INTRODUCTION

1. The dissertation necessity

Reducing Emissions from Deforestation and Forest Degradation (REDD) program was proposed since 2007, it was later supplemented into REDD+ with five action groups and became the official mechanism under the global climate change mitigation system by reducing emissions from the forest.

Participatory Carbon Monitoring (PCM) is an important part of REDD program (Casarim et al., 2013). Skutsch (2011) has indicated the necessary to link PCM with the national system of Measurement - Report - Verification (MRV) on greenhouse gas emissions.

Although there are community engagement activities involved in forest carbon monitoring within the framework of programs and projects (Huy et al., 2011a,b; Bao Huy, 2013; Huy et al., 2013); But most of the activities are developed mainly based on the community commitments. There was also guidelines to implement such as Huy et al., (2013) but these guidelines are mainly based on the experience of scientists and have not yet relied on any completed research to formulate arguments for the development of PCM guidelines.

To contribute to the scientific basis and practical of PCM in Vietnam as well as to meet the requirements of UNFCCC (2001), we carried out research titled: *"Developing methodology to be applied by ethnic minority communities for carbon measurement, monitoring in evergreen broad-leaved forests in the Central Highlands"*.

2. The thesis goals

Regarding the theory:

Development of a theoretical basis and approaches to develop forest carbon monitoring with the participation of community.

Regarding the reality:

Development of allometric equations for estimating tree/forest above and below ground biomass in evergreen broad-leaved forests in the Central Highland using the predictor variables to be measured by local community;

Development and cross validation of reliability, effectiveness of methods and tools which were applied in PCM;

Development of the PCM guidelines.

3. The scientific and practical significances of the dissertation

Provision of scientific basis for developing methodology and tools to assist the community in monitoring forest carbon achieved the reliability and effectiveness;

The PCM guideline was developed based on the selection of methods, tools, forest carbon pools to be monitored, measured by the community and gained the reliability and cost-effective.

4. New contributions of the dissertation

Supplement and update the scientific basis to develop allometrci equations for estimating tree/forest above and below ground biomass using the predictor variables to be measured by local community.

Development of appropriate methods and tools to be applied in forest carbon monitoring with the participation of community.

5. Structure of the dissertation

The dissertation consists of 132 pages (not including references and annexes), and includes as following parts:

Introduction. This part covers the contents: The disseration necessity, goals, scientific and practical significances, new contributions and structure of the dissertation.

Chapter 1: Overview of research issues

Chapter 2: Objects, contents and research methods.

Chapter 3: Research results and discussion.

Conclusions, limitations and recommendations.

References.

Annexes: Including 19 annexes s as the database to develop the thesis.

CHAPTER 1: OVERVIEW OF RESEARCH ISSUES

Overview of the study was based on 102 documents, including 13 in Vietnamese and 89 in English.

1.1. Research issues abroad

Participatory Forest Monitoring has an important role in the national forest monitoring systems and REDD program (Vickers, 2014). The participation of community should be organized and prioritized to ensure the transparency of MRV (UNFCCC, 2011; UN-REDD, 2011; Vicker, 2014; Bernard và Minang, 2011).

Currently, there have been studied the approaches to attract local people in PCM (MacDicken, 1997; Van Laake, 2008; Subedi et al., 2010; Skutsch, 2009, 2011; RECOFTC, 2010; Danielsen et al., 2013; Vickers, 2014).

The deviation for estimating forest biomass and carbon between two measurement communities and professional staffs only varied from 1 to 7%; and the costs of implementing PCM by the community was only approximately from 5 to 34% in comparison with implementation of professional agencies (Skutsch et al., 2008, 2009).

Community Forest Management (CFM) has been widely implemented and as the basis for the development of PCM in REDD program (Skutsch et al., 2009; Sikor et al., 2013).

1.2. In the country

Vietnam is one of nine countries has been chosen to pilot the program of UN-REDD. The Prime Minister issued Decision No.799/QĐ-TTg dated 27/6/2012 on approving the nation action program of "Reducing Emissions from Deforestation and Forest Degradation, sustainable forest management and conservation and increase of forest carbon", this is the basis for implementing the UN-REDD program.

The participatory approach in measurement, forest monitoring will provide information of forest with better quality and quantity (Wode and Bao Huy, 2009; Sikor et al., 2013). Casarim et al., (2013) proposed to assign clear responsibilities for three main relevant levels in Vietnam (national, local and community levels) in measurement and carbon monitoring. PCM was tested from the year 2010 to the year 2013 under UN-REDD program (Huy et al., 2013).

In order to develop a completion of PCM, some main contents as below should be studied and evaluated to select appropriate tools and methods:

- The ability of the community to identify forest status;
- The reliability when the community use some forest inventory equipments;
- Which shape and size of sample plots that suits to community ability, ensure the cost-effective;
- Which carbon pools that the community can monitor with the reliability and effective;
- What allometric equations for estimating forest biomass, carbon using the predictor variables to be measured by local community and ensure the reliability.

CHAPTER 2: OBJECT, CONTENT AND RESEARCH METHOD

2.1 The object of study

i) *The evergreen broad-leaved forests in the Central Highlands:* The evergreen broad-leaved forests in Lam Dong Province was subject to study methods, tools so that the community applies in PCM; sample plots and destructive sample trees were collected in four provinces of Gia Lai, Dak Lak, Dak Nong and Lam Dong for development and cross validation of models for estimating forest biomass.

ii) *Local and ethnic minority communities participated:* To develop and apply the method of PCM, the study location includes three Communes: Loc

Lam, Loc Bac, and Loc Bao under Bao Lam District, Lam Dong Province with the participation of Chau Ma ethnic minority community.

iii) *Carbon pools:* The models for estimating forest/tree above and below ground biomass and carbon. Evaluation of reliability and cost-effective in the measurement, supervise of five forest carbon pools (IPCC, 2006).

2.2 Characteristics of the study area

2.2.1 Characteristics of natural conditions in the study area

Climate and hydrology: There are two seasons in a year, rainy season starts from May to October, dry season starts from November to April next year. The average annual temperature is 22,4^{o}C, and average annual rainfall is 2.530mm. The study area is in the basin of Dong Nai River.

Terrain, soil: the terrain is quiet complex with many hills and mountains, the altitude varies from 450 - 1,137m above sea level. There are four main types of soils, including: Feralite soil grows on Basalt, Feralite soil grows on Granit, alluvial soil, accreted soil.

2.2.2 Characteristics of socio-economic conditions of three studied communes

The socio-economic information is summarized in Table 2.1:

Table 2.1: Population, ethnic composition and educational level of three studied communes

Commune	Number of household	Number of people	The rate of poor households (%)	The rate of ethnic minority (%)	Main ethnic minority composition	Education level
Loc Lam	610	2.321	31,3	80,3	Chau Ma (>90,0%)	Primary school: 61,5%;
Loc Bac	852	3.598	55,4	81,8	Chau Ma (95,0%)	Secondary school: 30,8%;
Loc Bao	726	3.110	48,2	72,0	Chau Ma (94,6%)	High school: 7,7%

2.2.3 The situation of management, use and protection of forest resources

The area of forestland planned for forestry is 57.363 ha, accounting for 89% of the natural land, in which the evergreen broad-leaved forests is 26.445 ha. Most of the forest area is under the management of Loc Bac and Loc Bao Forestry Companies. Forest environmental services in associated with forest protection contracts have been implemented early here.

2.3 The research contents

i) Develop and validate errors of the biomass estimation models using the predictor variables to be measured by local community; ii) Testing and evaluation of methods, tools, carbon pools to apply in PCM; iii) Synthesis and development of the PCM guidelines.

2.4 The research methods

2.4.1 Methodology and research approaches

The participatory approach of ethnic minority communities in the Central Highlands was applied to develop, validate the appropriate methods and tools for the PCM in order to provide two groups of data under IPCC (2006): i) Activity Data, ii) Emission Factors.

2.4.2 Methodology for developing and validating errors of the biomass estimation models using the predictor variables to be measured by local community

2.4.2.1 Data collection and information on variables of the models for estimating forest/tree biomass

To develop and make cross validation for the models of tree above and below ground biomass (AGB, BGB, kg): Inventory of 20 sample plots 2.000 m^2 and collect biomass information of 222 destructive sample trees in Dak Lak, Dak Nong, Gia Lai Provinces;

To establish and evaluate errors for the models of forest above and below ground biomass (TAGB, TBGB, ton/ha): 323 sample plots 1.000 m^2 was done in two provinces of Dak Nong and Lam Dong.

2.4.2.2 Selection of predictor variables, form of allometric equations

The simple predictor variables to be measured by local community including: Diameter at Breast Height (D, cm), tree Height (H, m) and Basal Area (G, m^2/ha) and power were chosen to develop the biomass models (Brown, 1997; Chave et al., 2014; Huy et al., 2016).

2.4.2.3 Selection of methods to develop the biomass models

Testing of 2 methods: i) Logarit transformation least square linear; ii) Weighted non-linear Maximum Likelihood with random effect of environmental factors. The open source software R was applied using nlme package (Pinheiro et al., 2014). Furnival's Index (FI) to compare and select the appropriate biomass model fitting method.

2.4.2.4 Method of establishment and cross validation the biomass models

In the software R, the random sampling with 70% of data to develop models, and 30% of data for cross validation, and 200 times realizations helped to select and provide correctly errors (Temesgen et al., 2014). The usage errors include % of deviation between observation and prediction through models (Bias%), Root Mean Square Error % (RMSE), and Mean Absolute Percentage Error % (MAPE) (Swanson et al., 2011). The best model chosen was based on AIC (Akaike Information Criterion) smaller than (Basuki et al., 2009). After selecting and validating the model, parameters of the final models were performed using entire data.

2.4.3 Testing and evaluation to select methods, tools, carbon pools to apply in PCM

There were three groups of Chau Ma ethnic minority (includes 3 – 5 farmers per group) along with a team of three technical staffs from forestry companies trained and involved in the progress.

2.4.3.1 The method for evaluating defined forest status by community

Each group defined different forest status twice and compared to the Circular no.34/2009/TT-BNNPTNT of the Ministry of Agriculture and Rural Development on the criteria for classifying forests.

2.4.3.2 The method for validating the reliability of GPS using skill of the community

The skill of using GPS was evaluated includes the measurement of forest area changes and identify the random sample plot coordinates. Each person practiced 2 to 3 times, total of 27 participants participated in the evaluation of this skill. Give score for each skill on the scale of five points. Calculation of average scores, coefficient of variation (CV%) for each GPS using skill of the local people.

2.4.3.3 The method for validating the reliability of biomass estimations based on the input data of the community in comparison with technical staffs

In order to validate the reliability of data measured by the community, there were 39 testing places in the field (Figure 2.4). Three community groups conducted to measure data; and at the same time, there was a group of three technical staffs also conducted the measurement. The data of two surveyed groups were collected, along with the recorded time, labor to compare the deviations and costs.

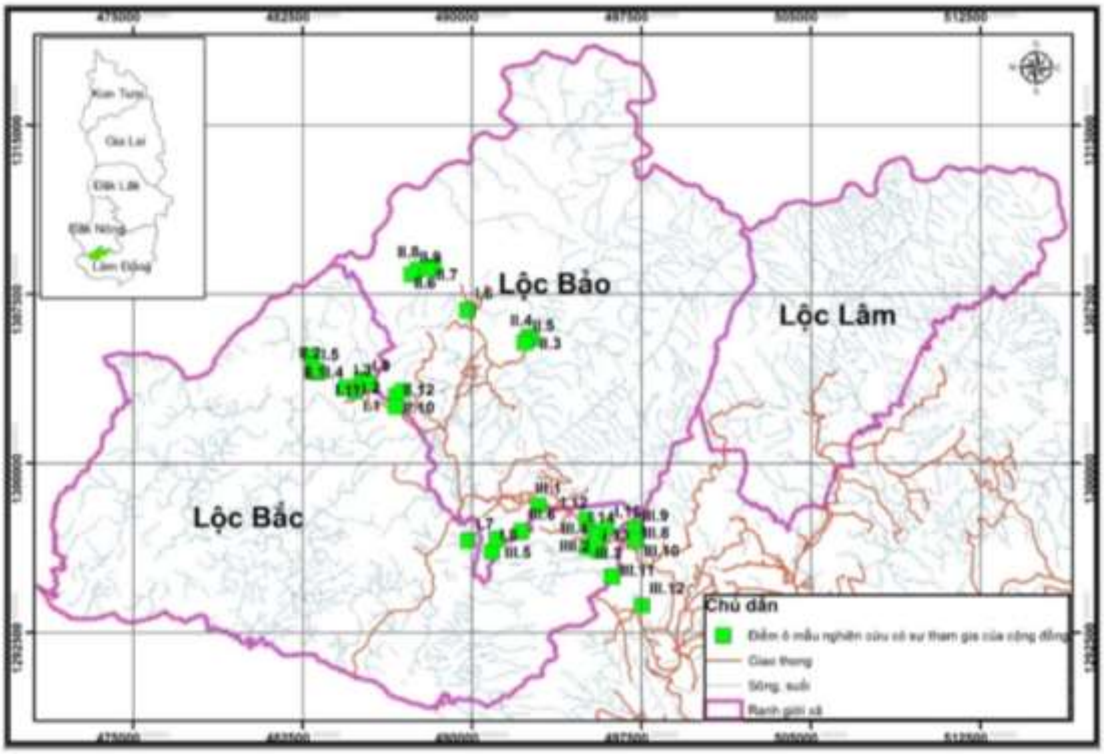

Figure 2.4: Location map of study area with the participation of community in three communes under Bao Lam District, Lam Dong Province

i) Evaluation of the errors in measurement of D, H and G of the community in comparison with technical staffs

The deviation calculation between measured value D, H (use Suunto) and G (use Bitterlich tool) of the community in comparison with the measurement of technical staffs by Bias% (formula 2.11), in which: y_i is the value measured by the community; $\hat{y}_i$ is the value measured by the technical staffs, n is the number of points/different checking plots:

$$Bias\ (\%) = \frac{100}{n}\sum_{i=1}^{n}\frac{y_i - \hat{y}_i}{y_i} \quad (2.11)$$

ii) Comparison method of Bias in estimation of AGB, BGB and Total Biomass (TB):

- *Develop the sample plots by difference shapes and sizes:*

There are four different types of plots tested: Nested circle plots 500 m^2 (R = 12,62 m) and 1.000 m^2 (R = 17,84 m) (Figure 2.5); Nested rectangular 500 m^2 (20 × 25 m), and 1.000 m^2 (20 × 50 m) (Figure 2.5 2.6). Total number of tested sample plots: 39 points × 4 types of sample plot = 156 plots and along with 39 points of Bitterlich to define the basal area (G).

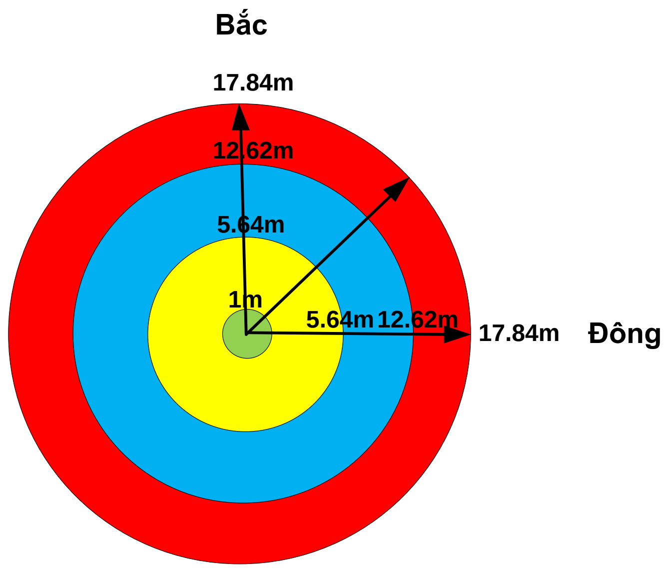

Figure 2.5: Nested circle plots 500 m^2 and 1.000 m^2

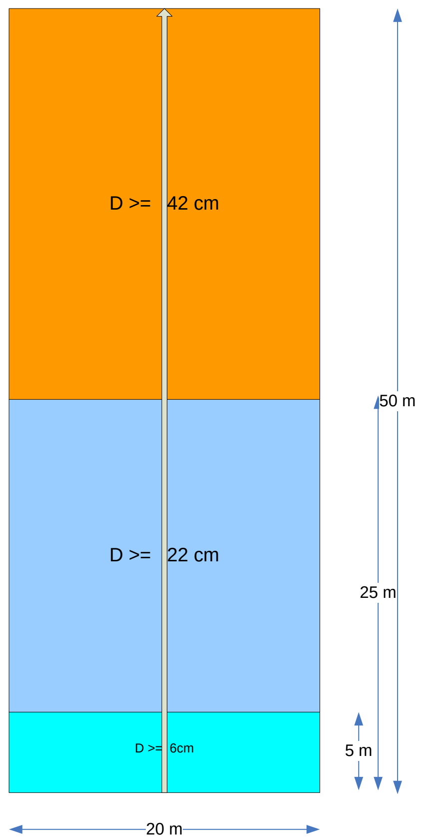

Figure 2.6: Nested rectangular plots 500 m^2 and 1.000 m^2

- *Estimation of AGB, BGB and TB by sample plots; estimation of TAGB, TBGB and TB of Bitterlich point:*

Use the estimation model of AGB, BGB to measure for the individual trees and refered to hectare for each sample plot; and model of TAGB and TBGB for the forest biomass estimation under G variable (Pham Tuan Anh and Bao Huy, 2016).

- *Criteria for checking errors of biomass from data to be measured by the community and technical staffs:*

Using the Bias% according to the formula (2.11). Checking the errors by non-parametter method of Wilcoxon in case two samples are related.

2.4.3.4 Selection method for type of sample plots for PCM

Select the optimal sample plot on the basis of identifying the total number of sample plots for each type of plot and cost-effective across the study area: i) Calculate the number of sample plots required for each M clasification stratum based on the TAGB deviation under the formula of Lackman (2011) with the confidence P = 95% and given error E% = 10%; ii) Calculate the diference labor costs corresponding to the types of sample plots in the study area.

2.4.3.5 Selection method of measurement for non-tree carbon pools

To identify the cost-effective in measurement of non-tree carbon pools, conducted to determine the labor costs and value of CO_2 emission reduction in these pools: soil organic carbon (SOC); deadwood; and in litter.

2.4.4 Method for development of PCM guideline

On the basis of the research results, a full process of PCM was developed by: i) Inherit the steps of conducting PCM (Huy et al., 2013); ii) Selection of steps, methods, tools that consistent with the community to gain the credibility and efficiency; iii) Selection of models for estimating forest/trees biomas had preditor variables to be measured by the community.

CHAPTER 3: RESULTS AND DISCUSSTION

3.1 The estimation models for forest/tree biomass using the predictor variables to be measured by local community

3.1.1. Selection of method to develop the biomass models

Using non-linear Maximum Likelihood with a weight of $1/D^k$ was selected because the FI is much smaller than the unweighted least squares linear method (Table 3.1).

Table 3.1: Use FI to evaluate two methods of fitting biomass model

The predictor variables	Model	Logarit least square linear method		Weighted non-linear Maximum Likelihood		
		Adj. R^2	FI	Weighted	Adj. R^2	FI
D	$AGB = a\times D^b$	0,950	27,3	$1/D^k$	0,801	0,054
	$BGB = a\times D^b$	0,901	2,4		0,484	0,004
D and H	$AGB = a\times(D^2H)^b$	0,958	25,1	$1/D^k$	0,908	0,058
	$BGB = a\times(D^2H)^b$	0,883	2,6		0,718	0,004

$AGB = a \times D^b \times H^c$	0,901	24,7	$1/D^k$	0,883	0,056
$BGB = a \times D^b \times H^c$	0,901	2,4		0,494	0,004

3.1.2.Models for estimating tree above ground biomass (AGB)

With the variable D, the model to be chosen by $AGB = a \times D^b$ and regarding D, H variables model of $AGB = a \times (D^2H)^b$ was selected. Random effect of G did not change parameters of the models (Table 3.2).

Table 3.2: Comparison and cross validation of biomass estimation models AGB with or without random effect of G

The predictor variables	**Model**	**Random effect**	**Weighted**	**AIC**	**Adj. R^2**	**RMSE %**	**Bias %**	**MAPE %**
D	$AGB = a \times D^b$	No (*)	$1/D^k$	1.489	0,795	47,8	-14,7	34,2
	$\mathrm{AGB = a \times D^b}$	G	$1/D^k$	1.491	0,806	48,2	-15,3	34,3
D + H	$AGB = a \times (D^2H)^b$	No (*)	$1/D^k$	1.464	0,908	43,6	-10,4	29,6
	$\mathrm{AGB = a \times D^b \times H^c}$	No	$1/D^k$	1.468	0,883	43,4	-12,0	29,9
	$\mathrm{AGB = a \times (D^2H)^b}$	G	$1/(D^2)^k$	1.452	0,911	43,8	-11,8	29,7

(*)The model was chosen according to the input variable

The model of combination variable of D^2H was more reliable than a variable of D. However, the measurement of tree height is difficult for the community. Hence, the model with variable H is used only to change the parameters by H to improve reliability when estimating AGB with only one input variable D. After the selection of models and cross evaluation, all parameters of the models were computed by entire data. The results in Table 3.3.

Table 3.3: Parameters of the selected AGB models with different input variables based on entire data

The predictor variables	**Model**	**Parameter**		**Standard error of the parameter**	
		a	**b**	**a**	**b**
D	$AGB = a \times D^b$	0,11469	2,47983	0,01182	0,03677
D+H	$AGB = a \times (D^2H)^b$	0,04434	0,96130	0,00464	0,01269

Note: All parameters have significance P-value < 0.0001

3.1.3. Model for estimating tree below ground biomass (BGB)

The tree root is an important part in forest carbon pools, approximately half of the annual forest carbon cycle is contributed by the tree root system (Vogt et al., 1996). While the model of BGB is very rare. The main reason is that the collection of forest root biomass data is difficult, high cost, especially in tropical forests with large diameter trees.

Table 3.4: Comparison and cross validation of biomass estimation models BGB with or without random effect G

The predictor variables	Model	Random effect	Weighted	AIC	Adj.R^2	RMSE%	Bias%	MAPE%
D	$BGB = a \times D^b$	No (*)	$1/D^k$	294	0,444	55,4	-17,8	40,6
	$BGB = a \times D^b$	G	$1/D^k$	294	0,466	57,4	-20,2	42,2
D + H	$BGB = a \times (D^2H)^b$	No	$1/D^k$	303	0,686	52,9	-13,6	40,8
	$BGB = a \times D^b \times H^c$	No	$1/D^k$	301	0,436	58,3	-20,4	43,3
	$BGB = a \times (D^2H)^b$	G	$1/(D^2H)^k$	311	0,459	60,7	-22,9	45,5

(*) The selection of model according to predictor variables.

Model for estimating tree BGB had the highest reliability with a variable D using form of $BGB = a \times D^b$. As a result in Table 3.4. G factor also had no significnace for changing parameters of the models. After selecting and evaluating, all data will be used to estimate the parameters of selected model, the result is in Table 3.5. For the model of BGB, only the variable D is appropriate with the community measurement data.

Table 3.5: Parameters of the BGB model was selected on the basis of the whole data

The predictor variables	Selected Model	Parameter		Standard error of the parameter	
		a	b	a	b
D	$BGB = a \times D^b$	0,015306	2,550949	0,003349	0,094112

Note: All parameters have a mean of P-value < 0.0001

3.1.4. The AGB models for site index

Model for estimating tree AGB with variable combination D^2H was more reliable than a variable of D. However, if the community measured H for the whole number of trees in the sample plots, there would be large errors. So development of ABG model by D and changes model parameters by site index was the good solution to improve the reliability. The community just need to be trained to make measurements of exactly 3 trees in a diameter class representative to determine of site index, the measurement of height will reduce errors due to the number of measured trees is very small (3 trees). In order to split the site index, the selected H/D relationship was selected in table 3.7 by form of power without a constant of 1.3 m.

Table 3.7: The selected parameters of model H = f(D), on the basis of entire data

Selected model	**Parameter**		**Standard error of the parameter**	
	a	**b**	**a**	**B**
$H = a \times D^b$	2,796423	0,568826	0,165503	0,021573

Note: All parameters have significance P-value < 0.0001

From the selected H/D model, devide the model into 3 levels of height; with site index is S_i at D = 35 cm:

$$S_i = \overline{H}_i \times (35 / \overline{D}_i)^{0.568826} \qquad (3.4)$$

Replacing the model of $H_i = a_i \times D^b$ with 3 levels of H into the model $AGB = a \times D^2H$, we got the model of AGB with a variable D and parameter a_i changed by S_i:

H 1: S_{26}: $AGB = 0.144171 \times D^{2.469418}$ (3.5)

H 2: S_{21}: $AGB = 0.116997 \times D^{2.469418}$ (3.6)

H 3: S_{16}: $AGB = 0.089569 \times D^{2.469418}$ (3.7)

Figure 3.8 shows that the estimation model of AGB with a variable D but being divided into 3 levels of S_i improved accuracy significantly.

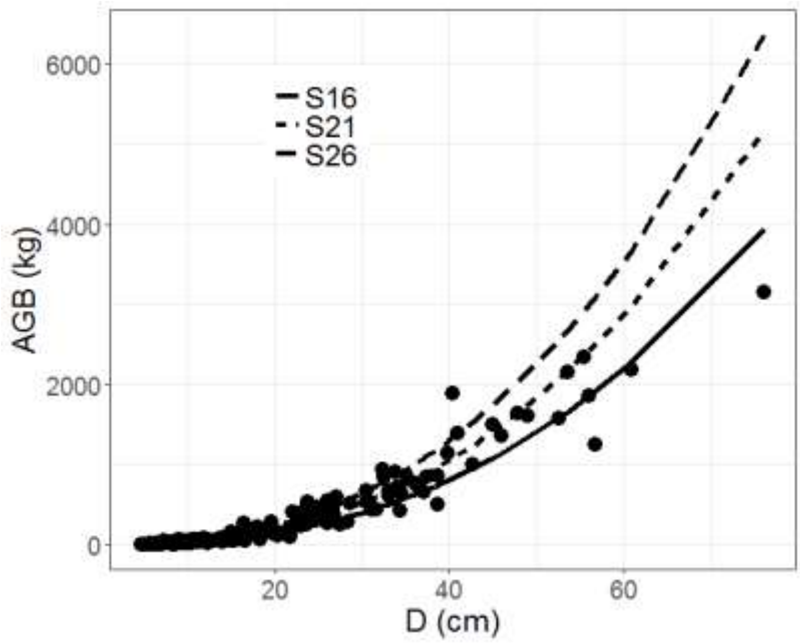

Figure 3.8: Prediction of AGB using a variable D and 3 levels of Si (S_{16}, S_{21} and S_{26} at D = 35 cm) compared to AGB data observed under D

3.1.5. Comparison the models of AGB and BGB of the evergreen broad-leaved forests fitted by different methods in the Central Highlands

We evaluated the models of AGB, BGB of some different authors with the models which were selected in this study aims to show which method with good reliable. The results in table 3.8 show that all AGB and BGB models using different predictor variables of this thesis had FI smaller significantly than those of Bao Huy (2013) and Huynh Nhan Tri (2014).

Table 3.8: Using Furnival's Index (FI) to compare the models of tree biomass in evergreen broad-leaved forests in the Central Highland was established by different methods

The predictor variables	Model/Author	Method of model fitting	Weighted	Adj. R^2	FI
AGB = f(D)	*This thesis (2017): AGB = 0.11469×$D^{2.47983}$*	Weighted non-linear Maximum Likelihood	$1/D^k$	0,799	0,054
	Bao Huy (2013): log(AGB) = -2.23927 + 2.49596×log(D)	Unweighted least square linear	-	0,950	27,3
	Huynh Nhan Tri (2014): log(AGB) = -2.25438 + 2.49193×log(D)	Weighted least square linear	1/D	0,926	27,3
AGB = f(D, H)	*This thesis (2017): AGB = 0.04434×$(D2H)^{0.96130}$*	Weighted non-linear Maximum Likelihood	$1/(D^2H)^k$	0,907	0,021

The predictor variables	Model/Author	Method of model fitting	Weighted	Adj. R^2	FI
	Bao Huy (2013): log(AGB) = -2.97660 + 0.53579×log(D) + 0.75932×log(D2H)	Unweighted least square linear	-	0,958	27,3
	Huynh Nhân Tri (2014): log(AGB) = -3.07831 + 2.01893×log(D) + 0.8262×log(H)	Weighted least square linear	1/D	0,938	24,7
BGB = f(D)	*This thesis (2017): BGB = 0.01531×$D^{2.55095}$*	Weighted non-linear Maximum Likelihood	$1/D^k$	0,484	0,004
	Bao Huy (2013): log(BGB) = -3.73687 + 2.32102×log(D)	Unweighted least square linear	-	0,901	2,4
	Huynh Nhân Tri (2014): log(BGB) = -3.86955 + 2.409×log(D)	Weighted least square linear	1/D	0,869	2,4

Note: k is the coefficient of the variance function

3.1.6. Models for forest above ground biomass and below ground biomass (TAGB, TBGB) according to G variable

The form of power: $TAGB = a \times G^b$ and $TBGB = a \times G^b$ were selected because of the average of AIC of 200 sampling times from 70% of data is smaller than the linear model.

The parameters of the selected forest biomass models are estimated from entire data shown in Table 3.10 3.10.

Table 3.10: Parameters of the selected TAGB, TBGB models using entire data

Selected Model	Parameters		Standard error of the parameter	
	a	b	a	b
$TAGB = a\times G^b$	3,992639	1,163908	0,215972	0,016557
$TBGB = a\times G^b$	0,638988	1,086061	0,022851	0,011119

Note: All parameters have a significance P-value < 0.001

Last but very important, the models established in this study were shown the correctly errors, stable due to applying the method of cross validation by random spliting with 70% of data to develop models and 30% of data to evaluate errors, and 200 realizations helped to provide correctly errors; the errors were averaged. This result overcomed the traditional method of validation.

3.2. Selection of methods, tools, carbon pools to be applied in PCM

3.2.1. Identify the forest status based on local knowledge

The identification results of forest status of Chau Ma ethnic minority community were consistent with Article 8, Circular 34/2009/TT-BNNPTNT dated 10/6/2009 of Ministry of Agriculture and Rural Development.

The community divided the evergreen broad-leaved forest in the Central Highlands into three simple stratum called: old forest, poor forest, young forest as very rich-rich, medium-poor and no-volume acoording to Circular no.34. It is recommended to monitor change the forest area in PCM, simplify under these three stratum to be able to classify forests based on the community.

3.2.2. The reliability when community use GPS to identify the changes of forest area and location of random sample plots

As the evaluation results, give the score for each skill of each member involved in testing which was shown in Table 3.12 and Table 3.13.

Table 3.12: The result validation of GPS usage skill to identify the changes of forest area. Maximum score = 5

No	Skills, activities	Total number of turns	Medium score	CV%	Min max with P=95%	
					Min	Max
1	Start GPS, go to Track	27	3,7	24,60%	3,3	4,1
2	Draw the area	27	4,3	14,30%	4,1	4,6
3	Save the results and name the area changed	27	3,7	22,70%	3,3	4,0
4	Read area measurements	27	4,0	19,60%	3,7	4,3

Table 3.13: The result validation of GPS usage skill to identify the location of random sample plots. Maximum score = 5

No	Skills, activities	Total number of turns	Medium score	CV%	Min Max with P=95%	
					Min	Max
1	Start GPS, go to Waypoint	27	3,7	23,60%	3,4	4,1
2	Find the code of sample plot	27	3,8	21,10%	3,5	4,1

3	Go to the random sample plots in the field	27	4,1	16,70%	3,9	4,4
4	Identify the location of sample plots	27	4,0	21.00%	3,6	4.3

From the results as above, the community has enough competence in using GPS to locate random sample plots in the field as well as identify the area of forest on a small scale of the forest block.

3.2.3. The reliability of biomass and carbon data estimated from the input data which was measured by community.

3.2.3.1. Different in measuring the variables of D, H and G between the community and technical staffs

Bias% on average of D, H, and G in Table 3.14 shown that data measured by the community compared to technicians is less than -5%. Therefore, the community can measure these three variables to estimate biomass, carbon for trees above and below ground through biometric models; in which the measurement of H is limited only three trees in a certain diameter class to reduce the error.

Table 3.14: Comparison results of CV% and Bias% measured by the community and technical staffs on average of D, H and G at 39 points

Measurement targets	Rating score (n)	Community		Technical Staff		Bias%
		Average	CV%	Average	CV%	
D (cm)	39	32,3	15,6%	32,6	15,3%	-1,2%
H (m)	39	22,0	18,5%	22,5	16,2%	-2,7%
G (m^2/ha)	39	16,7	22,1%	17,2	19,5%	-4,1%

In addition, the value of CV% of community in all three indicators was higher than the measurement of technical staffs, this reflects the reality about the unevenness in measurement skills among members in the community. However, the difference of CV% between the two groups is not significant.

3.2.3.2. Compare deviations of estimating above and below ground biomass and total biomass of Bitterlich measurement point and sample plots from data of community and technical staffs

Comparative results of error of TAGB, TBGB and TB from input data of the community and technical staffs by value of Bias% and Wilcoxon non-parametric for each different type of sample plots were presented in Table 3.17 (for deviations of TB). The results show that there was a difference in Bitterlich, but for the nested sample plots there were no difference in the estimation of TAGB, TBGB, and TB from data which was measured by the community in comparison with the measurement of technical staffs (Bias < -5%).

This result is consistent with other research results of in many countries such as India, Nepal and Tanzania (Skutsch et al., 2009), the difference of biomass estimation is only varying from 1 to 7% between two measurement subjects of community and professional staffs; therefore, getting attention the participation of community in PCM is legalistic as well as ensures reliability in providing input data to estimate emissions under the UN-REDD program as required by the IPCC (2003, 2006).

Table 3.17: Compare deviations of estimating above and below ground biomass and total biomass (TB, ton/ha) of Bitterlich measurement point and sample plots from input data of community and technical staffs by Bias% and the non-parametric test of Wilcoxon

Kind of points and plots	**Average TB (ton/ha)**			**P-value of Wilcoxon**	**Hypothesis of Ho:** *The median of the two ranges of TB of community and technical staff is equal*
	From community's data	*From technical staffs's data*	*Bias%*		
Bitterlich	119,6	124,0	-4,9	0,006	Rejected Ho
Circle plot stratified 500 m^2	265,2	270,0	-3,0	0,289	Accepted Ho
Circle plot stratified 1.000 m^2	259,5	264,1	-3,2	0,214	Accepted Ho
Rectangular plots stratified 500 m^2	255,1	259,5	-3,0	0,276	Accepted Ho
Rectangular plots stratified 1.000 m^2	258,3	263,6	-3,2	0,118	Accepted Ho

Pvalue > 0.05: Accepted Ho, two median samples with no difference

3.2.4. Selection of shape and size of sample pilots in PCM

In order to optimize both of reliability and cost-effectiveness in PCM, it is necessary to select the appropriate sample plots. The number of sample plots is allocated according to the area of three M levels. Number of necessary sample plots by plot form was computed based on the deviation of TAGB on total area of 26,446.5 ha, according to the method of Lackman (2010) with given error E% = 10% and the reliability P = 95%, the results are shown in Table 3.18.

Table 3.18: Number of necessary sample plots by volume level for each form of plot

M (m^3/ha)	**Area (ha)**	**Number of sample plots with the error of 10%**			
		Nested circle plot 500 m^2	Nested circle plot 1.000 m^2	Nested rectangular plots 500 m^2	Nested rectangular plots 500 m^2
>200	4.318,2	15	12	16	16
101 - 200	13.608,1	49	39	51	50
10 - 100	8.520,2	30	25	32	31
Total	**26.446,5**	**94**	**76**	**99**	**97**

Nested circle plot 1,000 m^2 had the smallest number of necessary sample plots (76 plots) in the four study plots. This proves that this type of plot has the smallest variation and stability compared to other sample plots.

Based on the labor cost for each type of plot, and the total number of sample plots to reach the error E% = 10% in the study area, we calculated total cost for four types of sample plots which were shown in Table 3.20.

Table 3.20: Total labor cost in surveying the sample plots under four different plot types of the whole study area

No	**Type of sample plot**	**Labor cost/plot (VND)**	**Total of plot**	**Total labor cost for plots in the whole study area (VND)**
1	Nested circle plot 500 m^2	244.925	94	23.059.838
2	Nested circle plot **1.000 m^2**	**292.308**	**76**	**22.284.312**
3	Nested rectangular plots 500 m^2	270.393	99	26.689.677
4	Nested rectangular plots 1.000 m^2	342.094	97	33.328.251

This result is consistent with the PCM guideline of Huy et al., (2013), it is therefore recommended to use the nested circle plot 1.000 m^2 in tree survey when implementing the PCM.

3.2.5. Selection of measurement for non-tree carbon pools in PCM

The question was whether the measurement of carbon pools outside the trees brings the economic efficiency when reducing emissions in the implementation of the UN-REDD program. The estimates of the measurement cost of CO_2 emissions in litter, deadwood and soil to make recommendations for whether should measure these carbon pools in the PCM.

Table 3.22 presents the result of estimating the biomass of deadwood, litter and soil organic carbon (SOC) calculated by hectares for types of sample plot.

Table 3.22: Average and deviation of biomass and carbon in 3 pools of deadwood, litter and in soil from different types of plots

Statistical indicators	**Soil Organic Carbon (SOC) (Carbon ton/ha)**	**Litter (biomass, ton/ha)**	**Deadwood (Biomass, ton/ha)**			
			Nested circle plot 500 m^2	*Nested circle plot 1.000 m^2*	Nested rectangular plot *500 m^2*	Nested rectangular plot *1.000 m^2*
n	39	39	39	39	39	39
Average	91,1	4,8	3,5	3,3	3,7	3,0
Error standard	23,4	1,8	5,3	6,4	6,4	5,7
CV%	26%	37%	153%	191%	172%	186%
min	83,5	4,2	1,8	1,3	1,6	1,2
max	98,7	5,3	5,2	5,4	5,8	4,9

Table 3.23 shown the value of CO_2 equivalent that reduce emissions per hectare per year. The calculation based on the percentage of deforestation in the past 15 years which is represented through the reference forest emissions level (FRL) (Chau, 2014) of Lam Dong province is 1,2%; the assumption that the forest is well managed; As such, carbon credit is the CO_2 equivalent on 1,2% of the forest area that at risk of losing. This is not mentioned for SOC because it is relatively stable when it is lost and degraded.

Table 3.23: Commercial value of CO_2 due to emission reduction at pools outside the trees convert into money average/ha/year

Pool	Biomass (ton/ha)	Carbon (ton/ha)	CO_2 equivalent (ton/ha)	CO_2 equivalent due to reducing deforestation 1,2%/year (ton/ha/year)	Unit price USD/ton CO_2	Value of CO_2 /ha due to emission reduction (USD/ha/year)	Total amount of money by reducing CO2 emissions (VND/ha/year)
Deadwood	3,3	1,57	5,76	0,07	10	0,7	15.545
Litter	4,8	2,24	8,21	0,10	10	1,0	22.172

The results shown that the economic efficiency brought from the value of CO_2 emission reduction of pools outside the forest trees is not significant; so it is not recommended for data collection to estimate the biomass and carbon for these pools in PCM.

3.3. Guideline of "Participatory Carbon Monitoring - PCM"

3.3.1. The necessary conditions or input data and the level of community participation in PCM

The community needs to be properly trained and provided with input information such as: forest map, sample plot coordinates are installed in GPS, inventory forms.

3.3.2. Organization of inventory and monitoring in the field

A team with minimum of five people, including: one forestry officer; four people are representatives of the community, they are knowledgeable about the forest in the area, and at least there are two people with education level from grade 6 to easily in recording and using forest inventory tools.

3.3.3. The input data required for PCM

The input data required for PCM including: i) Map of status; ii) Map of sample plot location; iii) Sample plot coordinates are converted to GPS. These data are provided by the District or Provincial Forestry Departments.

3.3.4. Monitoring the changes of forest area and status

Use GPS to measure the forest area lost or changed and provide data to specialized agencies or management units for updating and storing.

3.3.5. Set up sample plots, measure trees in plots

Use the nested circle plots 1,000 m^2 with three diameter classes of 6 - 22 cm, 22 - 42 cm and > 42 cm that corresponding to the area of 100, 500 and 1.000 m^2.

Including steps: i) Locate the sample plots in the field; ii) Set up the sample plots; iii) Measure trees in plots: Species, D and measure H of three trees at representative diameter class.

3.3.6. Synthesize data to estimate the emission or absorption of CO_2

The synthesis of data from PCM measurement results to estimate biomass, forest carbon needs to be conducted by specialized agencies. The results have two groups of data synthesized: i) Activity data; ii) Emission factor at the time of the survey. The process of synthesizing data to estimate CO_2 emission or absorption consists of the following basic steps:

3.3.6.1. Calculate the change of forest status area

From the results of tracking area changes by GPS, move into the map to adjust the area of forest status periodically.

3.3.6.2. Estimation the forest biomass and carbon at the time of the survey

Make D distribution (N/D): i) Divide the diameter into different classes with 4 cm interval; ii) Arrange the number of trees in the sample plots by diameter class; iii) Calculate the number of trees per hectare. Each sample plot was calculated for biomass and carbon through N/D distribution and converted from D to AGB by site index, BGB and carbon, CO_2 based on the biometric model which was established. From here it can be referred to hectares for each forest block.

3.3.6.3. Calculate changes of biomass and forest carbon

Use the Stock – difference method of IPCC (2006) to calculate changes of biomass and forest carbon.

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

1. Conclusions

From the research results, the dissertation had the following main conclusions:

i) Allometric equations for estimating tree/forest above and below ground biomass to apply in PCM:

- The methods of fitting power form were performed using weighted non-linear Maximum Likelihood with random effect of environmental factors provided the reliability higher than logarit transformation least square linear method. The random splitting with 70% of data to develop models, and 30% of data for cross validation, and 200 times realizations helped to select and provide correctly errors of the biomass estimation models.

- Model for estimating tree above ground biomass (AGB) using predictor variable as D to be measured by the community, the reliability of this model was improved when dividing the model into three levels of site index by $AGB = ai \times D^b$. Model for estimating tree below ground biomass (BGB) had the highest reliability with a variable D to be measured by the community using form of $BGB = a \times D^b$.

- The estimation models for forest above and below ground biomass: $TAGB = a \times G^b$ and $TBGB = a \times G^b$; in which the G was basal area measured by the community. However, using the model for forest level the error will accumulate from 9 to 12 percent compared with the model for individual tree.

ii) Selection of methods, tools, carbon pools to be applied in PCM:

- Using of local knowledge helped for monitoring the changes of forest status area based on community.

- Community was able to use GPS for monitoring forest land use changes at small-scale, identify random sample plots in the field.

- Data of D and the height of the tree (H) of three trees in a certain diameter class measured by the community had reliability that were applied for estimating AGB and BGB got a negligible deviation in comparison with measurement of technical staffs (Bias% < -5%).

- Nested circle plot 1,000 m^2 with three diameter classes showed the best effective cost, low deviation and ease in handling.

- The measurement of non-tree carbon pools did not gain the cost-effective, so it needs to focus only on measurement of tree above and below ground carbon in PCM.

iii) PCM guidelines:

The PCM guideline was developed that based on the results of appraisals, evaluates the reliability of methods, tools, models, includes the main activities as following: Team survey organization; Determine the input data required for PCM; Monitoring the changes in forest area and status; Establishment of sample plots and tree measurements; Synthesize data to estimate the emission or absorption of CO_2; Forms used in the field for PCM.

2. Limitations

The research for PCM development just only involved Chau Ma ethnic minority community of Lam Dong Province and still did not enough resources to expand to other ethnic minority community.

3. Recommendations

Based on the research, the thesis has the following recommendations:

i) Apply the PCM guidelines of this study in the UN-REDD Vietnam program areas; and the localities where implementing the payment policy for forest environment services according to Decree No.99/2010/NĐ-CP dated 24/9/2010 of the Government, Decree No.147/2016/NĐ-CP dated 02/11/2016 of the Government on amendments and supplements some articles of Decree No. 99/2010/NĐ-CP.

ii) Evaluate the application results of PCM guidelines outside the study area to finalize.