BIODIVERSITY, SPATIAL AND ASSOCIATION PATTERNS OF NATURAL TREE SPECIES IN TROPICAL BROADLEAVED FOREST IN NORTHERN VIETNAM

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SUMMARY

Ecological processes in forests can be studied via the spatial distribution of tree species. However, the distribution pattern of a species may be obscured by environmental heterogeneity. In order to answer these questions: What are the prevailing types of intraspecific spatial distributions and interspecific association patterns at tree species in a tropical rain forest? Which ecological processes could structure these patterns? The techniques of point pattern analysis were implemented on mapped two 1-ha forest plots in Ba Vi National Park, Cuc Phuong National Park. We analyzed (i) The effect of environmental heterogeneity on tree distributions; (ii) Intraspecific associations and (iii) Interspecific associations. Our analyses showed that: (i) Environmental conditions were homogeneous at all two plots. (ii) In two plots, almost dominant species were aggregated at various scales up to 50 m due to the limited distribution of each species while the rest was random distribution. (iii) Attraction and independence in two plots are remarkably higher than repulsion pattern of tree species. Overall, spatial aggregation of a species can be induced by limited seed dispersal or patchy habitat conditions while random distributions were effected by competitive relations or even human activities. The repulsive interactions between some tree species are explained by negative interactions of tree species.

Keywords: Environmental homogeneity, Northern Vietnam, spatial point pattern analysis, tropical broad-leaved forest.

I. INTRODUCTION

Spatial patterns of forest trees result from complex dynamic processes such as establishment, dispersal, mortality, land use and climate (Franklin et al., 2010), especially in tropical forests which were known as the world's most species-rich terrestrial ecosystems. An important question for all scientists in researching of forest ecology is how to understand the processes and mechanisms that control species coexistence and community structure, especially at various spatial scales. Studies on species-rich tropical forests produced numerous hypotheses on species co-existence, these relevant issues have been addressed in numerous studies (Chesson, 2000; Wright, 2002; Volkov et al., 2005). Barot (2004) highlighted the impact of both exogenous and endogenous factors on the spatial and temporal distributions of tree species. Other studies investigated dispersal limitation (Hubbell, 1979), intra- and inter-specific interactions (Callaway and Walker, 1997; Bruno et al., 2003), negative density dependence (Wright, 2002), or habitat preference (Condit et al., 2000). Tilman (2004) emphasized that in the processes of dispersal and competition, environmental niche effects and trade-offs among species are two main factors that made a big difference in spatial patterns of trees. Environmental heterogeneity (such as different soil types, rock outcrops or streams) makes spatial pattern analysis more complicated because it confounds biotic and abiotic effects (Li and Reynolds, 1995; Wiens, 2000). Getzin et al. (2008) found that plant ecology in terms of plant population dynamics and pattern formation may differ between homogeneous and heterogeneous sites, beyond the purely statistical effects of heterogeneity. Dispersal limitation is emphasized as a potential mechanism for separating species in space and reducing competitive exclusion (Seidler and Plotkin, 2006). Besides that, a patchy distribution of trees can also be caused by habitat preference where demographic processes and limiting resources may simultaneously influence spatial patterns (Wagner and Fortin, 2005; Getzin et al., 2008). Thus, spatial aggregation of a species can be induced by limited seed dispersal or patchy habitat conditions and may also be reinforced by both factors (Webb and Peart, 2000). In addition, negative density dependence or self-thinning is proposed as a prominent mechanism for regulating population dynamics and facilitating species coexistence (Wright, 2002). This mechanism has been considered by a negative density of conspecific distance relation in processes of forest dynamics such as recruitment, growth or survival (Condit et al., 1992; Peters, 2003; Uriarte et al., 2004).

The goal of this research aims to analyze and evaluate spatial and association patterns of natural tree species in tropical broad-leaved forests in Northern Vietnam. Moreover, ecological underlying mechanisms or processes structuring these spatial patterns are inferred which allow to interpret spatial structure of these forest stands.

II. RESEARCH METHODOLOGY

2.1. Study sites and data collection

Two 1-ha plots are designed in two different tropical broadleaved forests in Northern Vietnam including Ba Vi National Park (21°04'09.5" N and 105°21'36.5" E), Cuc Phuong National Park (20°17'18.9" N and 105°39'22.3" E). Establishing typical plots in evergreen broad-leaved forest in the core zone of two National Parks (NP). The plots represent for the forest stands in order to research ecological conditions, community structure and growth status. The area of each plot is 1 ha (100 m × 100 m). The plot is divided into 100 subplots of 100 m^2 (10 m × 10 m) by wooden poles and nylon strings. All trees (DBH ≥ 2.5 cm) were marked, identified the species name and measured the diameter at breast height at 1.3 m from ground. The relative position (x, y) of the trees in the subplot were measured by using the laser distance measurer Leica Disto D2 with a precision of 0.1 cm and a compass.

Ba Vi National Park is situated in the tropical monsoon climate. The average annual temperature in the region is 23.4^{o}C; at lowest temperatures down to 2.7^{o}C; highest temperature up to 42^{o}C. The annual average rainfall is 2,500 mm, about 70 - 80% of the total precipitation focusing on July - August; humidity of 86.1%.

Cuc Phuong National Park (located in Nho Quan district, Ninh Binh province) is surrounded by limestone mountains with mean maximum height of 300 - 400 m and is covered by tropical evergreen rainforest. In the core zone, mean annual temperature is 20.6°C, but mean temperature in winter is only 9°C. In the buffer zone, mean annual temperature is about 2° higher. Annual mean humidity is 85% and the average annual rainfall is 2,138 mm per year.

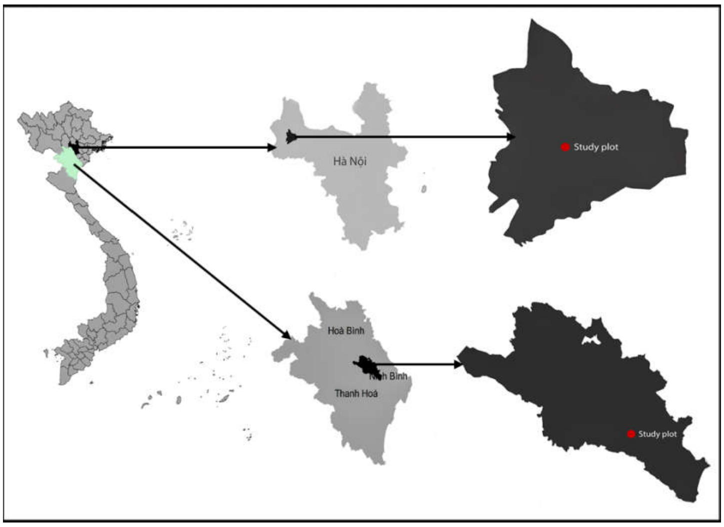

Figure 1. Map of studied plots at Ba Vi and Cuc Phuong National Park

2.2. Data analysis

Important value and diversity indices

Importance Value Index (IVI): was a measure of how dominant a species was in a given forest area.

Relative density (RD) was the number of individuals per area as a percent of the number of individuals of all species.

IVI (%) = (Relative density + relative Basal area)/2

Relative basal area was the total basal area of Species A as a percent of the total basal area of all species.

The Shannon-Wiener index was an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled. In the Shannon index, p was the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln was the natural log, Σ is the sum of the calculations, and s was the number of species.

$$\text{Shannon Wiener Index (H)} = \sum_{i=1}^{s} p_i ln p_i$$

The Simpson's index was a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity. In the Simpson index, p was the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ was still the sum of the calculations, and s was the number of species.

$$\text{Simpson's Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

III. RESULTS

3.1. Species property of tropical forest studied stands

Table 1. Forest stand characteristics in Ba Vi plot

No.	Species	N	DBH (cm)	IVI (%)	Properties	Shannon-Wiener	Simpson
1	*E. wightiana*	105	9.6 ± 3.9	5.01	Light demanding & fast growing	3.36	0.97
2	*X. noronhianum*	99	10.3 ± 4.7	4.98	Light demanding		
3	*N. baviensis*	55	16.8 ± 11.3	4.73	Light demanding		
4	*Q. bambusifolia*	37	22.3 ± 13	4.35	Moderate inclining to light demanding		
5	*Q. gemelliflora*	13	40.2 ± 18.2	3.58	Light demanding		
6	*C. lenticellata*	71	9.5 ± 4.5	3.41	Light demanding & fast growing		
7	*W. laevis*	68	9.4 ± 4.9	3.28	Shade tolerance		
8	*S. baviense*	44	14.4 ± 10.8	3.28	Light demanding & fast growing		
9	*C. zeylanicum*	37	17.1 ± 11.2	3.19	Light demanding		
10	*C. glaucescens*	59	11.2 ± 5.2	3.14	Light demanding		
11	*A. globiflora*	49	11.7 ± 5.8	2.71	Light demanding		
12	70 other species	830		58.34			

In Ba Vi NP plot, a total of 1,467 tree individuals with DBH ≥ 2.5 cm were enumerated in the 1-ha study plot. 81 species were identified and belonged to 26 families; Shannon - Weiner (H') = 3.36; Simpson (D) = 0.97. In 11 dominant species, there are 10 species with light demanding, approximately 91% of total. *E. wightiana* (Myrtaceae) was most abundant with 105 individual ha^{-1} with the average size is quite small (9.6 ± 3.9 cm). Moreover, depending on IVI there are 11 dominant species: *E. wightiana, X. noronhianum, N. baviensis, Q. bambusifolia, Q. gemelliflora, C. lenticellata, W. laevis, S. baviense, C. zeylanicum, C. glaucescens, A. globiflora* with total IVI is 41.66%. Only 10 of them except *Q. gemelliflora* were selected for further spatial pattern analyses.

Table 2. Forest stand characteristics in Cuc Phuong plot

No.	Species	N	DBH (cm)	IVI (%)	Properties	Shannon-Wiener	Simpson
1	*S. macrophyllus*	392	9.7 ± 7.3	25.72	Shade tolerance & lower storey		
2	*C. tonkinensis*	29	67.1 ± 30.5	18.39	Light demanding & fast growing		
3	*S. dives*	117	18.8 ± 12.7	12.28	Middle storey	2.78	0.82
4	*H. kuzii*	94	12.7 ± 8.8	7.1	Shade tolerance & middle storey		
5	85 other species	374		36.51			

In Cuc Phuong NP plot, the density of trees was quite high 1,006 trees/ha (DBH ≥ 2.5 cm). In total, 89 species were identified in this study plot and belonged to 24 families with the diversity indices: Shannon - Weiner (H’) = 2.78; Simpson (D) = 0.82. The average size of *S. macrophyllus* was small (9.7 ± 7.3 cm). Based on IV (%), it can be seen that *S. macrophyllus* with 3 other species: *C. tonkinensis, S. dives, H. kuzii* were eligible to form group of dominant tree species with total IVI was 63.49%. Three of four given species were shade tolerance and tend to grow in middle and lower storeys.

As the results from three plots, the study identified 11 species with highest IVI in Ba Vi plot with total IVI was 41.66%, 4 species in Cuc Phuong plot with total IVI was 63.49%.

Comparing diversity indices (D of Simpson), Ba Vi plot performed the highest values at 0.97 while Cuc Phuong plot had the lowest one at 0.82. Thus, the levels diversity in Ba Vi plot were strongly higher than Cuc Phuong site. In addition, the values of Shannon-Weiner (H’) of Ba Vi plot and Cuc Phuong plot, were 3.36, 2.78. Therefore, Ba Vi plot was at high level of population balance and richness.

3.2. Spatial patterns analysis

Analysis 1: *Environmental heterogeneity effects*

The spatial patterns of all adult trees (dbh ≥ 15 cm) in study plots were contrasted to the CSR null model to find significant departure at large scales. We used both cumulative and non-cumulative advantages of both L-function and g-functions in this analysis, respectively. The g-function showed that adults in all plots were regular at small scales and that could be evidences of strong tree-tree competition (results not shown). Moreover, L-function also showed no deviation from confidence envelopes at larger scales (results not shown). Therefore, no large scale departure from the CSR null model was observed and the hypothesis of environmental homogeneity was accepted in the study plots. Based on this finding, we applied the homogeneous g-function for the further spatial pattern analyses in this study.

Analysis 2: ***Intraspecific spatial distributions***

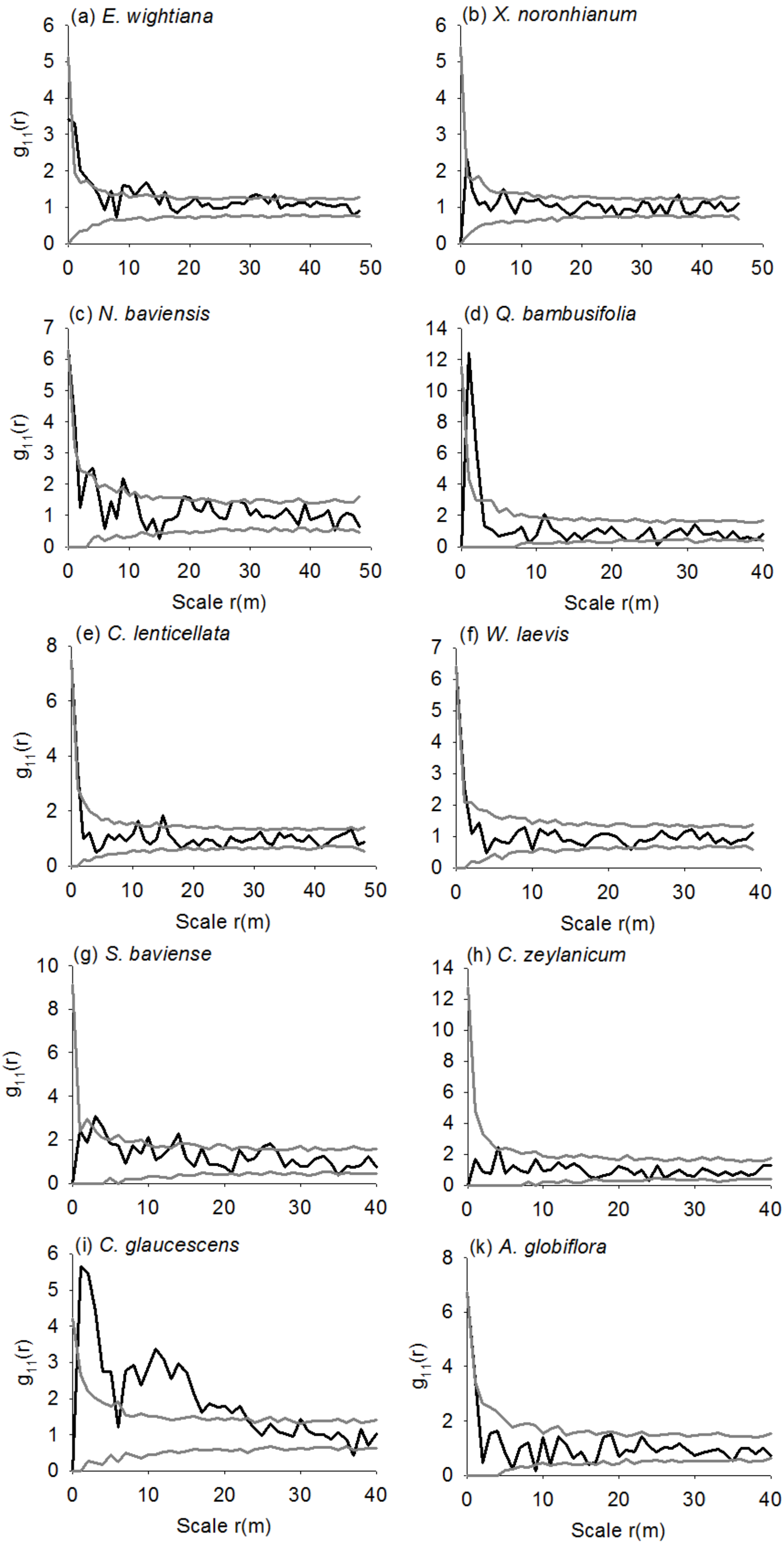

Figure 2. Spatial patterns of dominant tree species in Ba Vi plot analyzed by the pair correlation function $g_{11}(r)$ under null model of CSR

Black lines are observed patterns; grey lines are approximate 95% confidence envelopes

In Ba Vi plot, intraspecific spatial distributions was analyzed by the pair correlation function $g_{11}(r)$. *E. wightiana* was aggregated at 1 - 4 m and at large scales of 8 - 15 m (Figure 2a). In contrast, *X. noronhianum* showed a strong random distribution over the entire range of scales up to 46 m (Figure 2b). *N. baviensis* and *Q. bambusifolia* were aggregated at the begging of scales of 0 - 2 m (Figure 2c) and 1 - 4 m (Figure 2d). There was the same clustered distribution of *C. lenticellata, W. laevi* and *A.globiflora* at 0 - 2 m (Figure 2e, f, k). *S. baviense* was clustered at small scales of 3 - 5 m (Figure 2g). *C. glaucescens* was aggregate at large scales of 1 - 6 m and 7 - 22 m (Figure 2i). *A. globiflora* was random over the entire range of scales up to 40 m (Figure 2h).

In Cuc Phuong plot, based on IVI, there were 4 species: *S. macrophyllus*, *C. tonkinensis, S. dives, H. kuzii* are considered as dominant tree species and spatial distributions were shown in figure 3. *S. macrophyllus* was aggregated at 1 - 34 m (Figure 3a). *C. tonkinensis* and *S. dives* also showed clustered distribution at 2 - 12 m (Figure 3b) and 4 - 7 m (Figure 3c). *C. tonkinensis* was random at small scales (Figure 3d).

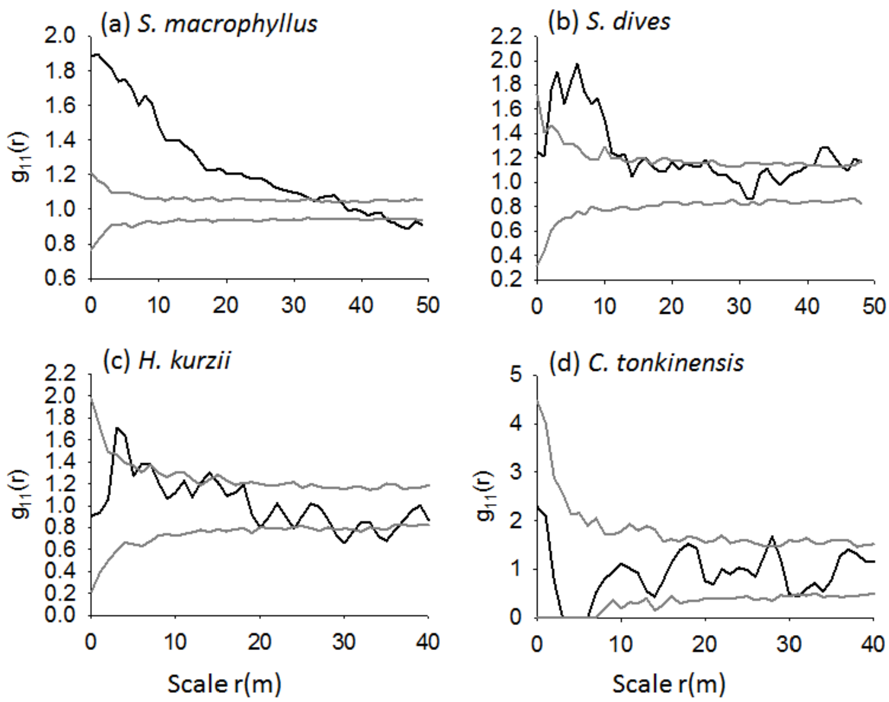

Figure 3. Spatial patterns of dominant tree species in Cuc Phuong plot analyzed by the pair correlation function $g_{11}(r)$ under null model of CSR

Black lines are observed patterns; grey lines are approximate 95% confidence envelopes

Analysis 3: *Interspecific spatial associations*

As the results were analyzed by analyzed by the bivariate pair correlation function $g_{12}(r)$ under null model of random labeling, we performed 90 bivariate point pattern analyzses for all pairs of dominant species for Ba Vi plot. Overall, independence occurred more frequently with 53.3% while attraction 28.8% and repulsion 17.9%. There were 13 significant positive interactions observed between *N. baviensis - E. wightiana; C. glaucescens - E. wightiana; C. lenticellata - X. noronhianum; S. baviense - X. noronhianum; A. globiflora - X. noronhianum; S. baviense - N. baviensis; C. glaucescens - N. baviensis; C. lenticellata - Q. bambusifolia; W. laevis - Q. bambusifolia; C. zeylanicum - Q. bambusifolia; A. globiflora - C. lenticellata; C. zeylanicum - W. laevis; C. glaucescens - S. baviense; C. glaucescens - C. zeylanicum.*

Table 3. Spatial associations of dominant tree species in Ba Vi plot

No.	Species	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	*E. wightiana*		0	+	-	0	0	-	-	+	0
(2)	*X. noronhianum*	0		-	-	+	-	+	0	0	+
(3)	*N. baviensis*	+	-		0	0	-	+	0	+	0
(4)	*Q. bambusifolia*	-	-	0		+	+	0	+	0	0
(5)	*C. lenticellata*	0	+	0	+		0	0	0	0	+
(6)	*W. laevis*	0	-	-	+	0		0	+	0	0
(7)	*S. baviense*	-	+	+	0	0	0		0	+	0
(8)	*C. zeylanicum*	-	0	0	+	0	+	0		0	0
(9)	*C. glaucescens*	+	0	+	0	0	0	+	0		-
(10)	*A. globiflora*	0	+	0	0	+	0	0	0	-	

Note: 0: independence; +: positive association (attraction); -: negative association (repulsion).

In contrast, repulsion occurred 8 times between *Q. bambusifolia - E. wightiana; S. baviense - E. wightiana; C. zeylanicum - E. wightiana; N. baviensis - X. noronhianum; Q. bambusifolia - X. noronhianum; W. laevis - X. noronhianum; W. laevis - N. baviensis; A. globiflora - C. glaucescens.* It can be seen that the interactions are mostly independence, for example: *X. noronhianum - E. wightiana; C. lenticellata - E. wightiana; C. zeylanicum - N. baviensis.*

Spatial associations of 4 dominant tree species in Cuc Phuong plot were showed and analyzed with the bivariate pair-correlation function under null model of random labeling (Figure 4). As the result, 2 pairs showed repulsion and 4 pairs independence. *S. macrophyllus - H. kuzii* (Figure 4b), *S. macrophyllus - C. tonkinensis* (Figure 4c) were relpusive associations. *S. macrophyllus - S. dives* (Figure 4a), *S. dives - H. kuzii* (Figure 4d), *S. dives - C. tonkinensis* (Figure 4e), *H. kuzii - C. tonkinensis* (Figure 4f) were independent in species interactions.

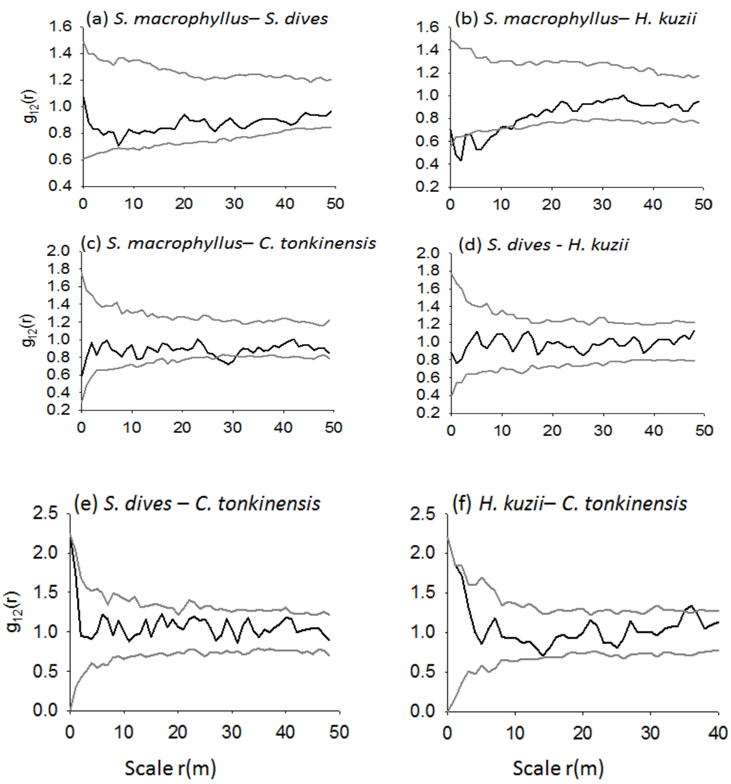

Figure 4. Association patterns of dominant tree species in Cuc Phuong analyzed by the bivariate pair correlation function $g_{12}(r)$ under null model of random labeling

Black lines are observed patterns; grey lines are approximate 95% confidence envelopes

The independent interaction between tree species is a very common in tropical forest with high level of diversity as in the study area. This is also explained by the fact that many species have similar ecological characteristics such as the demand of light or nutrition.

The repulsive association of tree species is explained by the fact that forest structure, species composition and forest canopy are altered by multiple impacts. This leads to light-demanding and fast-growing species that tend to grow, compete with other species, and dominate the population.

A possible explanation is that attraction patterns are the result of facilitation at small scales. Specifically, the local environment is modified by large trees or canopy gaps and facilitates small intra- and inter-specific associations of trees with similar habitat preferences, e.g. with similar light requirements in our case. Suzuki et al. (2012) highlighted that an attraction pattern may result from similarity in habitat preference of spatially associated species. Alternatively, attraction patterns among species could be consistent with the species-herd protection hypothesis which states that hetero-specific neighbors can promote coexistence by preventing the transmission of biotic plant pests (Peters, 2003; Lan et al., 2012).

The two study plots are significantly different in tree species structure, species diversity, and spatial patterns. The effects of forest disturbance by human activities were emphasized significantly through forest community structure. The findings can be used as suggestions for silvicultural treatments and biodiversity conservation of tropical rain forests in study regions.

IV. DISCUSSION AND CONCLUSION

4.1. Species diversity of studied forest stands

The research has been conducted quantitatively to help clarify the characteristics of natural forests in Vietnam. Regarding the characteristics of tree species, the study identified 11 species with highest IVI in Ba Vi plot with total IVI is 41.66%, 4 species in Cuc Phuong plot with total IVI is 63.49%. Based on IVI, it can be seen clearly that there are not predominantly dominant tree species in Ba Vi plot. However, the tree species are on the top of IVI still can associate with each other in order to form group of dominant tree species. Especially, in Cuc Phuong plot, group of dominant species formed with less than 10 species and $\sum \text{IVI} \geq 40\%$, will be named for whole community.

Comparing diversity indices (D of Simpson), Ba Vi plot performed the highest values at 0.97 while Cuc Phuong plot has the lowest one at 0.82. Thus, the levels diversity in Ba Vi plot is strongly higher than Cuc Phuong site. Moreover, the values of Shannon-Weiner (H') of 2 plots Ba Vi plot, Cuc Phuong plot are 3.36, 2.78. As the result, both values of (H') and (D) in Ba Vi plot are the highest comparing with the others, so it would be a representative of a diverse and equally distributed community.

4.2. Spatial patterns analysis

Environmental heterogeneity effects

After using both cumulative and non-cumulative advantages of both L-function and g-functions in this analysis, we can see that no large-scale departure from the CSR null model was observed and the hypothesis of environmental homogeneity was accepted in the study plots.

Intraspecific spatial distributions

In Ba Vi plot, almost the spacial distributions are aggregation except *X. noroniaum* and *A. globiflora* are performed as strong random distribution. In Cuc Phuong plot, only *C. tonkinensis* was random while the others were clustered. Thus, the cluster distribution is mainly due to the limited distribution of each species. The random distribution of a number of species studied can be controlled by a variety of ecological processes or mechanisms or even human activities but due to the secondary forest status has been affected and the number of individuals of these species is low, so this research cannot find the root causes of this distribution.

Interspecific spatial associations

In Ba Vi plot, with 90 bivariate point pattern analyzes, the independence occurred more frequently with 53.3% while attraction 28.8% and repulsion 17.9%. In Cuc Phuong plot, with 4 dominant species, the analyzes showed 4 pairs of repulsion and 8 pairs of independence. Under the influence of heterogeneous environmental conditions, spatial relations include repulsion, attraction and independence. However, homogeneous environment, attractive and independent interaction tend to increase. Especially, the repulsive interactions between some tree species Ba Vi plot and Cuc Phuong plot are explained by negative interactions of tree species. This leads to fast-growing, light demanding species that tend to grow, compete with other species, and dominate the population.

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PHÂN TÍCH MÔ HÌNH PHÂN BỐ VÀ QUAN HỆ KHÔNG GIAN CỦA MỘT SỐ CÁC LOÀI CÂY RỪNG LÁ RỘNG THƯỜNG XANH, MIỀN BẮC VIỆT NAM

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TÓM TẮT

Các quá trình sinh thái rừng có thể được nghiên cứu thông qua phân bố không gian của các loài cây. Tuy nhiên, mô hình phân bố của một số loài có thể bị ảnh hưởng bởi sự không đồng nhất của môi trường. Để trả lời cho những câu hỏi như: Các kiểu phân bố cây cùng loài và khác loài phổ biến trong rừng mưa nhiệt đới là gì? Những quá trình sinh thái nào ảnh hưởng tới sự cấu trúc và tổ thành đó? Phương pháp phân tích mô hình điểm không gian đã được thực hiện với 2 ô tiêu chuẩn 1 ha tại Vườn Quốc gia Ba Vì và Vườn Quốc gia Cúc Phương. Chúng tôi đã phân tích (i) Tác động của sự không đồng nhất môi trường tới sự phân bố của cây; (ii) Quan hệ cùng loài và (iii) Quan hệ khác loài của các loài cây trong khu vực nghiên cứu. Kết quả nghiên cứu cho thấy: (i) Các điều kiện môi trường là đồng nhất tại cả 2 ô tiêu chuẩn. (ii) Tại 2 ô tiêu chuẩn, hầu hết các loài cây ưu thế có phân bố cụm lên tới 50 m do sự phát tán hạn chế của mỗi loài, trong khi các loài khác lại xuất hiện phân bố ngẫu nhiên. (iii) Quan hệ tương hỗ và quan hệ độc lập giữa các loài cây là phổ biến hơn so với quan hệ cạnh tranh. Nhìn chung, phân bố cụm của một loài có thể do sự phát tán hạt hạn chế hoặc do thiếu hụt các điều kiện sống. Trong khi đó, phân bố ngẫu nhiên có thể được giải thích bởi sự ảnh hưởng từ các mối quan hệ cạnh tranh hoặc do các tác động của con người. Quan hệ cạnh tranh giữa hai loài có thể do nhu cầu ánh sáng và dinh dưỡng của mỗi loài.

Từ khóa: Môi trường không đồng nhất, phân tích mô hình điểm không gian, phía Bắc Việt Nam, rừng nhiệt đới lá rộng.

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