STRUCTURE, SPECIES COMPOSITION AND DIVERSITY OF TROPICAL MOIST EVERGREEN FORESTS IN THREE ECOLOGICAL REGIONS OF VIETNAM

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SUMMARY

Results of the study on structure, species composition and diversity of tropical moist evergreen forests in three ecological regions of Vietnam showed that 61 canopy tree species at the old-growth forest in Xuan Son National Park, 62 species in Cuc Phuong NP and 58 species in Pu Mat NP were encountered. The mean densities of canopy trees varied from 425 to 477 individuals per hectare but their densities were not strongly differed among three study sites. Unlike species richness and tree density, the values of three diversity indices at the plot level of the Cuc Phuong stand were significantly lower than those of Xuan Son and Pu Mat. Within a forest stand, the IVIs of the 10 most important tree species that were ranked in this study were not very different. However, three structural parameters including height, tree canopy cover and LAI were significantly different among the three stands. Regarding relationship between DBH and Height of tree species, the Bonger*et al.*'s model showed at the Xuan Son stand while the natural logarithmic model was the best fit model in cases of Cuc Phuong and Pu Mat stands.

Keywords: Diversity, forest structure, species composition, tropical moist evergreen forest.

I. INTRODUCTION

Tropical rain forest is diverse in tree species and extremely complex in structure (Richards 1952, 1996). Thus, understanding of such complicated structures of a tropical rainforest can help researchers to figure out more about the history, the function and succession of forest ecosystems (Speis 1998) as well as to contribute to a scientific basis for a recommendation of sound silvicultural practices which can be applied in forest restoration and rehabilitation programs.

Like in any other Asian countries, tropical rainforests in Vietnam have suffered from deforestation and forest degradation. High and medium old growth forests can now only be found in very remote areas (Gomiero, Pettenella *et al*. 2000) and in core zones of NPs, Nature Reserves and Biosphere Reserve Sites. However, there exist an insufficient knowledge on spatial patterns of forest structure, floristic composition and species diversity of tropical evergreen broadleaved forests under different eco-geographical conditions (the variation in soil types, soil nutrient and topography as well as the difference in biogeography, habitat and disturbance regimes).

Therefore, this paper will describe and compare tree species composition, forest structure and species diversity in order to determine the variation of tropical forest characteristics of tropical evergreen forests in three eco-geographical zones in North and Central Vietnam. The results are expected to enhance the scientific knowledge concerning the variation in structure, species composition and diversity of tropical rainforests in different ecological conditions in order to contribute important information for forest restoration, conservation and sustainable management activities.

II. MATERIALS AND METHODS

2.1. Study sites

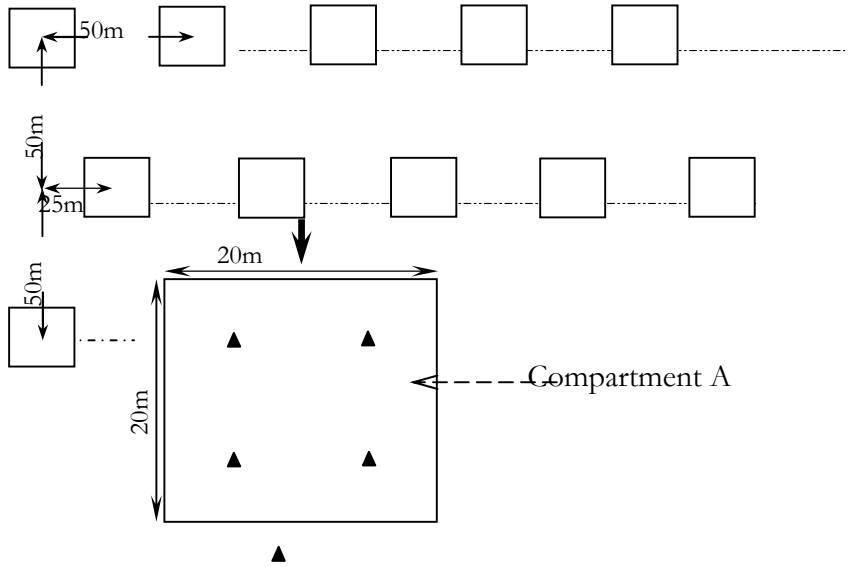
The study was conducted in the three ecological zones of Vietnam, including the North East, the Red River Delta and the North Center Coast. Detail information of three study sites is indecated in the table 01.

Table 01. Detail information of the three study sites

No.	Parameter	Xuan Son NP	Cuc Phuong NP	Pu Mat NP
1	**Cordination**			
	+ Latitude (N):	21°03'-21°12'	20°14'-20°24'	18°46'-19°12'
	+ Longitude (E):	104°51'-105°01'	105°29'-105°44'	104°24'-104°56'
2	Area (ha)	3,282	22,200	91,113
3	Mean annual temperature (°C)	22.6	20.6	23.5
4	Mean annual precipitation (mm)	1,786	2,148	1,791

2.2. Data collection

In each study site, twenty-five 20 m x 20 m sample plots,which account for one hectare, were systematically set up with a random start of the first plot within 350 m - 400 m latitude range. The sites were also situated in old-growth forests in the core zone of three Vietnamese National Parks. The forest structures of those forests were more or less intact indicated by the virtue of the standing mature trees (figure 01).



Where: ▲= Spot of canopy photos

Figure 01. Sample plot design in study area

(sample size: 1ha. sample plots: 25 units)

Within each plot, name of all trees with BDH ≥ 10 cm; their DBH, height, crown diameter were recorded in a data sheet. In order to achieve the canopy cover ratio and the leaf area index (LAI) of the study plots, the Macfarlane's method (2007) were applied by taking four images of the canopy at each of every plot of 400 m^2 (20 m x 20 m) during later afternoon.

2.3. Data analyses

The importance value index (Brook, Bakarr et al.) was determined by Curtis and McIntosh's method (1950). Canopy photos were processed using the Can-Eye software version 4.0. The Kruskal-Wallis test was performed,the Mann-Whitney U test was used to test for significance between the tree species

diversities of the different stands. However, the Boferroni correction was applied for multiple comparisons.

Tree species diversity of each study forest was determined using the Simpson and the Shannon-Wiener indices and the Shannon's measure of evenness. The Sörensen's coefficient, mentioned in the McCune and Grace (2002), was used to compare a similarity ratio of tree species in the composition of seedling, sapling and canopy storey of every study stand. The relationship between tree height and DBH was regressed using several models that have been applied in the forestry research.

All collected data were entered to a Microsoft Excel 2013 worksheets and later on transformed to Statistica 9.1 software for a particular analysis.

III. RESULTS AND DISCUSSIONS

3.1. Floristic composition

A total of 62 tree species were found in the old-growth forest at the Cuc Phuong site. It is followed by 61 tree species found in Xuan Son and 58 tree species found at the Pu Mat stand. At the Cuc Phuong stand, *Saraca dives* Pierre became one of the most important tree species in the old growth forest type with an IVI of 68.5. Other species that had a high IVI were *Hydnocarpus kurzii* Warb. (26.2) and *Caryodaphnopsis baviensis* (Lecomte) Airy Shaw (22.7). The study stand in Xuan Son NP was characterized by *Vatica odorata* (Griff.) Symington, which IVI was 26.3. It was followed by *Nephelium cuspidatum* Blume (20.1) and *Aphanamixis grandiflora* Blume (18.5). Similarly, the Pu Mat stand was characterized by *Vatica tonkinensis* A.Chev. which IVI was 41.3, followed by *Syzygium sp.* (22.1) and *Coffea sp.* (20.0). Interestingly, only *Vatica tonkinensis* A.Chev., one of the dominant species, could be found in both the Xuan Son and Pu Mat study stands.

Twenty-one out of the total 61 tree species encountered for the Xuan Son stand could also be found either in Cuc Phuong or in Pu Mat. Values of the Sörensen's coefficient of similarity also showed that the species similarity between Xuan Son and Pu Mat stands was 21.8 %, followed by 14.6% between Xuan Son and Cuc Phuong. A low degree of overlapping species between the stands in the three ecological regions indicated that a high diversity and a great variation in the floristic composition are typical characteristics of tropical rainforest on a larger scale.

Table 02. IVI values of the first three common species in one hectare plot at the study sites

Stand	Species	Abundance (n ha^{-1})	Dominance (m^2)	Frequency (%)	IVI
Xuan Son	*Vatica fleuryana*	32	4.15	80	26.3
	Nephelium chryseum	23	3.30	60	20.1
	Aphanamixis grandiflora	26	2.13	85	18.5
	Sub-total	**81**	**9.58**	**-**	**64.9**
	Other species (58)	*344*	*20.7*	-	*235.1*
	Total	**425**	**30.28**	**-**	**300.0**
Cuc Phuong	*Saraca dives*	145	8.00	76	68.5
	Hydnocarpus kurzii	59	1.60	64	26.2
	Caryodaphnopsis tonkinensis	19	3.55	60	22.7
	Sub-total	**223**	**13.15**	**-**	**117.4**
	Other species (59)	*202*	*17.65*		*182.6*
	Total	**425**	**30.8**		**300.0**

Stand	Species	Abundance (n ha^{-1})	Dominance (m^2)	Frequency (%)	IVI
	Vatica tonkinensis	62	6.86	92	41.3
	Syzygium sp.	43	2.38	72	22.1
Pu Mat	*Coffea sp.*	38	1.71	84	20.0
	Sub-total	143	10.95	-	83.4
	Other species (55)	*334*	*21.87*	-	*216.6*
	Total	**477**	**32.82**	**-**	**300.0**

3.2. Species diversity

The diversity values of all study stands do not show obvious differences (table 03). However, the Simpson, the Shannone-Wiener indices and the Shannon measure of evenness revealed at the Xuan Son stand were slightly higher than those revealed at the Cuc Phuong and the Pu Mat stands. The revealed values of the species richness did not very differ among the three study sites and they completely fell within the range of those normally recorded in primary lowland rainforests (Richards 1996) and were similar to the results recorded in a mature forest stand at the Vu Quang NP in the central region of Vietnam (Hung 2008).

Table 03. Species diversity indices of the different old growth forests in Vietnam

Stand	Diversity index				
	S	*N*	*1-D*	*H'*	*J'*
Xuan Son	61	425	0.96	3.62	0.88
Cuc Phuong	62	425	0.86	2.92	0.71
Pu Mat	58	477	0.95	3.41	0.84

S is the number of species recorded, N is the total number of individual enumerated, 1-D is the complements of Simpson's index, H' is the Shannon-Wiener index, J' is the Shannon measure of evenness.

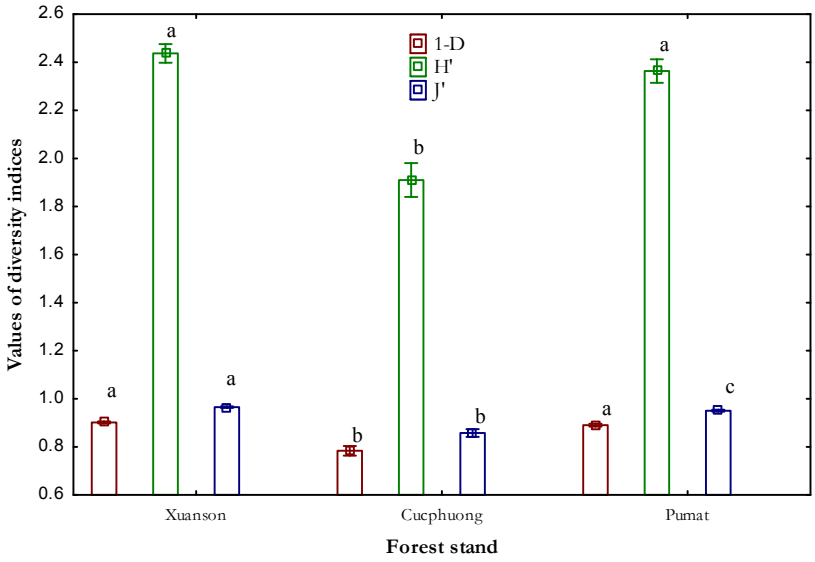


Figure 03. Species diversities of the different forest stands. The different letters indicate significant differences ($p \leq 0.0167$, the Mann-Whitney U test**)**

At the plot level, by using the nonparametric Mann-Whitney U test (with the Bonferroni correction proceduce, $p \leq 0.0167$), the study found out that the complement of the

Simpson index, the Shannon-Wiener index and the Shannon measure of evenness at both the Xuan Son and Pu Mat stand were significantly higher than those at the Cuc Phuong stand. In contrast, there was no difference found when the complement of the Simpson index and the Shannon-Wiener index of the Xuan Son and Pu Mat stands were compared (figure 03).

3.3. Structural characteristics of the stands

In this dtudy, the structural data of each study stand were recorded within the 25 sample plots of 400 m^2 each. Analyzed results are mentioned in table 04 as follows:

Table 04. Structural characteristics of the three old-growth stands

Stand characteristics	Forest stand			Kruskal-Wallis Test
	Xuan Son *Min±SE*	CucPhuong *Min±SE*	Pu Mat *Min±SE*	
Number of tree species	61	62	58	
Stem density (n ha^{-1})	425±20.0	425±17.8	477±25.8	H(2)=3.86, p=0.14
Mean DBH (cm)	25.6±0.9	26.5±0.7	25.4±0.6	H(2)=0.75, p=0.69
Basal area (m^2 ha^{-1})	30.27±2.3	30.79±1.6	32.80±2.2	H(2)=0.56, p=0.75
Mean tree height (m)	16.55±0.45	15.47±0.37	15.31±0.24	H(2)=8.06, p<0.05
Tree canopy cover	0.66±0.03	0.90±0.01	0.76±0.02	H(2)=18.0, p<0.01
Leaf area index (m^2 m^{-2})	3.64±0.14	4.32±0.16	3.38±0.11	H(2)=41.6, p<0.01

The general descriptions of the structures of all three study stands are summarized in Table 04. The tree species at the Cuc Phuong stand had the biggest mean DBH value (26.5 cm) while the other two stands had slightly lower values with a mean DBH value of 25.4 cm (Pu Mat) and 25.6 cm (Xuan Son).Total basal areasof the three stands ranged from 30.27 m^2 ha^{-1} (Xuan Son site) to 32.80 m^2 ha^{-1} (Pu Mat site). In contrast, the mean tree height was highest in the old growth forest which is distributed at the Xuan Son NP. It is 1.24 m and 1.08 m higher than those of the study stands at the Pu Mat and Cuc Phuong National Parks, respectively. Stem density of the canopy tree species was highest at the Pu Mat stand (477 stems ha^{-1}) which attained a canopy cover of 0.76 and a LAI of 3.38 m^2 m^{-2}. Stem densities of three study stands were the same (425 stems ha^{-1}) with a tree canopy cover of 0.66 and a LAI of 3.64 m^2 m^{-2} for Xuan Son, 0.90 and 4.32 m^2 m^{-2} for Cuc Phuong and 0.76 and 3.38 m^2 m^{-2} for Pu Mat stand. The density values that were recorded not strongly differed among three study sites. Especially, they were similar to values that had been identified in many lowland evergreen forests such as in Vu Quang NP, in the central region of Vietnam (Hung 2008), in La Selva, Costa Rica (Hartshorn 1983).

As can be seen in Table 04, H values or the calculated χ^2, revealed from the Kruskal-Wallis tests by comparing every stand structural parameters, show that the stem density, DBH and the basal area were similar among the three old growth forests while tree height, canopy cover and LAI were significantly different between them.

3.4. Size class distribution of stands

The size classes or diameter distributions of individuals of all 25 sample plots that belong to the three old growth forest stands are illustrated in figure 04. The interval of these classes was set at 5.0 cm.

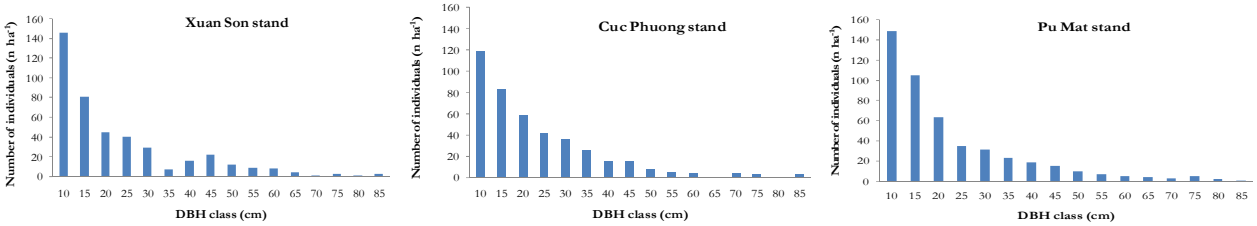


Figure 04. Diameter distribution of canopy trees in one hectare sampled in the three old growth stands (class width = 5 cm)

As can be seen in figure 04, the shapes of the size class distributions are nearly similar between the three stands and they show a typical inversed-J shape where the number of individuals decreases with increasing DBH. In the biggest size class (DBH ≥ 85 cm), only 2 out of 425 individuals at the Xuan Son stand, 4 out of 425 individuals at the Cuc Phuong stand and 2 out of 477 individuals at the Pu Mat stand could be found. At the Xuan Son stand, the two largest trees were *Dipterocarpus retusus* Blume and *Vatica fleuryana* Tardieu, which belong to the Diterocapaceae family. Their DBH was 88.5 and 90.1 cm, respectively. At the Cuc Phuong stand, they were *Pavieasia annamensis* Pierre (85.0 cm DBH, Sapindaceae), *Caryodaphnopsis tonkinensis* (Lecomte) Airy Shaw (87.0 cm, Lauraceae), *Elaeocarpus apiculatus* Mast. (90 cm, Elaeocarpaceae) and *Bischofia javanica* Blume (102.0 cm, Euphorbiaceae). At the Pu Mat stand, they were *Castanopsis indica* A.DC. (85.0 cm, Fagaceae) and *Madhuca pasquieri* H.J.Lam (87.0 cm, Sapotaceae). Based on the results of the Kolmogorov-Smirnov test between two stands, the study also confirmed that the patterns of the size class distribution of all three stands were not significantly different among each other when the p value was set at ≤ 0.05.

3.5. Height and diameter relation

Figure 05 showed the best fitted models of the DBH and the height for all trees at the Xuan Son, Cuc Phuong and Pu Mat's one-hectare plots.

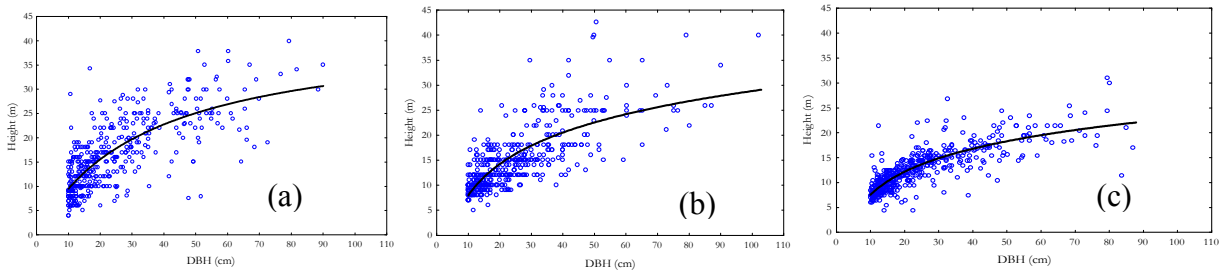


Figure 05. Relations between height and diameter for all trees in the three study sites

(a) *Xuan Son stand*: fitted with the Bongers*et al.*'s equation

Height = (42.48692 * DBH)/(DBH + 34.68391), $r^2 = 0.57$, $p < 0.001$

(b) *Cuc Phuong stand*: fitted with the natural logarithmic equation

Height = 6.2759 * ln(DBH) - 12.8657, $r^2 = 0.55$, $p < 0.001$

(b) *Pu Mat stand*: fitted with the natural logarithmic equation

Height = 5.17336 * ln(DBH) - 7.67187, $r^2 = 0.71$, $p < 0.001$

All three curves showed a relatively similar slope in the young phase (at the DBH ≤ 30 cm). This means that an increase in the DBH was coupled to an increase in tree height. However, in the mature phase, this pattern is completely reversed. At this phase, regression curves become shallower compared to the previous phase. Especially, in case of Xuan Son stand, the stem diameter still increases but it is not so much difference in comparision to increase in height when the trees reach the size class of greater than or equal to 60 cm.

In addition, the Bonger*et al.*'s model showed the best fit between DBH and height of tree species at the Xuan Son stand while the natural logarithmic model was the best fit model in cases of Cuc Phuong and Pu Mat stands. As can be seen in figure 05, scatters around the three regression curves increased with the increase in DBH. This indicates a low number of tree individuals in the larger size classes in comparison to those in the smaller size classes (Bongers, Popma et al. 1988). This distribution pattern also shows a clearly typical type of a vertical distribution of tropical forests when most of small to medium sized trees dominate in lower strata while only small number of mature trees distribute in the upper and the emergent stratum. Among the three stands, the height curve of the Xuan Son stand had a steeper slope than those of Cuc Phuong and Pu Mat stands. Those results reflect the development state of stand quality of the sites because mature stands tend to have shallower height curves compared to the younger stands (Hung 2008).

IV. CONCLUSION

In our study, a total of 61 tree species at the old-growth forest in Xuan Son, 62 species in Cuc Phuong and 58 species in Pu Mat were encountered. The mean densities of canopy trees varied from 425 to 477 tree individuals per hectare. The values that were recorded not strongly differed among three study sites.

Twenty-one out of the total 61 tree species encountered for the Xuan Son stand could be found either in Cuc Phuong or in Pu Mat. Values of the Sörensen showed that the species similarity between Xuan Son and Pu Mat stands was 21.8 %, followed by 14.6 % between Xuan Son and Cuc Phuong.

Unlike species richness and tree density, the diversity indices including the Simpson, the Shannon-Wiener indices as well as the Shannon measure of evenness at the plot level of the Cuc Phuong stand were significantly lower than those of Xuan Son and Pu Mat. Within a forest stand, the IVIs of the 10 most important tree species that were ranked in this study were not very different. However, three structural parameters including height, tree canopy cover and LAI were significantly different among the three stands.

Regarding relationship between DBH and Height of tree species, the Bonger*et al.*'s model showed at the Xuan Son stand while the natural logarithmic model was the best fit model in cases of Cuc Phuong and Pu Mat stands.

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ĐẶC ĐIỂM CẤU TRÚC, TỔ THÀNH VÀ ĐA DẠNG SINH HỌC RỪNG NHIỆT ĐỚI LÁ RỘNG THƯỜNG XANH Ở 3 VÙNG SINH THÁI CỦA VIỆT NAM

Phạm Minh Toại

Trường Đại học Lâm nghiệp

TÓM TẮT

Các kết quả nghiên cứu đặc điểm cấu trúc lâm phần, tổ thành loài cây và đa dạng sinh học rừng nhiệt đới là rộng thường xanh ở 03 vùng sinh thái của Việt Nam đã xác định được 61 loài cây trong rừng tự nhiên ở Vườn Quốc Gia (VQG) Xuân Sơn, 62 loài ở VQG Cúc Phương và 58 loài ở VQG Pù Mát. Mật độ trung bình của cây rừng ở tầng cây cao biến động từ 425 đến 477 cây/ha nhưng sự biến động này không có sự khác biệt rõ rệt giữa 3 điều kiện lập địa được nghiên cứu. Không giống như mức độ phong phú về loài và mật độ cây cao, giá trị của 3 chỉ số đa dạng sinh học quy mô ô tiêu chuẩn tại lâm phần rừng thuộc Cúc Phương thấp hơn rõ rệt so với 2 lâm phần nghiên cứu tại Xuân Sơn và Pù Mát. Trong một lâm phần, chỉ số độ quan trọng của loài cây (IVI) của 10 loài cây đứng đầu bảng xếp hạng không có sự khác biệt rõ rệt giữa 03 khu vực. Tuy nhiên, 3 chỉ tiêu cấu trúc bao gồm chiều cao, độ tàn che và chỉ số diện tích lá (LAI) của 03 lâm phần lại có sự khác biệt rõ rệt. Ngoài ra, tương quan giữa Đường kính ngang ngực và Chiều cao của lâm phần tại Xuân Sơn tuân thủ mô hình của Bonger và cộng sự trong khi các lâm phần tại Cúc Phương và Pù Mát tuân thủ mô hình logarit tự nhiên.

Từ khóa: Cấu trúc lâm phần, đa dạng sinh học, rừng nhiệt đới ẩm thường xanh, tổ thành loài.

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