Participatory Carbon Monitoring: Manual for Local Technical Staff

Bao Huy, Nguyen Thi Thanh Huong, Benktesh D. Sharma, Nguyen Vinh Quang

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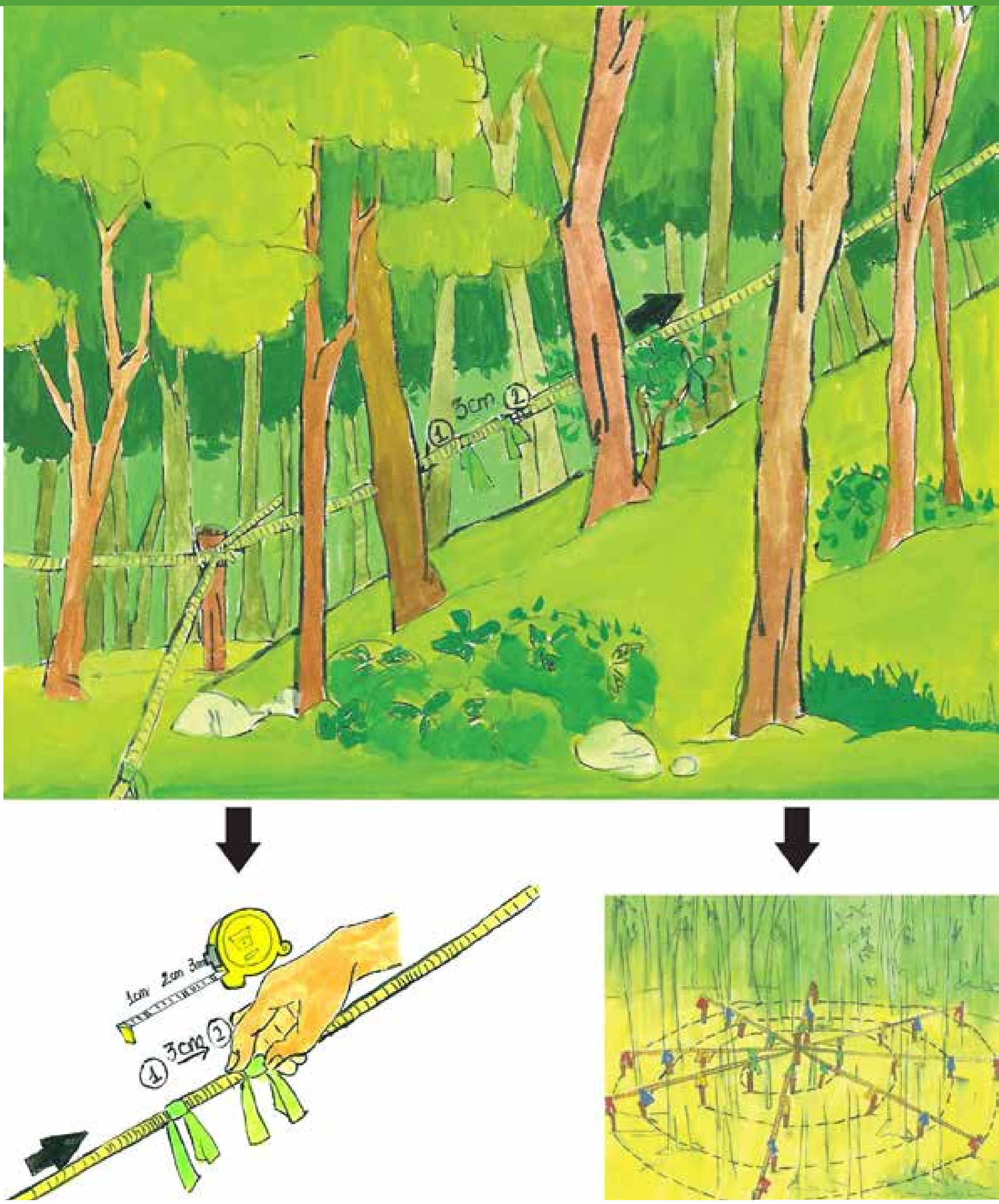

SNV

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Abbreviations

A	tree age
AGB	above-ground biomass
AGBB	above-ground bamboo biomass
BGB	below-ground biomass
C(AGBB)	carbon in above-ground bamboo biomass
AGC	carbon in above-ground biomass
BGC	carbon in below-ground biomass
DBH	diameter at breast height
EF	emission factor
FAO	Food and Agriculture Organization of the United Nations
FIPI	Forest Inventory and Planning Institute
FPD	Forest Protection Department
GIS	Geographic Information System
GPS	Global Positioning System
H	height (tree height)
IPCC	Intergovernmental Panel on Climate Change
MRV	MEASUREMENT, REPORTING AND VERIFICATION
NFI	National Forest Inventory
PCM	Participatory Carbon Monitoring
PES	Payment for Environment Services
PFM	Participatory Forest Monitoring
REDD	reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
TAGBC	total above-ground bamboo carbon
TAGTB	total above-ground tree biomass
TAGTC	total above-ground tree carbon
TBGTB	total below-ground tree biomass
TBGTC	total below-ground tree carbon
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations – REDD
V	volume

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Participatory carbon monitoring in natural forest resource management

The implementation of forestland allocation, management and protection of existing forests and development of new forestry programmes that incentivise people based on performance, such as REDD+ and/or Payment for Ecosystem Services (PES) from forest resources, needs a monitoring system to collect, store and analyse forest attributes in general and biomass carbon in particular, based on which performance can be evaluated. The system could benefit from direct participation of households and forest owners and local government agencies. Such a participatory approach in monitoring systems ensures improved forest conditions and provides greater quality and quantity of information on forests and the impacts of management interventions, thereby contributing to the National Forest Inventory (NFI).

Over the past few years, international climate change mitigation mechanisms aimed at reducing greenhouse gas (GHG) emissions or enhancing removals from tropical forests have emerged. One such mechanism is known as REDD+, which includes the following five eligible activities:

1. Reducing emissions from deforestation
2. Reducing emissions from forest degradation
3. Conservation of forest carbon stocks
4. Sustainable management of forest
5. Enhancement of forest carbon stock.

Developing countries like Vietnam could present evidence of emission reduction (ER)/ emission removal (ER) from land-use change in return for results-based ‘positive incentives’ from REDD+. A national measurement, reporting and verification (MRV) function serves as evidence of reduced emissions or enhanced removal of GHGs.

The UNFCCC, in addition to many international donors, requires national REDD+ programme design and implementation to promote and support full and effective participation of all relevant stakeholders, in particular indigenous peoples and local communities. Participatory carbon monitoring (PCM) –in which the national REDD+ authority, state forestry agencies, forest managers and local communities collaborate to collect, manage, verify, report and analyse data on the carbon stored in the forest – could be one of the options to demonstrate the engagement of all relevant stakeholders.

The Participatory Forest Carbon Monitoring manual presents simple participatory methods for measuring forest biomass carbon stocks to be applied by technical staff and forest owners so that they can measure and monitor forest carbon with the support of staff from state forestry agencies and ensure reliable information towards claims for REDD+ benefits under the NRAP.

Three individual manuals have been prepared to facilitate stakeholders’ participation in carbon monitoring. The **Manual for Local Technical Staff** is for use by local forestry staff for designing and implementing PCM activities in the field and analysing PCM data. Second in the series is the **Manual for Local People** which is for use by local households and communities for collecting and monitoring field data. A third in the series, the **Manual for Field Reference**, is to be used in the field for quick reference. In these manuals, approaches for forest biomass and carbon estimation applicable for a REDD+ programme are divided into the following two phases:

- Inventory of forest at forest management units
- Analysis of inventory data or synthesising inventory data - calculating errors, and estimating biomass and carbon stock and change at each ecological region, forest type and forest status and aggregating results at project, provincial or national level.

It is anticipated that data collected from PCM will be integrated in the NFI[1] in Vietnam following a simple framework as shown in Figure 1.

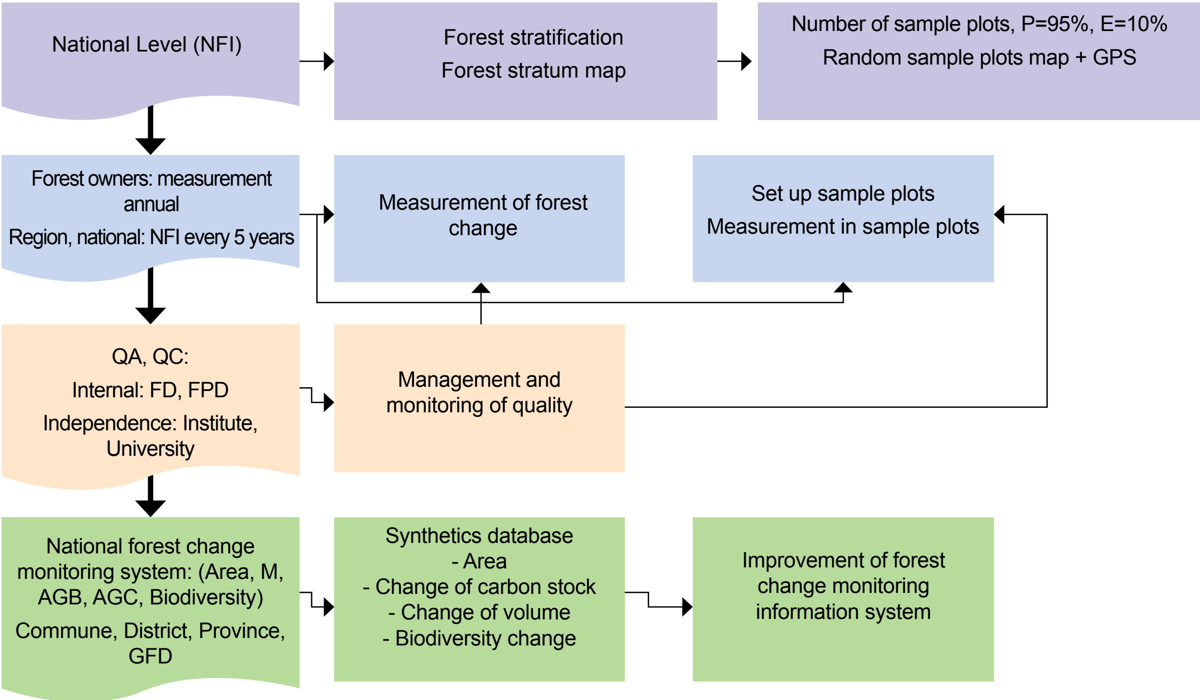


Figure 1. System of measuring, monitoring and reporting forest resources, biomass and carbon (integrated in PCM and the national system)

In the framework described in Figure 1, ***National Forest Inventory*** (NFI) provides forest stratification maps interpreted from remote sensing and Geographic Information System (GIS) technology. The NFI information can be used in determining the required number and location of sample plots as well as preparing maps of sample plots. These maps will be provided to forest owners and communities and are periodically measured, for example, every five years.

Households and communities who have been assigned to or are allocated with forest for management, and forest management organisations (forestry companies, management board of the special-use forest, management board of protection forest) are included actors in participatory carbon monitoring. The basic parameters such as tree species, diameter at breast height (DBH), height (H), animal and plant information are measured within sample plots determined/established by NFI or NFI administrating institutions within administrative boundaries (province, district, sub-ecoregion and forest type). The change in forest area is also monitored as frequently as annually.

Quality assurance and quality control of the measurement within plot and monitoring of forest area change are decentralisedto provincial level. The quality assurance activities can

1 A detailed guidance for such integration may be required.

be conducted by internal agencies such as Forestry Department or Forest Ranger; and by independent consultant, university and research institute.

Monitoring changes in forest resources and forest biomass carbon: There may already be a monitoring system for forest area change. For the REDD+ programme, other parameters such as biomass and carbon can be added into an existing monitoring system. The synthesis of data and update in the monitoring system follows a participatory approach involving stakeholders from household, commune, district, province and national level in which district and communal levels gather original data, while the provincial level synthesises it to estimate changes in forest area, biomass, carbon, volume and other fauna and flora before transferring them to the national system.

Objectives of manual and target audience 2

2.1 Objectives of the manual

- Provide local technical staff and local households and communities with simple procedures to monitor forest biomass and carbon and
- Assist technical staff and local households in surveying biomass and carbon, monitoring area and estimating change in forest biomass and carbon.

2.2 Target groups for these manuals

The target groups for this manual are agencies, organisations and individuals responsible for forest management who are also facilitator of REDD+ programme implementation. . These include:

- Government managers related to forestry at different levels to monitor the implementation REDD+ projects at forest management unit level
- Forestry staff of the Department of Agriculture and Rural Development, Forest Protection Department, Forestry Department and relevant departments at district and commune such as extension, ranger, national park, foresters in forestry company officials, commune forestry board and commune extension
- Local communities involved in field data collection.

Defining and standardising data collection approach 3

In order to measure and monitor forest biomass and carbon in each province and region, the two types of data collection and management approaches are defined and standardised. These are:

- Stratification map of forest status for each ecological zone. The map should be delineated to administrative boundary of province, district, commune, and forest management unit.
- Number and location of sample plots on different strata for each ecological zone and boundary demarcation of administrative units such as provinces, districts, communes and forest owners.

3.1 Mapping forest stratification and status

At minimum, the map should classify land area into six different land cover classes of IPCC (i.e. forestland, cropland, grassland, wetlands, settlements and other land). Within the forest land category, different forest types and status can also be included. The land cover maps must be built from high- to medium-resolution satellite images. The sub-categories within forestland must be determined based on forest type, density, volume, species or species groups so as to obtain homogeneity biomass.

Forest areas should be classified into homogeneous units or strata based on one or more of the following key characteristics:

- Forest types: major forest types such as broadleaved evergreen forest, deciduous forest, mixed broadleaved and conifer, mixed woody forest and bamboo, bamboo, dipterocarp forest, pine forest, mangrove forest and plantation forest etc.
- Degree of impact and degradation: the extent of forest degradation and change in volume and biomass such as rich, average, poor and young forests
- Dominant tree species: Dominant and co-dominant species at a given site. This mainly applies for plantation forest
- Tree density and stand volume: Different sites may have different tree density and volume. Remote sensing analysis may reveal differences in tree density. For example, plantation forests may show as dense forest or open forests
- Forest age: only applicable to plantation forest.

The mapping or stratification are conducted at provincial and national level. These maps are used to monitor forest areas, estimate biomass changes within a stratum and determine number and location of sample plots.

The forest maps for three categories of forests and forest change maps are available for Vietnam. These maps are updated every year by the forest ranger. In addition to national and provincial forest cover maps, individual projects may have more accurate maps that can be used for PCM. An example of such a map is given in Figure 2.

In order to undertake participatory forest carbon inventory, accurate forest maps from NFI should be used. However, as an intermediary measure and in the absence of a detailed and accurate map, currently available forest classification maps can be used on the conditions that sample plots will be redefined and redeployed when more accurate maps become available.

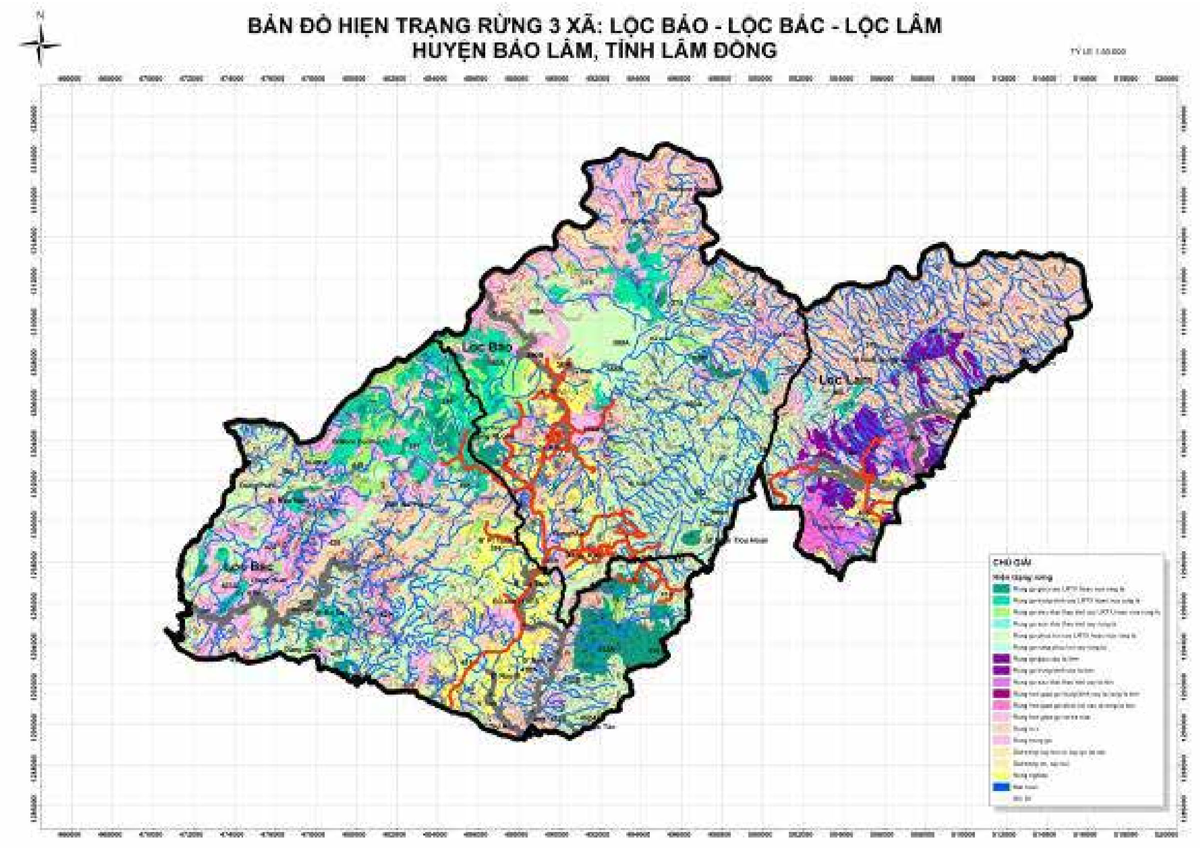


Figure 2. Map of forest status in three communes of Lộc Bảo, Lộc Bắc and Lộc Lâm, Bảo Lâm District, Lâm Đồng province.

(Source: Forest protection department of Lam Dong)

3.2 Define number of sample plots for each forest status and randomly arrange sample plots on forest map and Global Positioning System (GPS)

3.2.1 Identification of required number of sample plots

This work should be performed at national or provincial level. A preliminary inventory needs to be completed to estimate the expected variance of the carbon stock in the living trees in each forest stratum and to estimate the required number of permanent plots. Preliminary inventory must be carried out in 10 to 15 (preferably 30) randomly selected plots in each forest block and/or stratum within the owner's boundary and/or ecological zone.

According to IPCC, the number of sample plots for estimating biomass and forest carbon must be determined such that the error in estimation is below 10% of the mean at each stratum at 95% confidence level. If the error is greater than 10%, further investigation may be needed. Further dividing the strata into homogenous classes or increasing the sample plots may reduce the error.

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. Set the desired precision level of 10% of the mean at 95% confidence level.

Step 2. Select the location of the 10-15 (preferred 30 plots) 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 Hawths' tool of ArcGIS (http://www.spatialecology.com/htools/tooldesc.php).

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

Step 4. Calculate the standard deviation of carbon stock density [Mg C ha-1] for all the plots for each forest stratum.

Step 5. Calculate the number of plots in each strata by first estimating maximum possible number of sample plots in the forest (Eq 1) and in forest strata (Eq 2). Next, total number of sample plots required for the forest are estimated (Eq 3). Finally, the total number of sample plots required for each strata is estimated (Eq 4).

$$N = \frac{A}{AP} \quad \text{Eq 1}$$

$$N_i = \frac{A_i}{AP} \quad \text{Eq 2}$$

$$n = \frac{\left(\sum_{i=1}^{L} N_i \cdot S_i\right)^2}{\frac{N^2 \cdot E^2}{t^2} + \sum_{i=1}^{L} N_i \cdot S_i{}^2} \quad \text{Eq 3}$$

$$ni = n.\frac{N_i \cdot S_i}{\sum_{i=1}^{L} N_i \cdot S_i} \quad \text{Eq 4}$$

Where, N is the maximum possible number of sample plots in the forest area, A is the total area of the forest (ha), AP is sample plot size (ha), Ni is the maximum possible number of sample plots in stratum i, Ai is the area of stratum i (ha), n is required number of sample plots for stratum i, n is total number of required sample plots within forest area; S_i is standard deviation for each stratum i and E is desired level of precision.

E can be estimated as a percentage equivalent to the average value. Recommended percentage to apply is 10%. E = 10%*Xbq; Where Xbq is general average value of biomass stock density or carbon stock density for all strata which is : Xbq = $(1/\mathrm{N})\sum_{\mathrm{i=1}}^{\mathrm{L}} \mathrm{Ni} *$ xibq, xibq is the mean value of biomass/ha of stratum i.

For example, if the average biomass per ha (Xbq) is 83.8 and desired precision is 10%, then E is 83.8 * 10% or 8.38.

t is sample statistic from the t-distribution at 95% confidence level (t is usually set at 2 when sample size is not known).

Usually, the estimated number of sample plots is not a whole number. In that case, the required number of samples must be adjusted to the nearest integer that is not smaller than the estimated value. For example, if estimated sample size is 62.04 plots, then the adjusted number must be 63.

Sometimes sample plots are not accessible, lost or cannot be reoccupied for various reasons. For example, plots may be swept away by flood or burnt or be located on cliffs. Increasing the number of plots to some percentage over the required minimum can help meet the minimum requirement in situations when original plots are not available. Therefore, it is recommended that the minimum sample size should be increased by at least 15%.

Step 6. Visit the field and measure tree attributes biomass on the sample plots established in Step 5 and estimate biomass.

Step 7. Calculate the true relative half-width of the confidence interval around the mean for each stratum and compare these to the required precision 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 desired precision. Repeat steps 5-7 until the error <10%.

Relative error % (Precision level) compared with the average number of biomass/ carbon for each stratum is given by the following formula (Eq5):

$$Prececion\ level = \frac{SE_{ST} \cdot t_{0.05,n-1}}{X_{ST}}\ \% \qquad \text{Eq 5}$$

Where, SE_{ST} is the standard error of the stratified mean, SE_{ST} = Si/sqrt (ni), X_{ST} is the stratified mean of biomass/carbon and n is the number of sample plots. If the desired precision (i.e., 10%) is met, sampling can be finalised.

An example of calculating number of sample plots for strata

Input:

A is area of forest, which is equal to 57.670 ha; A_1 is medium forest stratum, A_2 is young forest stratum and A_3 is mixed wood-bamboo stratum. Strata A_1, A_2 and A_3 are respectively of size 38.708 ha, 10.027 ha and 8.935. Size of plot is 0.1 ha.

Then, N = A / AP = 576704.

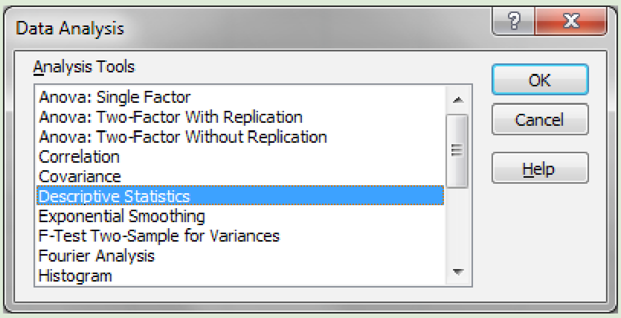
Ni inferred for each stratum i: N_1 = A1/AP = 387.083; N_2 = A_2/AP = 89.351; N_3 = A_3/AP = 100.270.

Number of sample plots for total strata of biomass/forest condition:

On the basis of the 26 sample plots taken, the total number of required sample plots are calculated by the formula:

$$n = \frac{\left(\sum_{i=1}^{L} NiSi\right)^2}{\frac{N^2E^2}{t^2} + \sum_{i=1}^{L} NiSi^2} \qquad \text{Eq 6}$$

The standard deviation of each stratum is calculated (Si) in Excel. S_1 = 59.699; S_2 = 62.354; S_3 = 19.359. Biomass/carbon was calculated from the database of sample plots. Database fields were created from sample plots for each stratum. Use sample statistics functions in Excel: Data / Data Analysis / Descriptive Statistics and get the value Si is Standard Deviation



E = Xbq* 10% = 83.8*10% = 8.38; t = 2 (P = 95%)

then n = 160 sample plots for three forest strata

Divide the number of sample plots for each forest stratum (ni):

$$ni = n.\frac{Ni.Si}{\sum_{i=1}^{L} Ni.Si} \qquad \text{Eq 7}$$

then n_1 = 121; n_2 = 29 and n_3 = 10.

The measurements are carried out in sample plots estimated above. The relative error % (precision level) compared with the average number of biomass/carbon for each stratum is calculated. If precision level is <10% the number of sample plots are considered enough. If 10% precision is not achieved in any stratum, additional samples must be taken or strata must be modified.

For example: with sampled n_2 = 29 plots in stratum i = 2 (young forest), then S_{EST} = S_2/sqrt (n_2) = 2.94, X_{ST} = 44.33 tone C / ha and t = 2. Mean error = (S_{EST} * t / X_{ST}) * 100 = (2.94 * 2/44.33) * 100 = 13.6%. Since such errors have not reached 10%, more plots must be added for this stratum to ensure the error is under 10%.

Because of low reliability of existing forest maps and unavailability of standard deviation information for forest strata, the required number of sample plots may not be calculated for each stratum in advance. In such a situation, the following alternative approach is recommended:

- Sampling 30 plots in each stratum.
- The number of required sample plots for all strata presented on the existing map should be determined. If the required sample plot number is larger than 30, then additional sample plot measurements must be conducted.

3.2.2 Design random sample plots on the stratum forest map

Sample plots in each forest status should be randomly assigned on a map with coordinates of every plot. These will form the basis for determining positions in the field where forest tree and biomass are measured. The random plot locations can be determined for each stratum using the “create random point” tool in ArcGIS.

The expected outcome:

Network of sample plots for each forest owner

Forest management units, where inventory and monitoring of forest resources and forest carbon take place, are marked on the map.

Preparation materials:

- Digital map of forest strata (interpreted from satellite imagery)
- ArcGIS software and GPS equipment such as DNR Garmin (including cables)
- Plotter or other printing device

Procedure:

i) Design and locate random sample plots for each stratum on forest map

The number of permanent sample plots is dependent on the size of forest stratum and size of plot. Size and shape of plot must be same for the entire area. Once the number of plots is determined, the random sample plots must initially be laid out for each stratum in a forest map using the “create random point” tool in ArcGIS. Use the following steps to achieve this:

Step 1: Dissolve spatially discreet forest blocks by forest status

Purpose of this step is to create homogeneous stratum of forest. Spatially discrete forest blocks with similar status are combined into one stratum. Use the following two steps in ArcGIS:

- Select the data layer that contains polygons of forest status blocks
- Use Dissolve to combine all polygons having the same status into one:
    - Click Dissolve tool
    - In the dialog box, select data layer containing forest status in Input Feature. For example, if sample plots are to be arranged by household or status block, layers of status blocks or households must be selected. Specify output file in Output Feature Class. Select forest status field under Dissolve Field. Click OK

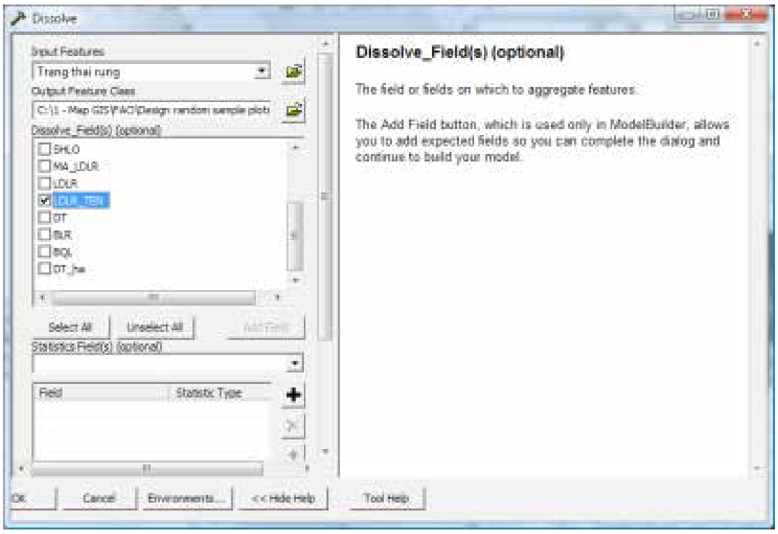


Figure 3. Dissolving forest status

Step 2: Design random sample plots on the forest map:

From this procedure, a network of random sample plots are created and overlaid on the dissolved forest blocks (polygons):

- A field (of type – numeric) is created in the GIS layer containing the dissolved blocks. This field stores the number of sample plots for each block. The number of samples for the status block of each forest type and ecological zone is calculated using Eq 8 (symbols are as explained earlier in 3.2.1):

$$ni = n.\frac{Ni.Si}{\sum_{i=1}^{L} Ni.Si} \qquad \text{Eq 8}$$

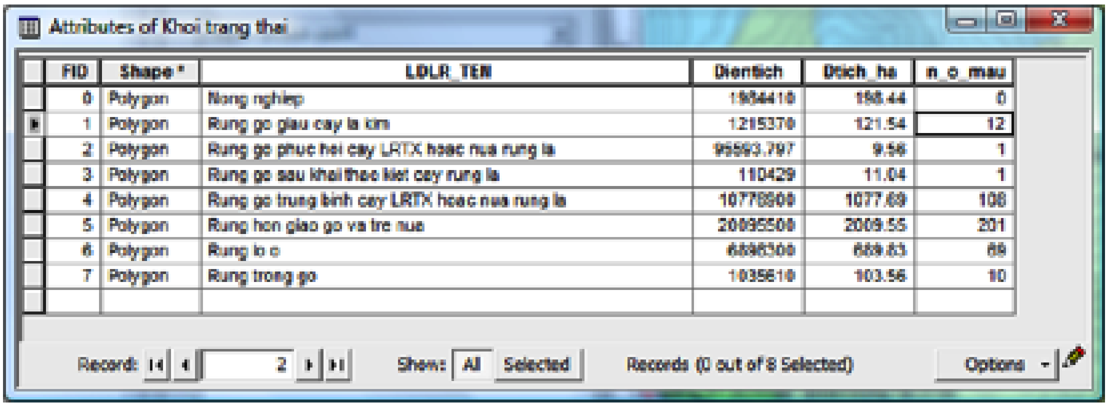
When sample plots are determined by a proportion of area (i.e. based on rate), the number of samples is determined as in Eq 9:

$$ni = \frac{1\%\ X\ Area\ of\ Block\ i\ (ha)}{Sample\ Plot\ Size\ (0.1\ ha)} \quad \text{Eq 9}$$

In this example, the rate of sampling is 1% of the area of forest status. The area of sample plot is of 0.1ha.

- Number of sample plots for each block is calculated using the Field Calculator function in ArcGIS (Figure 4) and the result can be verified in the field attribute table of the GIS shapefile (Figure 5).

Figure 4. Using Field Calculator to estimate assign number of plots to each stratum


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 giau 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	6896300	689.63	69
7	Polygon	Rung trong go	1035610	103.56	10

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

Figure 5. Attribute table of dissolved forest block layer showing number of plots for each stratum

Step 3: Location of required number of random sample plots for each stratum or block status is determined in ArcGIS using the following procedure:

- In ArcGIS tool, select Create Random Points
- In Number of Points, select the field created earlier storing number of plots for each block
- Enter an appropriate for Minimum Allowed Distance. This is the smallest distance

allowed between two random placed plots (with sample plot radius of 17.84 m then minimum distance between 2 plots should be 50 m)

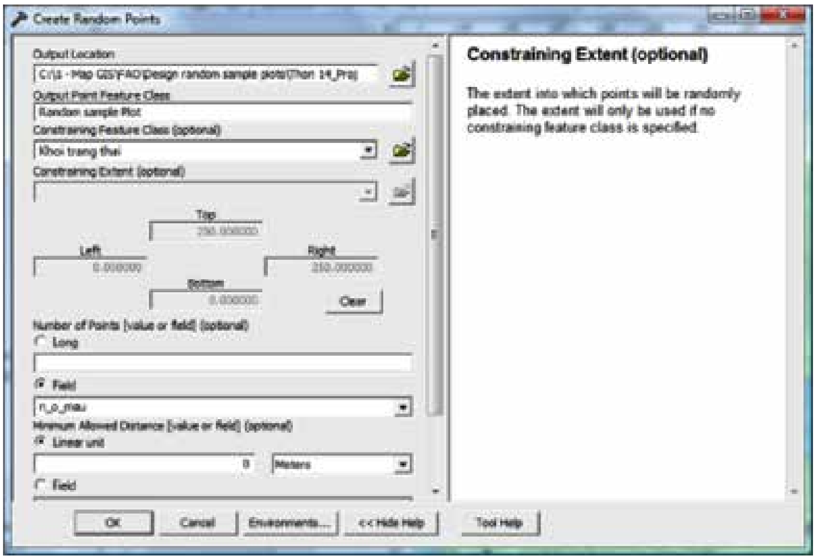


Figure 6. Create Random Points input dialog in ArcGIS

- The result is a network of plots on maps with the number of random plots in blocks determined
- A new file is created with location of random plots
- In ArcGIS add fields to X- and Y- coordinates and using Add XY Coordinates, calculate coordinates for each random plot
- Create a field for sample plot identification, e.g. “SO_hieu_o” and use Field Calculator to assign number to each point using: So_hieu_o = FID +1

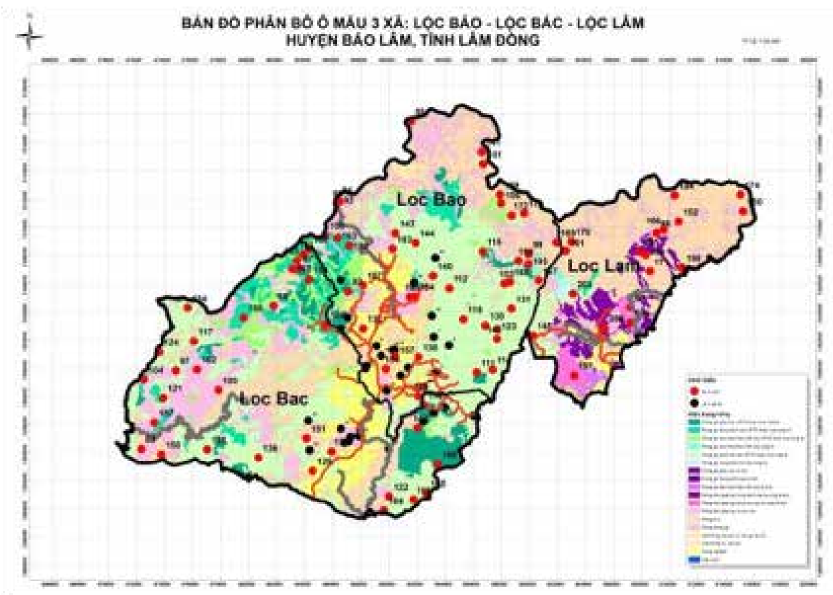


Figure 7. Location of random sample plots in the three communes of Lộc Bảo, Lộc Bắc and Lộc Lâm, Bảo Lâm District, Lâm Đồng province

Attributes of O mau ngau nhien

FID	Shape	CID	So_hieu_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

Record: 0 Show: All Selected Records (0 out of 402 Selected) Options

Figure 8. Attribute table of random sample plots showing plot id, and XY-coordinates

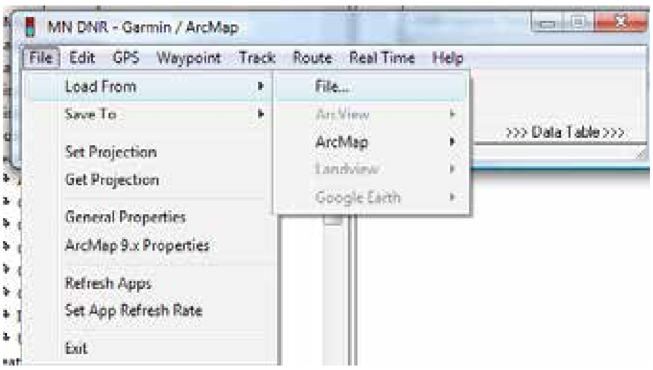
ii) Upload the coordinates of the random sample plots into the GPS

Positions of sample plots should be transferred into the GPS using the following steps:

Step 1: Open DNR Garmin software and connect the GPS.

Step 2: Set up coordinate system – select File/Set Projection. Load PRJ and select file of sample plot coordinates. The coordinate file has 'prj' or 'prg' extension, which contains information of coordinates (For example: VN2000).

Step 3: Open data set of established plot coordinates: File/Load from/File …. Select files in shapefile format to open saved coordinates. In identify field, select the field that has plot identification information, for example, So_hieu_o has plot identification number.



Step 4: Verify that all the plots are loaded in DNR Garmin

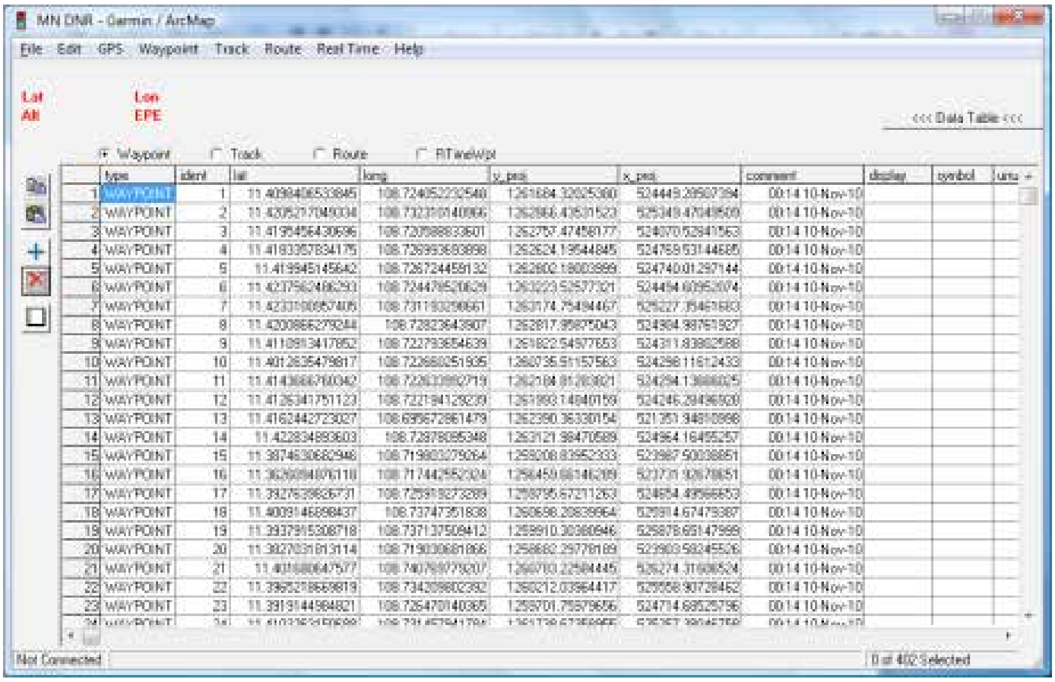
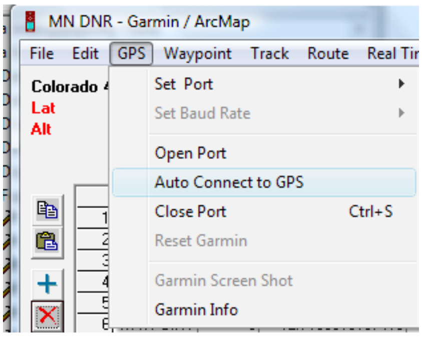
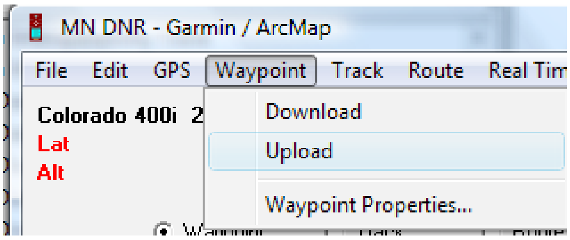


Figure 10. Loaded plots in DNR Garmin

Step 5. Upload data from file of sample plot coordinate into the GPS.





The completion of these steps will transfer the locations of sample plots into the GPS. Use GoTo function in the GPS to navigate to sample plots.

Organisation of measurement techniques in the field 4

The monitoring of forest area and measurements in the field is carried out with the participation of household, communities and forest owners. Until the full capacity of local stakeholders is developed, it is recommended that a forestry technician leads the local participation and continues to provide onsite support. It is recommended that the field team or crew includes one local forestry staff, with a minimum of intermediate proficiency, and four local people representing households, under represented groups such as women etc. Depending on terrain and distance to forest in the project pilot areas, one team can set up and measure 2-3 sample plots per day.

Field measurement 5

Two types of data for monitoring forest carbon are:

- Forest area and forest status changes
- Forest biomass and carbon in sample plots.

5.1 Monitoring forest area and forest status changes managed by forest owner

Communities, forest owners and households can use the GPS to measure the area of forest loss and forest changes and to provide this data for professional agencies. Forest owners, individual families, households and communities monitor forest area change frequently. If the change in forest boundaries of any owners or households are detected the changed areas are delineated using track enabled GPS. The delineated boundary is then transferred to the boundary map and forest cover change is estimated.

Expected outcomes:

- Forest boundaries of different forest owners are delineated, areas are estimated and they are shown on the boundary maps
- The status of forest changes are monitored (e.g. forest under selected logging may have reduced forest quality, such as going to poor forest from medium forest status). Likewise, the status of deforestation of the forest management unit when the forest area changes to non-forest area. These changes will be updated on the maps along with attribute data.

Material required:

- Topographic map and forest maps at scale 1:10,000 - 1:25,000. These maps may be derived from satellite imagery or air photos. In Vietnam, the latest available status maps are the planning maps produced in 2008. These were prepared using SPOT 5 imagery and projected into VN2000 coordinates. The actual forest area may have changed since these maps were produced. Until accurate forest status maps are available, the existing forest maps will be used. However, validation of forest area and forest status should be performed at the beginning of the process
- Map of forest boundaries depicting different forest owners
- GPS
- Suunto clinometer for measuring tree height and slope and compass for orientation
- Form for recording forest cover change (Form 1 in Appendix 1)

Procedure:

Each forest block of a forest owner should be digitised on base maps using Mapinfo or ArcGIS software for data input. The data tracking from the GPS receiver is downloaded as a shapefile though DNR Garmin software. The areas of individual forest blocks are specified after digitising the GPS data.

The steps are detailed as follows:

Step1: Delineation of forest boundaries of forest owners and forest status on the field - The change of forest area is reflected on the forest status map. Use the GPS to delineate the area (Figure 12).

Use of the GPS for delineating:

- Turn on the GPS
- Press Menu twice to access Track, then press Enter
- Using Clear button to delete all old tracks
- Press Menu and select Area Calculation
- Enter twice to start with track function
- Walk along the boundary to delineate the area boundary with the GPS
- To end the delineation, press enter twice to stop track
- Save and name the result, then press OK to finish the area delineation.

It is important to promptly turn off the track function once boundary delineation is complete before proceeding to the next area. If the GPS is left turned on, even not to use the track function, the delineated areas will connect together, consequently, it is difficult to disitize them on GIS.

In the initial stage, use of the GPS for delineating forest cover changes will be led and instructed by a member of technical staff.. Once local people feel confident in using the GPS, they can independently undertake the boundary delineation activity.

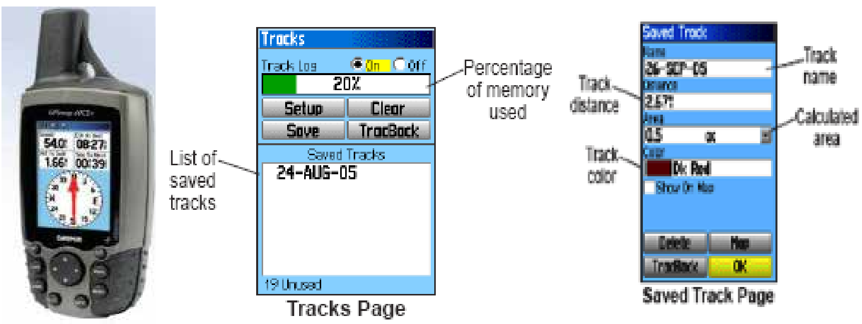


Figure 12. Picture of GPS 60CSx (left), track function of GPS (centre), and saved track page (right)

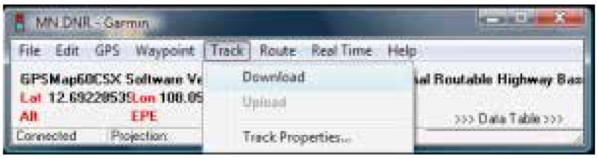
Step 2: Data recording forest cover changes - Use Field Form 1 to record following information on forest area change:

- General information about the location, forest owner, time of measurement and inventory personnel.
- VN2000 (X and Y) coordinates of four corners of the changed forest area or block or changed plots. This information is also recorded in the GPS
- Description of change with explanation of potential causes of such change.

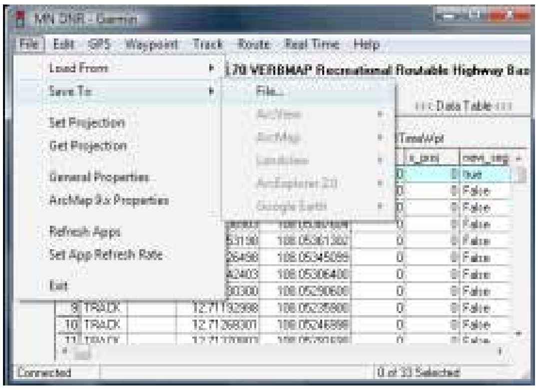
Step 3: Download track data from the GPS into GIS software (for both UTM and VN2000 coordinates) – Use the following procedure to download data:

For UTM coordinate: Using DNR Garmin software

- Connect the GPS to GIS equipped computer. Open DNR-Garmin
- Select GPS/Auto Connect to GPS
- Download track (delineate variable areas in GIS) by clicking Track/Download (Figure 13)
- Save the track data in shapefile format compatible with GIS software such as Mapinfo or ArcGIS: File/Save to (select type of file in *shapefile) (Figure 11). This file will be opened in GIS to modify or correct any discrepancies.



Download tracks from the GPS through DNR

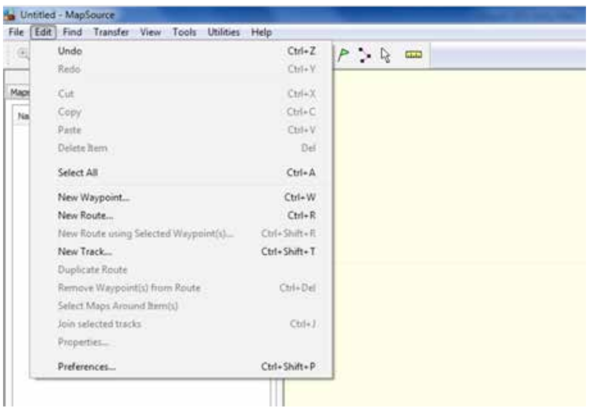


Tacks save in shapefile format in DNR

Figure 13. Illustration of saving track data from GPS into GIS equipped computer.

For VN2000 coordinate: Using MapSource software

- Connect the GPS to the computer by cable
- Start Mapsource/Menu: Transfer/Receive From Device, select GPS in Device box, then select data (in this case select Tracks/ Receive/OK)
- To preserve VN2000 coordinate, map datum and projection: Menu Edit/ Preferences/ Position and then select Grid and Datum as Figure 14



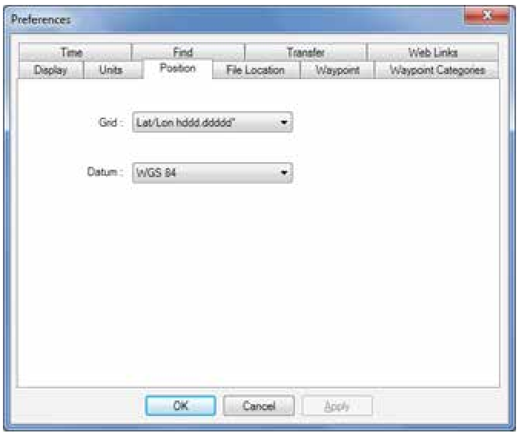


Figure 14. Illustration of Grid and Datum for VN2000 coordination in MapSource.

- Save data to transfer to GIS Mapinfo: click Save as in menu File, select Save As type as "DXF", name file and click Save
- Transfer data to Mapinfo: start Mapinfo, in menu Table/Import File, select File saved in Mapsource: click Open, select file of type to present the data (in this case tracks was selected) and select projection as Figure 15

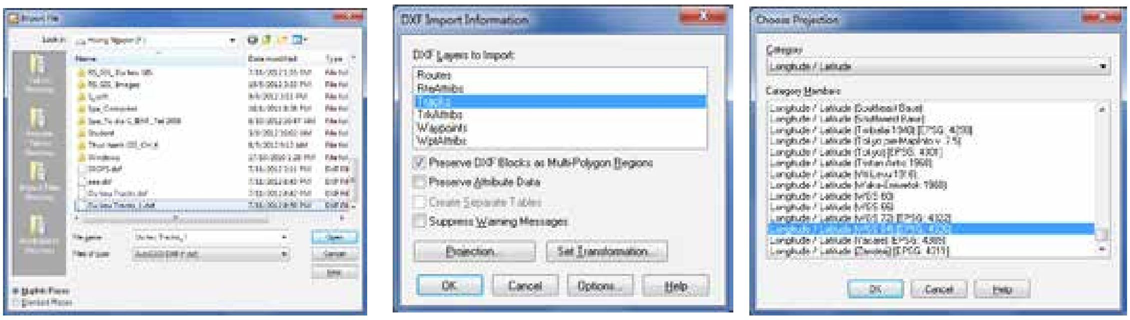


Figure 15. Transfer tracks data into Mapinfo

- Open file saved in Mapinfo, Save Copy As and select projection in coordinate system of VN2000.

As a result tracks data from GPS transferred to Mapinfo with seven parameters of coordinates of VN2000. This file can be transferred to shapefile which can be read in ArcGIS software.

Step 4: Split the forest area in GIS. The GIS software (such as MapInfo or ArcGIS) is used to overlay the GPS data of changes on the map. The split function may be used to cut the area of the forest plot changes (Figure 16).

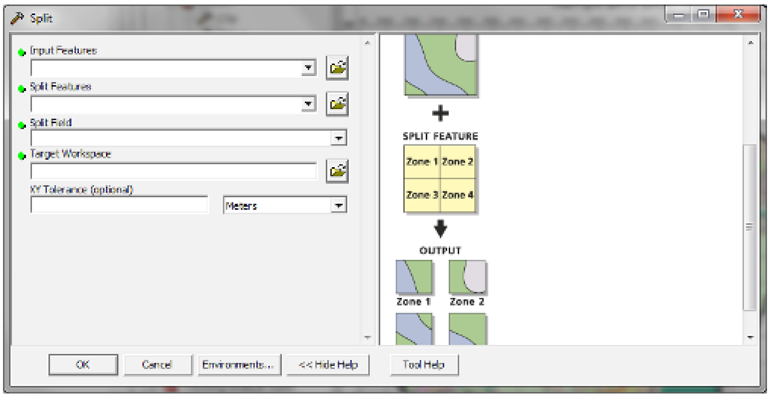


Figure 16. Using Split function to identify areas that were identified as changed

Completion of this step will result in forest maps that show changes within forest area. This data must be transferred to relevant management units for updating and recording.

5.2 Establish sample plot, measure forest parameters to convert to volume, above biomass/carbon

PCM is focused on measuring forest parameters to estimate volume, biomass and carbon by forest owners, households and communities every year through the measurements on sample plots. It also is used in periodic measuring every 5-year in NFI. While temporary plots can also be used in PCM, for simplicity, permanent sample plots are recommended for periodic measurements.

5.2.1 Determine location of sample plots in the field

Expected outcome:

- Randomly selected permanent sample plots in the field. These plots are monitored to periodically collect relevant data to estimate wood volume, biomass, carbon and others.

Materials required:

- Map of random sample plots overlaid on the forest map
- Suinto clinometers with compass for measuring tree height and slope as well as for navigation in the field
- GPS with coordinates of random sample plots uploaded
- Sheet to record code and coordinates of sample plots
- Iron board for making number sign for sample plots and recording coordinates of plots
- Hammer and nails to affix identification tag
- Paint to mark number or sign of sample plots and tree
- Digital camera (Optional)

Procedure:

Coordinates of random sample plots are loaded into the GPS from a map of sample plots through DNR Garmin software. The navigation function of the GPS is used along with a compass to determine the geographic location of the sample plot (usually plot centre).

- Press button Find/Waypoint in the GPS. Select the plot (name or identification number) and select Goto and select Off Road. A sheet of coordinates and relevant information such as forest status, forest block, sub-forest compartment and forest compartment, area is also prepared to check in the field Press Find, then press Enter to access Waypoint
- From the list of plots, select the plot to be sampled
- Press **Go to** and select **Off Road**
- Walk in the direction shown on the GPS. The GPS will sound an alarm when the destination plot is reached
- The coordinates of the defined plot centre should be checked in the GPS and on the map
- If s camera is available, **take a picture of the GPS** while the GPS is showing the coordinate position
- End Goto function by pressing **Menu** and then selecting **Stop Navigation**.

At the centre of permanent sample plots, **place the plot marker** i.e. concrete or wooden pillar and affix an iron board.

Write the identification number of sample plots and coordinates (i.e. VN2000 coordinates) directly onto the iron board with permanent paint or marker.

The permanent marker on the field will be useful for locating plots for repeated measurements.

Take a picture of the plot centre with the iron board and code of the plot clearly visible.

Figure 17. Determine position of random sample plot using the GPS

5.2.2 Design sample plot (shape, size) according to forest types

Permanent sample plots are established in the forest at predetermined random locations.

The shape of the plots can be rectangular, square or circular. In this document, circular sample plots are recommended for use, as they are relatively easy to establish in the field. Additionally, a concentric plot is convenient for households and communities in location plots in the field. Within the sample plot, trees of different sizes are measured in different sized sub-plots: larger trees are measured in larger sub-plots and smaller trees are measured in smaller sub-plots.

Expected outcome:

- Nested circular plots are established in the field.

Materials required:

- Suunto clinometer
- Four ropes with a range of colours knots at specified intervals equivalent to the radius of the sub-plots.
- Form for additional distances at different radius for plots located on slope.
- Digital camera (optional)

Procedure:

Design circular sample and sub-plot for different forest types:

Nested circular plot consisting of four concentric circles or sub-plots are used. Large trees are measured in larger circular plots while small trees are measured in smaller circular plots. The plot design also varies by forest type.

- For **evergreen, semi-deciduous, dipterocarp, and pine** forest:

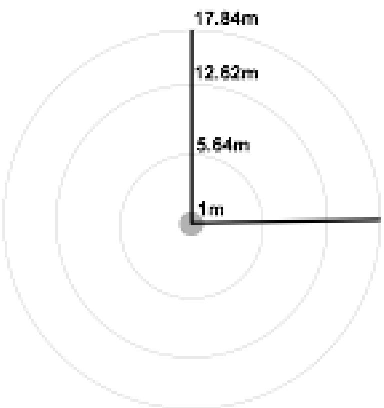


Figure 18. Layout of circular nested plot with four concentric sub-plots

- Sub-plot 1: radius 1 m, area 3.64 m2, measure regeneration with DBH < 6 cm and H ≥ 1.3 m
- Sub-plot 2: radius 5.64 m, area 100 m2, measure tree 6 cm ≤ DBH < 22 cm or bamboo
- Sub-plot 3: radius 12.62 m, area 500 m2, measure tree 22 cm ≤ DBH < 42 cm
- Sub-plot 4: Radius 17.84 m, area 1000 m2 to measure tree ≥ 42 cm DBH

- For **bamboo** forest, the size of sample plot is 100 m2.
- For **mixed woody – bamboo** forest, measure trees as in the case of evergreen forest in four concentric sub-plots and measure bamboo only in sub-plot 2.

- For **plantation forest**, the maximum diameter in plantation forest rarely exceeds 42 cm. Therefore, the measurement of the tree is conducted in sub-plot 3 in 500 m2 circular plots with a radius of 12.62 m.

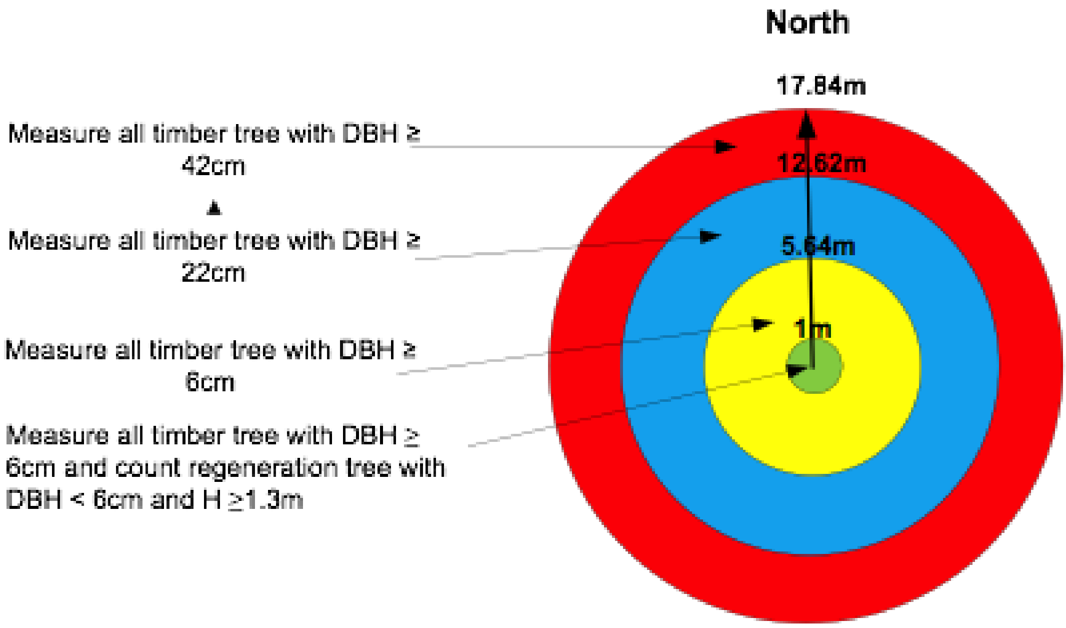
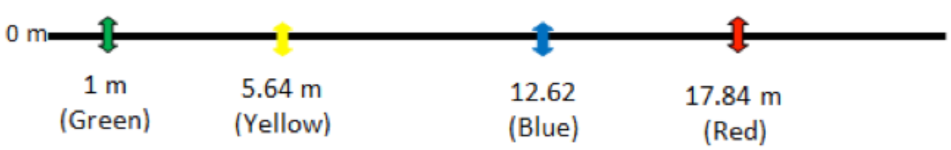


Figure 19. Measure diameter class according to radius of sample plot.

Within 1 m radius sub-plot (green), measure all trees with DBH ≥ 6cm and count regeneration trees with DBH< 6 cm and H ≥ 1.3 m; within 1 m - 5.54 m radius sub-plot (yellow), measure all trees with DBH ≥ 6 cm; within 5.64m - 12.62 m radius sub-plot (blue), measures trees DBH ≥ 22 cm; and within 12.62 m - 17.84 m radius sub-plot (red), measures trees DBH ≥ 42 cm (Figure 19).

Establish circular plot and sub-plots in the forest:

- Prepare a rope with several knots. Use different colours for individual knots. Put knots at intervals equivalent to the radius of the sub-plots. For example, make a green knot at 1 m, a yellow knot 5.6 m, a blue knot at 12.62 and a red knot at 17.8 m (Figure 20). The length of rope should be about 25 m. Four ropes with colour knots need to be prepared. On each rope, at each colour knot add another coloured (for example black) knot that is movable along the rope to adjust for the radius of sub-plots on slope.



- Measure slope of the ground at each plot using the clinometer in eight directions (i.e. every time rope is laid on the ground along plot radius) (Figure 21).
- Ask one field crew member to stand on the slope. With the clinometer, aim at the head of the person standing above or below the slope to create the line of sight (Figure 22). The line of sight must be parallel to the slope surface. The indicator on the left of the clinometer shows the slope angle, which must be recorded.

- A table with slope corrected horizontal distances can be taken to the field (see Appendix). The knots for representing the radius for the plot must be corrected accordingly. For example, if a plot is located at a slope of 20 degrees, then using the slope corrected distance, the green knot should be placed at 1.06 m distance, the yellow knot must be placed at 6 m, the blue knot must be placed at 13.43 m and the red knot must be placed at 18.98 m. Use linear tape to mark these locations in the field.

Figure 20. Compass and clinometer

Figure 21. Obtaining slope using clinomete

- First, stretch one rope from centre towards the north. Stretch another rope to the east. Stretch a third rope at 45 ˚ N between the first and second rope. As a result, two segments are established from north to east. Measurement is carried out from the left to the right segment (i.e. clock-wise) and from the centre towards the sub-plot radius indicated by the coloured knots.

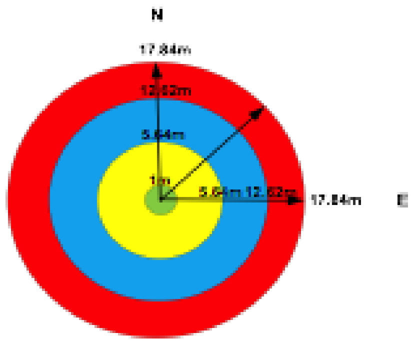


Figure 22. North-east section of plot

- Second, the north and east ropes are fixed while the rope that was in between is moved to the south (opposite to north). A fourth rope is stretched in between south and east. Two segments are created between the south and the east. Measurement is carried out from the left to the right segment and from the centre towards the sub-plot radius.

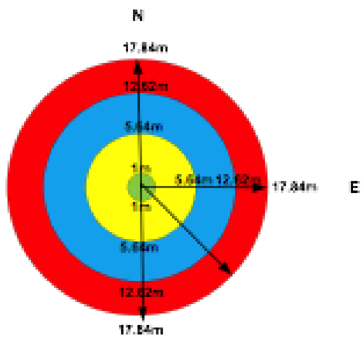


Figure 23. South-east section of plot

- Third, the north and south ropes are fixed while the rope in the east is moved to the west. The rope that was between east and south is moved in between south and west. Measurement is carried out from the left to the right segment and from the centre towards the sub-plot radius.

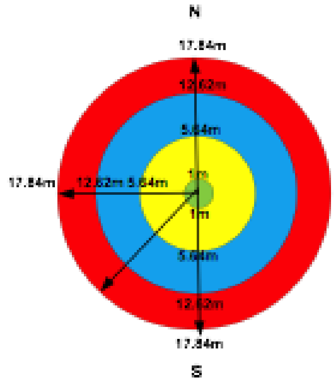
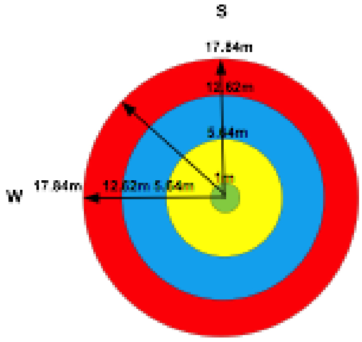


Figure 24. South-west section of plot

- Finally, the ropes in the north and west are fixed while another rope is placed between west and north. Measurement is carried out from the left to the right segment and from the centre towards the sub-plot radius.



- At the four directions of north, east, south and west, red painted wooden pillars are placed.

Figure 25. North-west section of plot

5.3 Measurement within sample plot

Result: Data of timber and bamboo and information on forest resources is collected annually on the plots.

Materials required:

- Diameter measurement tape (i.e. D tape)
- Chalk, marker or paint for marking the tree
- Iron board or tree tag for marking trees
- Hammer and nails to affix tree tag
- Paint to mark sign of sample plots
- Spreadsheet for recording inventory factors (Forms 2, 3 and 4 in Appendix 2)
- Digital camera for taking pictures (optional). Figure 26. Diameter measuring tape (D-tape)

Figure 26. Diameter measuring tape (D-tape Figure 26. Diameter measuring tape (D-tape)

Procedure:

- For woody tree, identify species and measure DBH if tree's DBH is greater than 6 cm. For trees with DBH < 6 cm and height ≥ 1.3 m, count the number within the sub-plot 1. Use tree tags to mark the trees and paint at 1.3m position (Figure 27).

- Bamboo is measured in 5.64 m radius plot. Age and individual DBH is measured. In case of certain species of bamboo, such as for neohouzeaua, species information must also be recorded (Figure 28)
- Use Figure 29 to determine the position of DBH on the tree during DBH measurement for irregular trees or for trees standing on slopes
- If a tree falls on the plot boundary and over 50% of the stem is inside the plot, then it is considered to fall inside the plot and is measured. Otherwise, the tree is excluded
- Take a picture of trees and of crews measuring trees, and give pictures names beginning with the plot name. For example, if plot id is 104, then the name of the picture can be "104_NorthWest".

Figure 27. DBH measurement and placing tree tag number sign

Figure 28. Measuring bamboo

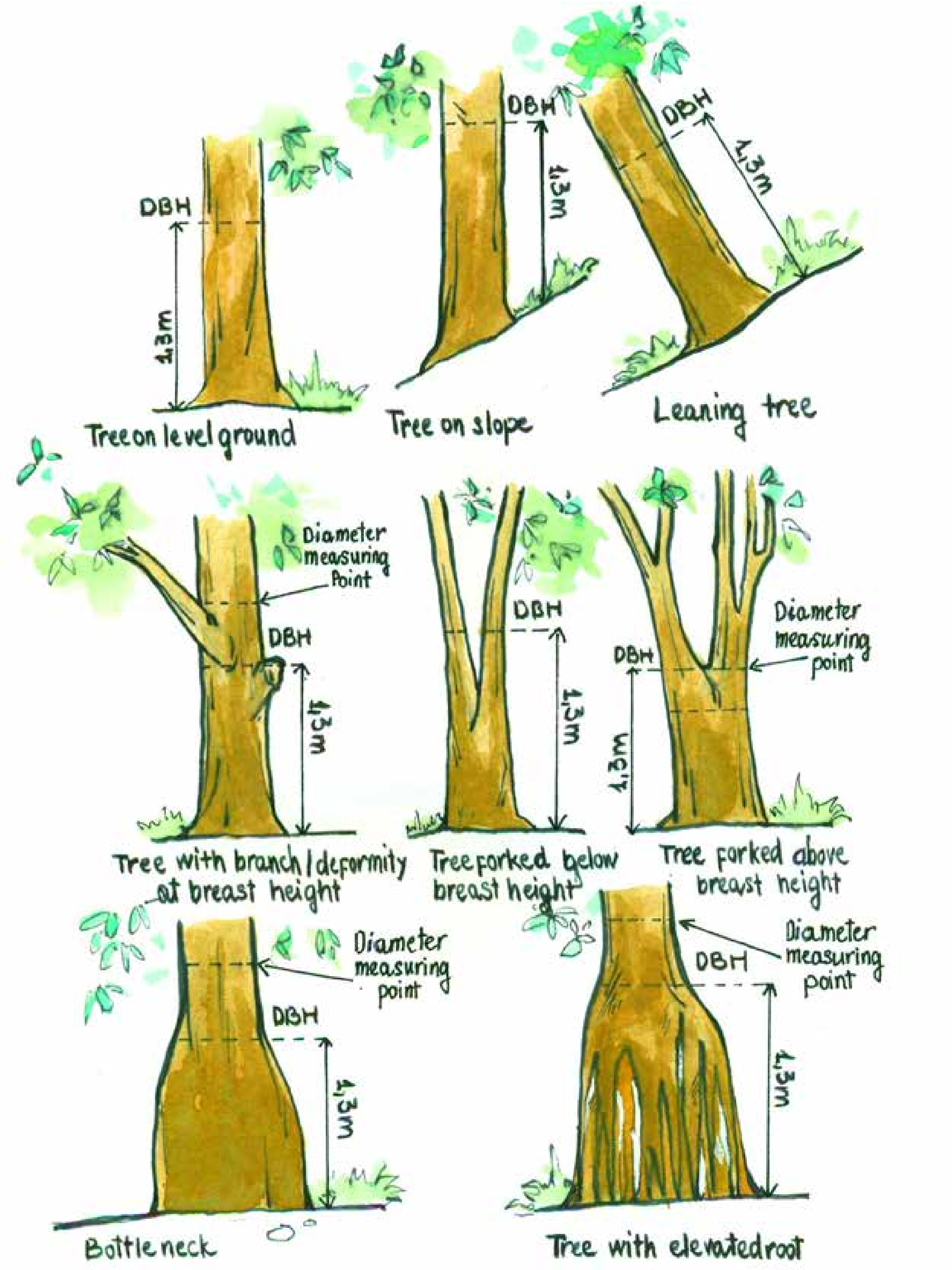


Figure 29. Measuring DBH tree

Method of estimating bamboo age based on aerial stem (Lam Xuan Sanh and Chau Quang Hien, 1984):

Age of bamboo plant can be assessed based on the following characteristics:

- *First year of age:* bamboo tree that finishes it growth period in previous rainy season, it has Characterised by
  - Sheath still exists on stem, usually near root
  - Stem colour light green and covered by a layer of “white powder”, but lichen has not developed.
  - Many small branches appear along the main stem. Very few young branches occur on the upper stem.
- *Second years of age:* Characterised by
  - Sheath is not present
  - Stem colour is green. Stem is covered by a layer of “white powder”, but less than that at the first year. No or minimal lichen present near root.
  - Many branches. Young sub-branches may occur.
- *Third years of age:* Characterised by
  - Main stem colour is dark green, lichens covers 30-40% of stem surface creating white spots in the stem. Green colour of stem is still visible.
  - Branches are mainly on top of tree. Old main branches manifest dark green with spotted lichen. Sub-branches may show.
- *Fourth years of age:* Characterised by
  - Stem is white due to strong presence of lichen (account for 70-80% of stem surface).
  - Branches are limited to the upper stem. Old main branches manifest dark green with spotted lichen.
- *Five years and more:* Characterised by
  - Stem colour changes to yellow, dense lichen develop along the stem
  - Decay and fall are apparent.

Frequency of plot inventory: The changes of stand volume and carbon are usually very slight within one year, however annual measurement allows forest owners to detect small changes caused by forest degradation activities e.g. logging. Therefore, an annual inventory should be conducted as long as resources permit.

Quality assurance (QA) and quality control (QC) in pcm

6

To ensure reliability and quality of information collected in the field, provisions for quality assurance (QA) and quality control (QC) must be made. A QA/QC system involving both internal and independent entities is recommended.

- *Internal monitoring is* performed by forestry agencies such as Forestry Department and Forest Protection Department (FPD).
- *Independent monitoring is* performed by research institutions or university if necessary.

The QA/QC provision should include:

- *Area monitoring* - Random sampling of 5 – 10% of total forest block to cross-check the reported forest area and forest cover change. An error of < 10% may be acceptable
- *Forest attributes* - Random sampling of 5- 10% of the sample plots. Compare the reported results. Acceptable if the error rate does not exceed 10%
- *Frequency of monitoring* - QA/QC must be done annually. It may be done at the time of inventory or immediately after the inventory. In the event of an abnormal or unexpected event influencing forest resources, such as flood, fire or other deforestation/afforestation activities, additional monitoring is conducted to ensure that changes occurring in forests after abnormal events are recorded.

Synthesise, update and monitor changes of stand volume and forest biomass/carbon 7

7.1 Synthesis of field data

The synthesis of data collected through PCM should be conducted by a professional forester or forestry agency, ideally at district or provincial level.

Expected outcome:

Two types of data synthesised: (i) area change of forest block, and ii) estimates of volume, biomass and forest carbon and their changes.

Materials required:

- Data form to record area change and coordinates from the GPS
- Data form for recording forest variables in the plot
- Computer or laptop, if available
- Form for standardising names of plant species
- Form for synthesising, converting to volume, biomass, carbon and CO2 equivalent
- Allometric equations to convert forest relevant variables to biomass and forest carbon. Relationship of H/DBH and tree volume equations to calculate stand volume.

Procedure:

i) **Forest area change:** data of forest cover change collected by GPS is uploaded to the GIS and area of forest block is estimated and updated.

ii) **Estimates of volume, biomass and forest carbon by inventory time:**

- Data collected from the plot is summarised for each forest owner and forest status
- Number of trees by DBH (N/DBH) or DBH classes is estimated
    + Assign each tree to DBH classes at 4 cm interval and 2 cm for bamboo
    + Estimate total number of trees within plot in each DBH class
    + Estimate trees per hectare: since each diameter class is measured in different sized plots, trees per hectare for different sized trees is estimated by using the following equations:

For regeneration with DBH < 6 cm and H > 1.3 m:

$$N/ha = \frac{10^4}{3.14 \cdot n_o} \sum N(DBH < 6cm) \qquad \text{Eq 10}$$

For DBH from 6 – 22 cm:

$$N/ha = \frac{10^4}{100 \cdot n_o} \sum N\ (6 \leq DBH < 22cm) \qquad \text{Eq 11}$$

For DBH from 22 - 42 cm:

$$N/ha = \frac{10^4}{500 \cdot n_o} \sum N\ (22 \leq DBH < 42cm) \qquad \text{Eq 12}$$

For DBH ≥42 cm

$$N/ha = \frac{10^4}{1000 \cdot n_o} \sum N\ (DBH \geq 42cm) \qquad \text{Eq 13}$$

Where no is number of plots of each status, DBH is diameter of trees, N/ha is trees per ha.

- Calculation of volume for plot and ha for each forest status: height - DBH relationship should be established to determine tree volume. Number of trees for DBH class (N/DBH) should be enumerated. Tree volume, plot volume and volume per ha for all forest strata is calculated using height - DBH relationship and trees per DBH class relationship and volume (V) equation from DBH and H. In the Central Highlands equations can be used (Bao Huy et al., 2012):

$H(m) = (0.799577 + 1.05918*\ln(DBH\_cm))^2$ Eq 14

$V(m3) = \exp(-9.802 + 1.8829*\ln(DBH) + 1.06268*\ln(H))$ Eq 15

- Computation of biomass and carbon per plot and per ha on each stratum: Biomass and carbon are calculated using allometric equations from height (H) - DBH or DBH.

Allometric equations developed by UNREDD (2012) for broad-leaved species and other forest types can be used. For pinus species, allometric equations available for IPCC (2006) can be used.

In cases when only the biomass equation is available, carbon is estimated from biomass using a conversion factor of 0.5 (i.e. Carbon = Biomass x 0.5). The estimated carbon can be converted into CO_2 using a factor of 3.67 (i.e. CO_2 = Carbon * 3.67).

Some existing allometric equations applicable for Vietnam are listed below:

- ***Evergreen natural broad-leaved forest in the Central Highland of Vietnam:***

Above-ground biomass (AGB) in stem, bark, leaf and branch are estimated using following allometric relationship developed by UNREDD Vietnam (2012):

$AGB = 0.222*DBH2.387$ Eq 16

The below-ground biomass (BGB) is estimated as fraction of AGB:

$BGB = 0.275 * AGB$ Eq 17

The above-ground carbon (AGC):

$AGC = 0.5* AGB$ Eq 18

The below-ground carbon (BGC):

$BGC = 0.5*BGB$ Eq 19

Where AGB is above-ground biomass in kg per tree, DBH is in cm, AGC is carbon in above-ground biomass (kg per tree), BGB is below-ground biomass (kg per tree), BGC is carbon in below-ground biomass (kg per tree).

- ***Bamboo in the Central Highlands:***

Above-ground biomass (ABG) in stem, leaf and branch for bamboo forests in the central highlands is estimated using the following allometric relationship developed by UNREDD Vietnam (2012):

$AGB = 0.182*DBH2.16$ Eq 20

$AGC = 0.5*AGB$ Eq 21

2 UN-REDD 2012. Tree allometric equation development for estimation of forest above-ground biomass in Vietnam. UN-REDD Programme Vietnam, Hanoi, Vietnam

Where AGB is above ground biomass in kg per tree, DBH is diameter in cm, AGC is carbon in above ground biomass (kg per tree)

- ***Pine forest:*** Biomass in pine forest is estimated using the following equations by Brown (1989)

AGB = exp(-1.170+2.119*ln(DBH)) Eq 22

AGC = 0.5 * exp(-1.170+2.119*ln(DBH)) or 0.5 * AGB Eq 23

Where AGB is above-ground biomass in kg per tree, DBH is diameter in cm, AGC is carbon in above-ground biomass (kg per tree)

For both pine forest and bamboo, use root to shoot ratio to estimate the below-ground biomass/carbon from above ground biomass/carbon. A default value for 0.275 as below-ground biomass is used (FAO 2008)

BGB = 0.275 * AGB Eq 24

BGC = 0.275 * AGC Eq 25

Where AGB is above-ground biomass in kg per tree, DBH is diameter in cm, AGC is carbon in above-ground biomass (kg per tree)

Table 1: Calculation of tree volume and carbon above ground in specific forest status

Forest type **Forest status**

Number of sample plots: Number sign of sample plots

Local: Commune, districts, provinces

Forest owners: Contractor: Calculation person: Date:

No.	DBH class (cm)	Mid-point of DBH class (cm)	Average H (m)	Number of tree in sample plots	Tree /ha	AGB (kg/ tree)	V (m^3/ tree)	M (m^3/ha)	TAGTB (tone/ha)	TAGTC (tone/ha)	CO_2 (tone/ ha)
			4				8	9			
1	< 6	4									
2	6 - 10	8									
3	10 - 14	12									
4	14 - 18	16									
5	18 - 22	20									
6	22 - 26	24									
7	26 - 30	28									
8	30 - 34	32									
9	34 - 38	36									
10	38 - 42	40									
11	42 - 46	44									
12	46 - 50	48									
13	50 - 54	52									
14	54 - 58	56									
15	58 - 62	60									
16	62 – 66	64									
17	66 – 70	68									
18	70 – 74	72									
19	74 - 78	76									
20	78 – 82	80									
21	82 – 86	84									
22	86 - 90	88									
23	90 - 94	92									
24	94 - 100	96									
25	> 100	100									

Explanation of Table 1:

- Column 1: Serial number.
- Column 2: DBH class (4 cm interval)
- Column 3: Midpoint of DBH class (cm)
- Column 4: Average height of trees in DBH class (from AE of H/DBH of Forest Inventory and Planning Institute (FIPI) or AEs built for specific area)
- Column 5: Total number of trees belonging to the same forest status
- Column 6: Conversion tree/ha following specific diameter class
- Column 7: Using AE of AGB according to DBH and counting each DBH class in mean DBH
- Column 8: Using AE of volume according to DBH and/or H.
- Column 9: Column 8*column 6
- Column 10: Column 7 * Column 6
- Column 11: Column 10*0.50
- Column 12: Column 11 * 3.67

Table 2: Calculation of biomass and carbon of bamboo

Forest type Forest status
Number of sample plots: Number sign of sample plots
Location: Commune, district, province
Forest owners: Contractor
Calculation person: Date

No.	Age	Diameter class (cm)	Average DBH (cm)	Number of tree in sample plots	Tree/ ha	AGB(kg/ tree)	TAGTB (tone/ ha)	TAGTC (tone/ ha)	CO_2 (tone/ ha)
1	2	3	4	5	6	7	8	9	10
1	1	0 – 2	1						
2	2	2 – 4	3						
3	3	4 – 6	5						
4	4	6 – 8	7						
5	5	8 – 10	9						
6	6	10 – 12	11						
Total									

Explanation of Table 2:

- Column 1: Number of diameter and age class
- Column 2: Age
- Column 3: DBH class, cm 2cm interval
- Column 4: Average DBH in diameter class
- Column 5: Number of trees in plot having the same forest status based on diameter class
- Column 6: Conversion tree/ha with an area of 100m2 for each diameter class
- Column 7: Using AE of AGB according to DBH of bamboo and counting each DBH class in mean DBH
- Column 8: Column 7 * Column 6
- Column 9: Column 8 * 0.5
- Column 1o: Column 9*3.67

Table 3: Synthesis of forest volume and carbon stored in area of forest owner and region

Location: commune, district, province

Forest owner:

Contractor:

Calculation person:

Date:

No.	Prov-ince	District	Com-mune	Forest owner	Compart-ment	Forest block (Fb)	Forest status	Area (ha)	M (m^3/ha)	Total M/Fb (m^3)	TAGTC tone/ha	TAGTC/Fb (tone)	CO_2/Fb (tone)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1													
2													
3													
Total in com-partment													
Total in com-mune													
Total in district													
Total area of forest owner													

Explanation of Table 3:

From time to time, M / ha, biomass / ha and C / ha and CO2/ha are computed for each forest status. The synthesis for specific forest block is carried out within that block; or forest block belonging to any forest status then its mean forest variables calculated based on mean forest variables of that any that forest status. Total stand volume, biomass and carbon will be determined based on the mean forest variables and area. Accordingly, total volume, biomass and carbon for the whole commune, district and forest owner will be calculated. The detail is as follows:

- Column 1: Number of forest block
- Column 2: Province name
- Column 3: District name
- Column 4: Commune name
- Column 5: Forest owner name
- Column 6: Number sign of compartment
- Column 7: Name of forest block
- Column 8: Forest status of forest block
- Column 9: Area of forest block on the forest map
- Column 10: Average volume (m3/ha) of forest status calculated in Forms 1 and 2
- Column 11: Column 10 * Column 9
- Column 12: Total carbon (tone/ha) of forest status computed in Forms 1 and 2
- Column 13: Column 12 * Column 9
- Column 14: Column 13 * 3.67

7.2 Compute change of volume, forest biomass and carbon

Stock – difference method (IPCC 2006) is used to estimate the change. In this case, based on two measurement points, change in carbon stock is estimated as:

$$\Delta C_B = \frac{C_{t_2} \quad C_{t_1}}{t_2 - t_1} \qquad \text{Eq 26}$$

ΔC_B is change of biomass/carbon; Ct_1 and Ct_2 is total biomass/carbon, respectively at time t_1 or t_2, t_1 and t_2 are time of measurement of biomass/carbon stock

In order to compute emissions factor i.e. the GHG emissions (forest carbon emissions) or removals (or forest carbon absorption), the amount of carbon at two points in time should be determined. The absorption or emission of CO_2 is computed from the results of activity data (Figure 31).

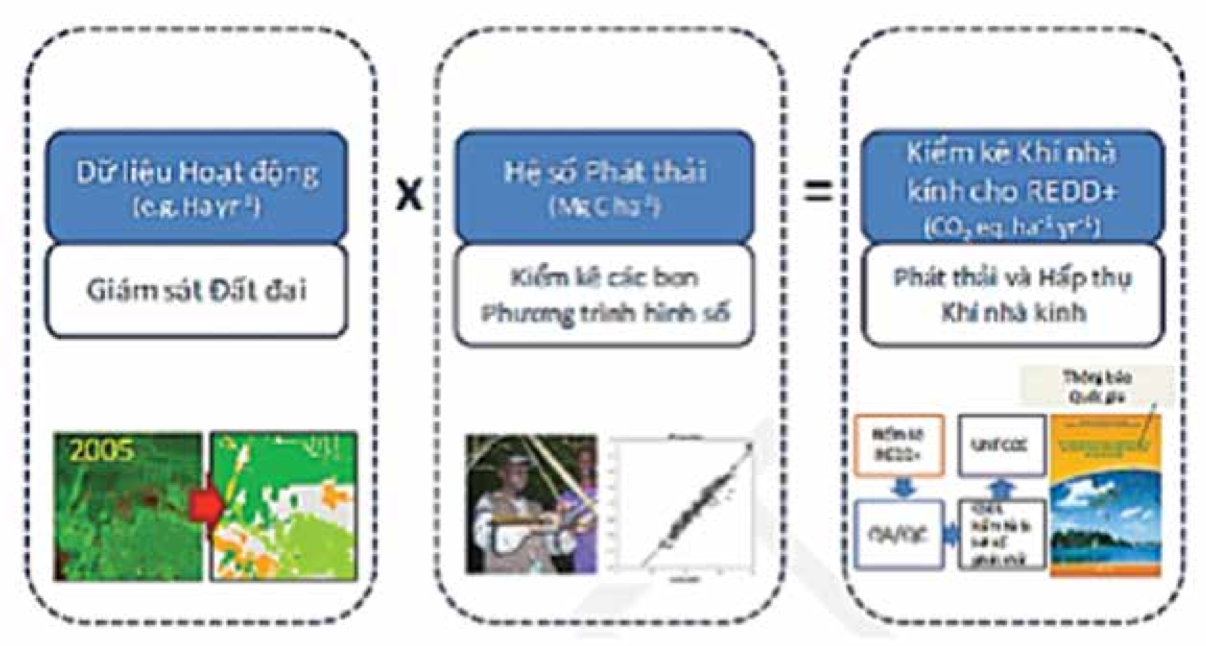


Figure 31. Approach of IPCC to compute greenhouse gas in forestry

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Appendix

Appendix 1. Form 1: Data sheet for measuring change in forest area, forest status and forest owner

Forest type and forest status on map:

Coordinate of plot centre (in VN2000): X: Y:

Forest type (observed): Forest status (Observed):

Forest owner: Contractor :

Location (village, commune, district, province):

Forest compartment:

Sub-compartment:

Block:

Measurement recorded by: Date: Time:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

No	VN2000 coordinates of 4 corners of forest block, forest owner				Description of change, (i) Loss of forest cover, (ii) Change in forest type	Underlying causes or reasons for change
	X/Y	X/Y	X/Y	X/Y		
1	2	3	4	5	6	7

Note: Information on change in area and status are stored as tracks in the GPS and are named to follow the identification number of delineated area.

Column 1: Identification number of delineated area. Numbers in serial order such as 1, 2, 3 can be used. Use separate form for each forest boundary. This identification number must be used to name the track in the GPS.

Columns 2, 3, 4 and 5: Record X,Y coordinates of foru corners from the GPS. On the GPS coordinates page, the value for x-coordinate is located at the top, and the y-coordinate is at the bottom.

Column 6: Description of change, either i) Forest loss, or ii) Reduced the quality of forest, e.g. selected logging/exploitation.

Column 7: Underlying causes or reason for change, e.g. logging forest for cropping, exploited as planned in 2013 etc.

Appendix 2: Sheets for forest inventory

Form 2: Data sheets for timber inventory

Plot No.: **Forest status on map:**

Coordinates: X Y

Forest type: Forest stratum/status:

Forest owner: Contractor:

Location (village, commune, district, province):

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by: Date:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

Measuring DBH ≥ 6cm in all sub-plots

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 3: Data Sheet for measuring DBH < 6 cm and H > 1.3 m in sub-plot with 1 m radius

Plot no.:

No.	Species		Number of tree	Comment	No.	Species		Num-ber of trees	Comment
	Local name	Common name				Local name	Popu-lar		
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 4: Data Sheet for bamboo inventory

Plot No.: **Forest status on map:**

VN2000 Coordinates: X Y

Location (village, commune, district, province):

Forest type: Forest stratum/status:

Forest owner: Contractor:

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by: Date:

Bamboo species: Height average (m):

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

For special bamboo: Every shoot is measured

Species: Average height (m)

Number of trees: Average DBH (cm):

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			

Appendix 3. Tools and equipment needed for PCM for a technical group

No.	Item	Unit	Qual-ity	Purpose
	Actual forest map with demar-cation of boundaries of forest owner, household contracted to protect forest	Map	1	Monitor area of forest plot, for-est owner
	Map with location of random sample plots	Map	1	Position sample plots on the field
	GPS	Unit	1	Define boundaries, change area, location of sample plots
	Battery for GPS	Unit	10	
	Digital camera	Unit	1	Take pictures
	Data sheet for measuring forest area (Form 1)	Form	50	Record area change
	Rope for sub-plot with coloured knots for different sub-plot radii	Rope	4	
	Compass, Sunnto clinometer	Equip-ment	1	Orientation, measuring tree height, slope angles
	Diameter	Equip-ment	2	Measure tree diameter
	Iron board to write plot number sign	Table	20	
	Paint	Box	5	
	Paintbrush	Paint-brush	5	
	Hammer	Ham-mer	1	
	Nail	kg	5	
	Data sheet form for measuring timber forest, bamboo forest (Form 2, 3, 4)	Form	50	

Appendix 4. Slope corrections for distance measurements

Slope (degree)	Radius (m)			
	1.00 Green	5.64 Yellow	12.62 Blue	17.84 Red
0	0.00	0.00	0.00	0.00
2	0.00	0.00	0.01	0.01
4	0.00	0.01	0.03	0.04
6	0.01	0.03	0.07	0.10
8	0.01	0.06	0.12	0.18
10	0.02	0.09	0.19	0.28
12	0.02	0.13	0.28	0.40
14	0.03	0.17	0.39	0.55
16	0.04	0.23	0.51	0.72
18	0.05	0.29	0.65	0.92
20	0.06	0.36	0.81	1.14
22	0.08	0.44	0.99	1.40
24	0.09	0.53	1.19	1.69
26	0.11	0.64	1.42	2.01
28	0.13	0.75	1.67	2.37
30	0.15	0.87	1.95	2.76
32	0.18	1.01	2.26	3.20
34	0.21	1.16	2.60	3.68
36	0.24	1.33	2.98	4.21
38	0.27	1.52	3.40	4.80
40	0.31	1.72	3.85	5.45
42	0.35	1.95	4.36	6.17
44	0.39	2.20	4.92	6.96
46	0.44	2.48	5.55	7.84
48	0.49	2.79	6.24	8.82
50	0.56	3.13	7.01	9.91

Appendix 5: Set up VN2000 coordinate system in GPS

Install GPS when using VN2000 follow the parameter of Ministry of Natural Resources and Environment with 2 zones: zone 48 and 49 and zone 30 or 60

For maps at scale of 1:10,000 or larger and meridian is in zone 30), use the following parameter for spatial coordinate system:

- Longitude Origin: Change this value depend on meridian (axis) of each province follow attached table below (for example: Dak Lak this parameter is changed to: E 108030.000)
- Scale: + 0.9999000
- False Easting: 500000.0m
- False Northing: 0.0m
- Datum:
  - DX = -192
  - DY = -39
  - DZ = -111
  - DA = 0
  - DF = 0

For maps at scale of 1: 25,000 or smaller and meridian is in zone 60, use the following parameters for spatial coordinate system:

- Longitude Origin: E1050 or E1110 or E1170 corresponding location in zone 48 (1020-1080) or 49 (1080-1140) or 50 (1140-1200).
- Scale: + 0.9996000
- False Easting: 500000.0m
- False Northing: 0.0m
- Datum:
  - DX = -192
  - DY = -39
  - DZ = -111
  - DA = 0
  - DF = 0

GPS 76 also shows 2 additional parameters DA and DF. DA and DF can be changed in Menu -> Set up ->Location ->Map Datum ->User. However GPS Garmin Colorado shows only 3 parameters Dx, Dy and Dz. To modify values for DA and DF in Garmin Colorado GPS, Prss Menu -> Set up -> Position format -> User Spheroid.

It is important to supply correct parameter for default meridian in VN2000 and zone that corresponds to each province. For example: for Dak Lak map, map scale is 1:100.000 and zone is 30 and meridian is 108030’. Therefore, scale is 0.9999 (corresponding to zone 30).

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