Development of country-specific allometric equations for Lao PDR

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Japan International Cooperation System (JICS) - Forest Preservation Programme in Lao People's Democratic Republic, Component on Allometric Equation Development and Forest Cover Rate Estimate

Development of country-specific allometric equations in Lao PDR

Forest Inventory Planning Division (FIPD)

Department of Forestry (DOF)

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Acronyms

Acronym	Name
AGB	Above Ground Biomass
B	Bamboo
BGB	Below Ground Biomass
CF	Coniferous Forest
DAFO	District Agriculture and Forestry Office
DBH	Diameter at Breast Height
DD	Dry Dipterocarps Forest
DOF	Department of Forestry
EF	Emission Factor
EG	Evergreen Forest
FFPRI	Forestry and Forest Products Research Institute
FIM	Forest Information Management Project
FIPD	Forestry Inventory and Planning Division
FREL/ FRL	Forest Reference Emission Level /Forest Reference Level
Lao PDR	The Lao People's Democratic Republic
JICS	Japan International Cooperation System
MAF	Ministry of Agriculture and Forestry
MCB	Mixed Coniferous Broadleaf Forest
MD	Mixed Deciduous Forest
NAFRI	National Agriculture and Forestry Research Institute of Laos
NFI	National Forest Inventory
NFIS	Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD+
NRTF	National REDD+ Task Force
NUoL	National University of Laos
P	Forest Plantation class
PAFO	Provincial Agriculture and Forest Office
PAREDD	Participatory Land and Forest Management Project for Reducing Deforestation in Lao PDR (2009-2015)
PFA	Production Forest Area
REDD+	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation of forests and enhancement of forest carbon stock
RV	Regenerating Vegetation

1 Executive Summary

Forests in Lao PDR have diminished severly, from its 70% coverage in the 1940s to 55% in 2010[1]. The drivers of deforestation are considered to be mainly land use changes including shifting cultivation, development of hydro power plants, agriculture expansions including industrial plantations.

Recognizing Reducing Emissions from Deforestation and Forest Degradation (REDD+) under the UNFCCC as an opportunity for enhancing forest governance, financial revenue and livelihoods of rural communities, the Government of Lao PDR has been engaging in REDD+ readiness since 2008, and has established the National REDD+ Task Force (NRTF) as a multi-ministerial coordination and decision making body for REDD+.

Lao PDR intends to submit its first Forest Reference Emission Level/Forest Reference Level (FREL/FRL) for REDD+ to the UNFCCC in January 2018. The first submission of the Emission Reduction Program Document (ERPD) for the Carbon Fund (CF) of Forest Carbon Partnership Facility (FCPF) including its FREL/FRL of the target area[2], is also due in January 2018. The work conducted to develop country-specific allometric equations contributes to the generation of emission factors of higher accuracy, used in the construction of FREL/FRLs necessary for both the national submission and for the ERPD submission.

With support from the Japan International Cooperation System (JICS) the "The Forest Preservation Programme in Lao People's Democratic Republic TA6: Allometric equation development and Forest cover rate estimation" was conducted and produced country-specific allometric equations of three forest types; Evergreen Forest, Mixed Deciduous Forest and Dry Dipterocarp Forest.

The allometric equations were developed using 36 sample trees per forest type with a wide DBH range and with samples from all regions of the country. The Lao-specific allometric equations facilitates precise estimation of carbon stock of forests in Lao PDR.

[1] Forest Type Map 2010

[2] Luang Namtha, Bokeo, Sayabouri, Oudomxay, Luang Prabang and Houaphan provinces in northern Lao PDR.

2 Introduction

2.1 Background

The Government of the Lao PDR has been working on all elements of REDD+ readiness, including the preparation of its Forest Reference Emission Level/Forest Reference Level (FREL/FRL).

Total forest carbon stock or its change can be estimated by multiplying the total forest area or change-area by carbon stock per unit area. Three Tiers are defiend based on accuracy of data, i.e. Tier 1 when default data available in the IPCC Guidelines and elsewhere is applied, Tier 2 for country-specific data and Tier 3 for more precise data based on periodic surveys.

In Lao PDR, the forest type maps of 2000, 2005, 2010 and 2015 (wall-to-wall maps which cover the entire land of Lao PDR) were developed with support from the Forest Information Program (FIM) (Japan's Environmental Grant Aid Program) and the successor JICA Technical Cooperation Projects[3]. Through the development of the multi-year forest type map, forest area estimate has achieved Tier 3 status.

Without country-specific allometric equations, carbon stock per unit area can only be estimated by applying IPCC default allometric equations, developed for generic contexts and not specific to Lao, to the result of 2nd National Forest Inventory (2nd NFI)[4]. Such an approach would not match the high precision level applied for forest area estimation through the forest type maps. In light of these contexts, the Government decided it appropriate to develop country-specific allometric equations to achieve overall higher accuracy in carbon estimation.

2.2 Objective

The objective was to develop country-specific allometric equations for Lao PDR, to contribute to the higher accuracy FREL/FRL construction and to submit these to the UNFCCC and FCPF Carbon Fund.

2.3 Working Group

A Working Group was set up with a members including MAF, DOF, experienced researchers of allometric equation development from the National University of Lao (NUOL) and the National Agriculture and Forestry Research Institute of Lao (NAFRI), experts from other donor projects, NGOs, private sector, Japanese consultants and an expert from Forestry and Forest Products Research Institute (FFPRI) of Japan.

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[3] Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD+ (NFIS) (2013 - 2015), and Sustainable Forest Management and REDD+ Support Project (F-REDD) (2015 – 2020)

[4] DOF, et al (2017) "The 2nd National Forest Inventory Survey in Lao People's Democratic Republic".

This Working Group was instrumental as a venue for technical discussions and decision-making, for example on the selection of target forest types, predictor variables to be used in the allometric equations and survey sites.

3 Preparation

3.1 Selection of forest types

The forest types for the survey were identified based on the original forest type map 2010, which was developed by JICA's Technical Cooperation Project (NFIS). The carbon stock was calculated by multiplying the area of each forest type with the average carbon stock per unit area of each forest type estimated from the 1st NFI data. The forest types with large carbon stocks were considered as priority for the development of allometric equations.

Table 1: Carbon stock per hectare and area of each forest type

Forest type		tCO2/ha (A&BGB) (1)	Area (ha) (2)	Total MtCO2 (A&BGB) (3)=(1)*(2)
Evergreen Forest	**EG**	521.7	2,979,349	**1,554**
Mixed Deciduous Forest	**MD**	284.6	7,077,578	**2,014**
Dry Dipterocarp Forest	**DD**	199.4	1,020,857	**204**
Coniferous Forest	CF	163.5	87,404	14
Mixed Coniferous Broadleaved Forest	MCB	381.8	218,241	83
Regenerating Vegetation	**RV**	39.8	7,761,687	**309**
Forest Plantation	P	213.4	73,182	16
Bamboo	B	103.3	134,252	14

* Data is as of April 2015

The Working Group identified the following three forest types as the highest priority for developing allometric equations (based on Table 1); Evergreen Forest, Mixed Deciduous Forest and Dry Dipterocarp Forest.[5]

3.2 Predictor variables s for the allometric equations

Common predictor variables of allometric equations for estimating tree biomass are Diameter at Breast Height (DBH), Height and Wood density (WD). The NFI campaigns conducted in Lao PDR

[5] Furthermore, the meeting also discussed the need to survey and estimate the biomass for Regenerating Vegetation (RV). See "Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest".

measured tree DBH, but, excluded Height measurement. Therefore, the Working Group determined that DBH should be the single predictor variable to be used in the allometric equations. Nevertheless, Height measurements were taken in the field survey, as such data may become useful into the future.

3.3 Number of trees and DBH variability

To the extent possible, the data set for developing allometric equations should include sufficient sample trees as well as cover the range of tree sizes from the largest size group to the smallest size group. Inclusion of the largest tree group in samples is important to reduce estimation errors in biomass estimation. The Working Group determined the DBH variants for destructive measurement as shown in the table below.

Table 2: DBH variability

Forest Type	10cm <= DBH < 30	30cm <= DBH < 50cm	>50cm <= DBH
EG	12 trees	12 trees	12 trees
MD	12 trees	12 trees	12 trees
DD	12 trees	12 trees	12 trees

3.4 Tree species

Allometric equations for Lao PDR are developed for specific forest types. Thus, selected sample trees should be representative of the tree species in each forest type. Table 3 shows the top 10 frequent tree species in each forest type, based on results from the 1st NFI. The survey team selected the tree species from the list, whenever possible. If the survey team could not find these tree species in the field, the sample tree was selected based on the surveyor's experience as a representative tree species in the forest type.

Table 3: List of top 10 frequent tree species in each forest type in 1st NFI

EF (Evergreen Forest)

Species name	Number of trees
Lagerstroemia toinentosa	63
Anisoptera sp.	54
Vatica cinerea	29
Feronia lucida	26
Dipterocarpus alatus	21
Irvingia sp.	14
Parkia streptocarpa	13
Parashorea stellata	10
Tetrameles nudifiora	9
Sandoricum indicum	9

MD (Mix Deciduous)

Species name	Number of trees
Lagerstroemia toinentosa	717
Dipterocarpus alatus	283
Feronia lucida	251
Irvingia sp.	179
Anisoptera sp.	161
Xylia kerrii	116
Vatica cinerea	95
Pterocarpus macrocarpus	72
Sindora cochinchiriensis	56
Tetrameles nudifiora	43

DD (Dry Dipterocarp)

Species name	Number of trees
Feronia lucida	232
Lepisanthes rubiginosa	94
Terminalia tomentosa	74
Dipterocarpus intricatus	63
Lagerstroemia toinentosa	58
Shorea siamensis	54
Dipterocarpus obtusifolius	48
Irvingia sp.	45
Xylia kerrii	41
Pterocarpus macrocarpus	39

3.5 Deadwood and Saplings

The surveys on deadwood and saplings were also designed to improve the carbon stock estimate for each of the three forest types; EG MD and DD. The data collected through this survey and by the 2nd NFI were be combined to develop the carbon stock per hectare.

Deadwood was measured and the samples were classified into three decay classes. Saplings were also measured by collecting and weighing 10 saplings at each time of tree felling. The biomass of saplings were included into the total AGB.

3.6 Survey sites

The site location was also taken into consideration to achieve representative samples from all relevant parts of the country for the development of the national level allometric equations. Therefore, the site selection for each forest type was designed in north, central and south regions, separately.

In the selection process, permission from the Government for logging was required. The survey sites were selected from the "Logging plan for infrastructure construction", which is a list of approved forest conversion sites for the given year, including areas for hydropower resevoirs, electric transmission lines and towers and governmental buildings, since permission to cut trees in such areas could be obtained more easily. Appropriate sites for MD forest were found in Bokeo, Khammouane and Attapeu provinces, and for DD forest in Khammouane and Attapeu provinces. However, it was unable to find the sites for EG forest in the north and central region. Therefore, sites for EG were selected from the Production Forest Area (PFA) in Attapeu, Xayabouly and Bolikhamxay provinces. This permission was issued from the Ministry of Agriculture and Forestry. This procedure took almost one year because MAF had not originally included logging in PFAs.

The survey was finally confirmed to be implemented in five provinces; Bokeo, Xayabouly, Bolikhamxay, Khammouane and Attapeu.

Table 4: Survey sites for each forest type

Forest Type	Province	Region	Number of Tree
EG	Xayabouly	North	12
	Bolikhamxay	Central	12
	Attapeu	South	12
MD	Bokeo	North	12
	Khammouane	Central	12
	Attapeu	South	12
DD	Khammouane	Central	18
	Attapeu	South	18
*Small DD area in the northern region in Lao PDR.			

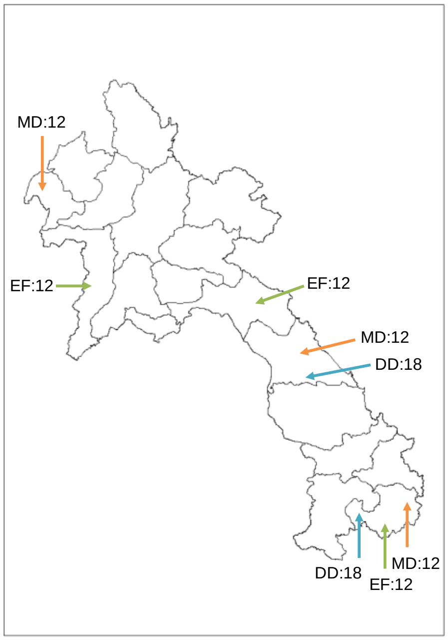

Figure 1: Survey site for each forest type

3.7 Implementation arrangements (survey team)

The survey was conducted by two teams (A and B) and each Survey team was composed of the following members.

Table 5: Survey team composition

Institution	Number of staff
FIPD (Forest Inventory and Planning Division)	2 or 3
Driver	2
PAFO (Provincial Agriculture and Forest Office)	1
DAFO (District Agriculture and Forest Office)	1
Villager	2
Chainsaw operator	1
Total	9 or 10

The survey consisted of two work components; one required certain techniques and knowledge for tree selection and weighing work; and the other engaged in simple operations such as cutting trees and carrying equipment and samples. The trained FIPD staffs were in charge of the former task and local employees were assigned to the latter.

3.8 Trainings

Before the commencement of the field survey, the 1st training was held in May 2015 under the support of Winrock International for 1 week with 18 staff of the inventory section from FIPD, DOF and 2 staff of the NUOL. In the classroom training, the trainees learned the general principles of allometric equation development. At a research forest in NUoL, trainees cut down three trees and learned the procedures of the survey such as cutting, measuring and weighing trees. Furthermore, supplementary trainings were given to the survey team before their departure to the field in February 2016 and November 2016.

3.9 Survey schedule

The survey was divided into two periods due to the delay in issuance of permission by MAF; February - March 2016 and December 2016 - January 2017. The table below shows the survey schedule.

Table 6: Survey schedule

Duration	Province	Region	Team	Forest Type
Feb 2016	Khammouane	Central	A	MD, DD
Mar 2016	Attapeu	South	B	EG, MD, DD
Mar 2016	Bokeo	North	A	MD
Dec 2017	Xayabouly	North	A	EG
Jan 2017	Bolikhamxay	Central	A	EG

4 Survey Method and Analysis

All destructive field and laboratory sampling methods for trees, deadwood and saplings were carried out based on Winrock International's standard operating procedures (Walker *et al.,* 2014). The following sections summarize the steps outlined in the above-mentioned standard operating procedures, and Figure 2 to Figure 7 were also sourced from the same source.

4.1 Field survey (cutting, weighing and collecting samples)

4.1.1 Calibration

Appropriate bottle of water (around 6kg) and metal weight (100g) as 'calibration weights' were used to calibrate hanging scales prior to going to the field.

4.1.2 Measurement of Trees

<u>Prior to Tree felling</u>

Surveying irregular trees such as leaning, standing dead and multi-stem trees was avoided. Trees with liana or vines were also avoided. Care was taken to seek the common species found in the 1st NFI (Table 3). Tree species were recorded and pictures of the whole scale were taken.

Tree diameter at breast height (DBH) was measured to the nearest 0.1 cm (e.g. Diameter of 10.2 cm not 10 cm). For each tree, a tree pole (1.3 m wooden pole) was placed against the tree to indicate the location of DBH measurement (Figure 2). The tree pole was always placed on the upslope side of the tree for the measurement (Figure 3). For trees with buttress taller than 1.3 m, the diameter was measured at 30 cm above the top of the buttress as shown in Figure 3. Tree height was measured to the nearest 0.1 cm (e.g. Height of 12.3 m not 12 m). For each tree, height was measured 15 or 20 m apart two times from different directions using clinometers.

Figure 2: Measurement of diameter using a diameter tape and a pole

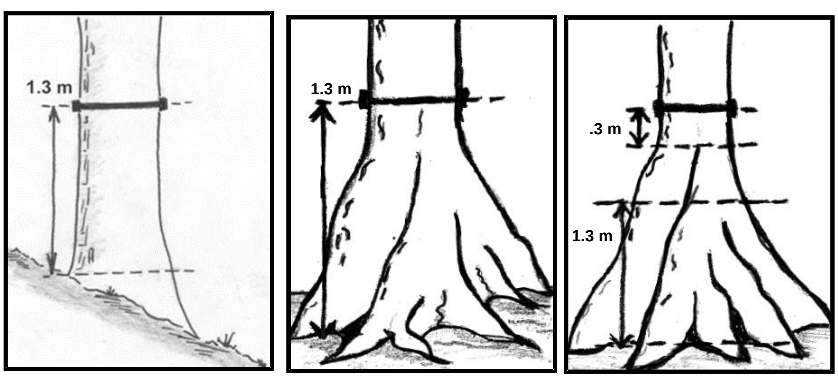

Figure 3: Proper placement of diameter tape

<u>After Tree Felling</u>

The following measurement was made after the tree felling (Figure 4):

a. Length of tree (from the stump to the top of the crown) (in meters to the nearest 0.01 m)
b. Length of bole (from the stump to the first main branch) (in meters to the nearest 0.01 m)

c. Diameter of stump (in cm to the nearest 0.1 cm)
d. Diameter at breast height (in cm to the nearest 0.1 cm)
e. Diameter at the center of bole (in cm to the nearest 0.1 cm)
f. Diameter at top of bole (in cm to the nearest 0.1 cm)

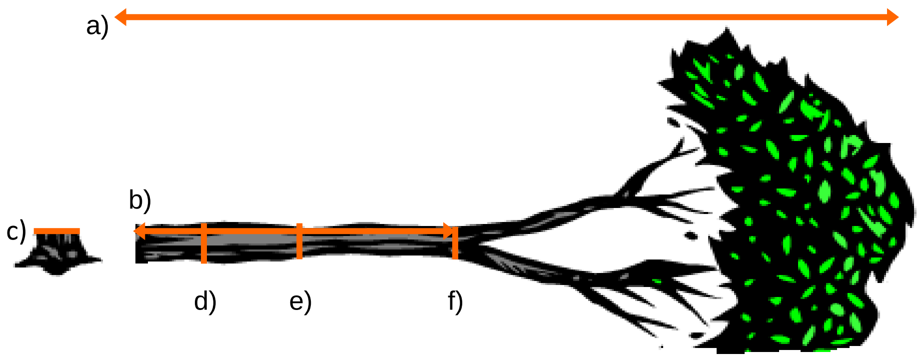

Figure 4: Tree measurement parts of tree

Trees were divided into “compartments”; bole, stump, buttress, leaves and branches less than 10 cm in diameter, branches 10cm or more to less than 20 cm in diameter and branches 20cm or more in diameter. All compartments were weighed as the following steps:

Boles

Boles, which are defined in this survey as stems from the stump to the first major branch, would be too large and heavy to measure in their entirety. Therefore, a different procedure was applied to estimate the bole biomass. Boles were cut into pieces in ~5m interval (Figure 5). For each piece, diameters at the bottom and the top and the length were measured and recorded.

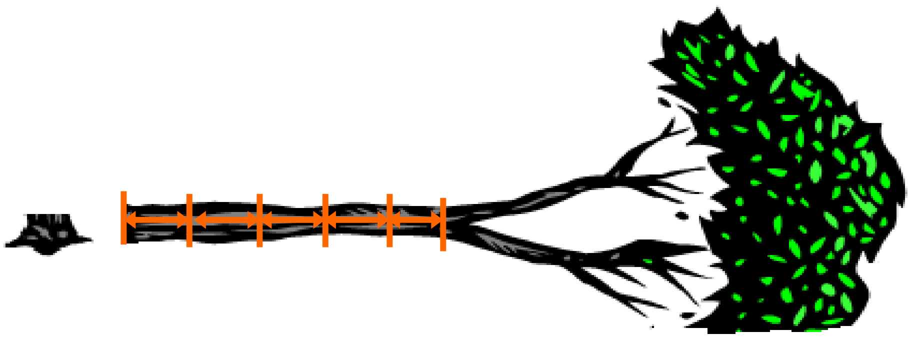

Figure 5: Measurements of diameter and length along the bole of tree

Disc samples were also collected from different sections of bole; bottom, middle and top to estimate wood density. The dimensions of the discs were recorded (Figure 6). Discs that were too large to fit into the cloth subsample bags were cut into half, quarter or one-eighth pieces after the measurement of the dimension and only cut pieces were returned to the FIPD office. Field sheets were annotated to this effect. The volume of the subsection was estimated as either a half, quarter or one-eighth of the total volume estimated from the diameter and thickness measurements in the FIPD.

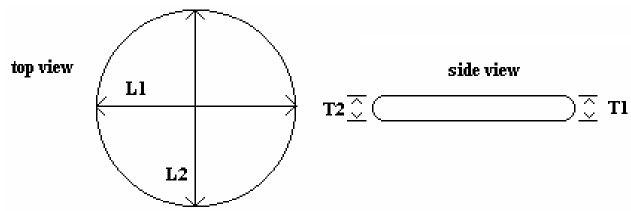

Figure 6: Wood disc measurement locations

Buttress

The buttresses, if any, were also cut into pieces and weighed by hanging scales. The weights were recorded on the Datasheets. Two 'pie pieces' as sub-samples were cut out including both the center and edge part in the 'pie piece'. The two sub-samples were also weighed and recorded. The sub-samples were put into cloth bags and labeled.

Stump

Relatively small stumps were cut as close to the ground as possible after the measurement of boles and buttress. The stumps were also cut into pieces and whole fresh weights were recorded. Then, two 'pie pieces' as sub-samples were cut out of the stump. They were weighed by hanging scales and recorded on the Datasheets. The sub-samples were put into cloth bags and taken to FIPD. Stumps that were too large to cut up and weigh their volume were estimated or measured with the combined procedure of weighing and estimation. The estimation models are shown in Figure 7. Tree density obtained from the bole measurements can be used to estimate the density of the stump.

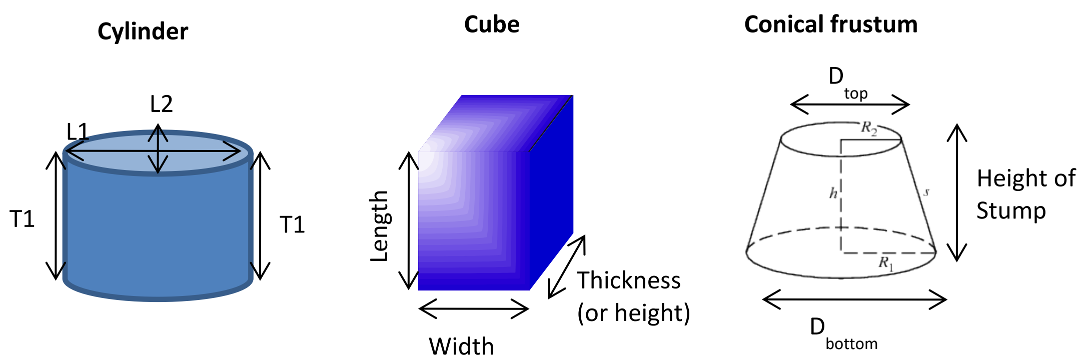

Figure 7: Volume estimation of remaining stumps

Branches more than 20 cm in diameter

Branches were selected as a diameter more than 20 cm using the diameter fork. The tarps were weighed and recorded beforehand. The selected branches were all piled up on the tarps and weighed by hanging scales. The weights were recorded on datasheets. Branches that were large enough were weighed directly using the hanging scale.

The cloth bags were weighed and recorded beforehand. Five sub-samples up to around 1000 g were put into each bag to be weighed and recorded. Each sub-sample was made up of a mix of the sizes of branches found. The bags were labeled with tree identification number, including provincial code and sub-sample identification number.

Branches from 10-20 cm in diameter

Branches were selected as a diameter from 10 to 20 cm using the diameter fork. The tarps were weighed and recorded beforehand. The selected branches were all piled up on the tarps and weighed by hanging scales. The weights were recorded on datasheets.

The cloth bags were weighed and recorded beforehand. Five sub-samples up to around 1000 g were put into each bag to be weighed and recorded. Each sub-sample was made up of a mix of the sizes of branches found. The bags were labeled with tree identification number, including provincial code and sub-sample identification number.

Leaves and branches < 10 cm in diameter

The plastic tarps were weighed and recorded beforehand. All the branches with a diameter less than 10 cm, all leaves, all flowers and all fruits were collected and piled up on the tarps. The leaves, flowers and fruits were NOT removed from the branches. All collected samples were weighed and recorded.

The cloth bags were weighed and recorded beforehand. 5 sub-samples about 200- 500g were put into each bag to be weighed and recorded. Each sub-sample was made up of a mix of the sizes of branches found and all the leaves, flowers and fruits. The bags were labeled with tree identification number, including provincial code and sub-sample identification number.

4.1.3 Deadwood

At least one deadwood sample was randomly collected at each tree felling site in consideration of both various decay stages and the three forest types for density determination (dry weight per green volume). All deadwood samples were classified into three decay classes: sound, intermediate, and rotten. These classes were determined using the 'machete test'. The 'machete test' consists of raising the machete up to shoulder height and allowing it come down to the dead wood piece with the force of gravity. No additional force must be applied to the motion of the machete.

a. <u>Sound</u>: Machete does not sink into the piece (bounces off)—this does not necessarily mean the wood shows no sign of decomposition—lying dead wood can lose all the sapwood and bark but yet the heartwood is still sound—this would be classified as sound
b. <u>Intermediate</u>: Machete sinks partly into the piece, and there has been some wood loss
c. <u>Rotten</u>: Machete sticks into the piece, there is more extensive wood loss, and the piece is crumbly—the key here is that the dead wood is decomposed throughout and very soft and crumbly

For the sound class of deadwood, discs or cylinders were cut from the selected piece of dead wood and the diameter (Diameter1 and Diameter2) and thickness (Width1 and Width2) of the sample were measured and recorded for volume estimation (Figure 8).

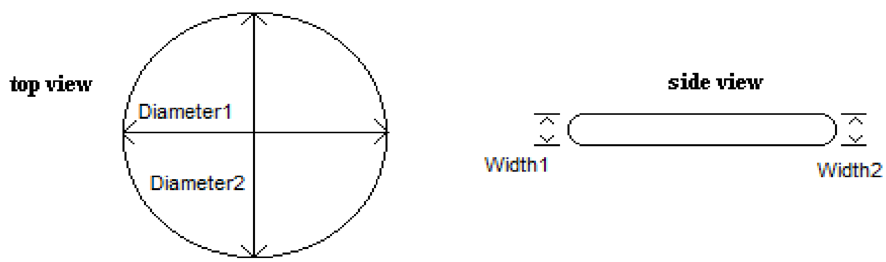

Figure 8: Measurements to be taken on disc cut from coarse dead wood samples

For intermediate and rotten classes, the samples were not measured in the field. However, very crumbly samples were tightly wrapped around the piece of wood before being placed in cloth bags.

4.1.4 Sapling

At each destructive tree sampling location, 10 saplings were chosen at random and cut at the base. All 10 saplings were weighed and recorded. The plastic tarps were weighed and recorded beforehand and the selected saplings were all piled up on the tarps and weighed by hanging scales. The weights were recorded on datasheets.
The cloth bags were weighed and recorded beforehand. A representative sub-sample was selected and about 200- 500 g were put into each bag to be weighed and recorded. The bags were labeled with tree identification number, including provincial code and sub-sample identification number.

4.2 Laboratory work

4.2.1 Sample drying and biomass estimation for Trees

The absolute dry mass or biomass was obtained in the following steps.

a. 80°C drying

First, all the fresh samples were dried at 80°C in the sawmill factory. The dried weight was determined and recorded after drying of more than one week. Through the drying process, the weight was monitored at regular intervals until reaching a constant. The wet-dry ratio at 80°C was obtained at the compartment level.

b. Species selecting for 100°C drying

Secondly, several species were selected from each forest type for drying at more than 100°C because no oven with the capacity of drying all the samples at more than 100°C was found in the country. To the extent possible, five species were selected based on the top 10 frequent species per forest type, from the 1st NFI (Table 3) to obtain the representative ratio between sample weight of 80°C drying and 100°C drying. Only four of the 1st NFI frequent species were found in the DD sample trees and one more species was selected at random. Although the selected EG trees contained a buttress tree, MD and DD did not. Therefore, one more buttress tree was selected for each group; MD and DD. 17 trees were finally selected from the view of size and variety of DBH (Table 7).

Table 7: Selected tree species for more than 100°C drying

Forest Type	Tree speices	DBH [cm]	Frequent species in 1st NFI
EG	*Irvingia harmandiana* Pierre	18.7	Yes
	Anisoptera robusta Pierre	35.2	Yes
	Vatica cinerea King	48.5	Yes
	Dipterocarpus alatus Roxb. ex G.Don	56.0	Yes
	Tetrameles nudiflora R. Br.	61.1	Yes
MD	*Irvingia harmandiana* Pierre	15.0	Yes
	Anisoptera cochinchinensis P.	25.0	Yes
	Vatica cinerea King	41.0	Yes
	Sindora cochinchinensis Baill.	42.0	No
	Dipterocarpus alatus Roxb. ex G.Don	46.9	Yes
	Tetrameles nudiflora R. Br.	68.5	Yes
DD	*Pterocarpus macrocarpus* Kurz	16.0	Yes
	Odina Woodier Roxb.	38.0	No
	Terminalia tomentosa Roxb (ex DC) Wight & Arn	39.5	Yes
	Xylia kerrii Craib & Hutch.	42.0	Yes
	Dipterocarpus obtusifolius Teysm. ex Miq.	52.2	Yes
	Bombax albidum Gagn.	61.0	No

c. 100°C Drying

The selected samples were dried out at more than 100°C in National University of Laos (NUoL). Throughout the entire drying process, the weight was monitored at regular intervals until it reached a constant. The dried weight was determined and recorded after drying of more than three days. At last, the 80-100°C ratio at the compartment level was obtained and the 80°C weight of the compartment was corrected with that ratio into absolute dry mass. However, the biomass of boles and some stumps were calculated with a different method as described below because they were not weighed in the field.

d. Wood density for estimation of boles and stumps biomass

The volume of discs was calculated as follows to calculate the wood density;

$$Volume = \pi * \left(\frac{Diameter_1 + Diameter_2}{2} \Big/ 2 \right)^2 * \left(\frac{Width_1 + Width_2}{2} \right)$$

Where:
Volume = Volume of bole sub-sample (discs); cm3
Diameter1 = First diameter of sample; cm
Diameter2 = Second diameter of sample; cm
Width1 = First width of sample; cm
Width2 = Second width of sample; cm

As the absolute dry weights were already obtained in the drying process, the wood density of each disc was calculated using the following formula;

$$\text{Density} = \frac{Dry\_weight}{Volume}$$

The wood densities of three discs were obtained on each tree. The wood density of an individual tree was determined as the average of those three wood densities. This process was conducted separately for bole, stump, and branch and leaves.

e. Biomass estimation by multiplying volume and wood density

The biomass of boles and stumps were determined. The biomass of boles was calculated by multiplying the estimated volume in the field and the wood density (ρ). The biomass of whole or part of stumps was calculated by multiplying the estimated volume in the field and the wood density (ρ). When the two different methods were combined for biomass estimation; the weighing and drying method only through procedures 1-3 and the multiplying volume and wood density method, the biomasses of stumps obtained by the different methods were summed up. The whole biomass of stumps was finally obtained at compartment level.

f. Estimation of whole biomass at individual tree level

The biomass at compartment level was summed up and the biomass at each individual tree level was determined.

4.2.2 Deadwood

a. Volume estimation

For sound wood class, the volume of each sample was calculated as follows;

$$Volume = \pi * \left(\frac{Diameter_1 + Diameter_2}{2} \Big/ 2 \right)^2 * \left(\frac{Width_1 + Width_2}{2} \right)$$

Where:
Volume = Volume of sample; cm3
Diameter 1 = First diameter of sample; cm
Diameter 2 = Second diameter of sample; cm
Width 1 = First width of sample; cm
Width 2 = Second width of sample; cm

For intermediate and rotten classes, the volume was estimated by the water displacement method as follows:

i. A subsample was separated from a deadwood sample brought from the field in order to fit inside the graduated cylinder to be used. Small enough samples were used without separation.
ii. The subsample was weighed and recorded.
iii. The graduated cylinder was filled with water to a known volume (e.g. 1L).
iv. The subsample was placed inside of the graduated cylinder.
v. The subsample was submerged under the water using a very fine elongated needle until completely submerged.
vi. The volume of water displaced by submerging the sample was recorded.

b. Sample drying and weight measurement

First, all the fresh samples were dried at 80°C in the sawmill factory. The dried weight was determined and recorded after drying of more than one week. Through the drying process, the weight was monitored at regular intervals until reaching a constant.

Some representative samples were selected for drying at more than 100°C in National University of Laos (NUoL). Throughout the entire drying process, the weight was monitored at regular intervals until it reached a constant. The dried weight was determined and recorded after drying of more than three days. The 80-100°C ratio was calculated dividing 80°C dry weight by 100°C dry weight. It was applied for other un-selected samples to estimate the absolute dry weight.

c. Wood density calculation

The deadwood density was calculated using the following formula:

$$\text{Density} = \frac{Dry\_weight}{Volume}$$

Where:
Density = Density of subsample; g/cm3
Volume = Volume of subsample; cm3
Dry Weight = Measured dry weight of subsample; g

The average of deadwood density by both forest type and decay class was calculated. The calculated density will be used to estimate the biomass of the entire deadwood in Lao PDR.

4.2.3 Saplings

a. Drying and weight measurement

The 80°C dry weight for every sapling was also obtained in the sawmill factory. Then, representative samples were selected from the samples and dried out at more than 100°C at NUoL. Throughout the entire drying process, the weight was monitored at regular intervals until it reached a constant. The dried weight was determined and recorded after drying of more than three days. The 80-100°C ratio was obtained from selected samples and this is applied to all other saplings to calculate the absolute dry weight of all samples.

b. Estimation of whole biomass at individual tree level

The fresh-dry ratio was calculated by dividing fresh weight of a sample by absolute dry weight of a sample. This ratio was used to estimate all the weight of ten saplings and then the calculated weight of ten saplings were divided by 10 for estimation of the weight of one sapling. The weights of one sapling were averaged for each forest type.

4.2.4 Model fitting

Several regression models were applied to develop the allometric equations with R software. Considering the concept of allometric equation of trees, one regression model for each forest type was finally determined.

5 Results

5.1 Measurement results

Table 8 presents the list of data, including DBH, Height and Total Above Ground Biomass (AGB), and Figure 9 is the scatter plot which shows the relationship between DBH and biomass (kg). Two sample trees, one for MD and the other for DD, were excluded since their data was found insufficient after eliminating some irregular values. Wood Density values of five samples were apparently irregular and were replaced by the data from either "Global Wood Density Database"[6] or "Estimating Biomass and Biomass Change of Tropical Forests: a Primer"[7]. The detailed information is shown in Annex 1.

Table 8: List of data: DBH, height, wood density and dried biomass

	EF				MD				DD			
	DBH (cm)	Height (m)	AGB (kg)	Density (g/cm3)	DBH (cm)	Height (m)	AGB (kg)	Density (g/cm3)	DBH (cm)	Height (m)	AGB (kg)	Density (g/cm3)
1	14.0	8.0	82.3	0.56	16.8	11.4	155.8	0.70	16.0	6.1	90.1	0.75
2	15.0	13.0	100.7	0.65	20.5	7.1	114.1	0.50	18.0	9.2	154.4	0.69
3	17.8	11.0	221.2	0.70	24.0	13.7	286.8	0.62	19.8	9.2	157.9	0.62
4	18.0	10.9	232.6	0.69	24.0	10.0	388.3	0.59	20.0	5.9	163.0	0.49
5	18.7	15.0	235.5	0.98	24.5	9.4	308.3	0.56	22.0	4.3	259.1	0.82
6	20.0	11.6	287.4	0.61	25.0	3.0	151.3	0.68	22.5	7.8	263.5	0.72
7	20.3	11.6	285.8	0.56	25.1	4.5	325.1	0.98	23.0	5.6	179.4	0.63
8	21.2	18.8	284.9	0.67	25.4	12.0	271.1	0.59	25.5	5.5	341.0	0.85
9	24.0	17.0	431.4	0.60	26.5	8.2	207.4	0.37	27.5	7.0	386.3	0.53
10	26.1	12.9	298.0	0.48	27.0	14.7	406.0	0.59	27.8	6.4	470.8	1.14
11	26.7	16.8	624.8	0.63	28.5	9.4	423.3	0.54	28.0	5.0	423.7	0.74
12	27.8	7.5	620.6	0.69	31.5	6.4	501.6	0.34	29.0	6.5	694.1	0.69
13	35.0	21.0	759.5	0.56	31.9	7.6	428.6	0.37	32.5	7.0	355.9	0.53
14	35.2	18.9	827.9	0.53	33.5	11.6	693.1	0.63	34.5	9.2	601.1	0.77
15	36.0	24.9	1338.9	0.62	36.0	8.0	774.4	0.73	36.0	14.0	811.9	0.60
16	36.7	13.0	937.6	0.63	36.3	10.5	568.5	0.42	38.0	8.4	663.3	0.60
17	40.5	12.0	748.2	0.52	39.0	7.8	964.8	0.71	39.5	8.0	1076.9	0.78
18	41.2	12.4	1121.6	0.75	41.0	14.0	1546.3	0.67	42.0	7.6	1444.5	0.70
19	42.3	13.8	2021.7	0.86	42.0	10.9	1099.4	0.66	42.7	12.0	993.1	0.48
20	42.5	14.8	1817.2	0.69	42.0	10.0	992.0	0.65	45.0	15.0	1101.2	0.57
21	45.0	12.2	1220.4	0.40	42.5	12.8	939.0	0.48	45.5	4.9	936.4	0.26
22	47.5	19.6	1707.0	0.45	44.4	9.0	1526.3	0.76	47.0	7.2	1025.9	0.59
23	48.5	19.2	2615.5	0.75	46.9	8.0	719.3	0.55	49.0	9.5	2009.5	0.56
24	48.8	15.9	899.7	0.29	53.0	8.4	1716.6	0.65	52.0	4.8	1253.0	0.37
25	50.5	14.5	1860.8	0.43	54.5	16.0	1770.8	0.41	52.0	4.3	2071.5	0.57
26	51.7	27.2	3534.9	0.76	55.0	16.0	1917.0	0.48	52.2	12.0	2080.6	0.60
27	53.2	10.6	1818.1	0.42	56.0	20.0	1894.4	0.57	53.0	14.0	1651.2	0.66
28	53.4	20.5	1956.8	0.60	58.0	10.3	1579.9	0.56	54.5	12.6	1998.9	0.80
29	55.0	17.1	2496.9	0.73	59.5	15.2	1458.5	0.37	56.0	5.1	1553.0	0.43
30	55.6	11.7	2474.5	0.78	62.0	18.0	2055.9	0.36	57.8	15.0	2873.1	0.68
31	56.0	26.8	2530.3	0.63	64.8	14.2	1922.2	0.43	58.0	11.0	3020.0	0.60
32	56.7	22.7	4358.2	0.78	68.5	19.5	1977.2	0.34	59.0	4.5	2333.8	0.83
33	57.0	23.5	1426.1	0.36	73.5	10.5	3087.8	0.54	59.0	7.0	1823.1	0.65
34	58.0	19.4	2850.1	0.48	76.0	11.3	2290.7	0.35	61.0	8.0	1486.7	0.27
35	58.9	21.9	3454.0	0.73	85.0	21.2	4364.0	0.51	67.0	7.1	1495.2	0.36
36	59.3	19.3	2175.4	0.53								

[6] http://datadryad.org/handle/10255/dryad.235.

[7] Brown, S. (1997). Estimating Biomass and Biomass Change of Tropical Forests: a Primer. FAO Forestry Paper - 134.

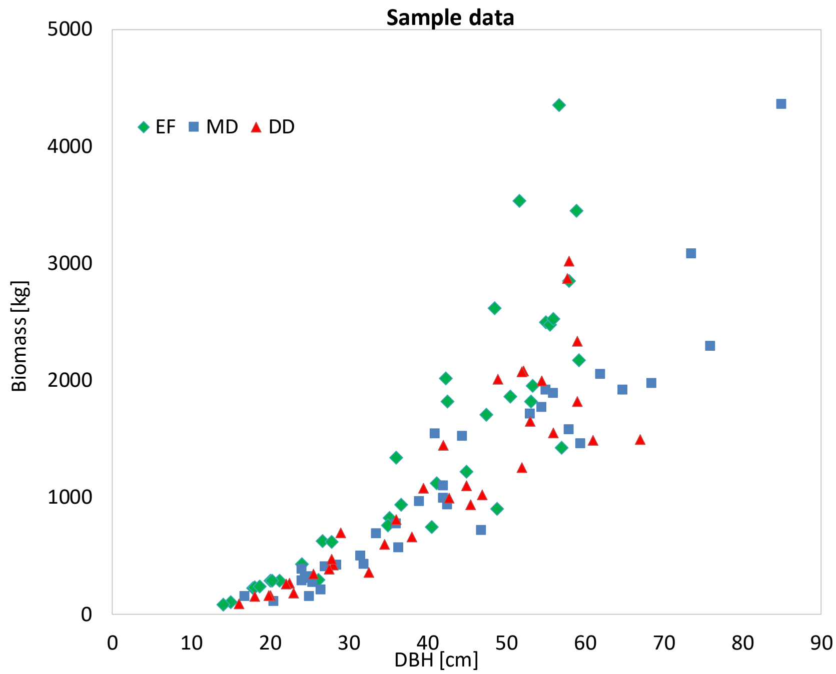

Figure 9: Sample data on scatter plot

Figure 10 shows the relationship between DBH and height of each sample tree.

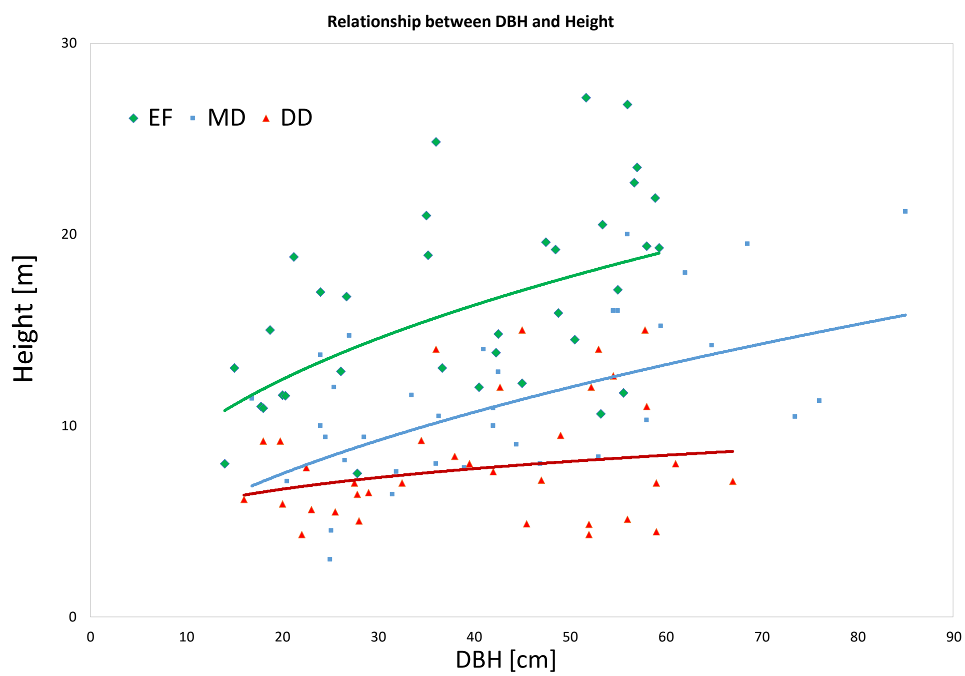

Figure 10: Relationship between DBH and Height

5.2 Allometric equations

5.2.1 Allometric equation for three forest types

The allometric equations were developed for each Forest Type as regression lines with a power approximation following the FAO manual (Picard *et al*., 2012) (Figure 11). A total of 10 regression analyses were analysed for each Forest Type and one regression model was selected for each forest type. Hereafter, we call any allometric equations developed in this survey as "Lao national equations".

Residual analysis on the three Lao national equations was also conducted. All the residual plots showed random patterns, which indicate that linear models provide a decent fit to the data.

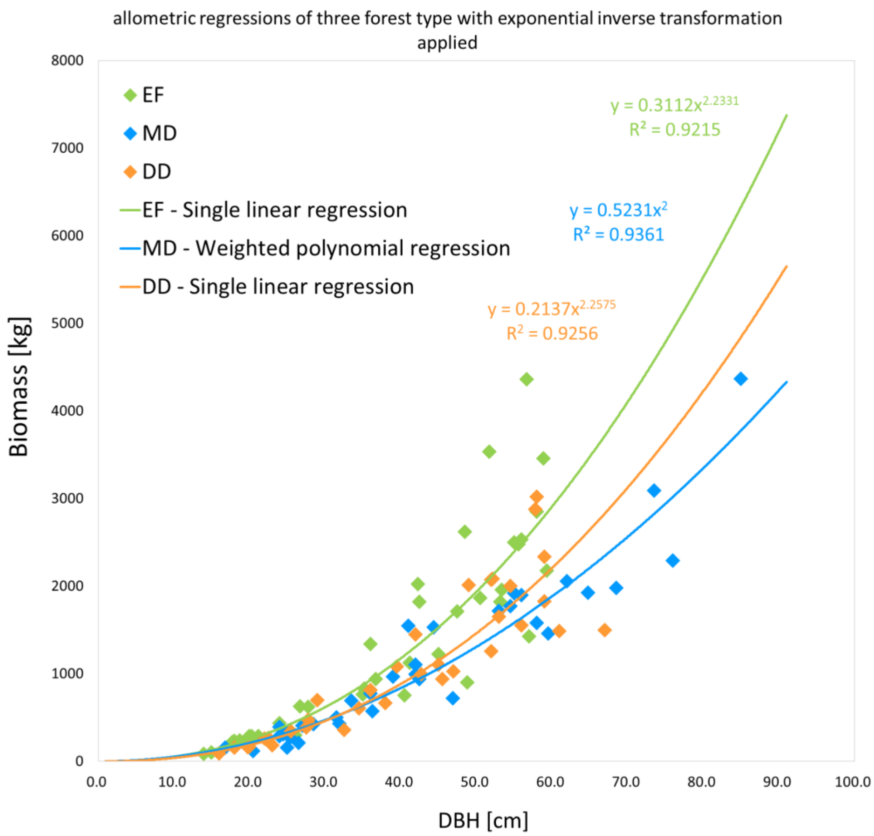

Figure 11: Allometric equations of three Forest Types

EG: the non-linear regression model with variance

$$\ln(\mathrm{AG}B) = -1.1674 + \ln(DBH)^{2.2331}$$

(n = 36, R^2 = 0.9215, AIC = 18.84)

Coefficients	Value	*p* value
A	-1.1674	0.00661
B	2.2331	2exp(-16)

If we 'naively' apply the exponential inverse transformation, the equation will be;

$$\text{AG}B = 0.3112 \text{ x } DBH^{2.2331}$$

MD: the weighted polynomial regression model

$$\text{AG}B = 0.5231 \text{ x } DBH^{2}$$

(n = 35, R^2 =0.9081, AIC = 477.24)

Coefficients	Value	*p* value
A	0.5231	2exp(-16)

DD: the non-linear regression model with variance

$$\ln(\text{AG}B) = -1.5434 + \ln{(DBH)}^{2.2575}$$

(n = 35, R^2 = 0.9256, AIC = 10.53)

Coefficients	Value	*p* value
A	-1.5434	0.000588
B	2.2575	2exp(-16)

If we 'naively' apply the exponential inverse transformation, the equation will be;

$$\text{AGB} = 0.2137 \text{ x DBH}^{2.2575}$$

In case of MD, non-linear regression model is also considered as a model. In fact, fitness is almost the same when compared with weighted polynomial regression model.

If the non-linear model is applied, the equation is:

$$AGB = 0.2999 \text{ x } DBH^{2.1417}$$

According to Figure 9, when the DBH becomes large, the growth amount of biomass is subtle compared to the other forest types. Also it has less power compared to that of EG and DD. Thus, the weighted polynomial regression model is applied.

5.2.2 AGB errors from equations

For estimating AGB errors, Standard errors (StE) were calculated based on the standard deviations (StD) and number of sample trees. The following equation[8] was used.

$$StD = \frac{100}{N} \sum_{i=1}^{n} \frac{|\hat{Y}i - Yi|}{Yi}$$

$$StE = \frac{StD}{\sqrt{N}}$$

Where N is the number of sample trees, $\hat{Y}i$ and *Yi* are the predicted and measured AGB of the *i*th tree.

Table 9 : AGB errors for each equation

Forest Type	N	StD	CI (95%)	StE
EF	36	23.6	7.7	3.9
MD	35	22.8	7.4	3.8
DD	35	21.7	7.1	3.6

5.3 Deadwood

The table below shows the number of sampled deadwoods by forest type.

Table 10: Number of samples of deadwood

Forest Type	Sound	Intermediate	Rotten	Total
EG	8	15	10	33
MD	17	10	7	34
DD	17	8	15	40
Total	42	33	32	107

The table below shows the density of deadwood.

[8] UN-REDD(2012), Tree allometric equations in Evergreen broadleaf forests in North Central Coastal region, Viet Nam, P9

Table 11: Density of dead wood in each class

The values show the average density of dead wood (g/cm^3) ± standard deviation by forest type.

Forest type	Sound	Intermediate	Rotten	Average
EF	0.39 ± 0.18	0.34 ± 0.09	0.26 ± 0.10	0.33 ± 0.13
MD	0.45 ± 0.13	0.30 ± 0.09	0.29 ± 0.13	0.38 ± 0.14
DD	0.44 ± 0.14	0.35 ± 0.19	0.32 ± 0.13	0.38 ± 0.14
Average	0.44 ± 0.14	0.33 ± 0.09	0.30 ± 0.12	0.36 ± 0.14

5.4 Saplings

The table below shows the average dry mass of saplings by forest type.

Table 12: Average dry mass of sapling

Forest Type	Biomass of one sapling ± standard deviation (g)
EF	112 ± 99
MD	252 ± 171
DD	191 ± 119
Average	184 ± 143

6 Discussion

6.1 Development of allometric equations

6.1.1 Predictor variables

The study examined the parameters to be used for the allometric equations and concluded to apply the single predictor variable, DBH, based on two main reasons.

The first is based on the constraints of the design of the 2nd NFI, which did not measure tree Height. The second reason is because the regression did not improve the fitness when the Height variable was added, as shown in Figure 10. There are studies (Chan *et al.*, 2013; and McNicol *et al.*, 2015) which argue that both predictor variables of DBH and Height are optimal for developing allometric equations. However, the allometric equations including Height shown below did not improve the fitness and the resulting R^2 values were actually lower.

$$\mathrm{AGB} = a \times (\mathrm{Height} \times DBH^2)^b$$

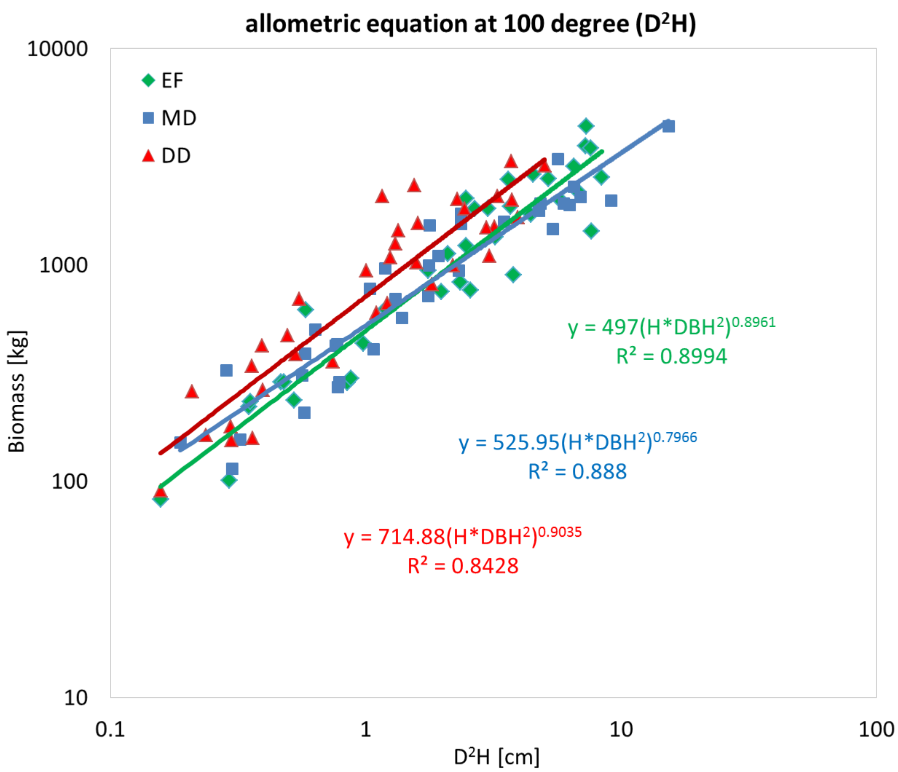

Figure 12: Allometric Equations using DBH and Height as predictor variables

6.1.2 Species selection

There are studies (Chan *et al*., 2013; and McNicol *et al*., 2015) which argue for the importance of considering all the species taken in developing the allometric equation. However, in Lao PDR, allometric equations could only be developed from major species in each forest type due to the limited knowledge of surveyors.

6.1.3 Integrated equations

Some equations were developed through data compilation of the forest types to consider the carbon stratification in terms of FREL/FRL development. The three options are shown below.

Option1: Three different allometric equations by forest type; EG, MD and DD
Option2: Two allometric equations - one for EG and the other which integrates MD with DD (shown as MDDD in Figure 13 below).
Option 3: One allometric equation with all forest types integrated (shown as ALL in Figure 13 below).

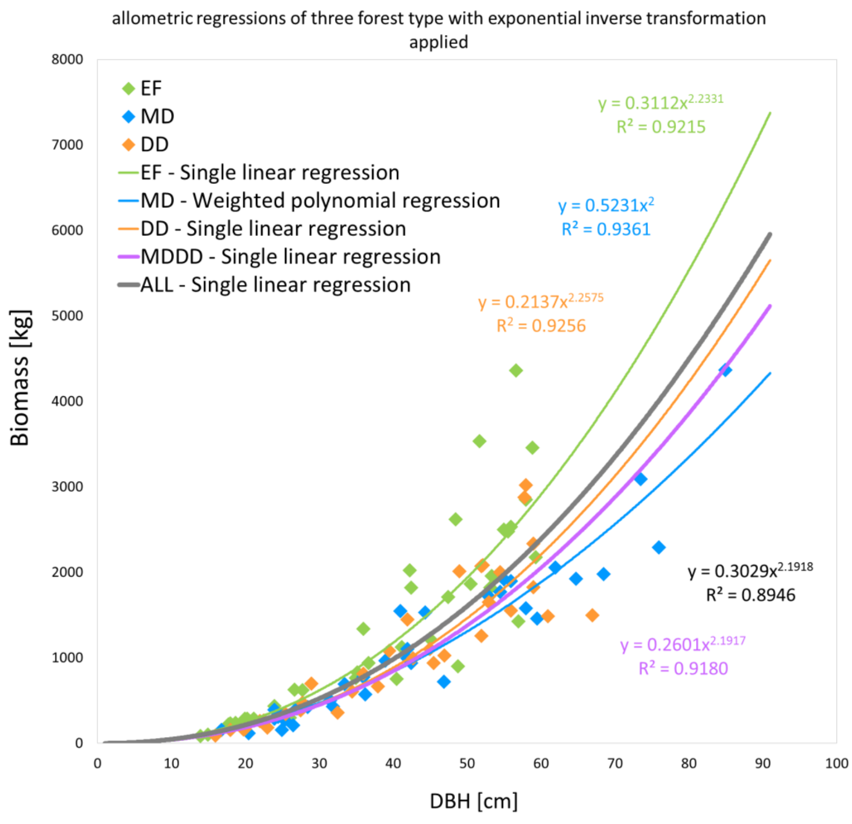

Figure 13: Integrated allometric equations

6.2 Comparative analysis with other data or equations[9]

The sample trees with DBH sizes outside the range of the surveyed samples is extrapolated to Lao national equations. The following table shows the minimum and maximum DBH range of the trees surveyed (and measured through destructive measurement) in each forest type.

Table 13: DBH range

	DBH size (cm)	
	Minimum	Maximum
EG	14.0	59.3
MD	15.0	85.0
DD	16.0	67.0

6.2.1 Comparison with allometric equations developed by PAREDD Project in northern Lao PDR

Through an earlier initiative under a project[10], allometric equations for Evergreen forest (EG) and Mixed Deciduous (MD) forest in Luang Prabang province (northern Lao) have been developed. The two figures below compare the data and equation from for EG and MD, (two forest types combined) developed for Luang Prabang province with the Lao national equations.

[9] Since the allometric equations existing in Lao PDR and surrounding countries are limited, the comparative analysis was conducted under certain limitations. Further comparisons could be done if new allometric equations are developed or found.

[10] PAREDD project (Participatory Land and Forest Management Project for Reducing Deforestation in Lao PDR (2009-2015)) by JICA.

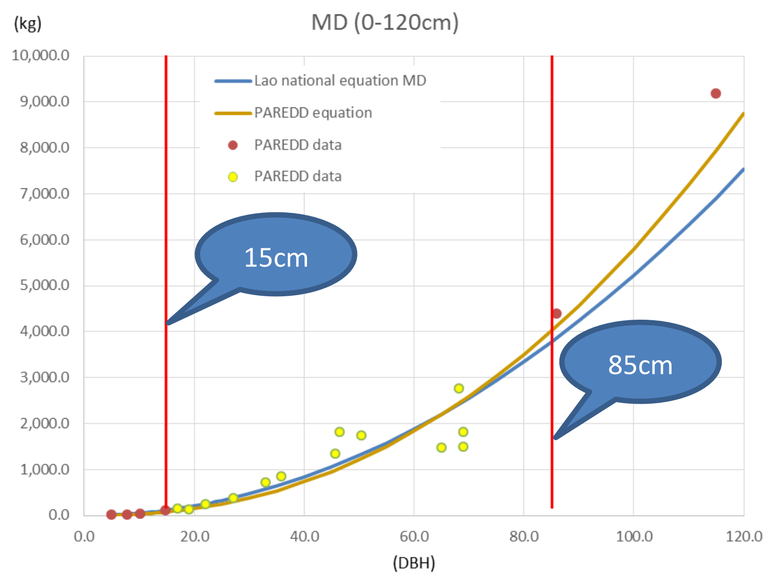

Figure 14: Comparison of Lao national equation for MD and the equation of PAREDD

Note: The red dots show data from Luang Prabang (PAREDD) which are out of the range of this survey; DBH smaller than 15 cm and greater than 85 cm. The yellow dots are data from Luang Prabang (PAREDD) which are within the range of this study.

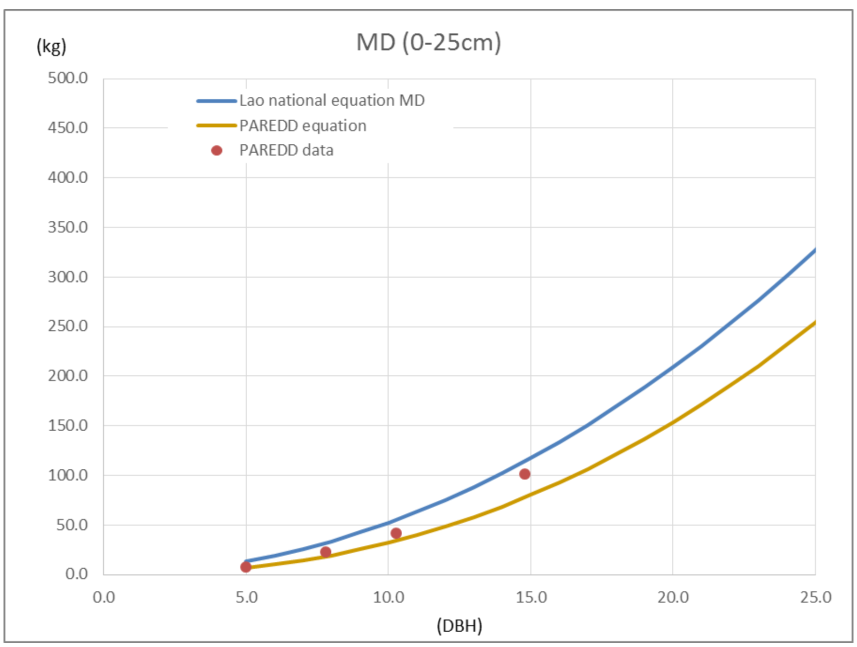

Figure 15: Comparison of Lao national equation for MD and the equation of PAREDD: DBH 0-25 cm

The biomass value estimated from the Lao national allometric equation and the value from the Luang Prabang equation (PAREDD) are almost the same for the extrapolated data of DBH smaller than 15cm. Thus, it is reasonable to use Lao national allometric equations. Similarly, even for the data with their DBH greater than 85cm, though the sample size is small, the figure indicates that the Lao national allometric equation is reasonable. Statistical analysis indicates that correlation is sufficiently high between the two values. R2 is 0.9959. As with MD, correlation is high in EG at the range of the interpolated area. R2 is 0.9342.

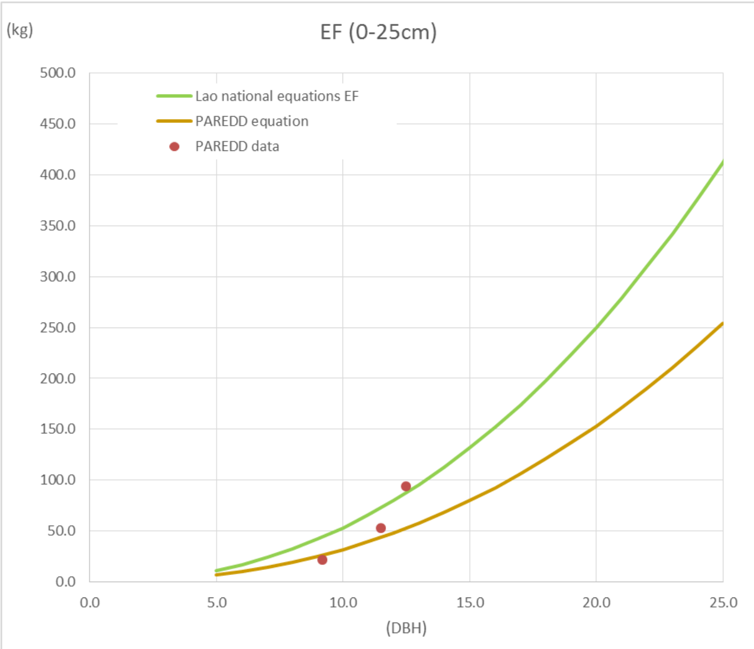

Figure 16: Comparison of Lao national equation for EG and the equation of PAREDD: DBH 0-25 cm

6.2.2 Comparison with an allometric equation developed in Cambodia

Monda *et al*. (2016) published the raw data of DD forest in Cambodia. The following figure shows the comparative analysis.

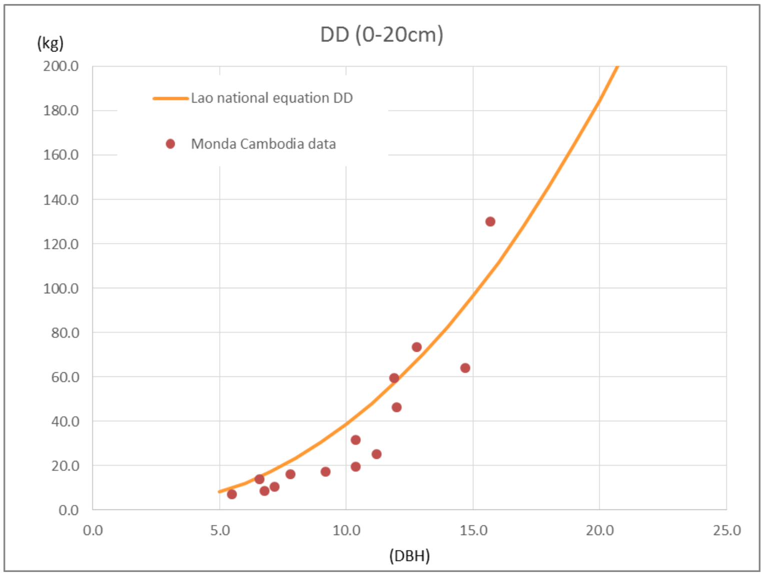

Figure 17: Comparison of Lao national equation of EG and equation for Cambodia (0-25 cm DBH)

Correlation is high in DD at the range of the interpolated area. R2 is 0.8558.

6.2.3 Comparison with equations developed by Chave et al.

Compared to some data of Chave et al. (2005, 2015), which were obtained in Southeast Asia, Lao national allometric equations estimate lower biomass.

From the data from Chave et al. (Figure 18), there is one sample which has biomass over 20,000 kg, and a few more large samples. In the survey conducted for the Lao national equations, the largest sample was only approximately 4,300 kg. However, it may be reasonable to apply the Lao national equations to data that is outside of the surveyed DBH range, as they are conservative in estimation.

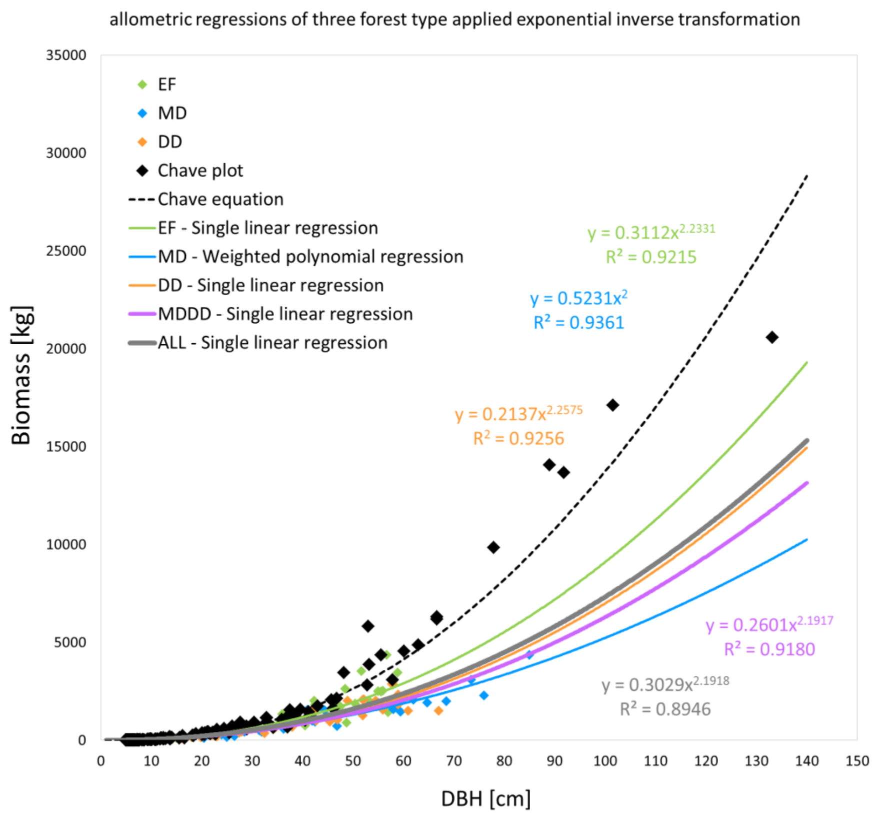

Figure 18: Comparison with Chave equation and Chave data in Southeast Asia

7 Conclusion

This study developed country-specific allometric equations for the estimation of above-ground biomass (AGB) in three different forest types in Lao PDR; Evergreen Forest (EG), Mixed Deciduous Forest (MD) and Dry Dipterocarp Forest (DD). The most relevant predictor variable for ABG in the three forest types was DBH. In the absence of Wood Density values, Wood Density-class-based equations were not analyzed in this study, though it may improve the accuracy of the estimation if conducted in the future. Although the fitness of the integrated models (Section 6.1.3) is not low, it is inferior to the individual models by forest type. According to comparative analysis with other data or equations, allometric equations developed in the study are reasonable to be applied to the tree measurement data which are out of the surveyed DBH range in this study, in terms of conservative estimation, and also due to the small DBH size of the trees sampled in Evergreen forest (EG).

8 References

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- Walker SM, Murray LT, Tepe T. 2015. Allometric Equation Evaluation Guidance Document. Winrock International for the Government of Laos PDR.

9 Attachment

9.1 List of data: DBH, Height and Dried biomass

Forest Type	Species	ID	DBH (cm)	Height (m)	Bole (kg)	Stump (kg)	Butress (kg)	B<10cm (kg)	B=10-20cm (kg)	B>20cm (kg)	Bole& Stump&Butress (kg)	Branch (kg)	**Whole** (kg)
	Polyalthia simiarum BENTH.HOOK	XA_EF_1	26.7	16.8	436.1	22.1		128.4	38.3		458.2	166.6	624.8
	Gradeniafrangeoi des	XA_EF_2	42.3	13.8	1231.0	76.8		242.4	167.6	303.9	1307.8	713.9	2021.7
	Terminalia nigrovenulosa P var gracilior GAGN	XA_EF_3	55.0	17.1	1572.1		44.7	380.8	486.0	14.1	1616.8	880.8	2497.6
	Anisoptera Robusta P	XA_EF_4	35.2	18.9	575.9	49.2		50.7	110.8	41.3	625.1	202.8	827.9
	Diospyros mun H.Lec	XA_EF_5	17.8	11.0	135.4	13.9		71.9			149.3	71.9	221.2
	Tetrameles nudiflora R.BR et BENN	XA_EF_6	53.2	10.6	1236.1		263.0	110.5	57.6	150.9	1499.1	319.0	1818.1
	Dipterocarpus alatus Roxb. ex G.Don	XA_EF_7	56.7	22.7	2395.6	1743.0		102.1	50.1	67.4	4138.6	219.6	4358.2
	Cananga iatitolia/ HOOK.F.et THOMS/F.et GAGN	XA_EF_8	50.5	14.5	950.0		276.5	199.3	226.8	208.3	1226.4	634.4	1860.8
	Arytera littoralis Bl.	XA_EF_9	21.2	18.8	239.5	16.7		28.7			256.2	28.7	284.9
	Polyalthia nemoralis Aug.DC.	XA_EF_10	36.7	13.0	501.5	38.9		173.9	179.4	43.8	540.3	397.2	937.6
	Anthocephalus indicus A.Rich.	XA_EF_12	26.1	12.9	224.3	15.3		37.6	20.7		239.7	58.3	298.0
	Mangifera indica	BL_EF_1	53.4	20.5	1707.9	26.7		91.9	99.4	30.9	1734.7	222.2	1956.8
	Zanthoxylum rhetsa DC	BL_EF_2	51.7	27.2	2945.2	18.7		258.1	205.7	107.2	2963.9	571.0	3534.9
	Achras sapota	BL_EF_3	55.6	11.7	1643.3	109.3		431.1	35.6	255.1	1752.6	721.8	2474.5
	Vatica cinerea KING	BL_EF_4	48.5	19.2	1881.6	83.4		269.8	221.5	159.1	1965.0	650.5	2615.5
	Alstonia scholaris/L/R.BL	BL_EF_5	48.8	15.9	562.0	45.1		114.6	130.5	47.4	607.1	292.6	899.7
	Dialium indum	BL_EF_6	42.5	14.8	927.8		243.4	365.1	256.3	24.6	1171.3	646.0	1817.2
EF	Dipterocarpus alatus Roxb. ex G.Don	BL_EF_7	36.0	24.9	1059.4	52.3		166.5	60.8		1111.6	227.3	1338.9
	Cinnamomum litseaefolium NEES	BL_EF_8	18.0	10.9	141.8	14.8		67.8	8.3		156.6	76.1	232.6
	Quercus serrata THUNB	BL_EF_9	24.0	17.0	325.6	18.5		52.6	34.6		344.1	87.3	431.4
	Aglaia merostela PELL	BL_EF_10	20.0	11.6	166.6	14.6		98.1	8.1		181.2	106.2	287.4
	Artocarpus asperulus Gagnep.	BL_EF_11	57.0	23.5	1037.9	19.8		233.9	83.0	51.4	1057.7	368.4	1426.1
	Lauraceae sp	BL_EF_12	20.3	11.6	168.2	24.2		72.4	21.0		192.3	93.4	285.8
	Eugenia compongensis	AT_EF_1	58.9	21.9	2538.8	82.9	106.4	169.5	175.6	380.8	2728.1	725.9	3454.0
	ສົ້ມໂມງ (not in the list)	AT_EF_2	45.0	12.2	550.1			120.3	173.1	376.8	550.1	670.3	1220.4
	Eugenia compongensis	AT_EF_3	35.0	21.0	572.2	26.8		87.9	72.6	0.0	599.0	160.5	759.5
	Irvingia harmandiana P. OLIV	AT_EF_4	18.7	15.0	168.0	34.7		32.8	0.0	0.0	202.7	32.8	235.5
	ຍາງສິງ (not in the list)	AT_EF_5	58.0	19.4	1836.6	26.9		283.2	239.4	464.0	1863.4	986.7	2850.1
	ຕາຍໂສ້ (not in the list)	AT_EF_6	47.5	19.6	1157.4	26.1		212.9	133.0	177.6	1183.5	523.5	1707.0
	hopea dealbata HANCE	AT_EF_7	59.3	19.3	1373.5	106.2		505.7	93.8	96.2	1479.7	695.7	2175.4
	hopea dealbata HANCE	AT_EF_8	27.8	7.5	256.5	16.8		272.5	55.7	19.1	273.3	347.3	620.6
	Pannarium annamense HANCE	AT_EF_9	40.5	12.0	414.8	19.2		223.8	58.1	32.2	434.1	314.1	748.2
	ສົ້ມໂມງ (not in the list)	AT_EF_10	15.0	13.0	95.3			5.4	0.0	0.0	95.3	5.4	100.7
	Dipterocarpus alatus Roxb. ex G.Don	AT_EF_11	56.0	26.8	1787.3	44.3		276.8	251.9	169.9	1831.7	698.6	2530.3
	ຕາຍໂສ້ (not in the list)	AT_EF_12	14.0	8.0	53.8	5.1		23.5			58.8	23.5	82.3

Forest Type	Species	ID	DBH (cm)	Height (m)	Bole (kg)	Stump (kg)	Butress (kg)	B<10cm (kg)	B=10-20cm (kg)	B>20cm (kg)	Bole& Stump&Butress (kg)	Branch (kg)	**Whole** (kg)
MD	Adina cordifolia (Roxb.) Hook. f.	BK_MD_1	36.3	10.5	283.3	19.6		110.1	95.4	60.0	303.0	265.5	568.5
	Polyalthia nemoralis Aug.DC.	BK_MD_2	24.0	13.7	218.3	13.3		46.9	8.4		231.5	55.2	286.8
	Anthocephalus indicus A.Rich.	BK_MD_3	59.5	15.2	883.1	85.3		366.0	76.4	47.6	968.4	490.1	1458.5
	ໄມ້ໃຈຍາງ (Not in the list)	BK_MD_4	85.0	21.2	3581.5	80.6		182.2	411.5	108.1	3662.1	701.8	4364.0
	Vatica cinerea KING	BK_MD_5	16.8	11.4	124.7	8.3		16.3	6.4		133.0	22.8	155.8
	Artocarpus asperulus Gagnep.	BK_MD_6	20.5	7.1	73.9	5.8		22.9	11.5		79.8	34.4	114.1
	ໄມ້ຈຳປີ (Not in the list)	BK_MD_7	64.8	14.2	1291.9	39.2		189.0	119.4	282.7	1331.1	591.1	1922.2
	Tetrameles nudiflora R. Br.	BK_MD_8	68.5	19.5	1096.1	257.5	142.2	148.5	192.7	140.1	1495.9	481.3	1977.2
	Pometia eximia HOOK	BK_MD_9	42.5	12.8	557.1	26.5		182.2	131.9	41.4	583.6	355.5	939.0
	Pometia pinnata J.R.Forst. & G.Forst.	BK_MD_10	31.9	7.6	169.7	24.6		105.5	65.7	63.1	194.2	234.3	428.6
	Xylia kerrii Craib & Hutch.	BK_MD_11	31.5	6.4	140.7	27.1		156.6	86.5	90.7	167.8	333.8	501.6
	ໝາກເກື້ອມ (Not in the list)	BK_MD_12	26.5	8.2	122.2	16.3		44.2	24.7		138.5	68.9	207.4
	Dipterocarpus alatus Roxb. ex G.Don	KH_MD_1	46.9	8.0	445.9	14.7		147.7	37.1	73.9	460.6	258.7	719.3
	Anisoptera cochinchinensis Pierre	KH_MD_2	25.0	3.0	78.9	2.2		40.8	21.6	7.8	81.1	70.2	151.3
	Ormosia cambodiana Gagnep.	KH_MD_3	44.4	9.0	557.2	274.1	95.0	230.1	167.1	202.7	926.3	599.9	1526.3
	Lagerstroemia balansae Koehne	KH_MD_4	25.1	4.5	153.2	11.7		104.4	44.9	10.9	164.8	160.2	325.1
	Dillenia baillonii Pierre ex Laness.	KH_MD_5	73.5	10.5	1458.7	42.8	151.8	491.3	406.6	536.5	1653.4	1434.4	3087.8
	ໄມ້ສະຜາງ (Not in the list)	KH_MD_7	27.0	14.7	302.0	2.9		66.5	34.6		305.0	101.0	406.0
	Eugenia compongensis	KH_MD_8	53.0	8.4	803.7	47.3		348.9	210.6	306.2	851.0	865.7	1716.6
	Sindora cochinchinensis Baill.	KH_MD_9	42.0	10.9	621.6	24.6		278.2	107.6	67.3	646.3	453.1	1099.4
	Adina cordifolia (Roxb.) Hook. f.	KH_MD_10	58.0	10.3	741.0	107.5		322.5	90.3	318.6	848.6	731.4	1579.9
	ໄມ້ແຫງບ (Not in the list)	KH_MD_11	33.5	11.6	354.4	52.7		150.8	72.9	62.4	407.1	286.0	693.1
	Nauclea orientalis (L.) L.	KH_MD_12	76.0	11.3	975.1	159.6		375.4	294.6	486.0	1134.8	1156.0	2290.7
	Cratoxylum formosum (Jacq.) Benth. & Hook.f. ex Dyer	AT_MD_1	36.0	8.0	410.9	31.9		175.6	30.5	125.4	442.8	331.5	774.4
	Mesua ferrea L.	AT_MD_2	28.5	9.4	230.0	12.8		128.8	51.7		242.8	180.5	423.3
	Vatica cinerea King	AT_MD_3	41.0	14.0	975.9	27.2		121.6	112.9	308.7	1003.2	543.1	1546.3
	ໄມ້ພ້າວຄຳ (Not in the list)	AT_MD_4	62.0	18.0	1143.9	129.3	27.8	178.2	154.7	422.0	1301.0	754.9	2055.9
	Parashorea stellata KURZ	AT_MD_5	54.5	16.0	1130.4	47.2		120.2	72.0	401.0	1177.6	593.2	1770.8
	Sandoricum indicum Cav.	AT_MD_6	24.0	10.0	204.4	16.5		98.8	68.5		221.0	167.3	388.3
	Shorea cochinchinensis Pierre	AT_MD_7	55.0	16.0	1144.3	90.6		201.3	138.3	342.5	1234.9	682.1	1917.0
	Sindora cochinchinensis Baill.	AT_MD_8	39.0	7.8	432.4	30.4		260.1	148.7	93.2	462.8	502.0	964.8
	Vitex peduncularis Wall. ex Schauer	AT_MD_9	24.5	9.4	170.3	8.7		85.2	44.2		179.0	129.3	308.3
	ໄມ້ປະອຸງ (Not in the list)	AT_MD_10	25.4	12.0	196.4	10.2		52.0	12.5		206.6	64.5	271.1
	Anisoptera cochinchinensis Pierre	AT_MD_11	56.0	20.0	1417.0	48.7		215.6	119.3	93.7	1465.8	428.6	1894.4
	Terminalia nigrovenulosa P var gracilior GAGN	AT_MD_12	42.0	10.0	576.0	44.1		88.4	107.8	175.8	620.1	371.9	992.0

Forest Type	Species	ID	DBH (cm)	Height (m)	Bole (kg)	Stump (kg)	Butress (kg)	B<10cm (kg)	B=10-20cm (kg)	B>20cm (kg)	Bole& Stump&Butress (kg)	Branch (kg)	**Whole** (kg)
	Shorea obtusa Wall. ex Blume	KH_DD_1	59.0	4.5	863.9	129.0		352.6	173.1	815.1	992.9	1340.9	2333.8
	Dipterocarpus obtusifolius Teijsm. ex Miq.	KH_DD_2	54.5	12.6	1234.0	81.3		210.3	250.8	222.5	1315.3	683.6	1998.9
	Odina wodier Roxb.	KH_DD_3	38.0	8.4	355.3	13.2		79.9	82.5	132.4	368.5	294.8	663.3
	Terminalia chebula Retz.	KH_DD_4	28.0	5.0	154.1	12.5		155.1	65.8	36.1	166.7	257.0	423.7
	Pterocarpus macrocarpus Kurz	KH_DD_5	16.0	6.1	67.8			22.3			67.8	22.3	90.1
	Schleichera trijuga Willd.	KH_DD_6	25.5	5.5	155.0	17.1		99.3	69.6		172.0	168.9	341.0
	ເບັນມອນ (Not in the list)	KH_DD_7	22.5	7.8	162.1			62.8	38.5		162.1	101.3	263.5
	ໄມ້ພັນຊີ (Not in the list)	KH_DD_8	32.5	7.0	210.2	6.6		77.8	61.4		216.8	139.2	355.9
	Dipterocarpus obtusifolius Teijsm. ex Miq.	KH_DD_9	47.0	7.2	421.0	68.7		75.9	133.9	326.4	489.6	536.3	1025.9
	Sandoricum indicum Cav.	KH_DD_10	34.5	9.2	386.2	18.8		91.6	46.1	58.4	405.1	196.0	601.1
	Careya sphaerica Roxb.	KH_DD_12	45.5	4.9	149.1	40.4		262.1	282.8	201.9	189.5	746.9	936.4
	Pometia pinnata J.R.Forst. & G.Forst.	KH_DD_13	20.0	5.9	54.1			81.1	27.8		54.1	108.8	163.0
	Dipterocarpus obtusifolius Teijsm. ex Miq.	KH_DD_14	18.0	9.2	118.8			35.6			118.8	35.6	154.4
	Albizia procera (Roxb.) Benth.	KH_DD_15	57.8	15.0	1618.8	219.9		248.9	291.4	494.0	1838.7	1034.4	2873.1
	Eugenia compongensis	KH_DD_16	56.0	5.1	395.2	71.8		453.3	271.7	361.0	467.0	1086.0	1553.0
	Dillenia baillonii Pierre ex Laness.	KH_DD_17	67.0	7.1	498.8	58.4		366.7	295.7	275.6	557.3	937.9	1495.2
	Detaportea amata THOREL.GAGN	KH_DD_18	52.0	4.8	284.5	67.6		452.5	216.5	231.9	352.1	900.9	1253.0
DD	Dipterocarpus obtusifolius Teijsm. ex Miq.	AT_DD_1	52.2	12.0	1054.5	112.2		303.1	190.1	420.7	1166.7	914.0	2080.6
	Lagerstroemia balansae Koehne	AT_DD_2	27.8	6.4	260.1	18.4		113.2	79.0		278.5	192.2	470.8
	Dipterocarpus tuberculatus Roxb.	AT_DD_3	42.7	12.0	499.2	20.9		228.1	163.1	81.7	520.2	472.9	993.1
	Pterocarpus macrocarpus Kurz	AT_DD_4	29.0	6.5	285.1	17.6		177.3	133.4	80.7	302.7	391.3	694.1
	Odina wodier Roxb.	AT_DD_5	42.0	7.6	580.7	67.6		238.2	265.8	292.2	648.2	796.3	1444.5
	Xylia kerrii Craib & Hutch.	AT_DD_6	52.0	4.3	446.1	60.5		344.5	417.4	803.1	506.6	1565.0	2071.5
	Schleichera trijuga Willd.	AT_DD_7	22.0	4.3	101.2	14.2		71.9	71.8	0.0	115.4	143.7	259.1
	Lagerstroemia macrocarpa Wall.	AT_DD_8	27.5	7.0	170.2	12.8		94.9	108.4	0.0	183.0	203.3	386.3
	Aporosa villosa (Lindl.) Baill.	AT_DD_9	23.0	5.6	92.7	5.6		59.6	21.4	0.0	98.3	81.1	179.4
	ໄມ້ຫູໜູ (Not in the list)	AT_DD_10	19.8	9.2	105.1	6.1		35.3	11.4	0.0	111.2	46.7	157.9
	ໄມ້ຕາກວາງ (Not in the lit)	AT_DD_11	45.0	15.0	718.5	38.1		176.8	83.2	84.5	756.7	344.6	1101.2
	Terminalia tomentosa Wight & Arn.	AT_DD_12	39.5	8.0	515.8	54.0		141.6	161.1	204.4	569.8	507.1	1076.9
	ໄມ້ຕາແບງ (Not in the list)	AT_DD_13	49.0	9.5	749.4	52.6		332.6	288.6	586.4	802.0	1207.5	2009.5
	ໄມ້ຍາງດິງ (Not in the list)	AT_DD_14	36.0	14.0	523.0	33.4		161.2	54.3	40.0	556.4	255.5	811.9
	Shorea obtusa Wall. ex Blume	AT_DD_15	58.0	11.0	1145.9	127.5		345.9	313.1	1087.6	1273.4	1746.6	3020.0
	Bombax albidum Gagnep.	AT_DD_16	61.0	8.0	458.8	44.4	48.7	203.2	255.3	476.2	552.0	934.7	1486.7
	Terminalia tomentosa Wight & Arn.	AT_DD_17	53.0	14.0	1029.5	62.7		122.7	141.4	295.0	1092.1	559.1	1651.2
	Eugenia compongensis	AT_DD_18	59.0	7.0	950.8	68.3		228.0	157.3	418.7	1019.1	804.0	1823.1

9.2 Activity photos


Training


On-site discussion


Measuring tree DBH


Cutting down tree at base


Measuring length of bole


Drying samples

9.3 Equipment list

Field Equipment:
Professional chainsaw operator
Chainsaw
Handsaws
Machetes
DBH tape
Clinometer
Laser Range Finder or measuring tape (to measure height)
Tree corer
50 kg scale
5 kg scale
~300 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
'Diameter fork' (see below)
Marker (to label bags and samples)
10 m of rope, 1 – 2 cm thick (to tie up scale and to weigh branches)
'Calibration weights' (see below)
Laboratory Equipment:
Drying oven
Laboratory scale

Diameter fork

Create Diameter Fork: Create a diameter fork that has two openings equating to the size classes that will be used during destructive sampling (see Figure below). For example: 20 cm wide and 10 cm wide. Or create different diameter forks – e.g. one 20 cm opening and another with a 10 cm opening. The 'diameter fork' can be made out of plastic or aluminum, anything that is relatively stiff and will not break apart easily.

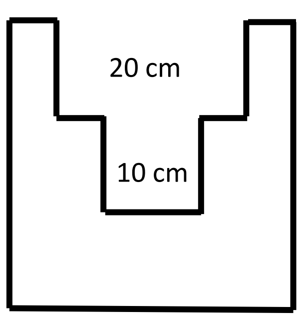


Figure Example of a diameter fork

9.4 Field data sheet

Prepared based on Winrock International's standard operating procedures (Walker *et al.*, 2014)

DESTRUCTIVE SAMPLING DATA SHEET

Tree ID: _______Location:__________GPS___________Lat: _________ Long: ___________

Date: ___________ Team Leader: ________Time start:___________Time end:____________

Forest type: _____________Photo ID: ________________________

MEASUREMENTS BEFORE TREE CUT

Species: ___________________ DBH: _______________ cm

Tree Height:

Height Measurement 1		Height Measurement 2	
Clinometer Height Measurement (m)	Distance to tree (m)	Clinometer Height Measurement (m)	Distance to tree (m)

MEASUREMENTS AFTER TREE CUT

Bole measurements

a) Length of tree: ________m

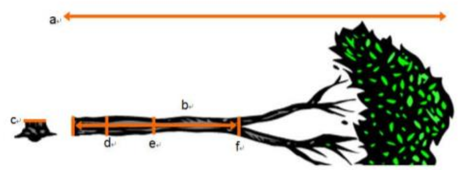
b) Length of bole: ________m

c) Diameter at bottom of bole: ________cm

d) DBH of bole: ________cm

e) Diameter at center of bole ________cm

f) Diameter at top of bole: ________cm

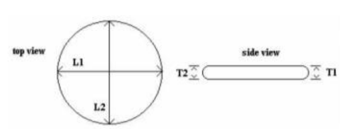


Starting at the bottom of the bole, divide the bole into 2-m sections and list the dimensions of each section below:

Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)	Section #	Lower diameter (cm)	Upper diameter (cm)	Length of section (cm)

For density determination:

Subsample disc 1	Subsample disc 2	Subsample disc 3
Label: ___________	Label: _________	Label: ___________
L1: _________ cm	L1: _________ cm	L1: _________ cm
L2: _________ cm	L2: _________ cm	L2: _________ cm
T1: _________ cm	T1: _________ cm	T1: _________ cm
T2: _________ cm	T2: _________ cm	T2: _________ cm



If disc is cut, check below by how much. Only do this if absolutely necessary and you ensure you are taking either half (½) or a quarter (¼) of the weight of the subsample; this needs to be as precise as possible.

Disc 1: ½ ☐ ¼ ☐ Disc 2: ½ ☐ ¼ ☐ Disc 3: ½ ☐ ¼ ☐

Preparation

Weight of plastic sheet A: ___________ g
Weight of plastic sheet B: ___________ g
Weight of plastic sheet C: ___________ g

Calibrating 100 kg scale:
Object weight: ________ g
Name of object: ___________ g
**Directions for calibrating scale: Weigh object on a high quality digit laboratory scale. If there is a difference in weight between field scale and laboratory scale, adjust data below accordingly.
Calibrating 5 kg scale:
Object weight: ________ g
Name of object: ___________ g
Calibrating 500 g scale:
Object weight: ________ g
Name of object: ___________ g

Stump measurements

①**Weigh:** If entire stump is weighed at once: Total fresh weight: ______kg
Weight of plastic sheet (or sheet name): _____________ g
If entire or a portion of the stump is weighed in sections (kg):

Weight	Sheet Name	Weight	Sheet Name	Weight	Sheet Name
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

2 Subsamples for determination of dry/wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g) * this is sample weight – bag weight	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

②**Volume estimates**: If stump is cut and part of it is estimated by volume rather than weighing the whole stump, pick shape and note its dimensions:

Frustum:

D_{bottom} ________ cm
D_{top} ________ cm
Height of stump ________ cm

Rectangular Prism:

Length ________ cm
Width ________ cm
Height ________ cm

Cylinder:

Dia1 ________ cm
Dia1 ________ cm
H1 ________ cm
H2 ________ cm

Buttress Measurements:

If entire buttress is weighed at once: Total fresh weight: ______kg
If entire buttress is weighed in sections (kg):

Weight	Sheet Name	Weight	Sheet Name	Weight	Sheet Name
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

2 Subsamples for determination of dry/wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Leaves & Branch:

Leaves and branches <10 cm:
If weighed at once: Total fresh weight: ______kg

If leaves and branches weighed in sections (kg):

Weight	Sheet Name	Weight	Sheet Name	Weight	Sheet Name
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

5 Subsamples for determination of dry/wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Branches 10-20 cm:
If weighed at once: Total fresh weight: ______kg
If branches 10-20 cm weighed in sections (kg):

Weight	Sheet Name	Weight	Sheet Name	Weight	Sheet Name
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

5 Subsamples for determination of dry/wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

Branches >20 cm:

If weighed at once: Total fresh weight: ______kg

If branches >20 cm weighed in sections (kg):

Weight	**Sheet Name**	**Weight**	**Sheet Name**	**Weight**	**Sheet Name**
1.		4.		7.	
2.		5.		8.	
3.		6.		9.	

5 Subsamples for determination of dry/wet ratio:

Tree ID	Subsample ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

NOTES FOR DESTRUCTIVE SAMPLING MEASUREMENTS

DEAD WOOD DENSITY DATA SHEET

Forest type: __________ Location:________________________
Date: ______/______/______ Data recorded by:___________________
Notes:

A minimum of 10 samples should be collected for each density class at the beginning of the field sampling effort. Diameter and width should be recorded for each sample. Volume and Dry Weight to be measured in the laboratory.

	Plot ID	Dead Wood ID	Wood Density Class: S, I, R*	Diameter2 (cm)	Diameter2 (cm)	Width1 (cm)	Width2 (cm)	Volume (cm^3)	Dry weight (g)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

* S = sound, I = intermediate, R = rotten

※Diameter and Width have to be measured only Sound class. Not necessary to measure for Intermediate and Rotten class

DATA SHEET FOR SAPLINGS

Forest type:__________ Location:________________________

Date:__________ Data recorded by:________________

Notes:

At least 10 saplings must be cut and weighed in each plot.

Calibrating 5 kg scale: **Weight of sheet: _______ g**

Object weight: ________ g

Name of object: ___________ g

Calibrating 500 g scale:

Object weight: ________ g

Name of object: ___________ g

	Plot ID	Sapling ID	DBH	Species	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							