

# Allometric relations between biomass and diameter at breast height and height of tree in natural forests at Me Linh Station for Biodiversity, Vinh Phuc Province, Vietnam

*Mối tương quan giữa sinh khối với hai nhân tố đường kính và chiều cao cây của cây gỗ trong các quần xã thực vật tự nhiên tại Trạm Đa dạng Sinh học Mê Linh, tỉnh Vĩnh Phúc, Việt Nam*

Research article

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Stem diameter at breast height ( $D_{1.3m}$ ) and tree height ( $H$ ) are commonly used measures of tree growth. Based on correlation analysis between biomass of stem, branches and leaves and stem diameter and height of tree we can identify allometric equation for predicting biomass and carbon sequestration of the vegetation. This study was carried out in the natural forests of Me Linh Station for biodiversity to develop allometric equation between biomass and diameter at breast height and height of tree. The study results indicated that twenty tree species dominate in natural forests in Me Linh Station for Biodiversity and they were selected for sampling. Through the 80 established linear equation models for above and below –ground biomass (AGB and BGB), we found that the biomass of tree species in Me Linh Station for Biodiversity were closely correlated with the diameter factor ( $R > 0.902$ ) and not clearly correlated with the height (correlation coefficient = 0.5498,  $R^2 < 0.549$ ). Four regression equations were established, including:  $P_{stem} = 25.3051 * (D_{1.3m})^{0.4627}$  ( $R^2 : 9.661$ );  $P_{branch} = 12.1043 * (D_{1.3m})^{0.5416}$  ( $R^2 : 9.8$ );  $P_{leaves} = 9.446 * (D_{1.3m})^{0.5976}$  ( $R^2 : 0.9363$ );  $P_{total\ biomass\ of\ forest} = 25.882 * D^{1.725}$  with  $R^2 : 0.8561$ ) for estimating biomass and carbon sequestration of natural forest at the research site.

Đường kính ngang ngực ( $D_{1.3m}$ ) và chiều cao ( $H$ ) cây là hai nhân tố thường được dùng để đánh giá sự phát triển của cây gỗ. Việc xây dựng các phương trình tương quan giữa sinh khối (SK) thân, cành, lá, sinh khối tầng cây gỗ, sinh khối của quần xã thực vật với đường kính và chiều cao cây góp phần rất lớn trong dự báo sinh khối và khả năng hấp thụ khí carbon của thảm thực vật. Kết quả nghiên cứu cho thấy 20 loài cây gỗ chiếm ưu thế trong rừng tự nhiên và chúng được chọn để thu mẫu. Mối tương quan giữa sinh khối với 2 nhân tố điều tra rừng là đường kính ngang ngực và chiều cao cây đã được kiểm tra thông qua 80 phương trình tương quan. Nhìn chung, sinh khối có tương quan chặt chẽ với nhân tố đường kính (hệ số tương quan  $R > 0,902$ ), và không tương quan rõ với nhân tố chiều cao ( $R < 0,5498$ ). Bốn phương trình tính sinh khối cho thảm rừng tại khu vực nghiên cứu đã được thiết lập:  $SK_{thân} = 25,3051 * (D_{1.3m})^{0,4627}$  ( $R^2 : 9,661$ );  $SK_{cành}$ :  $12,1043 * (D_{1.3m})^{0,5416}$  ( $R^2 : 9,8$ );  $SK_{lá}$ :  $9,446 * (D_{1.3m})^{0,5976}$  ( $R^2 : 0,9363$ ) và  $SK_{tổng} = 25,882 * D^{1,725}$  with  $R^2 : 0,8561$ ).

**Keywords:** height, diameter, allometric, tree biomass equation, correlation coefficient ( $R^2$ )

## 1. Introduction

Biomass is the most important indicator which aims to assess the productivity of a forest stand, it is also used to calculate the capacity and dynamics of forest carbon sequestration. Therefore, Brown & Lugo (1992)[3] pointed out that, the biomass survey is also a part of the carbon sequestration study. The current focus of scientists is to develop an appropriate method to assess the value of forest in use and for predicting the ability of biomass accumulation as well as CO<sub>2</sub> absorption in a forest ecosystem. From that point, a sustainable forest management and utilization could be established. At the present, methods of surveying and collecting samples for the calculation of forest biomass can be done, but they are difficult task and labor intensive, especially for the identification of natural forest production (Raae K., 2010; Timothy R.H., 2007) [9,10].

Diameter at breast height and height of tree are measurements that can be obtained without high labour investment. Stem diameter is used either as a single input-variable or in combination with height or wood density. The studies suggested that the use of regional height-diameter models introduces significant biases in above ground biomass estimates, and that different height-diameter models might be preferred for different forest types and they will be applied in future studies. However, there is a debate on which type of model should be selected to build a local site-specific height-diameter model. Biomass of the tree was estimated by extracting core samples at the breast height and mid height of the tree. When tested, there was no significant difference of density along the stem. Therefore, stem biomass was estimated using the density at breast height. Besides, there was no significant density difference between three sites. The study of allometry is extremely important in dealing with measurements and data analysis in the practice of forestry. Allometry studies the relative size of organs or parts of organisms. Tree allometry narrows the definition to applications involving measurements of the growth or size of trees. Allometric relationships are often used to estimate difficult tree measurements, such as volume, from an easily measured attribute such as D<sub>1.3m</sub> (Bào Huy, 2012) [2].

The regression analysis was used with pooled data to find out the relationship between the stem biomass with the tree diameter and height. Using variables of total height (H), diameter at breast height (D<sub>1.3m</sub>) and their transformations, several models were established. The best model was selected by testing for the R<sup>2</sup> value, standard residual distribution, modelling efficiency and bias (IPPC, 2006; Brown, 1992; FAO, 2004) [3,5,7].

Studying and exploring the correlation equations between biomass and surveying factors (D<sub>1.3m</sub> and H) to collect the actual a production basis, hence it would be used for inventorying and predicting forest biomass of typical vegetation in the Me Linh Biodiversity Stations, Vinh Phuc province.

## 2. Materials and methods

### 2.1. Study sites

The study is conducted in secondary forests of Me Linh Biodiversity Station, Vinh Phuc province, Vietnam, which is located in 21°23'57" - 21°25'35" S latitude and 105°42'40" - 105°46'65" E longitude (Fig. 1), distributed between 100m and 500m above sea level (a.s.l) with total area of about 178ha and is adjacent to Tam Dao National Park. According to report of Vinh Phuc province in 2010, the average annual precipitation is about 1358.7mm, temperature is 23.9°C and it has tropical monsoon climate, ferrallit soil (FAO classification; FAO, 2006) [5] and high humidity. The main soil properties were high content of iron and aluminum, hence the soil is acidity, thin layer and rocky.

FOREST MAPPING OF ME LINH STATION FOR BIODIVERSITY

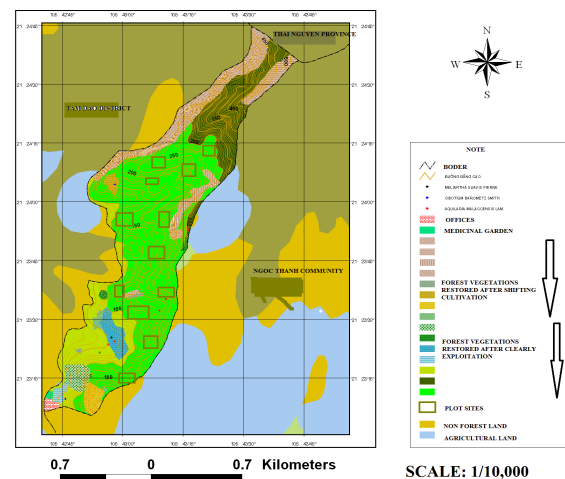


Figure 1. Plots plan in Me Linh Biodiversity Station, Vinh Phuc province

Forest and Flora: the forests in the study area derived from tropical monsoon evergreen closed forest and they were significantly disturbed through exploiting activity of human, such as selective logging, clear cutting, grazing and collection of fuel-wood. Hence, most of the primary forests here are changed into two main secondary forest types: the secondary forest restored after shifting cultivation and the secondary forest restored after clearing cutting exploitation (Le Dong Tan, 2003) [8]. The area of the secondary forests restored after clear cutting exploitation is larger than that of the other type, about 85.7ha (48.01% of total area of the Station) and it is often distributed on the altitude of above 95m. The area of the secondary forest restored after shifting cultivation accounted about 38.9 ha (21.79%) and distributed on the altitude of from 55m to 79m.

The flora contains 166 families, 651 genera and 1129 species belonging to four divisions of higher vascular plant, including: Lycopodiophyta, Equisetophyta, Polypodiophyta, Magnoliophyta. The most abundant families are: Lauraceae, Fagaceae, Moraceae, Magnoliaceae, Fabaceae, Anacardiaceae, Burseraceae, Sapindaceae, Hamamelidaceae and Bombacaceae (Nguyen Tien Ban, 2000) [1].

*Plot selection*

Plots are selected in homogenous vegetation patches. Each plot has the size of 50m x 50m (0.25ha plot), A total of ten plots is chosen to survey and to measure parameters in two forest types. In each of plot five subplots with the size of (5m x 5m) have been created to survey and to collect data on shrub, grass and litter. The tasks performed in plots include collecting and identifying species specimen and measuring all trees with a diameter above 5 cm (at 1.3m) and higher 5m in height.

**2.2. Methods of sampling**

*Selecting sample tree (represented tree)*

Tree is selected that is dominant species in each community with its diameter value in the medium of each diameter class (diameter parameter is divided into five classes such as class I: 5-10cm; class II: >10-15cm; class 3: >15-20 cm; class 4: >20-25cm and class 5: > 25cm). For one diameter class of each tree species we selected one sample tree to cut down and to calculate fresh biomass in the field as well as to take represented sample estimation dry biomass. So, the total number of samples accounted 100 individuals.

A tree is cut down close to the ground and divided into three parts: stem, branch and leave then is weighted to estimate the above ground fresh biomass. Root is a part of the tree to determine below ground fresh biomass. All the roots of a diameter of greater than 2 mm are dug and collected.

*Selecting sample in shrub and grass layer*

Samples of shrub and herbaceous plants are collected in each subplot. All shrubs and herbaceous plants are cut down and weighted to determine fresh biomass.

*Selecting sample for estimating oven-dry biomass*

Dry biomass samples are taken from stem, branch, leave and root.

- + Stem: taking 3 different positions as top of stem, bottom of stem and bottom of the fork, cutting each position with a thickness of 3 cm, the sample volume accounted for approximately 0.2% of the fresh weight.
- + Branch: taking 4 small cutting boards with total weight of 0.5 kg.
- + Leave: mixing leaves and taking 01 sample of 0.5 kg,

+ Root: taking a sample in tap-root and another in lateral root with total volume of 0.5 kg.

All samples are cut small and dried in the oven at 70-85°C and the heating time depends on the part of plant body, but until gets constant weight.

**2.3. Data analysis**

Estimation of oven-dry biomass of tree/shrub/grass/litter by:

$$Mki = Mi \times \frac{mk_i}{m_i}$$

(kg)

Where:

Mki: oven-dry biomass of each part of individual; Mi: fresh biomass of each part of individual; mki: mass of dry sample of each part after drying and mi: mass of fresh sample of each part of individual

Estimation of dry biomass of represented tree (sampled tree) by:

$$P_{i-tree} = P_{i-stem} + P_{i-branch} + P_{i-leaf} + P_{i-root} \quad (\text{kg})$$

Where: P<sub>i</sub>: dry biomass of each part of sampled tree for a diameter class

*Biomass equations for tree*

A comprehensive review has been conducted for the biomass equations of 65 North American tree species (Michael T. Ter-Mikaelian and Michael D. Korzukhin (1997). All equations are of the form M = aDb, where M is the oven-dry weight of the biomass component of a tree (kg), D is diameter at breast height (DBH) (cm), and a and b are parameters. The equations for biomass estimation were developed by relating biomass to tree diameter (D<sub>1.3m</sub>) and other tree characteristics.

**3. Results and discussion**

**3.1. Biomass of sample tree**

Sample tree is chosen from dominant species in forests. Representatives of twenty dominant tree species are collected and cut down to account biomass of a tree of each species in each diameter class. Summarizing data on this biomass allowed to estimate average of each species and the results are shown in table 1.

**Table 1. Biomass of sample tree species in two forests in Me Linh Biodiversity Station**

Scientific name	AGB	BGB	Σ P	D <sub>1.3m</sub>	H	Scientific name	AGB	BGB	Σ P	D <sub>1.3m</sub>	H
1. <i>Hydnocarpus kurzii</i> (King) Warb.	65.53	20.55	86.08	23.27	10.14	11. <i>Wendlandia paniculata</i> (Roxb.) DC.	23.22	6.90	30.12	10.77	6.93
2. <i>Saraca dives</i> Pierre	30.70	6.85	37.55	9.50	7.94	12. <i>Styrax tonkinensis</i> (Pierre) Craib. ex Hartwiss	40.56	13.81	54.37	9.37	8.90
3. <i>Machilus parviflora</i> Meisn.	40.60	7.28	47.88	16.6	7.71	13. <i>Liquidambar formosana</i> Hance	52.62	12.78	65.40	11.64	7.35
4. <i>Diospyros eriantha</i> Champ. ex Benth	55.65	13.68	69.34	13.5	9.03	14. <i>Garcinia oblongifolia</i> Champ. ex Benth.	67.13	13.31	80.44	16.80	8.82
5. <i>Syzygium cinereum</i> Wall. ex Merr.	68.55	18.61	87.16	10.90	7.92	15. <i>Trema orientalis</i> (L.) Blume	38.16	6.42	44.58	14.56	7.90
6. <i>Aglaiia spectabilis</i> (Miq.) Jain	68.19	21.48	89.68	15.03	8.27	16. <i>Duabanga grandiflora</i> (Roxb. ex DC.) Walp.	59.17	10.82	69.99	15.05	8.92
7. <i>Engelhardtia roxburghiana</i> Wall.	37.57	14.48	52.05	19.17	7.66	17. <i>Castanopsis indica</i> (Roxb.) A. DC.	64.61	33.52	98.13	10.88	6.00
8. <i>Bischofia javanica</i> Blume	61.95	13.20	75.15	20.6	14.29	18. <i>Aquilaria crassna</i> Pierre ex Lecomte	92.58	32.67	125.2	9.02	6.70
9. <i>Knema globularia</i> (Lamk.) Warrb.	55.82	10.54	66.36	12.40	7.54	19. <i>Canarium tonkinense</i> Engl.	41.86	8.97	50.83	9.95	7.77
10. <i>Litsea cubeba</i> (Lour.) Pers.	92.02	19.43	111.4	23.73	11.95	20. <i>Macaranga denticulata</i> (Blume) Muell.-Arg.	26.11	7.09	33.20	10.50	6.70

Note: AGB: above ground biomass and BGB: Below ground biomass; Unit: kg.sample<sup>-1</sup>

The data in table 1 indicated that each tree species has its own average biomass like the biomass of *Bischofia javanica* achieved 75.15 kg. tree<sup>-1</sup>; *Macaranga denticulata* (Blume) Muell.-Arg.: 33.20kg. tree<sup>-1</sup>; *Liquidambar formosana* Hance: 65.40 kg. tree<sup>-1</sup>; etc.

In any of these tree species, the biomass identified mainly concentrated in AGB, approximately 60-75 percent of total biomass. For example: biomass of *Engelhardtia roxburghiana* Wall. divided into AGB: 37.57 kg.tree<sup>-1</sup> (72.18%) and BGB: 14.48kg.tree<sup>-1</sup> (27.82%); biomass of *Castanopsis indica* (Roxb.) A. DC. Accounted AGB: 64.61 kg.tree<sup>-1</sup> (65.84%) and BGB: 33.52 kg.tree<sup>-1</sup> (34.16%).

### 3.2. Allometric relationships between biomass and two forest factors (D<sub>1.3m</sub> and H)

Experiment results on statistical software SPSS 16.0 showed that the relationship between biomass of the sample tree with H was simulated well with the main function equation  $Y = B_0 + B_1 D_{1.3}$  (Y is the biomass).

#### 3.2.1. Using Power function to identify allometric relation between biomass and diameter at the breast height of tree (D<sub>1.3m</sub>).

A lot of research reports showed that individual-tree biomass estimates are usually based on a known allometric relationship between an easily measurable dimension (e.g., diameter at breast height) and biomass.

**Table 2. Allometric equations between Fresh and Dry Biomass of tree species and diameter at the breast height (D<sub>1.3m</sub>) in Me Linh Station for Biodiversity**

Scientific name	Allometric model	R	S	Sig.F	PT
1. <i>Hydnocarpus kurzii</i> (King) Warb.	$P_{fresh} = 22.42 + 1.12 D_{1.3m}$	0.957	0.169	0.000	4.1
	$P_{dry} = 13.721 + 1.12 D_{1.3m}$	0.982	0.171	0.000	4.2
2. <i>Saraca dives</i> Pierre	$P_{fresh} = 18.726 + 1.13 D_{1.3m}$	0.979	0.143	0.000	4.3
	$P_{dry} = 9.5 + 1.13 D_{1.3m}$	0.968	0.144	0.000	4.4
3. <i>Machilus parviflora</i> Meisn.	$P_{fresh} = 39.91 + 1.09 D_{1.3m}$	0.943	0.122	0.000	4.5
	$P_{dry} = 22.48 + 1.09 D_{1.3m}$	0.902	0.129	0.000	4.6
4. <i>Diospyros eriantha</i> Champ. ex Benth	$P_{fresh} = 41.43 + 1. D_{1.3m}$	0.936	0.159	0.000	4.7
	$P_{dry} = 23.65 + 1.09 D_{1.3m}$	0.969	0.156	0.000	4.8
5. <i>Syzygium cinereum</i> Wall. ex Merr.	$P_{fresh} = 36.03 + 1. D_{1.3m}$	0.981	0.106	0.000	4.9
	$P_{dry} = 15.4 + 1.1 D_{1.3m}$	0.980	0.114	0.000	4.10

Scientific name	Allometric model	R	S	Sig.F	PT
6. <i>Aglaiia spectabilis</i> (Miq.) Jain	$P_{\text{fresh}} = 55.81 + 1.085 D_{1.3m}$	0.986	0.111	0.000	4.11
	$P_{\text{dry}} = 26.74 + 1.092 D_{1.3m}$	0.969	0.121	0.000	4.12
7. <i>Engelhardtia roxburghiana</i> Wall.	$P_{\text{fresh}} = 24.1 + 1.121 D_{1.3m}$	0.987	0.111	0.000	4.13
	$P_{\text{dry}} = 11.529 + 1.127 D_{1.3m}$	0.981	0.118	0.000	4.14
8. <i>Bischofia javanica</i> Blume	$P_{\text{fresh}} = 23.74 + 1.12 D_{1.3m}$	0.988	0.124	0.000	4.15
	$P_{\text{dry}} = 10.487 + 1.127 D_{1.3m}$	0.990	0.127	0.000	4.16
9. <i>Knema globularia</i> (Lamk.) Warrb.	$P_{\text{fresh}} = 35.99 + 1.113 D_{1.3m}$	0.985	0.109	0.000	4.17
	$P_{\text{dry}} = 20.26 + 1.116 D_{1.3m}$	0.976	0.109	0.000	4.18
	$P_{\text{fresh}} = 28.78 + 1.126 D_{1.3m}$	0.969	0.095	0.000	4.19
10. <i>Litsea cubeba</i> (Lour.) Pers.	$P_{\text{dry}} = 12.196 + 1.133 D_{1.3m}$	0.989	0.104	0.000	4.20
	$P_{\text{fresh}} = 22.49 + 1.113 D_{1.3m}$	0.988	0.087	0.000	4.21
11. <i>Wendlandia paniculata</i> (Roxb.) DC.	$P_{\text{dry}} = 12.69 + 1.116 D_{1.3m}$	0.985	0.091	0.000	4.22
	$P_{\text{fresh}} = 17.84 + 1.126 D_{1.3m}$	0.988	0.105	0.000	4.23
12. <i>Styrax tonkinensis</i> (Pierre) Craib. ex Hartwiss	$P_{\text{dry}} = 8.52 + 1.131 D_{1.3m}$	0.986	0.108	0.000	4.24
	$P_{\text{fresh}} = 29.21 + 1.12 D_{1.3m}$	0.966	0.167	0.000	4.25
13. <i>Liquidambar formosana</i> Hance	$P_{\text{dry}} = 18.884 + 1.123 D_{1.3m}$	0.967	0.169	0.000	4.26
	$P_{\text{fresh}} = 41.38 + 1.111 D_{1.3m}$	0.980	0.128	0.000	4.27
14. <i>Garcinia oblongifolia</i> Champ. ex Benth.	$P_{\text{dry}} = 26.649 + 1.116 D_{1.3m}$	0.978	0.140	0.000	4.28
	$P_{\text{fresh}} = 32.04 + 1.127 D_{1.3m}$	0.973	0.151	0.000	4.29
	$P_{\text{dry}} = 17.38 + 1.13 D_{1.3m}$	0.951	0.219	0.000	4.30
15. <i>Trema orientalis</i> (L.) Blume	$P_{\text{fresh}} = 18.79 + 1.029 D_{1.3m}$	0.957	0.059	0.000	4.31
	$P_{\text{dry}} = 10.175 + 1.103 D_{1.3m}$	0.963	0.107	0.000	4.32
16. <i>Duabanga grandiflora</i> (Roxb. ex DC.) Walp.	$P_{\text{fresh}} = 25.68 + 1.027 D_{1.3m}$	0.988	0.115	0.000	4.33
17. <i>Castanopsis indica</i> (Roxb.) A. DC. ex Lecomte	$P_{\text{dry}} = 19.279 + 1.055 D_{1.3m}$	0.968	0.167	0.000	4.34
	$P_{\text{fresh}} = 32.06 + 2.001 D_{1.3m}$	0.977	0.099	0.000	4.35
18. <i>Aquilaria crassna</i> Pierre	$P_{\text{dry}} = 24.096 + 1.503 D_{1.3m}$	0.980	0.113	0.000	4.36
	$P_{\text{fresh}} = 19.08 + 2.028 D_{1.3m}$	0.936	0.167	0.000	4.37
19. <i>Canarium tonkinense</i> Engl.	$P_{\text{dry}} = 11.015 + 1.227 D_{1.3m}$	0.950	0.145	0.000	4.38
	$P_{\text{fresh}} = 14.082 + 2.061 D_{1.3m}$	0.978	0.128	0.000	4.39
20. <i>Macaranga denticulata</i> (Blume) Muell.-Arg.	$P_{\text{dry}} = 12.330 + 1.817 D_{1.3m}$	0.980	0.166	0.000	4.50

For one tree species two equations have been established to find out allometric between fresh biomass or dry biomass of tree and  $D_{1.3m}$ . All of forty regression equations in table 2 show that correlation coefficients recorded the lowest value was 0.902 ( $R^2 < 0.902$ ), such as: Fresh and dry Biomass of *Aquilaria crassna* were expressed strongly relation with  $D_{1.3m}$  ( $R^2$ : 0.977 and 0.980); *Styrax tonkinensis* ( $R^2$ : 0.988 and 0.986); *Machilus parviflora* ( $R^2$ : 0.943 and 0.902). It is suggested that all the biomass of tree species in the natural vegetation at the Me Linh Biodiversity Station is strongly correlated with the diameter factor. When the stem diameter increases so biomass will also increase.

### 3.2.2. Using Power function to simulate allometric relation between biomass and height of tree (H).

Tree heights can be difficult to measure under the best conditions. Height measurements are dependent on forest conditions, observer experience, and the equipment used. Tropical forests typically include significant obstacles for traditional field-based estimates of tree heights, including dense understory vegetation, tall canopies, and closed-canopy conditions that limit the line of sight. Tree height measurements in tropical forests both are labor intensive and have potentially large errors. Although researchers agree that height is a valuable addition when estimating biomass, the degree of acceptable error has been debated. We evaluate how tree height accuracy affects biomass estimation accuracy for moist tropical forests in Me Linh Station for Biodiversity by the allometric equations in table 3.

**Table 3. Allometric equations between Fresh and Dry Biomass of tree species and height of tree (H) in Me Linh Station for Biodiversity**

Scientific name	Allometric model	R	S	Sig.F	PT
1. <i>Hydnocarpus kurzii</i> (King) Warb.	$P_{\text{fresh}} = 10.93+0.29H$	0.483	0.02	0.000	2.2
	$P_{\text{dry}} = 8.001+0.82 H$	0.501	0.171	0.000	2.7
2. <i>Saraca dives</i> Pierre	$P_{\text{fresh}} = 8.726+1.13 H$	0.502	0.143	0.000	1.8
	$P_{\text{dry}} = 9.5+1.13 H$	0.425	0.144	0.000	2.0
3. <i>Machilus parviflora</i> Meisn.	$P_{\text{fresh}} = 9.82+1.68 H$	0.328	0.122	0.000	2.0
	$P_{\text{dry}} = 11.57+1.09 H$	0.522	0.129	0.000	2.4
4. <i>Diospyros eriantha</i> Champ. ex Benth	$P_{\text{fresh}} = 11.33+1.0 H$	0.364	0.120	0.000	1.7
	$P_{\text{dry}} = 5.65+0.39 H$	0.52	0.106	0.000	2.8
5. <i>Syzygium cinereum</i> Wall. ex Merr.	$P_{\text{fresh}} = 146.23+1.0 H$	0.503	0.106	0.000	2.2
	$P_{\text{dry}} = 5.7+0.908H$	0.482	0.135	0.000	2.10
6. <i>Aglaia spectabilis</i> (Miq.) Jain	$P_{\text{fresh}} = 15.01+0.85H$	0.460	0.122	0.000	2.1
	$P_{\text{dry}} = 16.40+0.95 H$	0.471	0.101	0.000	2.12
7. <i>Engelhardtia roxburghiana</i> Wall.	$P_{\text{fresh}} = 14.3+0.90 H$	0.487	0.105	0.000	2.13
	$P_{\text{dry}} = 10.9+1.07 H$	0.455	0.119	0.000	2.14
8. <i>Bischofia javanica</i> Blume	$P_{\text{fresh}} = 10.64+1.02 H$	0.480	0.117	0.000	2.4
	$P_{\text{dry}} = 5.55+1.7 H$	0.492	0.127	0.000	2.3
9. <i>Knema globularia</i> (Lamk.) Warrb.	$P_{\text{fresh}} = 15.0+0.93 H$	0.486	0.109	0.000	2.0
	$P_{\text{dry}} = 10.06+0.6 H$	0.476	0.189	0.000	2.4
10. <i>Litsea cubeba</i> (Lour.) Pers.	$P_{\text{fresh}} = 719+0.65 H$	0.440	0.080	0.000	2.5
	$P_{\text{dry}} = 8.96+1.63 H$	0.409	0.104	0.000	2.2
11. <i>Wendlandia paniculata</i> (Roxb.) DC.	$P_{\text{fresh}} = 12.4+1.3 H$	0.440	0.087	0.000	2.3
	$P_{\text{dry}} = 12.15+0.61 H$	0.471	0.082	0.000	1.9
12. <i>Styrax tonkinensis</i> (Pierre) Craib. ex Hartwiss	$P_{\text{fresh}} = 10.22+.92H$	0.380	0.129	0.000	2.2
	$P_{\text{dry}} = 8.052+1.26 H$	0.503	0.145	0.000	2.4
13. <i>Liquidambar formosana</i> Hance	$P_{\text{fresh}} = 14.0+1.12 H$	0.499	0.133	0.000	2.3
	$P_{\text{dry}} = 7.55+0.84 H$	0.552	0.145	0.000	2.2
14. <i>Garcinia oblongifolia</i> Champ. ex Benth.	$P_{\text{fresh}} = 4.34+0.8 H$	0.487	0.130	0.000	2.0
	$P_{\text{dry}} = 6.05+0.66 H$	0.433	0.148	0.000	1.7
	$P_{\text{fresh}} = 12.04+0.72 H$	0.502	0.151	0.000	1.9
15. <i>Trema orientalis</i> (L.) Blume	$P_{\text{dry}} = 7.38+0.32 H$	0.511	0.212	0.000	2.5
	$P_{\text{fresh}} = 7.92+0.29 H$	0.533	0.101	0.000	1.9
16. <i>Duabanga grandiflora</i> (Roxb. ex DC.) Walp.	$P_{\text{dry}} = 10.175+0.88 H$	0.505	0.107	0.000	2.4
17. <i>Castanopsis indica</i> (Roxb.) A. DC. ex Lecomte	$P_{\text{fresh}} = 15.55+07 H$	0.476	0.109	0.000	2.3
	$P_{\text{dry}} = 19.279+1.055 H$	0.557	0.166	0.000	2.2
18. <i>Aquilaria crassna</i> Pierre	$P_{\text{fresh}} = 9.06+1.12 H$	0.300	0.076	0.000	1.9
	$P_{\text{dry}} = 14.61+0.6 H$	0.302	0.143	0.000	2.3
19. <i>Canarium tonkinense</i> Engl.	$P_{\text{fresh}} = 10.01+0.81 H$	0.543	0.151	0.000	2.5
	$P_{\text{dry}} = 10.15+0.87 H$	0.409	0.143	0.000	2.3
20. <i>Macaranga denticulata</i> (Blume) Muell.-Arg.	$P_{\text{fresh}} = 9.00+0.61 H$	0.488	0.104	0.000	2.0
	$P_{\text{dry}} = 9.0+0.55 H$	0.455	0.166	0.000	2.2

The table 3 showed that the correlation between fresh and dry biomass with the tree height of 20 species of sample

trees. The correlation coefficient of 40 regression equations was relatively low, the highest R value was 0.549 of

*Garcinia oblongifolia* Champ. ex Benth and almost these values were vary from 0.403 to 0.502, including some species: *Liquidambar formosana* Hance, *Bischofia javanica* Blume, *Canarium tonkinense* Engl, ect. This is true of the status of natural forests cover in the research site, in which almost young forest areas have been recovered from shifting cultivation and have been exploited for the past 20 years. Therefore, the tree height is still low, ranging from 5.9m to 10.3m and the trees are unstable both in height and the species composition.

**3.2.3. Using Power Function to find out allometric relation between tree biomass and two factors (D<sub>1.3m</sub>, H)**

Based on the above results, correlations of biomass of tree parts (such as: stem, branch, leaves and root) and two forest factors (D<sub>1.3m</sub> and H) were tested and the results are shown in table 4.

**Table 4. The correlation between above ground biomass (P<sub>AGB</sub>) of tree parts (stem, branch, leaves) and two forest factors**

Indicator	Statistic	D <sub>1.3m</sub> (cm)	H (m)	P <sub>AGB.stem</sub> (kg)	P <sub>AGB.branch</sub> (kg)	P <sub>AGB.leaves</sub> (kg)	Total biomass (kg)
D <sub>1.3m</sub> (cm)	R2	-	0.9743	0.9817	0.8914	0.9061	0.9338
	P	-	0.001	0.001	0.001	0.001	0.001
H (m)	R2	0.9743	-	0.6311	0.4826	0.5023	0.4919
	P	0.001	-	0.001	0.001	0.001	0.001

The correlation coefficient of above ground biomass of parts was recorded closed correlation with diameter at the breast height (D<sub>1.3m</sub>) (R<sup>2</sup><sub>total biomass</sub> : 0.9338; R<sup>2</sup><sub>P<sub>AGB.stem</sub></sub> :

0.9817; R<sup>2</sup><sub>P<sub>AGB.branch</sub></sub> : 0.8914; R<sup>2</sup><sub>P<sub>AGB.leaves</sub></sub> : 0.9061; P<0.001) but the relation between biomass and tree height is not clear (R<sup>2</sup> < 0.4919) as shown in table 5.

**Table 5. Biomass Models for tree species in Me Linh Biodiversity Station**

No.	Scientific name	Biomass equations	No.	Scientific name	Biomass equations
1	<i>Hydnocarpus kurzii</i> (King) Warb.	P = 11.6.D <sup>2.781</sup> H R <sup>2</sup> : 0.5583	11	<i>Wendlandia paniculata</i> (Roxb.) DC.	P = 9.29D <sup>2.660</sup> H R <sup>2</sup> : 0.4066
2	<i>Saraca dives</i> Pierre	P = 19.91D <sup>1.104</sup> H R <sup>2</sup> : 0.802	12	<i>Styrax tonkinensis</i> (Pierre) Craib. ex Hartwiss	P = 13.59D <sup>1.589</sup> H R <sup>2</sup> : 0.4557
3	<i>Machilus parviflora</i> Meisn.	P = 10.05D <sup>2.668</sup> H R <sup>2</sup> : 0.3052	13	<i>Liquidambar formosana</i> Hance	P = 11.95D <sup>2.058</sup> H R <sup>2</sup> : 0.5022
4	<i>Diospyros eriantha</i> Champ. ex Benth	P = 15.56D <sup>0.998</sup> H R <sup>2</sup> : 0.5809	14	<i>Garcinia oblongifolia</i> Champ. ex Benth.	P = 8.771D <sup>1.614</sup> H R <sup>2</sup> : 0.6111
5	<i>Syzygium cinereum</i> Wall. ex Merr.	P = 9.794D <sup>2.450</sup> H R <sup>2</sup> : 0.6770	15	<i>Trema orientalis</i> (L.) Blume	P = 1.550D <sup>2.290</sup> H R <sup>2</sup> : 0.4400
6	<i>Aglaia spectabilis</i> (Miq.) Jain	P = 3.629D <sup>1.776</sup> H R <sup>2</sup> : 0.4077	16	<i>Duabanga grandiflora</i> (Roxb. ex DC.) Walp.	P = 6.403D <sup>2.037</sup> H R <sup>2</sup> : 0.5089
7	<i>Engelhardtia roxburghiana</i> Wall.	P = 22.845D <sup>1.007</sup> H R <sup>2</sup> : 0.9020	17	<i>Castanopsis indica</i> (Roxb.) A. DC.	P = 7.05D <sup>2.668</sup> H R <sup>2</sup> : 0.6540
8	<i>Bischofia javanica</i> Blume	P = 21.239D <sup>2.001</sup> H R <sup>2</sup> : 0.3881	18	<i>Aquilaria crassna</i> Pierre ex Lecomte	P = 12.103D <sup>1.66</sup> H R <sup>2</sup> : 0.3380
9	<i>Knema globularia</i> (Lamk.) Warrb.	P = 6.905D <sup>1.115</sup> H R <sup>2</sup> : 0.6333	19	<i>Canarium tonkinense</i> Engl.	P = 1.998.D <sup>0.557</sup> H R <sup>2</sup> : 0.7031
10	<i>Litsea cubeba</i> (Lour.) Pers.	P = 15.790D <sup>2.643</sup> H R <sup>2</sup> : 0.8112	20	<i>Macaranga denticulata</i> (Blume) Muell.-Arg.	P = 3.008.D <sup>0.99</sup> H R <sup>2</sup> : 0.5720

Table 5 presents twenty allometric models that were designed for estimating tree biomass of 20 species based on two forest factors (D and H). However, some species showed close correlation such as: *Saraca dives* Pierre, *Engelhardtia roxburghiana* Wall., *Litsea cubeba* (Lour.)

Pers. *Canarium tonkinense* Engl. (R<sup>2</sup> > 0.7031). For other species it was not clearly or weak correlation, including: *Bischofia javanica* Blume, *Machilus parviflora* Meisn., *Styrax tonkinensis* (Pierre) Craib. ex Hartwiss, ect.

## 4. Conclusion

As the results show the allometric equations gives the most correlation coefficient between biomass and diameter inventory factors higher than 0.8589 ( $R^2 > 0.8589$ ,  $P < 0.0001$ ) and expressed that this is closed relation. However, the allometric between biomass and the height factor is still showed clearly and continue test.

Four allometric equations were established to estimate natural forest biomass in Me Linh Station for Biodiversity:

$$P_{\text{stem}} = 25.3051 * (D_{1.3m})^{0.4627} \quad (R^2 : 9.661)$$

$$P_{\text{branch}} = 12.1043 * (D_{1.3m})^{0.5416} \quad (R^2 : 9.8)$$

$$P_{\text{leaves}} = 9.446 * (D_{1.3m})^{0.5976} \quad (R^2 : 0.9363)$$

$$P_{\text{toatla biomass forest}} = 25.882 * D^{1.725} \quad \text{with } R^2: 0.8561$$

All equations will be applied to estimate biomass for each tree species or natural forest in Me Linh Station for Biodiversity in recently.

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