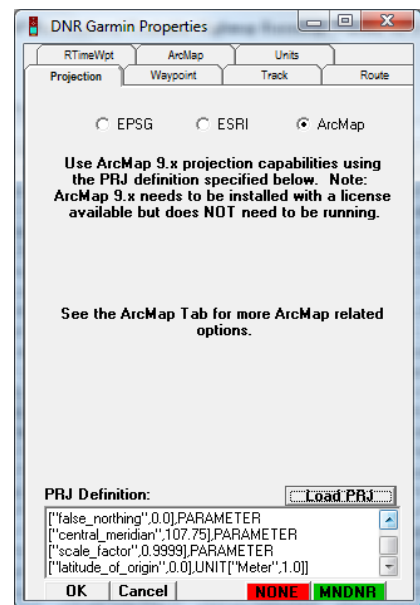
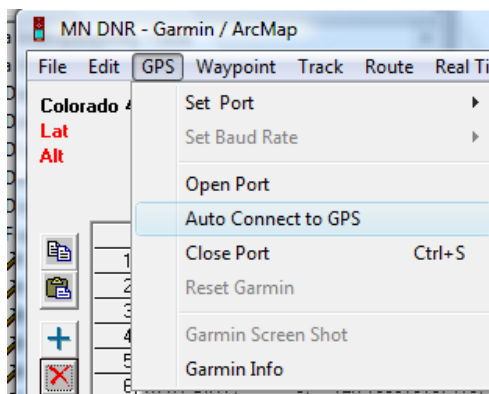
Use of DNRGarmin software to turn number signs and their coordinates to the GPS: Open data set of established plot coordinates: File/Load from/File .... Select file shape format and open coordinates stored in Vn2000 or UTM. Select ident is "SO\_HIEU\_O"



Results of coordinates file is transferred to the DNR, then connect to GPS and upload data of plots in GPS.



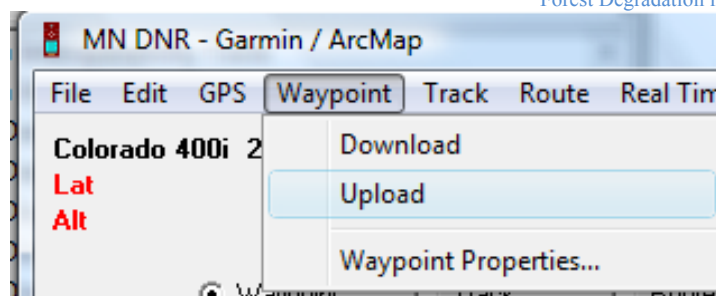
type	ident	lat	long	u_proj	x_proj	comment	display	symbol	unu
WAYPOINT	1	11.4098406533845	108.724052232549	1261684.32025360	524449.28507394	00.14.10-Nov-10			
WAYPOINT	2	11.4205217049334	108.732310140966	1262866.43531523	525349.47049509	00.14.10-Nov-10			
WAYPOINT	3	11.4195456430696	108.720888833601	1262757.47458177	524070.52841563	00.14.10-Nov-10			
WAYPOINT	4	11.4183357834175	108.726933633898	1262624.19544845	524769.53144685	00.14.10-Nov-10			
WAYPOINT	5	11.419945145642	108.726724459132	1262802.18003999	524740.01297144	00.14.10-Nov-10			
WAYPOINT	6	11.4237562486293	108.724478520629	1263223.52577321	524494.60952074	00.14.10-Nov-10			
WAYPOINT	7	11.4233100957405	108.731193296661	1263174.75494467	525227.35461683	00.14.10-Nov-10			
WAYPOINT	8	11.4200866279244	108.72823643907	1262817.95875043	524904.98761927	00.14.10-Nov-10			
WAYPOINT	9	11.4110913417852	108.722793654639	1261822.54977653	524311.83802588	00.14.10-Nov-10			
WAYPOINT	10	11.4012635479817	108.722660251935	1260735.51157963	524298.11612433	00.14.10-Nov-10			
WAYPOINT	11	11.4143666760342	108.722633992719	1262184.81283821	524294.13666025	00.14.10-Nov-10			
WAYPOINT	12	11.4126341751123	108.722194129239	1261993.14840159	524246.28496928	00.14.10-Nov-10			
WAYPOINT	13	11.4162442723027	108.696672861479	1262390.36330154	521351.94810998	00.14.10-Nov-10			
WAYPOINT	14	11.422834893603	108.72878095348	1263121.98470589	524964.16455257	00.14.10-Nov-10			
WAYPOINT	15	11.3874630682946	108.719803279264	1259208.83952333	523987.50038851	00.14.10-Nov-10			
WAYPOINT	16	11.3626094876118	108.717442552324	1256459.66146289	523731.92678651	00.14.10-Nov-10			
WAYPOINT	17	11.3527639826731	108.725919273289	1259795.67211263	524654.49566653	00.14.10-Nov-10			
WAYPOINT	18	11.4009146898437	108.73747351838	1260698.20839964	525914.67479387	00.14.10-Nov-10			
WAYPOINT	19	11.3937915308718	108.737137509412	1259910.30380946	525878.65147999	00.14.10-Nov-10			
WAYPOINT	20	11.3827031813114	108.719030681866	1258682.29778189	523903.68245526	00.14.10-Nov-10			
WAYPOINT	21	11.401680647577	108.740769779207	1260783.22584445	526274.31606524	00.14.10-Nov-10			
WAYPOINT	22	11.3965218669819	108.734209802392	1260212.03964417	525558.90728462	00.14.10-Nov-10			
WAYPOINT	23	11.3919144984821	108.726470140365	1259701.75979656	524714.68525796	00.14.10-Nov-10			
WAYPOINT	24	11.4102363160688	108.721457941794	1261738.67368959	525367.38046758	00.14.10-Nov-10			



Set up coordinate system: File/Set Projection.  
Load PRJ and select file of sample plot  
coordinates under format of \*.prj which  
contains information of coordinates (For  
example: Vn2000)

Upload data from file of sample plot coordinate into GPS.





The results will give a random sample plot system on the map and their point has been transferred to GPS. Thence, use of function of “goto” of GPS to go right position of each plot in the field.

### Step 3: Permanent Pilot Measurement

#### Objective:

Set up a system of random sample plot which fixed on the field to collect relevant data to convert to forest stored carbon and absorbed CO<sub>2</sub> periodically

#### Result:

- The random permanent plots are fixed landmark to periodically inventory.
- Data on forest resources are obtained to be able to convert to biomass, carbon in the sample plots according to the forest status, forest blocks and are repeated periodically.

#### Preparation, materials

- Establish key groups of farmers and technical staff of the forest management agencies (especially those who know the forest). Each group has five people, 4 farmers and one technical staff.
- Forest status maps, topographical maps and forest block map at 1:10.000 scale.
- Transparency paper (enough to cover maps) with pin
- Pen writing table to write on transparency paper and permanent marker to delineate map; alcohol and cotton to wipe the wrong markings
- Ruler 50cm to make the grid cell for permanent plots
- Compass to orient the map
- GPS for locating sample plots
- Tape for making sample plot
- Diameter measuring tape

- Sununto clinometer
- Chalk for marking on the tree
- Iron board for recording number sign of tree
- Iron board for recording number sign of sample plot
- Hammer, nails to hammer board on the tree
- Paint to paint the number sign of sample plots
- Frame of 50x50cm to establish sub-sample to measure litter, grass, herb, and shrubs
- Tool for soil bunk density
- Packaging for containing fresh branches to weight
- Scales 12 - 20 kg to weight biomass of grass, shrub, herb, litter, and branches
- Electronic scale 200 g, accurate to 0.1g to weight sample of fresh and rotten carpet, and soil
- Knife for cutting foliage
- Shovel to dig the soil sample
- Packaging for soil sample, biomass specimen
- Color carr
- Nilon bags
- Spreadsheet for recording inventory factors

## Performance

### i) Determine random sample plot coordinates in the field

The plots' coordinates are loaded into the GPS; e.g., using DNR Garmin software. Use navigation function of GPS along with compass to determine centre position of the sample plots which are randomly chosen in individual forest status. Cemented or wooden pillars marked with permanent paint are used to fix the centre of each plot permanently, on the pillars are written Vn2000 coordination of the sample plot, number code of sample plot. The marking in the centre of the plots has proved to be very valuable in annual monitoring as GPS alone could give a few meters of difference in locating the centre of the permanent plot for subsequent measurements. Use of GPS: Press button Find/Waypoint, then select plot number sign which needs to access and select Go to

### ii) Design sample plot (shape, size) according to forest types:

The shape and size of plot depend on density of forest trees and forest type.

Forest carbon measurement can be carried out in both rectangular and circular plots. Nevertheless, circular samples are recommended for the study because they are

relatively easy to establish. The radius of plot is dependent on the density of the forest and each of diameter.

**Table 3: Plot radius for carbon inventory plots**

Plot size [m <sup>2</sup> ]	Plot radius [m]	Typical area per tree [m <sup>2</sup> ]	Tree density
100	5.64	0 to 15	Very dense vegetation, stands with large numbers of stems small in diameter, uniform distribution of larger stems
250	8.92	15 to 40	Moderately dense woody vegetation
500	12.62	40 to 70	Moderately sparse woody vegetation
666.7	14.56	70 to 100	Sparse woody vegetation
1000	17.84	More than 100	Very sparse vegetation

Source: MacDicken (1997)

In addition some sub-plots are divided to measure trees of different sizes according to principle of the larger diameter trees, the lower density and size of sub-plots should be larger and vice versa. This will reduce labour but still ensure a number of trees per area unit of the sample according to the principles of statistics.

Below is the form and size of the permanent sample plot suggested for participatory carbon measurement in Vietnam:

**- Type of evergreen, semi-deciduous, dipterocarp, and pine forest:**

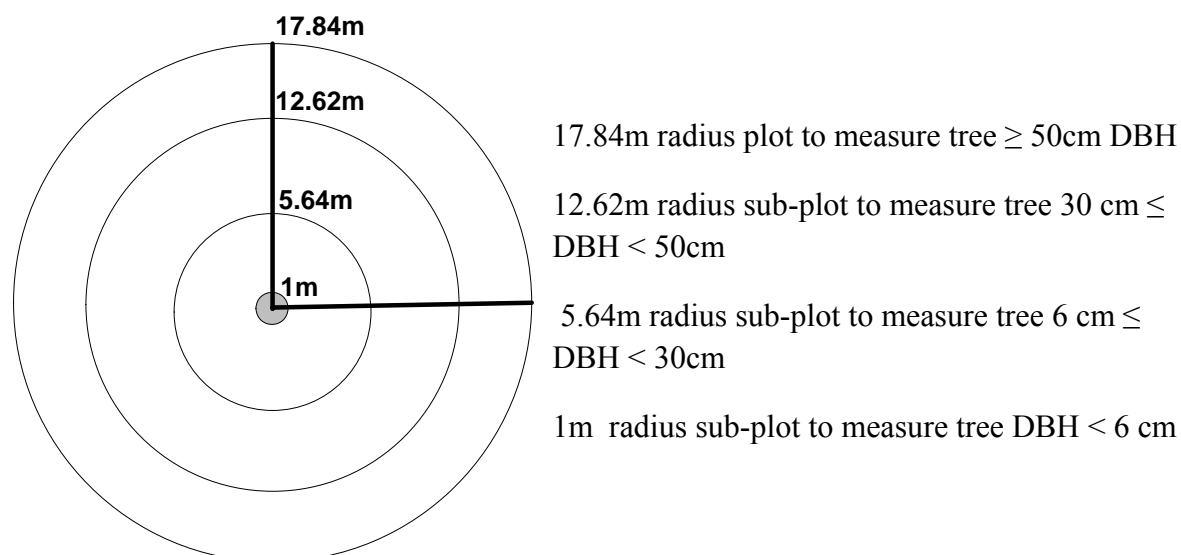


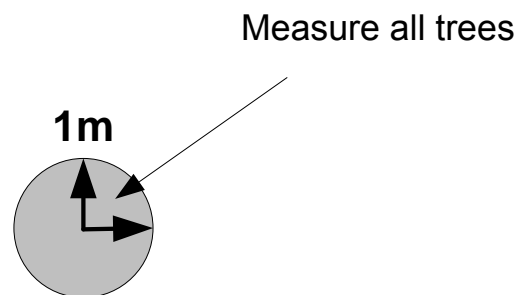
Figure 4: Sampling design of circular plot with 1000m<sup>2</sup> of plot size

Using circular plot divided into sub-plots with different sizes depending on the tree diameter classes:

- ✓ 17.84m radius circle plot with an area of 1000m<sup>2</sup>: Measurement of timber trees  $\geq 50$  cm DBH
- ✓ 12.62m radius circle sub-plot with an area of 500m<sup>2</sup>: Measurement of the tree with  $30 \leq \text{DBH} < 50$  cm
- ✓ 5.64m radius circle sub-plot with an area of 100m<sup>2</sup>: Measurement of the tree with  $6 \text{ cm} \leq \text{DBH} < 30$  cm
- ✓ 1m radius circle sub-plot with an area of 3.14m<sup>2</sup>: Measurement of the tree with  $\text{DBH} \leq 6$  cm and record of dead wood
- ✓ 4 sub-plots 50x50cm square with an area of 0.25m<sup>2</sup>:

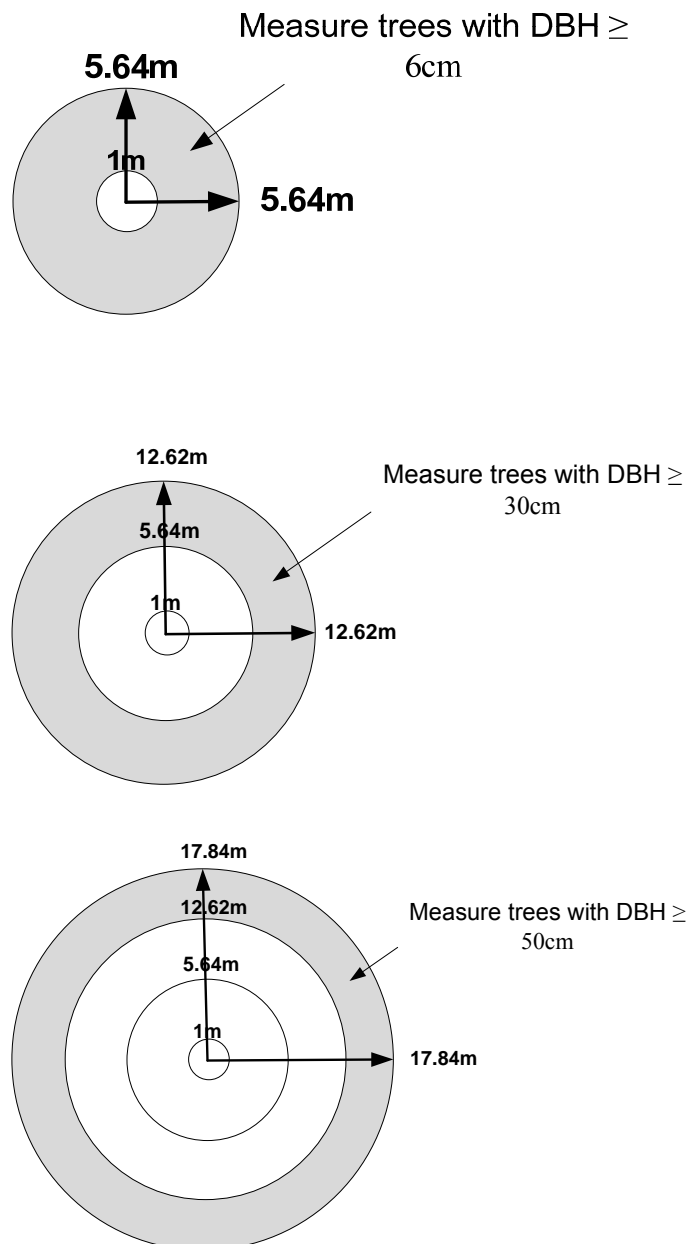
**How to design circular sample plot and sub-plot:**

- Prepare a knotted rope in the range of colors in the radius of the sub-plots, respectively, 1m, 5.64m, 12.62m and 17.84m. So there are 4 positions determined by the band of colors, each color for each location. To conduct a sub-sample, it needs at least two such ropes, preferably 4 ropes.
- One by one set of sub-plot from small to large: sub-plot with radius of 1m, 5.64m, 12.52m and 17.84m
- The center position of the plot is identified and marked. A fixed-suspended table is used to indicate the number sign and coordinates referencing to Vn2000.
- For first sub-plot, there are at least 4 positions, respectively to 4 segments, is specified. The first is the knot with a radius of 1 meter; landmarks and tie the color band at that position and record the radius. Then the second rope is pulled in a clockwise direction at an angle from 45 to 90° and also mark the position of the radius of the sub-plots and color band that is uniform with the same sub-plot radius size. Landmark and the radius of sub-plot are shown. All woody trees from the smallest to largest are measured in the first segment in 1m radius sub-plot. Moving the first rope in a-clockwise by 45 to 90° and marked with colored strips; landmarks, recording radius. Keep doing this until the circle is closed.



- The left sub-plots with radius of 5.64m, 12.62m, and 17.84m are done in a similar way. However, measurements are done only in the area extending from a radius of 1m - 5.64m; 5.64m - 12.62m, and 12.62m - 17.84m, respectively. Trees in each sub-plot are separately recorded in individual segments within the sub-plot:

- o For 5.64m radius sub-plot, only trees with DBH  $\geq$  6 cm are measured.
- o For 12.62m radius sub-plot, only trees with DBH  $\geq$  30 cm are measured.
- o For 17.84m radius sub-plot, only trees with DBH  $\geq$  50 cm are measured.



**Note:**

- The radius locations of the all sub-plots from small to large are fixed landmarks and tied with different color bands. Radiuses of the sub-plots are inscribed so that later surveys can be repeated.
- Slope correction: While placing a permanent sample plot, care must be taken to do a correction for any slopes in the area. A Clinometer can be used to measure slope angles. A calculator can be used in the field to make the simple trigonometric calculation (distance on the sloping ground is equal to the cosine of the angle of the slope divided by the desired radius) necessary to determine



the slope. Alternatively, a chart with horizontal distances calculated according to the slope angle could be taken to the field. (Attached in Annex). Slope is defined by Clinometer Sunto.

*Địa bàn và thước đo  
cao, đo dốc  
(Compass-  
Clinometer)*

- ✓ 4 sub-sample 50x50cm square with an area of 0.25m<sup>2</sup>: Used to collect the volume of grass, herb, bushes, non-timber forest products, litter and soil samples in 30 cm thick layer. The 4 sub-plots should be placed outside the sample plot. In the first inventory, they should be placed in 4 directions of north, south, east, and west adjacent to the circular plot. In the latter survey, the directions will spin clockwise down under 45°.

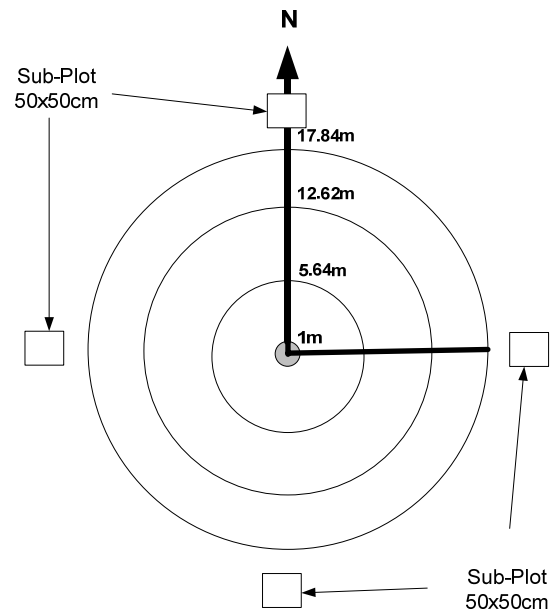


Figure 5: Location of 4 sub-plots 50x50 cm for measuring biomass of LHG and soil

The distributed diameter classes above are consistent with the diameter class of the in volume tables which used for statistics of volume of currently Vietnamese forest with 4cm in intervals of DBH. Tree diameter for measuring is  $\geq 6$ cm; tree with DBH  $< 6$  cm is considered as regeneration tree.

- **Bamboo forest:**

For the bamboo forest, the sample size is 100m<sup>2</sup>, a circle sample with a radius of 5.64m used to measure the bamboo and 4 sub-plots with 50x50cm employed to

measure litter, grass, herb, and shrub biomass (LHG), soil samples are taken in soil layer of 30 cm depth like wood forest surveys.

- **Mixed woody – bamboo forest:**

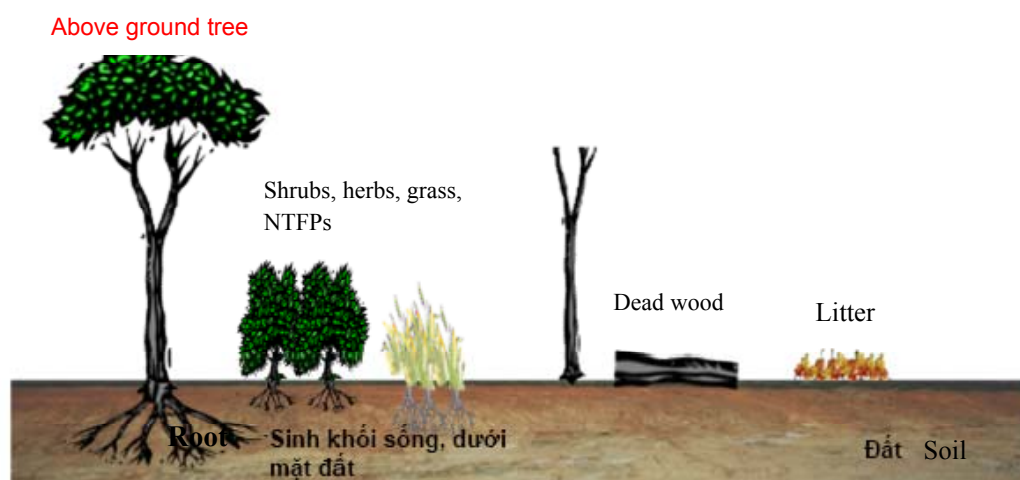
For this forest type, both two groups of wood and bamboo are measured. The measurement of woody tree in the circular plot with an area of 1000m<sup>2</sup> divided into sub-plots according to diameter classes. Bamboo is measured separately in the plot size of 100m<sup>2</sup> with a radius of 5.64m as bamboo forest only. Dead wood are measured in 1 meter radius circular sub-plot. Similar to 2 forest types above, 4 sub-plots 50x50cm employed to measure litter, grass, herb, and shrub biomass (LHG), soil samples are taken in soil layer of 30 cm depth like wood forest surveys.

- **Plantation forest:**

For this forest type, the measurement of the tree is done in 500m<sup>2</sup> circular plot with a radius of 12.62m as maximum diameter of the plantation forest is not exceeding 50cm. Dead trees, fallen branches were measured in the circle sub-plot with 1 meter radius while 4 50x50cm sub-plots are set to measure the fresh biomass such as grass, herb, shrub, and litter. Soil profile with 30cm deep is also collected .

**iii) Forest variables in sample plot to estimate stored carbon and absorbed CO<sub>2</sub>**

There are 6 carbon sinks in the forest, including: i) above ground tree, ii) shrubs – herbs grass – NTFPs; iii) Litter; iv) Dead wood; v) root and iv) soil.





- ✓ **Above ground tree and bamboo:** DBH. Species or adding tree height (H) measured to specify biomass of woody tree above ground (AGTB) and carbon in tree through the model:  $AGTB = f(DBH)$ ,  $AGTC = f(DBH)$ . For bamboo, DBH, H and density should be recorded to predict biomass and carbon by allometric model

For example of following models (Bảo Huy, 2009 – 2010):

*Evergreen forest:*

$$AGTB \text{ (kg)} = 0.2137 * DBH^{2.4514} \quad R^2 = 0.9545$$

$$AGTC \text{ (kg)} = 0.0428 * DBH^{2.4628} \quad R^2 = 0.9378 \text{ (Carbon in tree)}$$

*Deciduous forest:*

$$AGTB \text{ (kg)} = 0.1910 * DBH^{2.5136} \quad R^2 = 0.9695$$

$$AGTC \text{ (kg)} = 0.0332 * DBH^{2.7147} \quad R^2 = 0.9573 \text{ (Carbon in tree)}$$

*For Bamboo forest:*

$$AGBB \text{ (kg)} = 1.032A^2 - 3.5025A + 19.162 \text{ (B : Bamboo Biomass ; A : Age of bamboo); } R^2 = 0.9454$$

$$AGBC \text{ (kg)} = 0.2786A^2 - 0.9496A + 4.3803 \text{ (Carbon in bamboo tree); } R^2 = 0.9377$$

$$AGBC \text{ (ton/ha)} = 26.478N^{0.203} \text{ (N : Number of bamboo trees per ha); } R^2 = 0.7255$$

$$AGBC \text{ (ton/ha)} = -104.423 + 27.0988 * \log(\sqrt{D}) * N \text{ (D: Mean of DBH of bamboo)} \\ R^2 = 0, 649$$

- ✓ **Shrub, herb, grass and NTFPs:** The factor for measurement is fresh biomass which are brought to the laboratory to determine moisture content, from which total dry mass and carbon can then be calculated.
- ✓ **Litter:** The factor for measurement is litter, and is brought to the laboratory to determine moisture content, from which total dry mass and carbon can then be calculated.
- ✓ **Dead tree:** The factor for measurement is their weigh and volume. Their sample is used to determine dry biomass and carbon.
- ✓ **Root of tree and bamboo:** It is impossible to directly measure biomass of the root, thus, this factor is not measured. However below biomass and carbon in root (BC) can be calculated by two ways: i) through the models of BB,  $BC = f(DBH)$  or ii) Through rate of 20% of AGTB.
- ✓ For instance of models developed by (2010) to estimate biomass and carbon in tree root:

For evergreen broad-leaved forests:

$$BB \text{ (kg)} = 0.039 * DBH^{2.288} \quad R^2 = 0.9577$$

$$BC \text{ (kg)} = 0.051 * DBH^2 - 0.6756 * DBH + 2.8901 \quad R^2 = 0.9983 \text{ (Carbon in the root of tree)}$$

- ✓ **Forest soil:** To inventory carbon in soil (Soil organic carbon-SOC), soil bulk density should be defined ( $\rho$ ), soil thickness layer ( $d$ ) and soil sampling to analysis rate % carbon in soil.  $SOC/ha = \rho \cdot d \cdot 10^8 \cdot \%C$

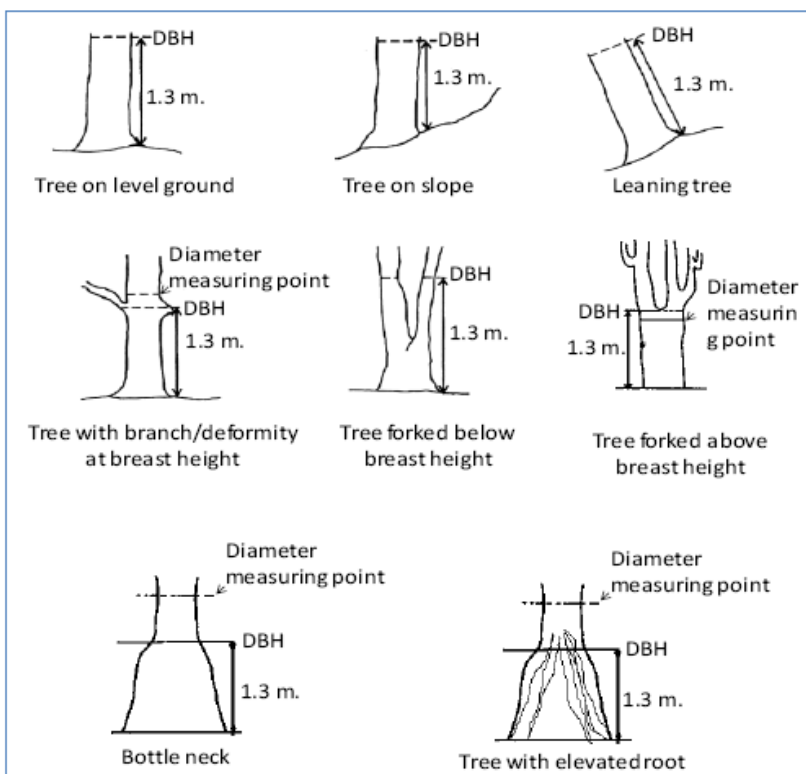
#### iv) Inventory in sample plot

Including 5 factors mentioned above (exception for tree root):

- **Measuring woody layer:** Recording from small to large plot: In the 1 m radius plot all trees are recorded with tree species and DBH, except for 6cm in DBH regeneration trees which only specified tree species and number of trees. For 5.64m radius plot, DBH is measured for only the  $DBH \geq 6$ cm trees. For 12.62m radius, DBH is measured for only the  $DBH \geq 30$  cm trees, and for the largest radius plot with 17.84m, DBH is measured for only the  $DBH \geq 50$ cm trees. The trees having  $DBH \geq 6$ cm are fixed specific for monitoring in increment, death, or logged (recorded factors are DBH and tree species).

Diameter tape is used to measure DBH. This tape is already converted to diameter by producer, the accuracy reaches 0.1cm. Positions measured are presented at below

Figure 6: Measuring DBH tree (Source: Bhisma et al, 2010)



If the tree which is located in the border at over 50% of the stem, then it will be measured, otherwise it is not measured.

- **Bamboo measurement:** Bamboo is measured in 5.64m radius plot with factors of age (A), individual DBH, and average height.



- **Shrub, herb, grass, NTFPs measurement:** In 4 50x50cm sub-plots, weighting fresh biomass and 100g of evenly mixed sub-samples are brought to the laboratory to determine moisture content, from which total dry mass/carbon can then be calculated.



*Weighting to sample fresh*



*Weighting shrub, grass, herb*

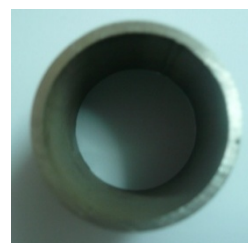


*Frame 50x50cm to take fresh and litter*

- **Litter measurement:** In 4 50x50cm sub-plots, weighting fresh biomass and 100g of evenly mixed sub-samples are brought to the laboratory to determine moisture content, from which total dry mass/carbon can then be calculated.

- **Dead wood measurement:** in 1m radius sub-plot, quality and volume of dead wood are specified. A sample of 100g which mixed all components to carbon and dry biomass analysis is taken.

**Soil sampling:** in 50x50cm sub-plot, small soil profile with 30cm in deep is dug Soil color, soil bunk density are determined. A sample of 500g (mixed 4 samples of 4 sub-plots) is collected for laboratory working to figure out carbon storage.



*Tool for soil bunk density:  
Plug the tool into the soil,  
the soil taken and weighed,  
then divided by tube  
volume (50cm<sup>3</sup>) to have  
soil bunk density*

The sample plots should be clear signs to know the exact

The sample plot should be clearly and accurately signed to know origin and enable to aggregate data which can calculate the carbon at a higher level.

Symbol of plots should include information: forest owner, forest type, forest status, and number sign of plot. For example: **NB-TX-TB-10**: forest under management of Nam Ban forest protection board, evergreen forest, medium status, and number sign of plot (10).

Symbols of samples taken for analysis: including the information of the sample plot + sign of samples. For example: **NB-TX-TB-10-TT** (including: TT (fresh) or TM (litter), or CN (dead wood), or D (soil).

All sample plot data is numbered, referenced coordination and arranged according to forest block, forest status, forest owner. These data will be submitted to agency who has responsible to manage and analyse data to convert to biomass, carbon sequestration fro each ecological zone, in the whole country.



## References

1. Bao Huy and Pham Tuan Anh, 2008, Estimating CO<sub>2</sub> sequestration in natural broad-leaved evergreen forests in Vietnam. *Asia-Pacific Agroforestry Newsletter – APANews, FAO, SEANAFE*; No.32, May 2008, ISSN 0859-9742.
2. Bao Huy and Aschenbach C., 2009, *Participatory Carbon Stock Assessment Guideline for Community Forest Management Areas in Vietnam*. GTZ/GFA Consulting Group.
3. Bao Huy and Vo Hung, 2009, Increased income and absorbed carbon found in *Litsea glutinosa* – cassava agroforestry model. *APANews (Asia-Pacific Agroforestry Newsletter)*, No. 35, ISSN 0859-9742, FAO, SEANAFE, pp 4-5.
4. Bao Huy 2009, Methodology for research on CO<sub>2</sub> sequestration in Natural Forests to join the program of Reducing emissions from deforestation and degradation (REDD). *National Journal on Agriculture and Rural Development, No1/2009*, Hanoi, ISSN 0866-7020, pp85-91.
5. Bhishma P. S., Shiva S. P., Ajay P., Eak B. R., Sanjeeb B., Tibendra R. B., Shambhu C., and Rijan T., 2010, Forest Carbon Stock Measurement. Guidelines for measuring carbon stocks in community – managed forests. Asia Network for Sustainable, Agriculture and Bioresources (ANSAB). Federation of Community Forest, Users, Nepal (FECOFUN). International Centre for Integrated, Mountain Development (ICIMOD).
6. Eleonor B. S. et al., 2009, *REDD là gì*. AIPP, FPP, IWGIA.
7. Silva H. P., Erin S., Michael N., Sarah M. W., Sandra B, 2010, *Manual – Technical Issues Related to Implementing REDD<sup>+</sup> Programs in Mekong Countries*. Winrock International.



## Part III : Annex

### Annex 1: Tools, equipment needed for PCM

<b>Id</b>	<b>Items</b>	<b>Unit</b>	<b>Quantity</b>	<b>Purpose</b>
<b>I Mapping, plot navigation</b>				
1	Base map, topography map	Map	1	Plot navigation
2	Forest Status map	Map	1	Identify forest block
3	GPS	Unit	5	Boundary survey
4	Battery for GPS	Unit	50	
5	Transparency Ao size	m	10	Cover on the map and farmer can draw on map
6	Color pen	box	5	Sketch making
7	Alcohol	Unit	5	Sketch making
8	Compass – Clinometer	Unit	5	To identify the trend of map and transect of plots
<b>II Permanent plot establishment</b>				
1	Rope	m	200	Plot boundary delineation
2	Linear tape	Unit	5	Distance measurement of plot boundary
	Color tape	Unit	5	For marking position of sample plot
3	Chalk	Box	5	Marking the trees
4	Slope measurement	Unit	5	To indentify to length of plot boundary on sloping land
5	Metal tags for tree	Unit	200	Permanent marking of tress
6	Metal tags for plot		5	Showing direction of plot
7	Enamel	Box	5	Numbering metal tags
8	Brush	Unit	5	Numbering metal tags
9	Hammer	Unit	5	Fixing metal tags on tree
10	Nails	Unit	5	Placing the tags
<b>III Height and Diameter Measurement</b>				
1	Diameter tape	Unit	10	Measure DBH
2	Linear tape	Unit	5	Measure distance between the tree and measurer
3	Clinometers	Unit	5	Measuring the ground slope, top and bottom angle to the tree
<b>IV Weighting Leaf litter, herb/Shrub, dead wood</b>				

<b>Id</b>	<b>Items</b>	<b>Unit</b>	<b>Quantity</b>	<b>Purpose</b>
1	Knife or sickle	Unit	10	Cutting herb/shrub
2	Weighting machine	Unit 12-20 kg	5	Weighting herb, shrub, grass, leaf, litter
3	Scissors	Unit	10	Cutting herb/shrub
4	Bag	Unit	5	Contain herb, shrub, grass, leaf, litter for weighting
5	Frame 0.5 x 0.5m (PCV)	Unit	5	Sampling grass, shrub, herb
<b>V</b>	<b>Measuring Soil</b>			
1	Spade	Unit	5	Digging soil
2	Metal scale	Unit	5	Measuring soil depth
3	Soil bulk density	Unit	5	
4	Weighting machine (Digital) 0.1g	Unit	5	Measuring soil weight
5	Trowel	Unit	5	Taking out soil
6	Pocket	kg	2	Contain soil for weighting
<b>VI</b>	<b>Stationery for training</b>			
1	Ao paper	Unit	20	Training at commune
2	Color paper sheet (A4)	Unit	100	Idem
3	Color pen	Box	5	Idem
4	Sticking	Unit	10	Idem
5	Pin Board	Unit	2	Idem
6	Calculator	Unit	5	Calculation of data at the community -

## Annex 2: Guide to set up GPS for Vn2000 Coordination Projection

Change parameters in GPS to reference Vn2000 coordinates according to Ministry of Natural Resources and Environment (MNRE) for zone 48 and zone 49 at 3<sup>0</sup> and 6<sup>0</sup>

### 1) For the group of maps with scale of 1/10.000 upwards (reference zone 3<sup>0</sup>)

- Longitude Origine: this parameter is changed depending on the meridian (axis) of each province according to the table attached below (Example: Dak Lak This parameter is changed: E 108<sup>0</sup>30.000).
- Scale: + 0.9999000
- False Easting: 500000.0m
- False Northing: 0.0m
- Datum:
  - o DX = -192
  - o DY = -39
  - o DZ = -111
  - o DA = 0
  - o DF = 0 (or 0.00000002)

### 2) For the group of maps with scale of 1/25.000 or below (reference zone 6<sup>0</sup>):

- Longitude Origin: E105<sup>0</sup> or E111<sup>0</sup> hoặc E117<sup>0</sup> corresponding to position of the map in reference zone 48 (102<sup>0</sup>-108<sup>0</sup>) or 49 (108<sup>0</sup>-114<sup>0</sup>) or 50 (114<sup>0</sup>-120<sup>0</sup>).
- Scale: + 0.9996000
- False Easting: 500000.0m
- False Northing: 0.0m
- Datum:
  - o DX = -192
  - o DY = -39
  - o DZ = -111
  - o DA = 0
  - o DF = 0

#### Notice:

- For GPS 76, apart from the parameters Dx, Dy, DZ, two remaining parameters of DA and DF parameters can be changed in the Set Up Menu / Location / Map Datum / User. However the Garmin Colorado GPS locator shows only three parameters Dx, Dy and DZ. DA and DF should go to Set up Menu / Position format / User Spheroid where the two parameters shown.
- In some cases coordinates do not match with maps Vn2000, two parameters of **False Easting False Northing** need to be changed based a number of control points and their mean value to declare.
- In individual province, two important values of meridian and reference zone should be taken into account. Example: Map of Dak Lak at scale 1:100,000, the meridian is defined is 111<sup>0</sup>E with scale is 0.9996, but that is 108<sup>0</sup>30' for reference zone 3<sup>0</sup> and scale is 0.9999

#### Longitude for each the location/province with 3<sup>0</sup> reference zones, for larger maps 1:10.000

	Province, city	Meridian		Province, city	Meridian
1	Lai Châu	103 <sup>0</sup> 00'	8	Phú Thọ	104 <sup>0</sup> 45'

	Province, city	Meridian		Province, city	Meridian
2	Son La	104 <sup>00</sup> '	9	An Giang	104 <sup>45</sup> '
3	Kiên Giang	104 <sup>30</sup> '	10	Thanh Hoá	105 <sup>00</sup> '
4	Cà Mau	104 <sup>30</sup> '	11	Vĩnh Phúc	105 <sup>00</sup> '
5	Lào Cai	104 <sup>45</sup> '	12	Hà Tây	105 <sup>00</sup> '
6	Yên Bái	104 <sup>45</sup> '	13	Đồng Tháp	105 <sup>00</sup> '
7	Nghệ An	104 <sup>45</sup> '	14	Cần Thơ	105 <sup>00</sup> '
15	Bạc Liêu	105 <sup>00</sup> '	39	Quảng Bình	106 <sup>00</sup> '
16	Hà Nội	105 <sup>00</sup> '	40	Quảng Trị	106 <sup>15</sup> '
17	Ninh Bình	105 <sup>00</sup> '	41	Bình Phước	106 <sup>15</sup> '
18	Hà Nam	105 <sup>00</sup> '	42	Bắc Kạn	106 <sup>30</sup> '
19	Hà Giang	105 <sup>30</sup> '	43	Thái Nguyên	106 <sup>30</sup> '
20	Hải Dương	105 <sup>30</sup> '	44	Bắc Giang	107 <sup>00</sup> '
21	Hà Tĩnh	105 <sup>30</sup> '	45	TT-Huế	107 <sup>00</sup> '
22	Bắc Ninh	105 <sup>30</sup> '	46	Lạng Sơn	107 <sup>15</sup> '
23	Hung Yên	105 <sup>30</sup> '	47	Kon Tum	107 <sup>30</sup> '
24	Thái Bình	105 <sup>30</sup> '	48	Quảng Ninh	107 <sup>45</sup> '
25	Nam Định	105 <sup>30</sup> '	49	Đồng Nai	107 <sup>45</sup> '
26	Tây Ninh	105 <sup>30</sup> '	50	BR_Vũng Tàu	107 <sup>45</sup> '
27	Vĩnh Long	105 <sup>30</sup> '	51	Quảng Nam	107 <sup>45</sup> '
28	Sóc Trăng	105 <sup>30</sup> '	52	Lâm Đồng	107 <sup>45</sup> '
29	Trà Vinh	105 <sup>30</sup> '	53	Đà Nẵng	107 <sup>45</sup> '
30	Cao Bằng	105 <sup>45</sup> '	54	Quảng Ngãi	108 <sup>00</sup> '
31	Long An	105 <sup>45</sup> '	55	Ninh Thuận	108 <sup>15</sup> '
32	Tiền Giang	105 <sup>45</sup> '	56	Khánh Hoà	108 <sup>15</sup> '
33	Bến Tre	105 <sup>45</sup> '	57	Bình Định	108 <sup>15</sup> '
34	Hải Phòng	105 <sup>45</sup> '	58	<b>Đắc Lắc</b>	<b>108<sup>30</sup>'</b>
35	TP. HCM	105 <sup>45</sup> '	59	Phú Yên	108 <sup>30</sup> '
36	Bình Dương	105 <sup>45</sup> '	60	Gia Lai	108 <sup>30</sup> '
37	Tuyên Quang	106 <sup>00</sup> '	61	Bình Thuận	108 <sup>30</sup> '
38	Hoà Bình	106 <sup>00</sup> '			

Source: MoNRE

### Annex 3: Slope correction for the radius of the circle

<b>Slope correction for the radius of the circle</b>					
<b>Slope (Degrees)</b>	<b>Radius (m)</b>				
	<b>0.56</b>	<b>1</b>	<b>5.64</b>	<b>12.62</b>	<b>17.84</b>
<b>0</b>	0.56	1.00	5.64	12.62	17.84
<b>2</b>	0.56	1.00	5.64	12.63	17.85
<b>4</b>	0.56	1.00	5.65	12.65	17.88
<b>6</b>	0.56	1.01	5.67	12.69	17.94
<b>8</b>	0.57	1.01	5.70	12.74	18.02
<b>10</b>	0.57	1.02	5.73	12.81	18.12
<b>12</b>	0.57	1.02	5.77	12.90	18.24
<b>14</b>	0.58	1.03	5.81	13.01	18.39
<b>16</b>	0.58	1.04	5.87	13.13	18.56
<b>18</b>	0.59	1.05	5.93	13.27	18.76
<b>20</b>	0.60	1.06	6.00	13.43	18.98
<b>22</b>	0.60	1.08	6.08	13.61	19.24
<b>24</b>	0.61	1.09	6.17	13.81	19.53
<b>26</b>	0.62	1.11	6.28	14.04	19.85
<b>28</b>	0.63	1.13	6.39	14.29	20.21
<b>30</b>	0.65	1.15	6.51	14.57	20.60
<b>32</b>	0.66	1.18	6.65	14.88	21.04
<b>34</b>	0.68	1.21	6.80	15.22	21.52
<b>36</b>	0.69	1.24	6.97	15.60	22.05
<b>38</b>	0.71	1.27	7.16	16.02	22.64
<b>40</b>	0.73	1.31	7.36	16.47	23.29
<b>42</b>	0.75	1.35	7.59	16.98	24.01
<b>44</b>	0.78	1.39	7.84	17.54	24.80
<b>46</b>	0.81	1.44	8.12	18.17	25.68
<b>48</b>	0.84	1.49	8.43	18.86	26.66
<b>50</b>	0.87	1.56	8.77	19.63	27.75

## Annex 4: Data Sheet forms for pilot inventory

### Form 1: Data Sheet form for timber plot inventory

#### Form 1.1: Data Sheet form for measuring DBH ≥ 6cm in sub-plots 5.64m and greater

Plot No.: Forest type:  
 Vn2000 coordination: Forest stratum/status  
 Forest Owner: Contractor:  
 Location (Village, Commune, District, Province)  
 Tiểu khu Altitude (m)  
 Khoảnh Canopy cover (%)  
 Forest Block Slope (degree)  
 Measurement conducted by:  
 Date:

No.	Species		DBH (cm)	Comment	No.	Species		DBH (cm)	Comment
	Local name	Popular				Local name	Popular		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				



**Form 1.2: Data Sheet form for measuring DBH < 6cm in sub-plot with 1m radius**

**Plot no.:**

No.	Species		Number of tree	Comment	No.	Species		Number of tree	Comment
	Local name	Popular				Local name	Popular		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				

**Form 1.3: Data Sheet form for LHG 4 sub-plots 50x50cm**

**Plot no.:**

No	Item	Fresh Biomass (kg)			
		1	2	3	4
1	Herb, grass,				
2	Litter				

*Take specimen 100g per item*

**Form 1.4: Data Sheet form for dead wood in sub-plot inventory 1m radius**

**Plot No.:**

No	Item	Biomass (kg)
1	Fallen stumps, dead wood	

*Take specimen 100g*

**Form 1.5: Data Sheet form for Soil plot inventory in 4 phụ 50x50cm sub-plot**

**Plot no.:**

No	Layer	$\rho$ (g/cm <sup>3</sup> )			
		1	2	3	4
1	0 - 30 cm				

*Take specimen 500g*

## Form 2: Data Sheet form for bamboo inventory in plot with 5.64m radius

Plot No.: Forest type:  
 Vn2000 coordination: Forest stratum/status  
 Forest Owner: Contractor:  
 Location (Village, Commune, District, Province)  
 Tiểu khu Altitude (m)  
 Khoản Canopy cover (%)  
 Forest Block Slope (degree)  
 Bamboo species: Height Average (m)

No.	DBH (cm)	Age	Comment	No.	DBH (cm)	Age	Comment
1				26			
2				27			
3				28			
4				29			
5				30			
6				31			
7				32			
8				33			
9				34			
10				35			
11				36			
12				37			
13				38			
14				39			
15				40			
16				41			
17				42			
18				43			
19				44			
20				45			
21				46			
22				47			
23				48			
24				49			
25				50			

**Author: Assoc.Prof.Dr. Bao Huy**  
**November 2010**

