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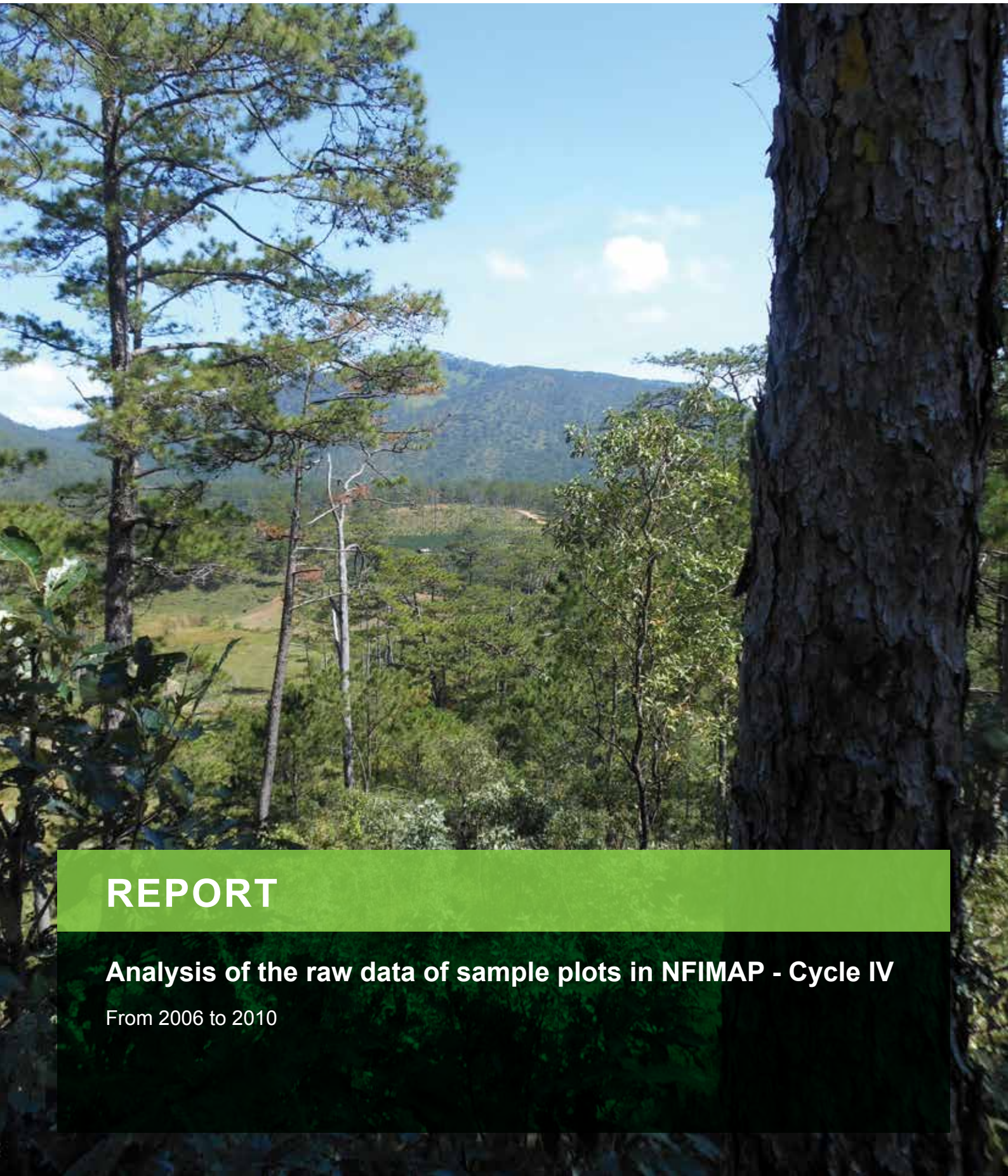

REPORT

Analysis of the raw data of sample plots in NFIMAP - Cycle IV

From 2006 to 2010

This report has been produced by the USAID-funded Lowering Emissions in Asia's Forests (USAID LEAF) program in its support for the development of the Lam Dong Provincial REDD+ Action Plan (PRAP). The report details the results of an analysis of the raw data of primary sample plots (PSPs) collected during Cycle IV of the National Forest Inventory and Monitoring Programme (NFIMAP) in Lam Dong, which was conducted in 2010 to support GHG emission factor estimations (EFs). It is one of five technical reports that have been developed to help the Lam Dong Department of Agriculture and Rural Development (DARD) in defining an appropriate Forest Reference Level FRL for the Province from which its policies and measures introduced to reduce emissions and increase greenhouse gas (GHG) removals from the forestry sector can be measured against. These studies will strongly support the on-going development of the Lam Dong PRAP.

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The report is available through the USAID LEAF website at:

http://www.leafasia.org/resources_tools

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Abbreviations

DARD	Department of Agriculture and Rural Development
DBH	diameter at breast height
GHG	greenhouse gas
FIPI	Forest Inventory and Planning Institute
FRL	forest reference level
LEAF	Lowering Emissions in Asia's Forests
MARD	Ministry of Agriculture and Rural Development
NFIMAP	National Forest Inventory, Monitoring and Assessment Program
NRAP	National REDD+ Action Program
PRAP	Provincial REDD+ Action Plan
PSP	primary sample plot
REL	reference emission level
SNV	SNV Netherlands Development Organisation
SSP	secondary sample plot
RECOFTC	The Center for People and Forests
REDD+	Reducing Emissions from Deforestation and Forest Degradation
USAID/ RDMA	United States Agency for International Development / Regional Development Mission for Asia
WD	basic wood density

Introduction

Over the past decade, various national and international organizations have made significant efforts to work out mechanisms to combat deforestation and reduce emissions of greenhouse gases (GHG) from the forest and land use sectors. They have attempted to quantify different values of forest resources and forest environmental services and propose workable market payment incentive mechanisms so as to effectively manage these valuable resources. Among these efforts, the most prominent initiative is the 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 (REDD+) mechanism. This performance based mechanism is aimed at compensating developing countries for conserving and protecting their forest resources, thereby reducing GHG emissions and increasing GHG removals. REDD+ mechanisms also seek to generate additional social and environmental benefits, or 'multiple-benefits', which include biodiversity conservation, improvement of local livelihoods and gender equity.

The United States Agency for International Development (USAID) funded Program "Lowering Emissions in Asia's Forests" (LEAF) is being implemented by Winrock International in partnership with SNV Netherlands Development Organisation, Climate Focus and The Center for People and Forests (RECOFTC) in six countries: Viet Nam, Laos, Cambodia, Thailand, Malaysia and Papua New Guinea. The purpose of the program is to strengthen the capacity of developing countries in the Asian region to produce meaningful and sustained reductions in GHG emissions from the forestry and land use sectors, thereby allowing these countries to benefit from the emerging international REDD+ program framework.

In Viet Nam, the USAID LEAF program was approved by the Ministry of Agriculture and Rural Development (MARD). USAID LEAF will provide support for the successful implementation of the Vietnam National REDD+ Action Program (NRAP).

The province of Lam Dong has been selected as one of six pilot provinces under the NRAP to pilot REDD+. USAID LEAF is supporting the development of the Lam Dong Provincial REDD+ Action Plan (PRAP).

Since 1990, Vietnam has implemented the National Forest Inventory and Monitoring and Assessment Program (NFIMAP) conducted by the Forest Inventory and Planning Institute (FIPI). Under the program, a huge dataset of forest resources has been collected and archived for the entire country. This report presents the methodology and outcomes of collating and analyzing the raw data of the fourth cycle of the NFIMAP (2006-2010) in Lam Dong province. It is from analysis of this data that forest carbon stocks and emission factors have been derived for inclusion in the Lam Dong Forest Reference Level.

1 Objectives, process and methods

1.1 Objectives

The main objective was to process and analyze the raw data of primary sample plots (PSPs) collected in Cycle IV of the NFIMAP in Lam Dong province to support emission factor estimation and consequently RELs/FRLs establishment for the PRAP in Lam Dong.

1.2 Process

1.2.1 Data processing

a. Data was converted from Microsoft Access format into Microsoft Excel format for analysis. The dataset included required parameters measured at the subplot, including: sample plot code number, subplot number, collection date, site description, coordinate of sample plots and subplots (VN2000), tree DBH, tree height, bamboo DBH and bamboo height.

b. The subplots were grouped into datasets per forest class (rich, medium, poor) of forest types, plantation forest and bamboo forest (following MARD forest classification system - Circular 34/2009/TT-BNN).

1.2.2 Data analysis

All collected data was analyzed and the following outputs generated:

a. Per secondary sample plot (SSP): range (minimum, maximum and median) of tree DBH and heights together with volume and carbon stocks of each SSP.

b. Per dataset for each forest type: range of volume and carbon stock (minimum, maximum, and median) and statistical values of volume and carbon stock (standard deviation, error at 95% confidence level).

1.3 Methods for data processing and analysis

1.3.1 Calculation of missing tree heights

In each SSP, three normal trees nearest to the plot center were chosen for total height measurement. Based on data from these trees, the heights of other trees were estimated. The calculation was as follows:

Step 1: Based on the heights of measured trees, height curves were calculated using regression methods. The chosen model was the logarithm function, which is of the form:

$$Hvn=a+b\ ln(DBH)\ (1)$$

Where *Hvn* is the total heights of the trees, measured in meters (m), *DBH* is the diameter at the 1.3 m height position, expressed in centimeters (cm) and *a* and *b* are the coefficients of the function. Their optimal values can be found by using a regression method. In this case, the regression was conducted using Microsoft Excel software (the "Data analysis" tool in the "Data" menu).

The height curves were calculated specifically for each forest type: evergreen broadleaf forest, deciduous forest, coniferous forest and plantations. For plantations, height curves specific to each species were developed if the number of sample trees for this species was ≥ 30. The forest types used for developing the height curves were based on the forest types collected in the field, not based on the forest types taken from the forest cover map.

Step 2: The developed height curves were used to calculate the total heights for other trees that had not had their total heights measured.

1.3.2 Calculation of standing volume for individual trees

In Vietnam, the standing volume of a tree is the volume of the stem from the base to the stem top. The calculation of standing volume for each field-collected forest type was as follows:

a. Natural evergreen broadleaf forest

The national two-parameter volume tables in the Forest Inventory and Planning Manual (FIPI, 1995) were applied. There are five national volume tables corresponding to five form groups. The volume table for form group 1 gives the smallest volumes and the volumes increase as the form group goes from 1 to 5. Here, the national volume table for form group 3 was used, since most of the tree species belonged to this group. To make the calculation easier an allometric equation equivalent to the volume table for form group 3 was used. The equation was:

$$V = 0.748 \times DBH^{2} \times Hmt^{0.764} \times 10^{-4}\ (2)$$

Where *DBH* is the diameter at the 1.3m height position, in cm and *Hmt* is the length of the tree stem, in m. According to the Forest Inventory and Planning Manual (FIPI, 1995), the length along the tree stem can be calculated from the total tree height using the following formula:

$$Hmt = Hvn \times 1.04\ (3)$$

b. Natural deciduous forest

The allometric volume equation specific to natural deciduous forest in the Central Highlands in the Forest Inventory and Planning Manual (FIPI, 1995) was applied:

$$V = 0.686 \times DBH^{1.9825} \times Hmt^{0.8163} \times 10^{-4} \quad (4)$$

c. Natural coniferous forest

The allometric volume equation specific to natural coniferous forest in the Central Highlands in the Forest Inventory and Planning Manual (FIPI, 1995) was applied:

$$V = 0.744 \times DBH^{1.9909} \times Hmt^{0.7814} \times 10^{-4} \quad (5)$$

d. Plantations

In Lam Dong province there were mainly four types of plantation: *Pinus spp., Acacia hybrid, Acacia auriculiformis and Anacardium occidentale.*

For Pinus spp. plantations, the formula for calculating tree volume as specified in section (b) natural coniferous forest above was applied.

For other plantations, the same standing volume equation as for natural evergreen broadleaf forest was applied.

1.3.3 Calculation of dry biomass

a. For *Acacia hybrid* and *Acacia auriculiformis* plantations

The allometric equations for calculation of dry biomass (including above-ground and below-ground biomass) for individual trees in these two plantations have already been developed (Hai, 2008).

- *Acacia hybrid* plantations

  The allometric biomass equation developed for Acacia hybrid was applied:

$$B = AGB+BGB=0.2250 \times DBH^{2.244} \quad (6)$$

- *Acacia auriculiformis* plantations

  The allometric biomass equation developed for Acacia auriculiformis was applied:

$$B = AGB+BGB=0.3116 \times DBH^{2.107} \quad (7)$$

Next, the sum of dry biomass of all individual trees in each SSP was used to calculate the total dry biomass of the SSPs.

b. For other forest types

Calculation of above-ground biomass for individual trees

- Natural evergreen broadleaf forest

  The allometric biomass equation developed specifically for evergreen broadleaf forest in Binh Thuan province (Hung et al. 2012) was applied:

$$AGB = 0.1277 \times DBH^{2.3943} \quad (8)$$

- Natural deciduous forest

  The allometric biomass equation specific to deciduous forest in Binh Thuan province (Hung et al. 2012) was applied:

$$AGB = 0.0670 \times DBH^{2.5915} \quad (9)$$

- Natural coniferous forest

  Since no allometric biomass equation specific to Vietnam coniferous forest was available, the indirect method of calculation via tree volume was used as follows:

$$AGB = V \times BEF \times WD \quad (10)$$

  Where BEF is the biomass expansion factor and WD is the basic wood density. Since the tree volume used in Vietnam is not the merchantable volume, the default BEF value provided in IPCC guidelines was not appropriate. In this study, the BEF of 1.3 (Brown, 1997) and the WD of 500 kg/m3 were used for coniferous forest.

- Bamboo forest

  The allometric biomass equation developed for Lo o (Bambusa balcoa) species in Binh Thuan province (Hung et al. 2012) was applied:

$$AGB = 0.182 \times DBH^{2.160} \quad (11)$$

- *Pinus spp.* plantations

  The same method was applied as for natural coniferous forest.

- Cashew (*Anacardium occidentale*) plantations

  The same method was applied as for natural evergreen broadleaf forest.

Calculation of dry biomass for each SSP

- The total AGB of each SSP was calculated by summing up the AGB of all individual trees in the SSP.

$$AGB_i = \sum_{j=1}^{n_i} AGB_{ij} \quad (12)$$

Where AGBi is the AGB of the ith SSP, ni is the number of trees in the ith SSP and AGB_{ij} is the AGB of the *j*th tree in the *i*th SSP.

- BGB was not calculated for each individual tree but was only calculated for each SSP. The calculation formula was as follows:

$$BGB_i = AGB_i \times R \ (13)$$

Where BGB_i is the BGB of the *i*th SSP and *R* is the ratio between AGB and BGB. Here, the default values proposed by Mokany et al. (2006) were used. The value *R* = 0.205 was applied for SSPs having AGB < 125 tons/ha and the value *R* = 0.235 was applied for SSPs having AGB > 125 tons/ha.

- The total dry biomass of the *i*th SSP is equal to the sum of dry AGB and dry BGB of this SSP:

$$B_i = AGB_i + BGB_i \ (14)$$

1.3.4 Conversion from dry biomass to carbon stock

Carbon stock of SSP *i* was calculated using the following formula:

$$C_i = B_i \times CF \ (15)$$

Where *Bi* is the dry biomass (including above-ground and below-ground) of SSP *i*, measured in kilograms (kg) and *CF* is the carbon fraction factor. Here, the default value of 0.47 was used (McGroddy et al. 2004).

The carbon stock value calculated as above is expressed in kg in an area of one SSP (i.e., 500 m^2). The following formula was used to convert to the unit of tons/ha:

$$tC/ha_i = \frac{C_i \times 10^4}{10^3 \times 500} = \frac{C_i}{50} \quad (16)$$

1.3.5 Conducting statistics by land cover classes

a. Calculation of the mean value

The mean of volume or carbon stock for class *i* is the average value of all SSP on that class, that is:

$$\bar{x}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{ij} \qquad (17)$$

Where *ni* is the number of SSPs in class *i* and x_{ij} is the value (basal area, volume, or carbon stock) of the *j*th SSP in class *i*.

b. Calculation of coefficient of variation

Coefficient of variation of class i was calculated by the following formula:

$$CV\%_i = \frac{S_i}{x_i} \qquad (18)$$

Where S_i is the standard error of all SSPs in class *i* and was calculated by the following formula:

$$S_i = \frac{1}{\sum_{j=1}^{l_i} m_{ij}} \sqrt{\frac{l_i}{l_i - 1} \sum_{j=1}^{l_i} (y_{ij} - \bar{x}_i . m_{ij})^2} \qquad (19)$$

1. Where l_i is the number of PSPs having at least one SSP of class i, y_{ij} is the sum of values over all SSPs of class *i* in the *j*th PSP, $\bar{x}_i$ is the mean value in class *i* and m_{ij} is the number of SSPs of class *i* in the PSP *j*.

c. Calculation of error (with the confidence level of 95%)

The following formula for error calculation (with the confidence level of 95%) was applied for class *i*:

$$E\%_i = t_{05,li-1} \times CV\%_i \ (20)$$

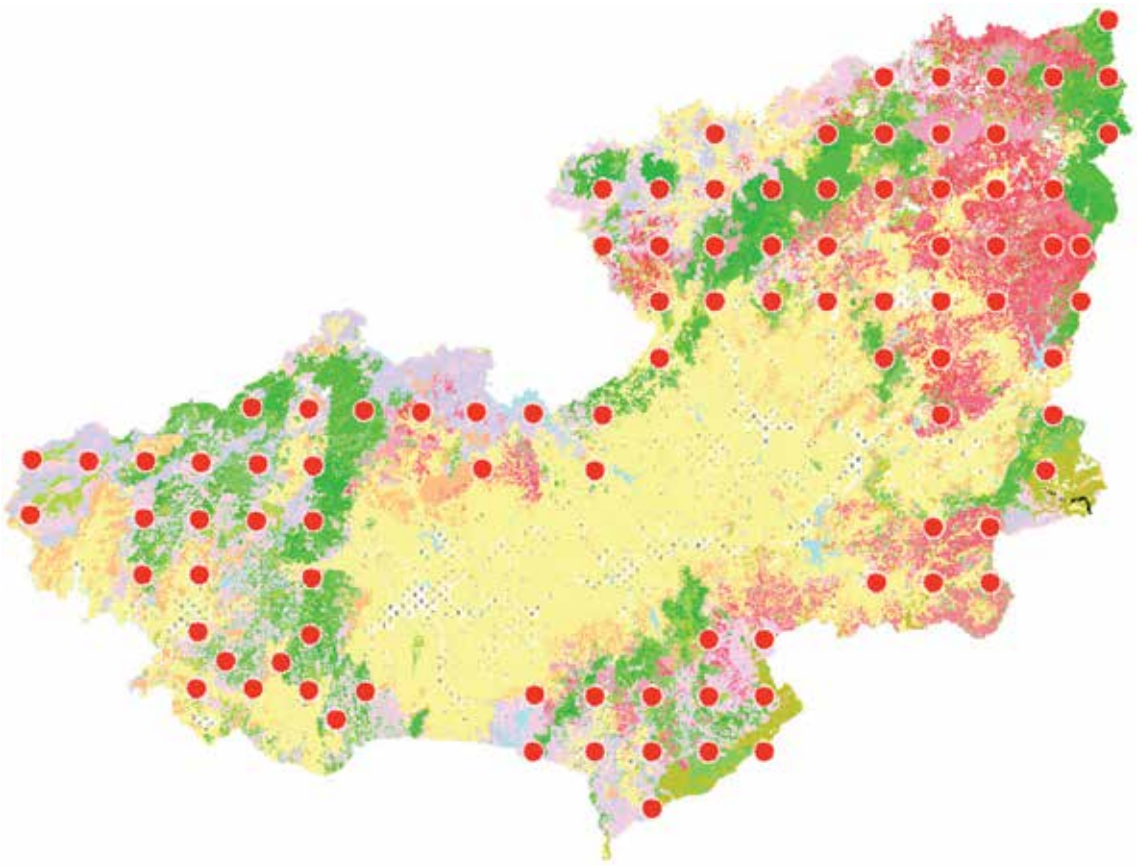
Where $t_{05,li-1}$ is the value of the t distribution of l_i-1 degrees of freedom for the 95% confidence level.

2 Results and discussions

2.1 Land categories

There were a total of 95 PSPs in Lam Dong province in Cycle IV- NFIMAP. The locations of these 95 PSPs in Lam Dong province are provided in Figure 1.

Figure 1: Locations of the 95 primary sample plots in Lam Dong province



As described in the parallel report titled “Accuracy Assessment for Forest and Land Use Maps from 1990-2010, Lam Dong Province, Viet Nam”, each PSP had 40 SSPs. Therefore, there were a total of 3,800 SSPs in Lam Dong in Cycle IV- NFIMAP. Based on the field data, they were in 63 different land categories, which were classified following Regulation No. 84. These 63 land categories are listed in Table 1 below.

Table 1: List of field-based land categories of SSPs.

No	Code	Description	No of SSPs
1	CAT	Sandy land	3
2	CD	Special-use land	34
3	CF	Coffee	239
4	DC	Residence area	19
5	DIEU	Cashew plantations	67
6	IA	Bare land with grass	52
7	Ib	Bare land with shrubs	65
8	IC	Bare land with scattered trees	9
9	IIA	Young forest without volume stock	82
10	IIA+L	Young forest without volume stock + bamboos	40
11	IIB	Young forest with volume stock	192
12	IIB+L	Young forest with volume stock + bamboos	185
13	IIB+M	Young forest with volume stock + bamboos	18
14	IIIA1	Evergreen broadleaf forest - poor	43
15	IIIA1+L	Evergreen broadleaf forest - poor + bamboos	87
16	IIIA1+M	Evergreen broadleaf forest - poor + bamboos	40
17	IIIA1+TH5	Evergreen broadleaf forest - poor + matured Pinus trees	1
18	IIIA2	Evergreen broadleaf forest - medium	306
19	IIIA2+L	Evergreen broadleaf forest - medium + bamboos	28
20	IIIA2+M	Evergreen broadleaf forest - medium + bamboos	6
21	IIIA3	Evergreen broadleaf forest - rich (IIIA3)	239
22	IIIA3+L	Evergreen broadleaf forest - rich + bamboos	141
23	IIIA3+N	Evergreen broadleaf forest - rich + bamboos	7
24	IIIB	Evergreen broadleaf forest - rich (IIIB)	547
25	IVA	Evergreen broadleaf forest - primary	40
26	KL.I	Acacia hybrid plantations - age class I	3
27	KL.II	Acacia hybrid plantations - age class II	14
28	KLT.I	Acacia auriculiformis plantations - age class I	7
29	KLT.II	Acacia auriculiformis plantations - age class II	15
30	L.IIa	Bamboo forest	3
31	L.IIIA	Bamboo forest	6
32	L.IIIb	Mixed wood - bamboo forest	114
33	MN	Water bodies	13
34	NI+IIA	Small bamboos + regrowth forest	1

No	Code	Description	No of SSPs
35	NN	Agriculture land	162
36	RAY	Slash and burn fields	99
37	RI	Deciduous ecosystem with scattered trees	6
38	RII	Young regrowth deciduous forest	63
39	RII+TH5	Young regrowth deciduous forest + matured pinus trees	2
40	RIIIA1	Deciduous forest - poor	21
41	RIIIA2+L	Deciduous forest - medium + bamboos	25
42	RIIIB+L	Deciduous forest - medium + bamboos	15
43	RIIIB+Le	Deciduous forest - medium + bamboos	21
44	Th21	Coniferous forest - young small trees	39
45	Th22	Coniferous forest - young large trees	51
46	Th22+RII	Coniferous forest - small trees + young deciduous forest	13
47	Th31	Coniferous forest - medium-aged small trees	164
48	Th31+RIIIA1	Coniferous forest - medium-aged small trees + deciduous forest - poor	15
49	Th32	Coniferous forest - medium-aged large trees	211
50	TH32+RIIIA1	Coniferous forest - medium-aged large trees + deciduous forest - poor	1
51	TH4	Coniferous forest - nearly matured	57
52	Th5	Coniferous forest - matured	13
53	Th5+IIB	Coniferous forest - matured + young forest	51
54	Th5+IIIA1	Coniferous forest - matured + wooden forest - poor	1
55	Th5+RIIIA1	Coniferous forest - matured + deciduous forest - poor	5
56	ThI	Pinus plantations - age class 1	34
57	THII	Pinus plantations - age class 2	24
58	ThII+BDII	Pinus plantations - age class 2 + Eucalyptus robusta plantations - age class 2	2
59	ThIII	Pinus plantations - age class 3	20
60	ThIII+TIII	Pinus plantations - age class 3 + Acacia auriculiformis plantations - age class 3	4
61	THIV	Pinus plantations - age class 4	7
62	ThV	Pinus plantations - age class 5	3
63	ThV+BDV	Pinus plantations - age class 5 + Eucalyptus robusta plantations - age class 5	5
Total			**3800**

These SSPs were overlaid on the forest cover map of the year 2010 and the map-based forest types of these SSPs were taken. The forest types in the forest cover map were classified following Circular 34 and provided in Table 2 below.

Table 2: List of map-based land cover classes of SSPs

Land cover classes	Description	No of SSPs
DC	Residence area	16
MN	Water bodies	28
TN	Bamboo forest	38
RK	Broadleaf-coniferous mixed forest	88
DT	Bare land	97
RL	Deciduous forest	92
NG	Evergreen broadleaf forest - poor	141
PH	Evergreen broadleaf forest - regrowth	169
LKG	Coniferous forest - rich	217
RT	Plantation	153
LKNG	Coniferous forest - poor	193
LKTB	Coniferous forest - medium	198
NN	Agriculture or other land	472
TB	Evergreen broadleaf forest - medium	566
G	Evergreen broadleaf forest - rich	561
HG	Timber-bamboo mixed forest	693
Total		3,722

Note that 78 SSPs were not in the Lam Dong province boundary so they do not have map-based land cover classes.

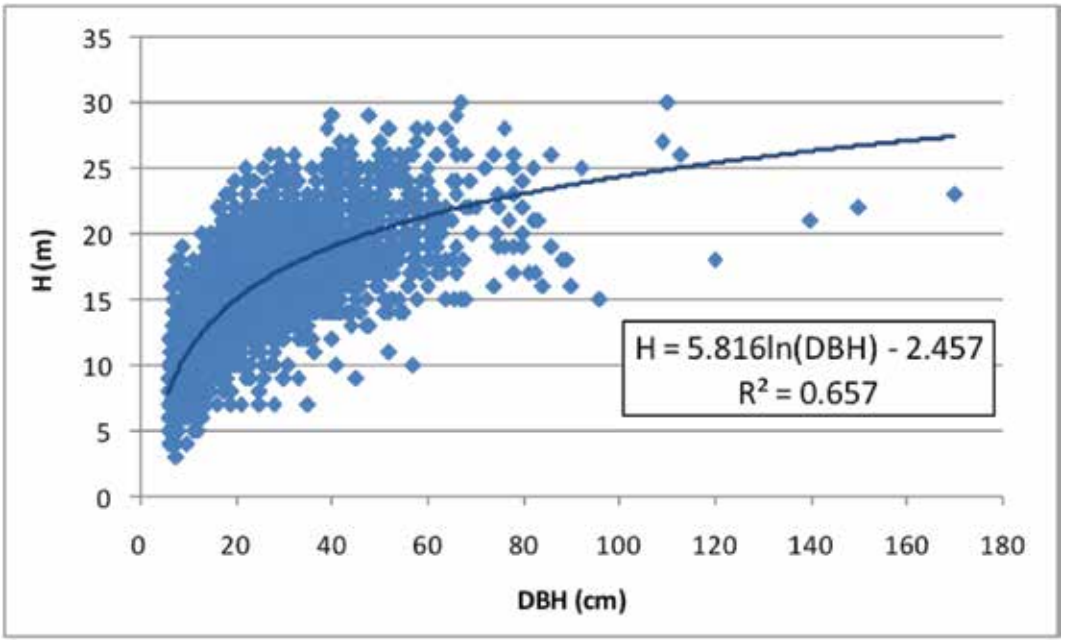
Because the time the satellite image was taken is different from the time the ground surveys were conducted, it is possible that the land categories collected on the field do not match the land cover classes on the map. Therefore, the 95 PSPs were examined carefully and it was found that 9 PSPs contained many SSPs having field-based land categories different from map-based land cover classes. These nine PSPs were not considered when calculating the average criteria and statistical values. The IDs of these nine PSPs are: 155_81, 156_80, 157_83, 158_77, 159_77, 162_76, 163_70, 164_69 and 164_71.

2.2 Developing height curves and calculating missing tree heights

2.2.1 Natural evergreen broadleaf forest

In natural evergreen broadleaf forest, 6,253 trees had their total heights measured. The height curve of this forest type is given in Figure 2 below.

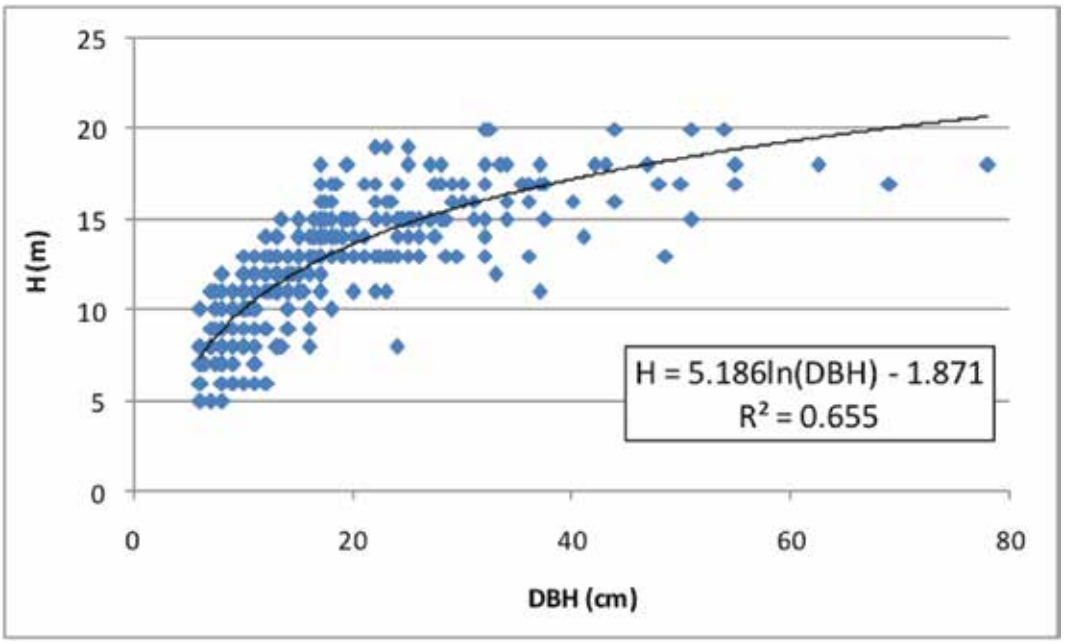
Figure 2: The height curve of the natural evergreen broadleaf forest



2.2.2 Natural deciduous forest

In SSPs of natural deciduous forest, 432 trees had their total heights measured. The height curve of this forest type is given in Figure 3 below.

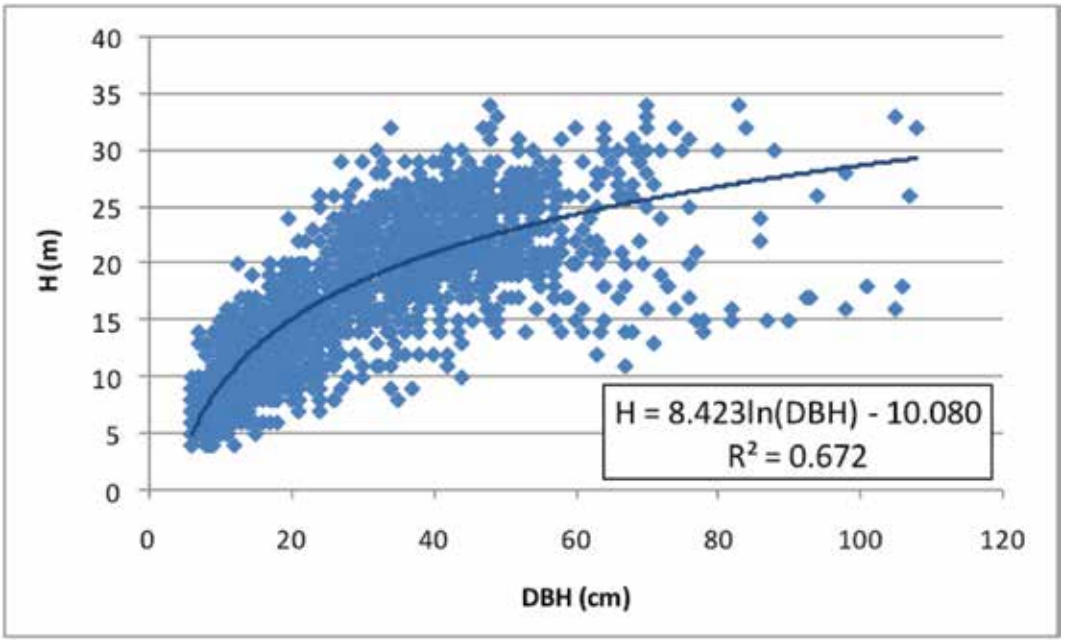
Figure 3: The height curve of the natural deciduous forest



2.2.3 Natural coniferous forest

In SSPs of natural coniferous forest, 1,848 trees had their total heights measured. The height curve developed from these trees is given in Figure 4 below.

Figure 4: The height curve of the natural coniferous forest

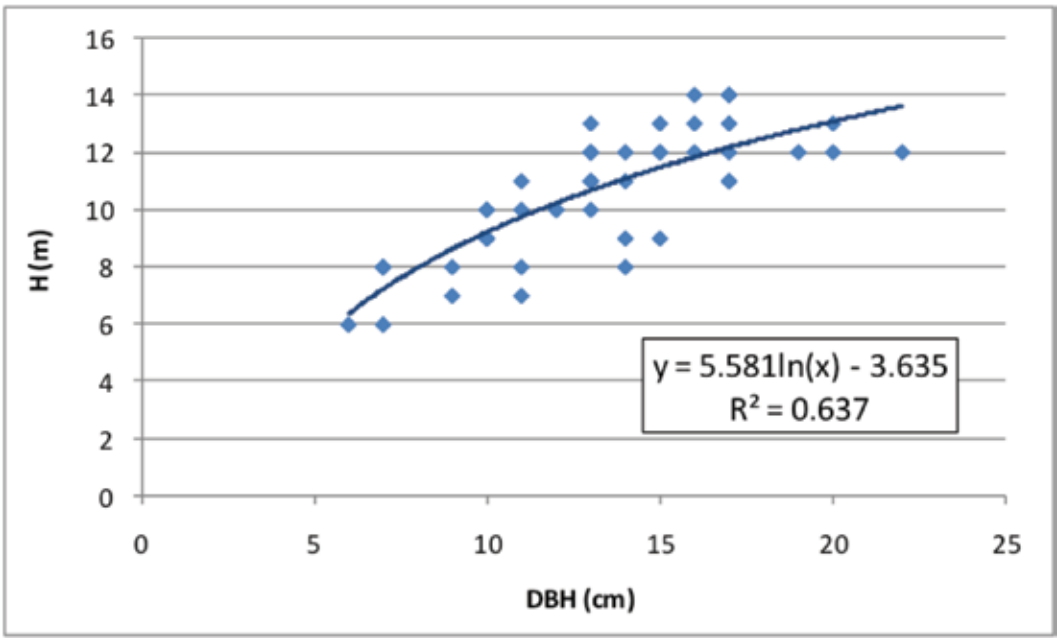


2.2.4 Plantations

Acacia auriculiformis plantations

In SSPs of Acacia auriculiformis plantations, 47 trees had their total heights measured, including 40 Acacia auriculiformis trees and 7 other trees. The height curve is given in Figure 5 below.

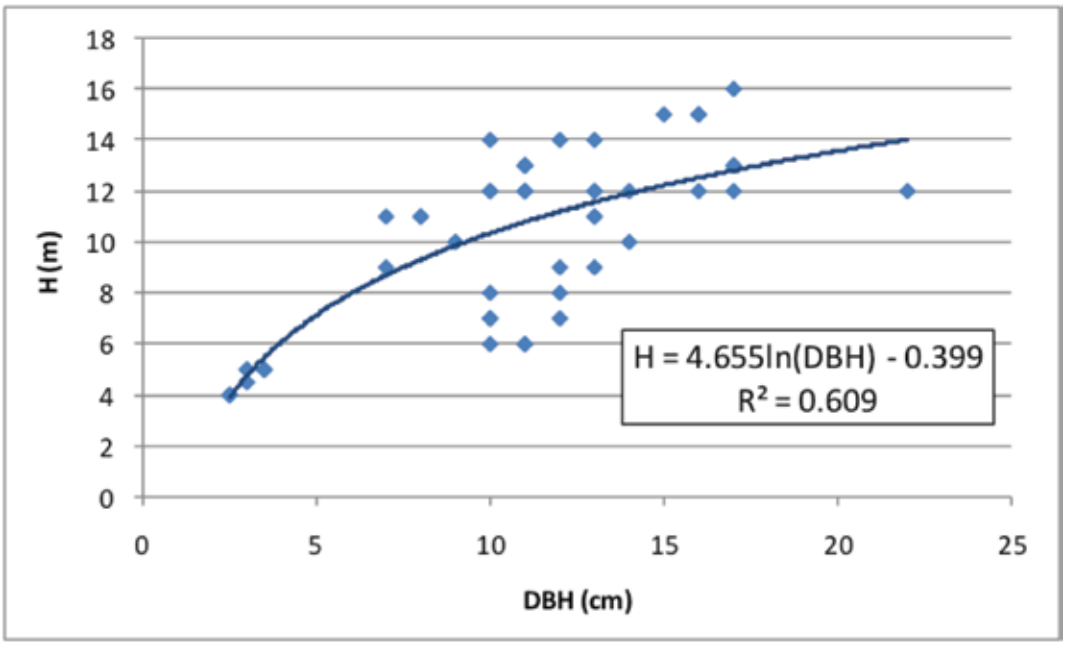
Figure 5: The height curve of Acacia auriculiformis plantations



2.2.5 Acacia hybrid plantations

In SSPs of Acacia hybrid plantations, 51 Acacia hybrid trees had their total heights measured. The height curve developed from these trees is shown in Figure 6.

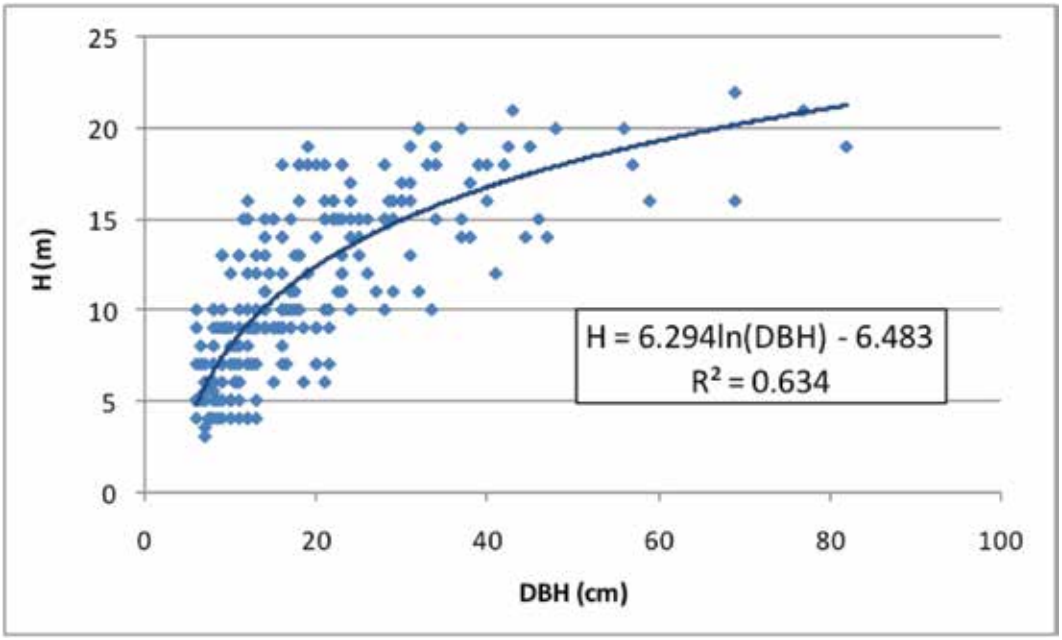
Figure 6: The height curve of Acacia hybrid plantations



2.2.6 Pinus spp. plantations

In SSPs of Pinus spp. plantations, 252 trees had their total heights measured, including 212 Pinus spp. trees. The height curve of trees in Pinus spp. plantations is shown in Figure 7 below.

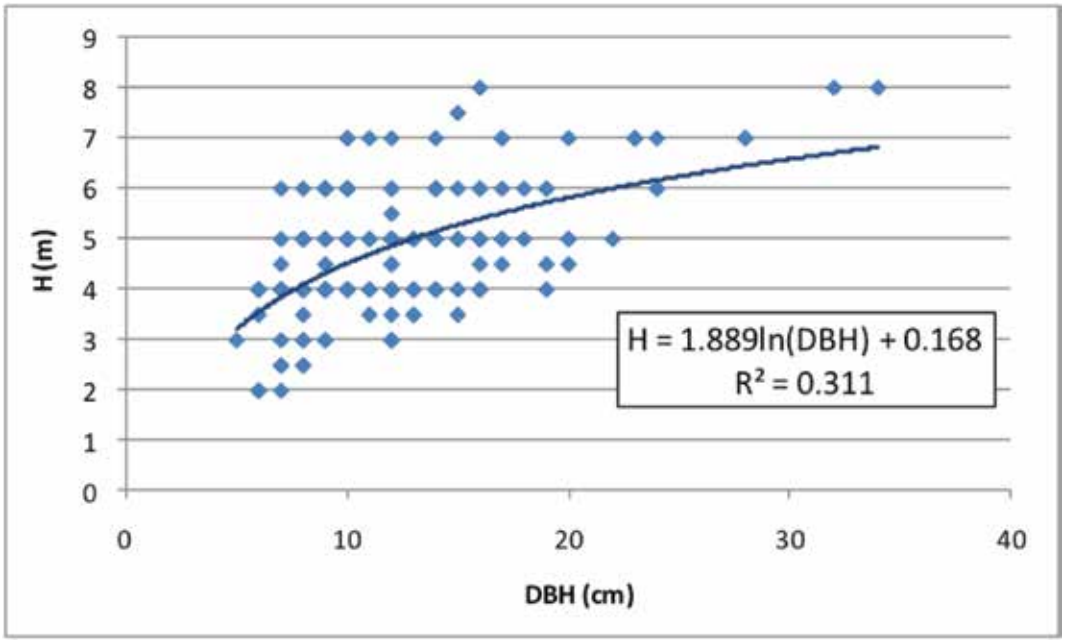
Figure 7: The height curve of Pinus spp. plantations



2.2.7 Cashew *(Anacardium occidentale)* plantations

In 67 SSPs of cashew plantations, 179 cashew trees had their total heights measured. The height curve of cashew plantations is given in Figure 8. It can be observed that this equation had quite low R2 (0.311). This was probably due to the rounding to 0.5m when measuring total tree heights, since cashew trees are often quite short (≤ 8m).

Figure 8: The height curve of cashew plantations



2.3. Calculation of missing tree heights

Table 3 provides a summary of height curves used for calculating missing tree heights. It can be seen that all equations, except those for Acacia hybrid and cashew plantations, could be used. For Acacia hybrid and cashew plantations, the value of parameter a is not statistically significant (at α=0.05 level). An attempt was made to develop a height curve for two Acacia plantations but this did not solve the issue. However, the proportion of plantations' carbon stock in Lam Dong province was observed to be quite small, so, in the author's opinion, it is still acceptable to use these equations for calculating missing tree heights.

Table 3: Summary of height curves used for calculating missing tree heights

No	Forest type	*n*	*a*	*b*	R^2	p_F	p_a	p_b
1	Natural evergreen broadleaf forest	6,253	-2.457	5.816	0.657	<0.01	<0.01	<0.01
2	Natural deciduous forest	432	-1.871	5.186	0.655	<0.01	<0.01	<0.01
3	Natural coniferous forest	1,848	-10.080	8.423	0.672	<0.01	<0.01	<0.01
4	*Acacia auriculiformis* plantations	47	-3.635	5.581	0.637	<0.01	<0.05	<0.01
5	*Acacia hybrid* plantations	51	-0.399	4.655	0.609	<0.01	0.75	<0.01
6	*Pinus spp.* plantations	252	-6.483	6.294	0.634	<0.01	<0.01	<0.01
7	Cashew plantations	179	0.168	1.889	0.311	<0.01	0.75	<0.01

2.4 Calculation of average criteria

The average criteria, such as number of trees per ha, number of bamboos per ha and average DBH, were calculated for each map-based land cover class. The results are given in Table 4 below.

Table 4: Average criteria by land cover classes

No	Land cover types	No. of PSPs	No. of trees / ha	No. of bamboos /ha	Avg. DBH (cm)
1	Residence area	3	30.0 ±583.6%	0	1.0 ±583.6%
2	Bare land	11	42.6 ±134.9%	0	3.5 ±113.2%
3	Water bodies	8	42.2 ±181.1%	325.9 ±187.8%	4.3 ±168.1%
4	Agriculture or other land	28	105.9 ±86.3%	208.5 ±129.0%	5.5 ±47.4%
5	Evergreen broadleaf forest - rich	25	657.2 ±13.9%	126.1 ±122.5%	25.1 ±5.6%
6	Evergreen broadleaf forest - medium	29	678.2 ±13.4%	370.9 ±79.6%	22.0 ±5.7%
7	Evergreen broadleaf forest - poor	23	463.9 ±27.3%	970.3 ±78.5%	20.4 ±9.0%
8	Evergreen broadleaf forest - regrowth	16	786.8 ±22.6%	117.5 ±166.8%	14.5 ±10.5%
9	Coniferous forest - rich	13	287.8 ±24.6%	0	32.3 ±15.8%
10	Coniferous forest - medium	19	432.4 ±17.4%	32.2 ±218.8%	25.1 ±10.7%
11	Coniferous forest - poor	19	300.9 ±45.7%	0	23.9 ±23.8%
12	Deciduous forest	5	495.0 ±60.2%	282.6 ±179.4%	14.2 ±70.7%
13	Timber-bamboo mixed forest	30	383.6 ±25.1%	2,152.4 ±30.8%	17.4 ±13.9%
14	Broadleaf-coniferous mixed forest	8	560.0 ±37.1%	0	20.7 ±31.6%
15	Plantations	11	366.3 ±15.9%	108.4 ±229.3%	13.3 ±58.6%
16	Bamboo forest	3	36.0 ±114.1%	100.0 ±375.1%	4.9 ±105.7%

In this table, the errors are calculated at 95% confidence level (i.e., using Formula 20 above). It can be observed that most of the criteria are quite appropriate. However, the average criteria for bamboo forest seem to be incorrect. This indicates that this land cover class may be difficult to classify using satellite imagery.

2.5 Total basal area/ha by land cover classes

Next, statistical values for total basal area/ha were calculated. The results are given in Table 5 below.

Table 5: Total basal area/ha by land cover classes

No	Land cover types	No. of PSPs	Min of ∑G/ha (m^2)	Max of ∑G/ha (m^2)	Avg of ∑G/ha (m^2)	Std. error	CV (%)	Error (%)
1	Residence area	3	0.00	2.68	0.19	0.26	135.64	583.62
2	Bare land	11	0.00	31.71	2.04	1.36	66.58	148.34
3	Water bodies	8	0.00	25.07	2.24	1.88	84.08	198.82
4	Agriculture or other land	28	0.00	29.28	1.92	0.48	25.04	51.37
5	Evergreen broadleaf forest - rich	25	5.29	149.84	31.17	1.60	5.14	10.61
6	Evergreen broadleaf forest - medium	29	0.00	81.39	25.43	1.54	6.05	12.40
7	Evergreen broadleaf forest - poor	23	0.00	76.73	14.61	1.83	12.51	25.95
8	Evergreen broadleaf forest - regrowth	16	0.00	52.65	14.09	2.47	17.52	37.33
9	Coniferous forest - rich	13	0.32	56.60	20.79	1.62	7.79	16.98
10	Coniferous forest - medium	19	0.00	55.33	18.85	0.93	4.95	10.41
11	Coniferous forest - poor	19	0.00	48.15	13.47	2.60	19.33	40.60
12	Deciduous forest	5	0.00	61.69	11.28	5.03	44.62	123.89
13	Timber-bamboo mixed forest	30	0.00	83.84	9.57	1.15	12.01	24.57
14	Broadleaf-coniferous mixed forest	8	0.00	75.25	19.48	5.33	27.37	64.71
15	Plantations	11	0.00	55.29	7.75	3.25	41.88	93.32
16	Bamboo forest	3	0.00	6.40	0.63	0.24	37.16	159.90

As can be seen, only 4 (evergreen broadleaf forest – rich, evergreen broadleaf forest – medium, coniferous forest - rich and coniferous forest - medium) out of 16 land cover classes had errors < 20%. Among the forest land classes, bamboo forest, plantations, broadleaf-coniferous mixed forest and deciduous forest had the largest errors. This is understandable as these forest classes were classified based on forest characteristics, not on forest volume.

2.6 Timber volume/ha by land cover classes

Subsequently, statistical values for timber volume/ha were calculated by map-based land cover classes. The results are given in Table 6.

Table 6: Volume /ha by land cover classes

No	Land cover types	No. of PSPs	Min of M/ha (m3)	Max of M/ha (m3)	Avg of M/ha (m3)	Std. error	CV (%)	Error (%)
1	Residence area	3	0.00	8.58	0.60	0.81	135.64	583.62
2	Bare land	11	0.00	283.14	17.84	11.98	67.12	149.55
3	Water bodies	8	0.00	233.60	19.88	17.06	85.82	202.93
4	Agriculture or other land	28	0.00	275.65	14.57	4.21	28.88	59.26
5	Evergreen broadleaf forest - rich	25	38.98	1720.83	281.78	15.44	5.48	11.31
6	Evergreen broadleaf forest - medium	29	0.00	823.16	223.80	14.62	6.53	13.38
7	Evergreen broadleaf forest - poor	23	0.00	856.91	126.77	17.78	14.03	29.09
8	Evergreen broadleaf forest - regrowth	16	0.00	490.77	111.07	21.59	19.44	41.44
9	Coniferous forest - rich	13	1.47	695.54	214.62	20.22	9.42	20.53
10	Coniferous forest - medium	19	0.00	562.67	177.55	11.31	6.37	13.39
11	Coniferous forest - poor	19	0.00	497.87	121.78	23.72	19.47	40.91
12	Deciduous forest	5	0.00	635.64	89.75	44.41	49.48	137.39
13	Timber-bamboo mixed forest	30	0.00	903.95	79.59	10.73	13.49	27.58
14	Broadleaf-coniferous mixed forest	8	0.00	914.52	187.10	64.19	34.31	81.13
15	Plantations	11	0.00	488.21	57.64	27.62	47.92	106.76
16	Bamboo forest	3	0.00	51.70	4.79	2.16	45.05	193.81

It can be observed that the values of average volume/ha for all land cover classes, except bamboo forest, would seem appropriate and match field norms. Similar to total basal area/ha, only three classes (evergreen broadleaf forest – rich, evergreen broadleaf forest – medium and coniferous forest - medium) had errors < 20%. Among forest land classes, the errors of bamboo forest, plantations, broadleaf-coniferous mixed forest and deciduous forest were quite high.

2.7 Carbon stock/ha by land cover classes

Finally, statistical values for carbon stock/ha were calculated by map-based land cover classes. The results are given in Table 7.

Table 7: Carbon stock/ha by land cover classes

No	Land cover types	No. of PSPs	Min of C/ha (tC)	Max of C/ha (tC)	Avg of C/ha (tC)	Std. error	CV (%)	Error (%)
1	Residence area	3	0.00	6.59	0.46	0.62	135.64	583.62
2	Bare land	11	0.00	125.61	7.59	5.05	66.49	148.16
3	Water bodies	8	0.00	106.96	9.11	7.82	85.85	203.00
4	Agriculture or other land	28	0.00	123.47	7.05	1.82	25.78	52.89
5	Evergreen broadleaf forest - rich	25	15.03	956.02	123.53	6.98	5.65	11.65
6	Evergreen broadleaf forest - medium	29	0.00	398.59	97.28	6.49	6.67	13.66
7	Evergreen broadleaf forest - poor	23	0.00	420.47	56.28	7.96	14.14	29.32
8	Evergreen broadleaf forest - regrowth	16	0.00	225.97	46.28	9.39	20.30	43.26
9	Coniferous forest - rich	13	0.54	262.42	80.64	7.65	9.48	20.66
10	Coniferous forest - medium	19	0.00	212.29	67.67	4.34	6.41	13.48
11	Coniferous forest - poor	19	0.00	226.23	48.02	9.53	19.86	41.72
12	Deciduous forest	5	0.00	325.93	40.42	21.60	53.44	148.38
13	Timber-bamboo mixed forest	30	0.00	464.05	40.10	4.32	10.76	22.01
14	Broadleaf-coniferous mixed forest	8	0.00	345.04	72.07	24.24	33.63	79.53
15	Plantations	11	0.00	184.20	22.86	9.86	43.11	96.05
16	Bamboo forest	3	0.00	23.99	2.12	1.05	49.51	213.02

The errors of carbon stock/ha were very similar to those of volume/ha. Only 3 (evergreen broadleaf forest – rich, evergreen broadleaf forest – medium and coniferous forest - medium) out of 16 classes had errors < 20%. Among forest land classes, errors of bamboo forest, plantations, broadleaf-coniferous mixed forest, deciduous forest and evergreen broadleaf forest – regrowth were high because these classes were not classified by forest volume. In addition, the

number of PSPs for these classes may not have been sufficient. Although they were classified by quality and the number of SSPs was sufficient large (19), the error for coniferous forest – poor classes was still quite high (~42%). This may have been because it was difficult to classify these classes accurately from satellite imagery.

3 Conclusions and recommendations

In this report, the average carbon stocks/ha for each forest type in Lam Dong province were estimated using the field data of 95 PSPs, which were collected in Cycle IV of NFIMAP. The calculated results showed that only 3 out of 16 land cover classes, all forest land, had average carbon stock/ha errors which met the requirements (≤20% with a confidence level of 95%). Among the 12 forest land classes, 9 classes had errors larger than the target level, in particular those that are not classified by forest volume.

In order to reduce the uncertainty of the carbon stock estimates for Lam Dong province, it is proposed that the forest land classes having errors larger than the target level should be stratified further or that more sample plots be inventoried.

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