ANALYZING OF SPATIAL STRUCTURE CHARACTERISTICS OF TROPICAL EVERGREEN FOREST STANDS UNDER ENVIRONMENTAL HETEROGENEITY

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SUMMARY

Structural complexity and local diversity of species-rich tropical forests can be characterized by their nearest neighbour characteristics. Aiming to describe spatial patterns, species mingling and dominance of species at fine spatial scales, we applied the quantitative analyses based on relationships of nearest neighboring trees. In two 1-ha plot of tropical evergreen forest stands in Babe National park, northern Vietnam, all tree individuals with diameter at breast height-DBH ≥ 2.5 cm were mapped and their characteristics (i.e., DBH and species) were recorded. The findings showed that: Most of studied species in the forests were highly mixed with other species, while conspecifics were regular to aggregated distribution but mainly focused at random pattern at small spatial scales. DBH dominance values ranged from low to high levels, except species including *H. kurzii*, *S. wightianum* and *B. hsienmu* completely dominated their neighbouring trees. We assumed the main ecological processes such as dispersal limitation and Neutral theory, regulating spatial structures of these forest stands. The spatial structural parameters offer direct and valuable information about spatial structure of forest stand as advantageous approaches. Those information can be used in thinning of sustainable forest management, modelling and restoration.

Keywords: Dominance, mingling, nearest neighborhood, tropical evergreen forest, uniform Angle index.

1. INTRODUCTION

Forest spatial structure describes the spatial relationships of tree positions and their attributes among different species in the forest community (Nguyen et al., 2018). Spatial distribution patterns directly reflect the way individuals assemble or scatter in space, which may in turn be associated with conditions of competition and utilization of environmental resources among adjacent trees (Nguyen et al., 2018). Tree size is directly related to the degree of maturation of a tree population and to the competitive advantage of the population within the community, it may also be directly related to the survive viability and ecological niche of the population. Intraspecific aggregation involves isolation between species in the same community and regulating processes is related to seed dispersal, regeneration capacity and growth.

A number of methods for describing forest structural attributes have been largely developed for recent decades. However, an exact description of small-scale structural attributes is considered to be increasingly importance (Corral-Rivas et al., 2010). Recently, new individual tree indices of nearest neighbour characteristics including uniform angle index, species mingling and dominance have been developed (Gadow et al., 1998; Aguirre et al., 2003; Hui et al., 2011). The basic idea of these indices is to characterize the neighborhood of a reference tree by its using n-nearest neighbors. The techniques of nearest neighbor statistics allow us determining the relationship within neighborhood groups of trees such as species and size class at small scales (Nguyen et al., 2018). This method has several advantages over using expression frequency to describe the attributes among individuals when compared to the traditional methods (Pommerening, 2002). For instance, greater inhomogeneity in species and homogeneity in size classes indicate greater structural diversity (Gadow et al., 2012).

In this study, our overall goal is to characterize spatial attributes of neighborhood forest trees by applying the current techniques of nearest neighbor statistics. For a better understanding of structural units, we used bivariate distributions that combine pair structural units for each species in our analyses, such as mingling-uniform angle index, mingling-dominance and dominance-uniform angle index. We used two fully mapped 1-ha plots of all trees in two sites which are geographically contrasting conditions aiming to investigate spatial distribution of similarly abundant tree species and environmental effect on their demographics as well. We aimed to compare the spatial structure characteristics of two tropical evergreen forests in northern Vietnam based on the relationships with nearest neighbouring trees.

2. RESEARCH METHODOLOGY

2.1. Study site and data collection

The study was conducted at Babe National Park (NP), northern Vietnam, about 254 km north from Hanoi. Annually, mean temperature is 22^{0}C, mean rainfall of about 1378 mm, and mean humidity is about 83.3%. The weather in this region is strongly regulated by 500 ha surface water of the Babe natural lake which is surrounded by straight and dangerous cliffs of karst mountains.

Two plots were chosen in core zone of NP to get the least effect from human activity and other factors. The study site is classified as tropical evergreen lowland forest which is one of several sub-type rainforests here (RCFEE, 2011). Soil was yellow-brown ferralsol with thick layer and clay to sandy clay particle size classes (Hai et al., 2014).

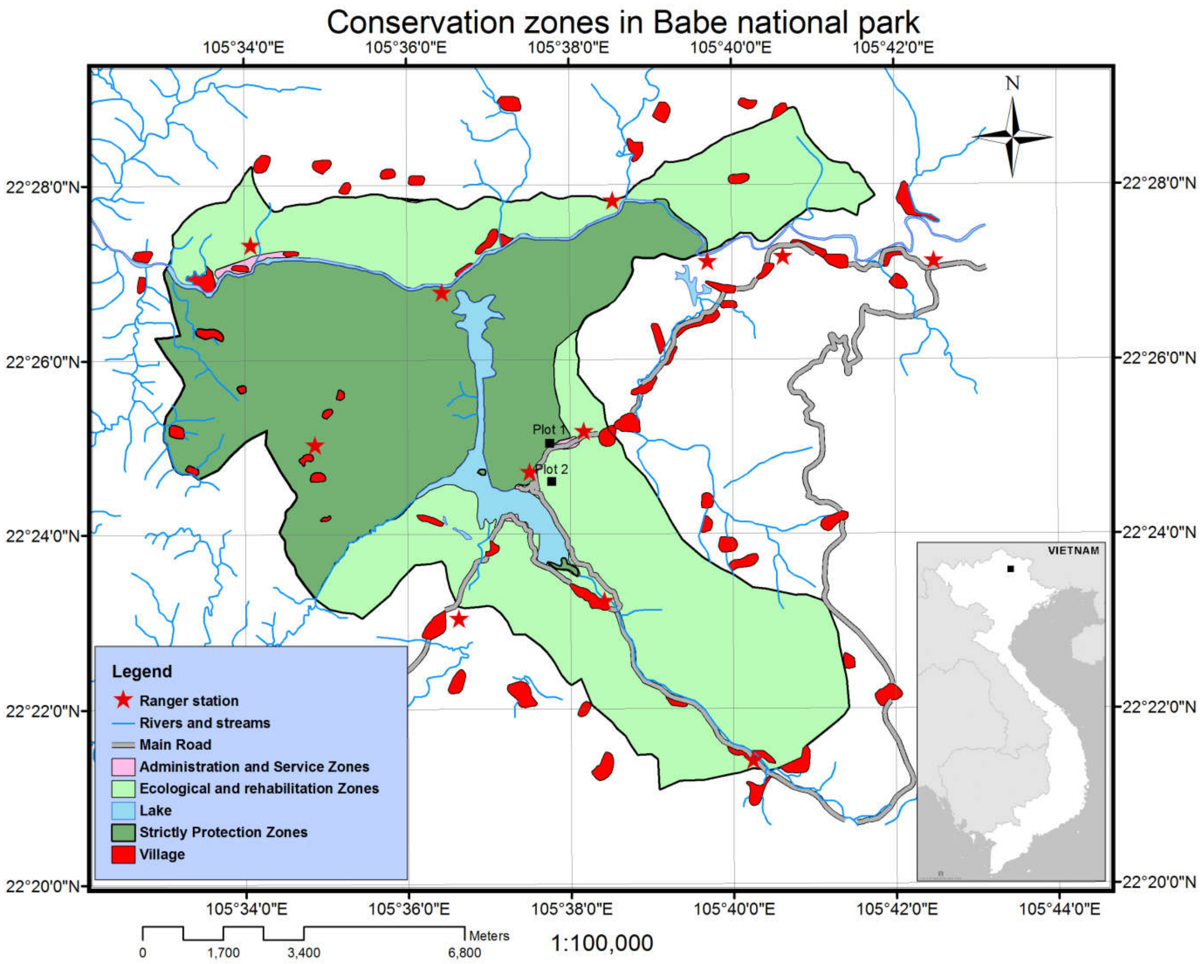

Fig. 1. Map of Babe NP and locations of study plots (Plot 1 and Plot 2)

Table. 1. Environmental characteristics of the two 1-ha forest plots designed in Babe NP

	Plot P1	Plot P2
Area (ha)	1 (100 x 100 m)	1 (100 x 100 m)
Coordinates	$22^0$24'567"N, $105^0$37'784" E	$22^0$25'053" N, $105^0$37'744" E
Elevation (m)	323	331
Average slope (^{0})	30	20
Slope facing	East	East
Rock outcrops	Little	Abundant
Position	Foot-hill	Side-hill

We selected two study sites based on geographical difference such as location (foothill and sidehill), rock outcrop (low and high abundance), and slope (table 1). In each site, 1-ha (100 m x 100 m) plot was established and subdivided into one hundred (10 m × 10 m) subplots. The diameter at breast height (dbh; at 1.3 m above the ground), tree coordinates (x,y) and tree species were recorded for all woody plants with dbh ≥ 2.5 cm in each subplot. Stem-mapping of individuals was done using a laser distance measurement (Leica Disto D5) and compass. Tree name was classified on field or identified in the herbarium of the NP.

2.2. Data analysis

We applied current techniques of nearest neighbor statistics which are based on the assumption that the spatial structure of a forest stand determined by the distribution of specific structural relationships within neighborhood groups of trees. A forest stand is composed by neighborhood structural units of n-trees. We used three structural indices proposed by Gadow and Hui (2002) such as species mingling, dominance and uniform angle index to describe homogeneity or heterogeneity of trees through a variety of species, diameter classes and spatial arrangements with equations from 1 - 3 (Gadow et al., 1998, Aguirre et al., 2003, Hui et al., 2011, Pommerening et al., 2011)

Species mingling (M): depicts the species composition and spatial pattern of forest trees. It is defined as the proportion of the n nearest neighbours that are different species from the reference tree (Fig. 2a).

$$M_i = \frac{1}{4}\sum_{j=1}^{4} v_j \qquad (1)$$

v_j = 1 if neighbor j is not the same species as reference tree i, otherwise v_j = 0.

Dominance (U): depicts the size differentiation between a reference tree and its four nearest neighbors. It is defined as the proportion of n nearest neighbors that are smaller than reference tree (Fig. 2b).

$$U_i = \frac{1}{4}\sum_{j=1}^{4} v_j \qquad (2)$$

v_j = 0 if neighbor j is smaller than reference tree i, otherwise v_j = 1.

Uniform angle index (W): depicts the degree of regularity for the four nearest neighbors as reference tree. It is defined as the proportion of angle (α) smaller than the standard angle α_0 (Fig. 2c).

$$W = \frac{1}{4}\sum_{j=1}^{4} w_j \qquad (3)$$

W_i = 1 if $\alpha_j < \alpha_0$, otherwise W_i = 0, α_0= 360°/(n+1).

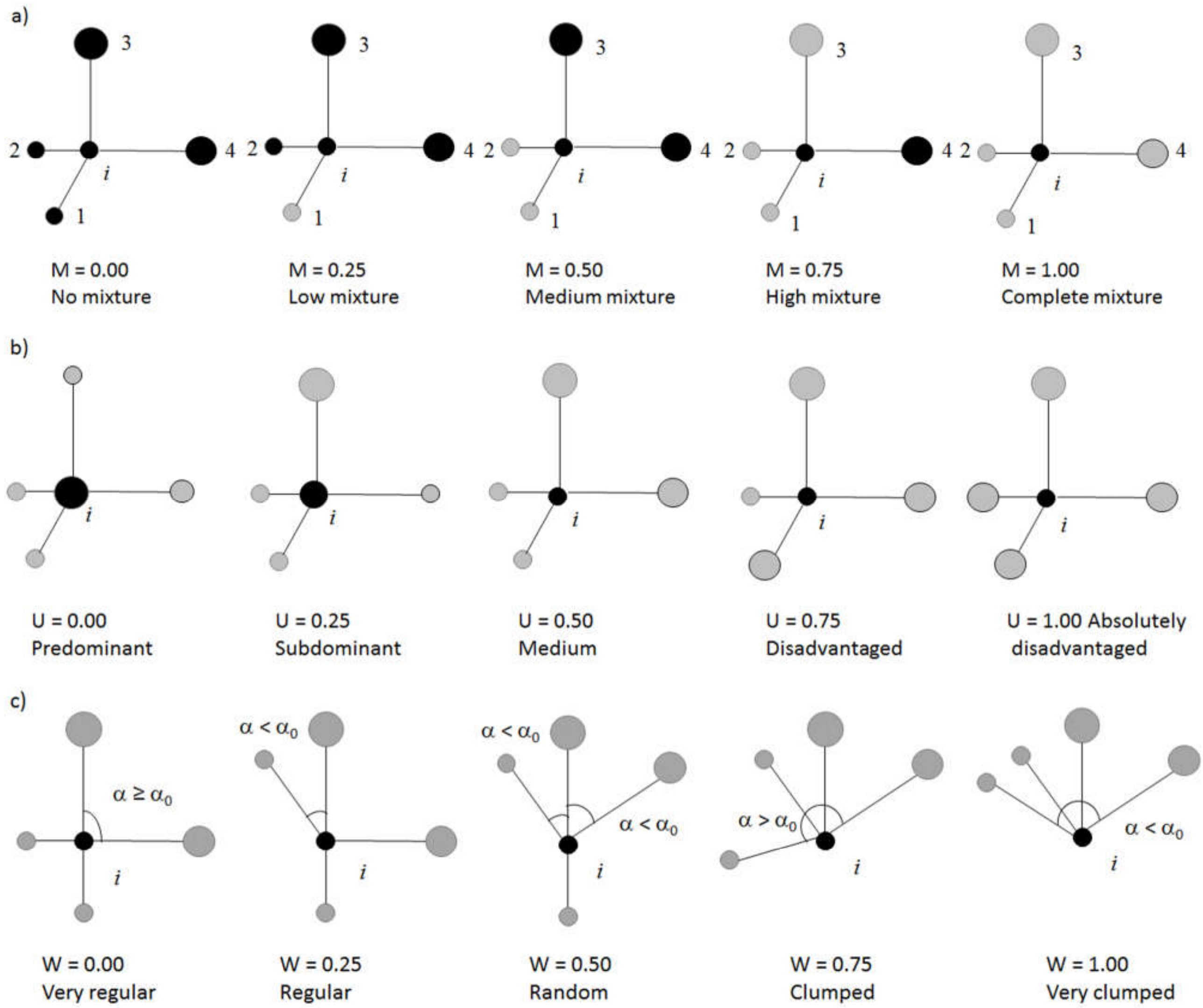

Fig. 2. Definition of the spatial parameters: Mingling (a), Dominance (b) and Uniform Angle Index (c)

The methods described above were implemented by using softwares Crancord (http://www.pommerening.org/wiki/index.php?title=CRANCOD_-_A_Program_for_the_Analysis_and_Reconstruction_of_Spatial_Forest_Structure).

To eliminate the edge effect of the estimates in M_i, W_i and U_i calculation, we applied the nearest neighbor edge correction method proposed by Pommerening and Stoyan (2006).

3. RESULTS

We aimed to explorer nearest neighbour characteristics of the five most abundant tree species in each plot (having ≥ 50 individuals) under environmental heterogeneity (Hai et al., 2014). Four in five species were similar: *Diospyros sylvatica* (Ebenaceae); *Burretiodendron hsienmu* (Tiliaceae); *Hydnocarpus kurrzii* (Flacourtiaceae); *Syzygium wightianum* (Myrtaceae); and two different species were *Taxotrophis ilicifolia* and *Streblus macrophyllus* (Moraceae) in both study plots. Shade tolerant species are *T. ilicifolia* and *S. macrophyllus* which develop well on thick and humid soil layer while *H. kurrzi*, *B. hsienmu*, *S. wightianum* are shade intolerant species (FIPI, 1996).

In total, 1475 individuals belonging to 17 species and 1762 individuals of 26 species were recorded in P1 and P2, respectively (Table 2). Tree species seem growth better in P1 than P2 with lower densities but covering higher basal area such as *D. sylvatica*, *H. kurzii*, *S. wightianum* and *B. hsienmu*.

Table 2. Characteristics of tree species in the two study plot

Species	Family	Density (N/ha)	Basal area (m^2/ha)	Mean M	Mean U	Mean W
Plot P1		1475	34.71			
D. sylvatica	Ebenaceae	414	4.62	0.51	0.42	0.49
T. ilicifolia	Flacourtiaceae	316	1.93	0.38	0.37	0.50
H. kurzii	Flacourtiaceae	246	10.81	0.78	0.66	0.48
S. wightianum	Myrtaceae	193	4.51	0.81	0.60	0.51
B. hsienmu	Tiliaceae	53	6.41	0.91	0.90	0.49
12 other species		253				
Plot P2		1762	29.31			
D. sylvatica	Ebenaceae	461	3.56	0.51	0.37	0.51
S. macrophyllus	Moraceae	397	4.13	0.40	0.48	0.49
S. wightianum	Myrtaceae	219	1.98	0.80	0.47	0.51
H. kurzii	Flacourtiaceae	146	2.23	0.81	0.48	0.50
B. hsienmu	Tiliaceae	101	5.91	0.79	0.69	0.49
21 other species		438				

M-W bivariate distributions

The M-W index models (Figure 3) showed that M values concentrated and increased from 0.5 - 1 while W indices ranged from 0.25 - 0.75 for most of species in P1 and P2. The highest frequency of these species were M index = 1 and W index = 0.5. That means reference species were highly mixed with other species in all four neighbours and these dominant species had regular to aggregated, but mainly random distribution patterns (Figure 3.a, c-e, h-j). Three species showing low mixture with other species were *T. ilicifolia* (Figure 3b), *D. sylvatica* (Figure 3f) and *S. macrophyllus* (Figure 3g) illustrating by M indices from 0 to 0.75.

M-U bivariate distributions

The M-U bivariate models showed different distribution patterns of most abundant tree species in both plots. *D. sylvatica* (Figure 4a, f), *T. ilicifolia* (Figure 4b) and *S. macrophyllus* (Figure 4g) were evenly distributed at each grade of M and U from 0-1, meaning that they were from low to high mixture with other neighbour species and from low to high diameter dominance. *H. kurzii* (Figure 4c) and *S. wightianum* (Figure 4d), and *B. hsienmu* (Figure 4e) were concentrated at maximum values of M = 1 and U = 1 showing that they were completely mixed and dominated with nearest neighbours. *S. wightianum* (Figure 4h) and *H. kurzii* (Figure 4i) showed increasing values of M from 0 - 1 while U indices were evenly distributed from 0 - 1. These patterns mean that they distributed from low to high mixture and dominated also from low to high levels with neighbourhood species.

W-U bivariate distributions

The W-U models showed two groups of frequency distribution (Figure 5). The first type was W values concentrated from 0.25 - 0.75 and U values ranged evenly from 0-1 containg *D. sylvatica* (Figure 5a, f), *T. ilicifolia* (Figure 5b), *S. macrophyllus* (Figure 5g), *S. wightianum* (Figure 5d, h), *H. kurzii* (Figure 5i). The bivariate patterns showed that those species distributed from regularity to aggregation and dbh dominance ranged from low to high with nearest neighbours. The second group, containing *H. kurzii* (Figure 5c) and *B. hsienmu* (Figure 5e, j), showed a similar spatial distribution pattern but strong dbh dominance to neighbours (U = 0.5 - 1).

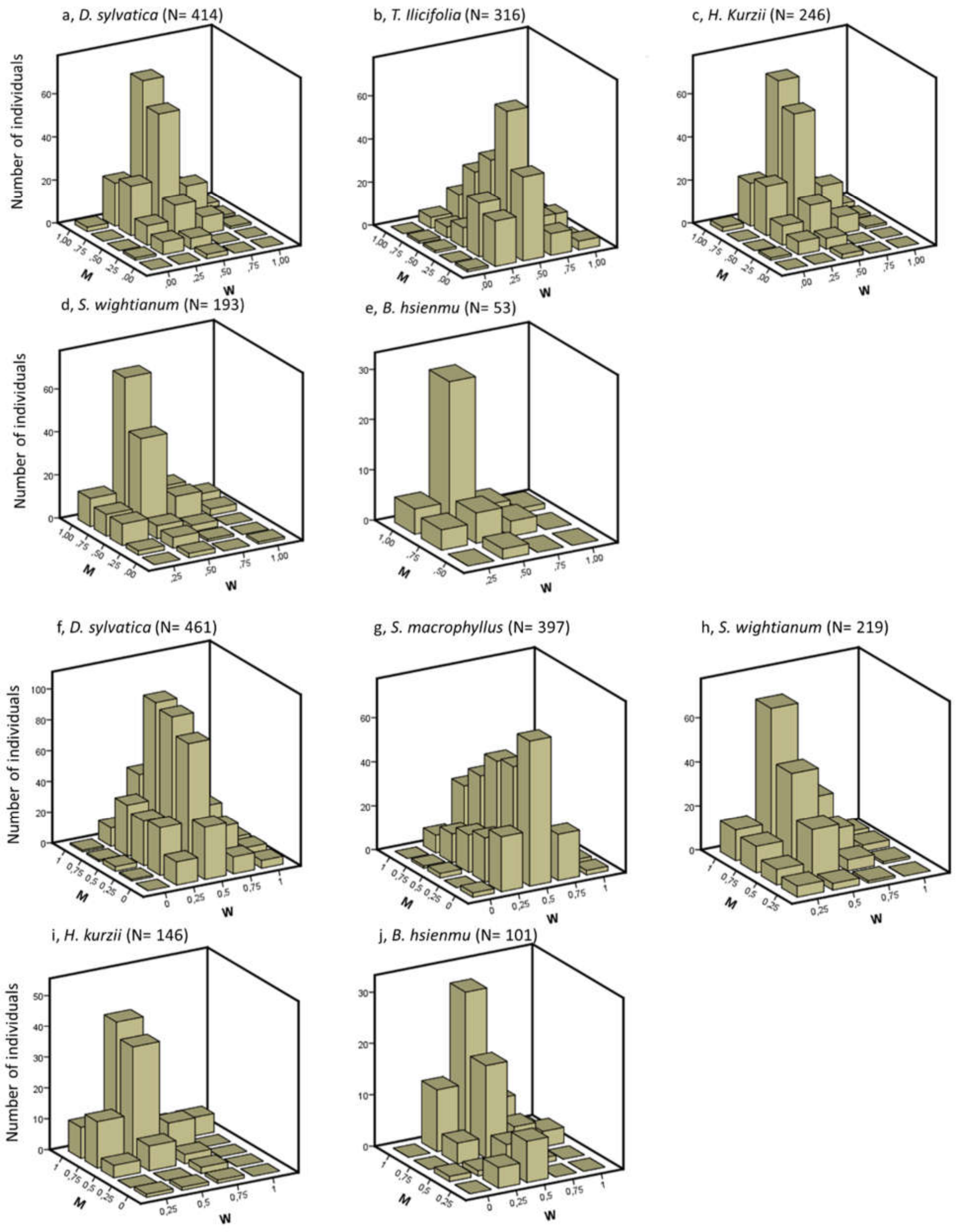

Fig. 3. Bivariate distributions of Mingling (M) vs. Uniform Angle Index (W) for the most abundant species in P1 and P2. N- Number of species individuals

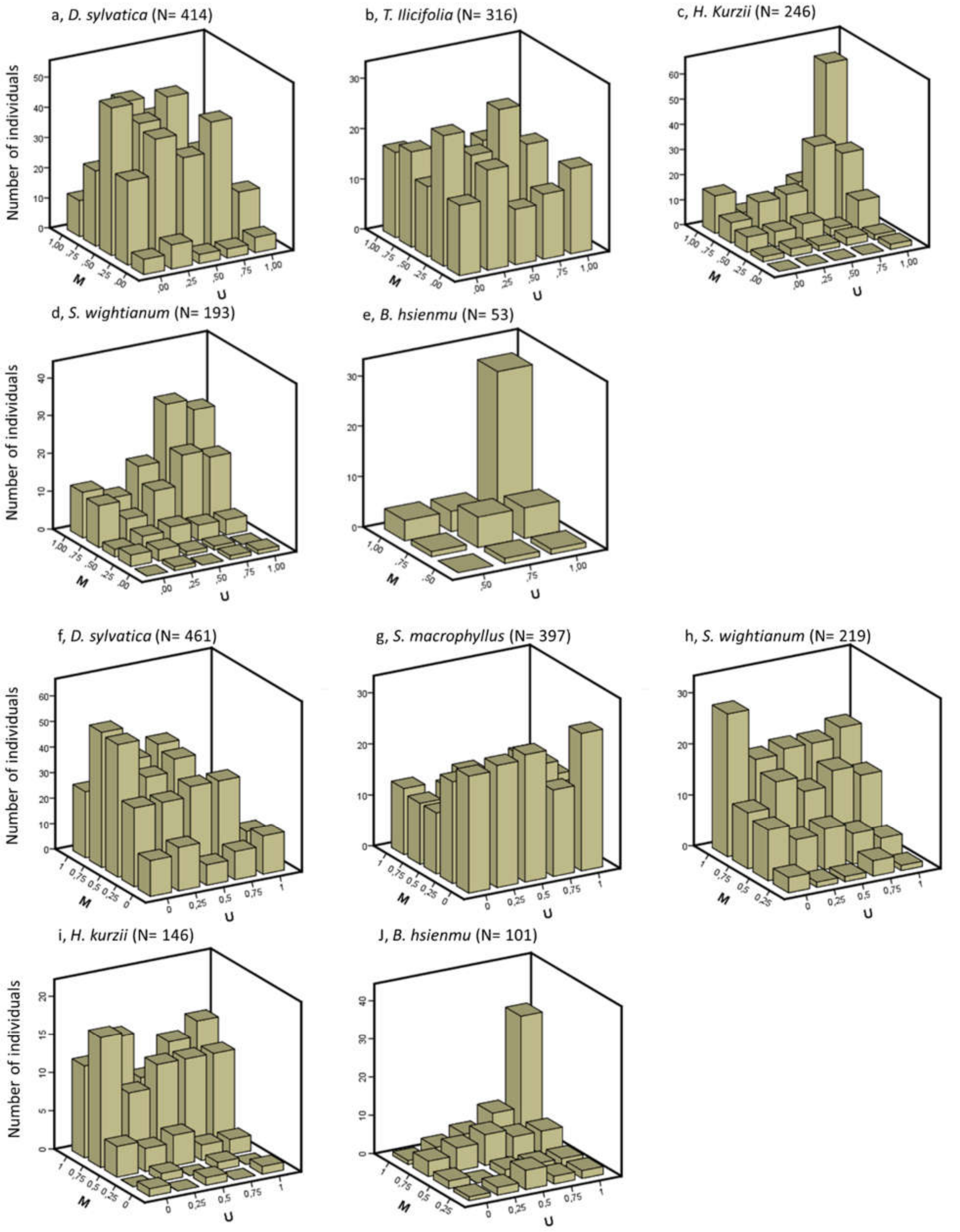

Fig. 4. Bivariate distributions of Mingling (M) vs. Dbh dominance (U) for the most abundant species in P1 and P2. N- Number of species individuals

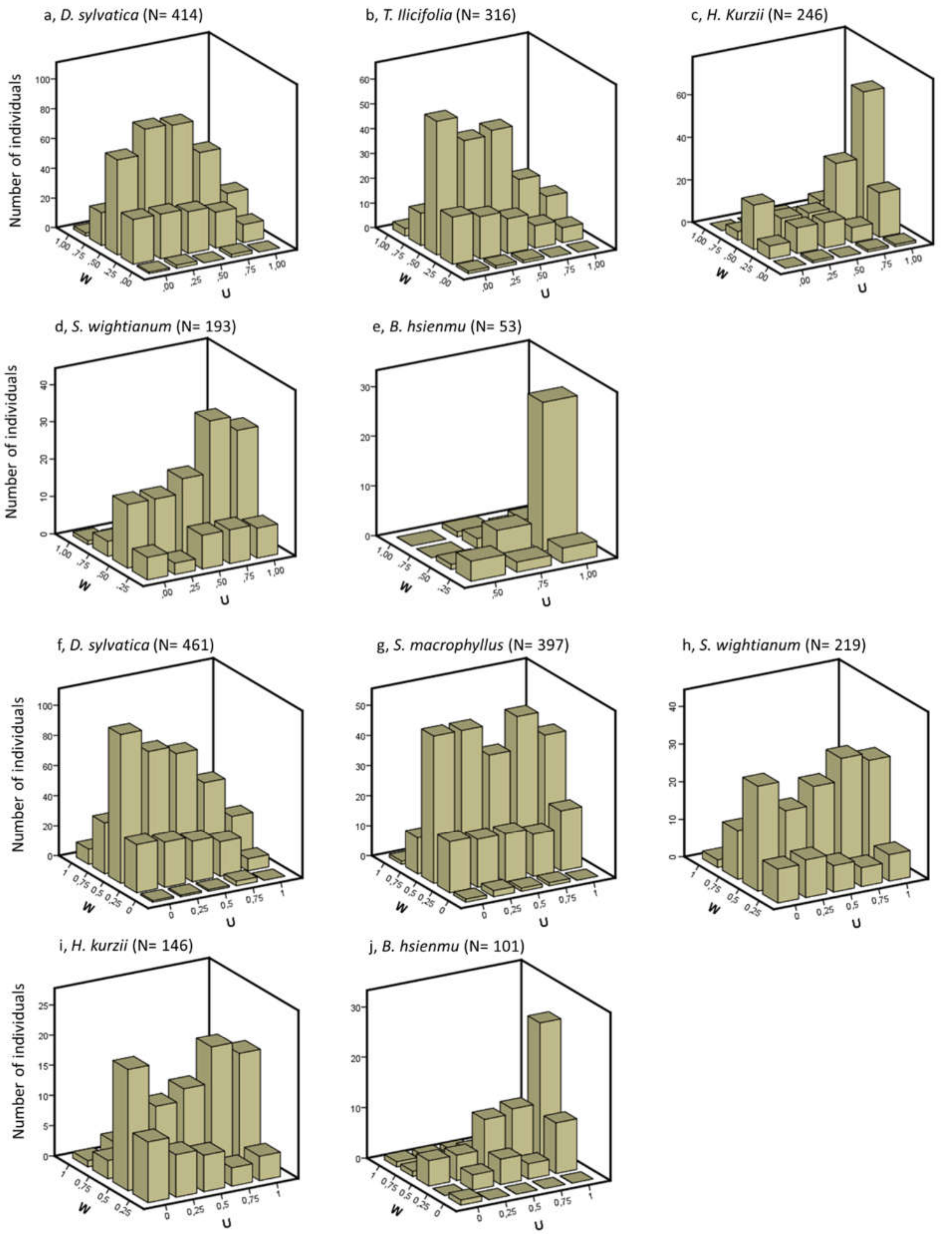

Fig. 5. Bivariate distributions of Uniform Angle Index (W) vs. Dbh dominance (U) for the most abundant species in P1 and P2. N- Number of species individuals

4. DISCUSSION

The relationship between tree individuals and their nearest neighbors is considered to be highly potential to elucidate interactions for limited environmental resources, the mutual dependence and species coexistence (Gadow et al., 1998). In this study, the structural parameters such as Mingling, Uniform Angle Index and Dbh dominance were used to explorer species association between each specific individual and its four nearest neighboring trees though the relationship between mixture, size differentiation and distribution pattern.

The results showed evidences that most of studied species were found highly mixed with other species and distributed from regularity to aggregation. These finding may be a reflection of dispersal limitation and competitive interaction of tree species these forest communities. In species-rich communities, two individual of the same species may share only a few common species among their nearest neighbors Hubbell and Foster (1986). High diversity species meaning high mixture may also involve neutral theory (Hubbell, 2006) in which functionally similar species may produce ecological equivalence, reduce interspecific competition and therefore facilitate more diversity species in their neighbourhood.

Aggregated distribution of tree species is a common pattern in tropical forest, especially in high tree species diversity forests (Wright, 2002), which is mainly resulted from dispersal limitation and habitat heterogeneity. Using spatial point pattern analysis, Hai et al. (2014) found aggregated distribution of most abundant species in these forest communities at different spatial scales and evidences of self-thinning which are consistent with the Janzen-Connell hypothesis. Regular distribution pattern can be resulted by interspecific competition between tree species making greater distance between interspecific individuals and related to self-thinning process where number of saplings are decreased as average tree size increases over time, consequently increasing chance to replace by other species.

In combination with DBH dominance analysis, most of dominant tree species showed from low to high diameter dominance, especially *H. kurzii*, *S. wightianum* and *B. hsienmu* were concentrated at maximum values of M = 1 and U = 1 that means they were completely mixed and dominated with nearest neighbours. High diameter dominance showed strongly competitive interaction for light and nutrient resources. That is also an agreement with their ecological characteristics as shade intolerant species such as *H. kurzii*, *B. hsienmu* and *S. wightianum*. These evidences were supported by findings from (Hai et al., 2014) where positive species association was frequently in P1 while negative association was observed in P2.

The important practical advantage of this approach is that stand spatial attributes can be determined simply by evaluating the immediate neighbourhoods of a given number of reference trees. This method does not require to conduct a comprehensive survey based on the tree structure unit (Zhang et al., 2018), therefore it can save much time and effort. Consequently, management strategies, such as thinning or conservation for high priority species, can be based on considering spatial attributes (size, species and distribution pattern) of each tree, allowing comparison of spatial structure between actual and ideal stand distributions. For example, according to the frequency distribution, forest development can be promoted by adjusted community structure toward less dominance, more random pattern and more mixture of tree species.

5. CONCLUSION

Similar distribution patters of the most abundant tree species showed that no significant effect of environmental habitat heterogeneity was detected at local scales. Ecological processes such as dispersal limitation and neutral theory were assumed regulating spatial distribution of tree species in these forest stands. Nearest neighbour approach seems to be advantageous in terms of saving time and cost for studying spatial structure of forest community.

Conflicts of Interest: The authors declare no conflict of interest.

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PHÂN TÍCH ĐẶC ĐIỂM CẤU TRÚC KHÔNG GIAN CỦA RỪNG NHIỆT ĐỚI THƯỜNG XANH TRONG ĐIỀU KIỆN MÔI TRƯỜNG SỐNG KHÔNG ĐỒNG NHẤT

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TÓM TẮT

Cấu trúc phức tạp và đa dạng loài lân cận của rừng nhiệt đới có thể được mô tả bởi đặc điểm của cây lân cận. Với mục đích mô tả phân bố không gian, hỗn loài và ưu thế của các loài trong phạm vi hẹp, chúng tôi áp dụng các phân tích định lượng dựa vào quan hệ của các cây lân cận. Trong hai ô tiêu chuẩn 1-ha của rừng thường xanh ở Vườn quốc gia Ba Bể, phía Bắc Việt Nam, tất cả các cây gỗ có đường kính ngang ngực – DBH 2,5 cm được định vị và đo đếm (DBH và tên loài). Các kết quả phân tích cho thấy: hầu hết các loài cây được nghiên cứu đều trộn lẫn cao với các loài khác, trong khi phân bố không gian cùng loài là kiểu đều đến cụm nhưng chủ yếu là dạng ngẫu nhiên ở phạm vi hẹp. Thứ bậc của ưu thế đường kính từ thấp đến cao ngoại trừ các loài cây *H. kurzii*, *S. wightianum* và *B. hsienmu* là có ưu thế trội hoàn toàn với các loài cây khác lân cận chúng. Chúng tôi cho rằng các quá trình sinh thái chính như phát tán hạn chế và lý thuyết trung lập đã điều chỉnh cấu trúc không gian của các lâm phần này. Cung cấp các thông tin trực tiếp và giá trị về cấu trúc không gian của các lâm phần được coi là các ưu điểm của cách tiếp cận này. Các thông tin trên có thể được sử dụng trong biện pháp tỉa thưa của quản lý rừng bền vững, mô hình hóa và phục hồi rừng.

Từ khóa: Cây lân cận, chỉ số đồng góc, rừng thường xanh, trộn lẫn, ưu thế,

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