NEAREST NEIGHBOR PATTERNS OF DOMINANT TREE SPECIES IN TROPICAL FORESTS, PHOU KHAO KHOUAY NATIONAL PARK, LAOS

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ABSTRACT

Target-tree management is a silviculture technique that aims to achieve sustainable forest management by considering the spatial structure of forests. In this study, a new quantitative method was used to analyze the spatial structure of natural forest stands in the Phou Khao Khouay national park in Laos. The method involved mapping and measuring all individual trees with a diameter at breast height (DBH) greater than or equal to 5 cm in 32 permanent plots of 50 m × 50 m. The analysis focused on four spatial structural parameters: uniform angle index, species mingling, height dominance, and crowding. The results showed that (1) the dominant species in the three forest types had a species mingling degree ranging from medium to complete mixture; (2) the target trees were found to have a dominant height compared to their nearest neighbors; (3) the distribution patterns of trees in the stands varied from regular to clumped; and (4) the crowding index indicated a distribution density of trees from sparse to dense. Dispersal limitation and competition among neighboring trees were the main mechanisms driving the forest's spatial structure in the study area. The findings of the present study provide valuable information for proposing silvicultural measures that promote sustainable forest management in Phou Khao Khouay National Park. By understanding the spatial structure of forests, target-tree management can be used to improve forest health, increase biodiversity, and enhance the ecosystem services provided by forests.

Keywords: Crancord software, crowding index, dominant species, target tree, uniform angle index.

1. INTRODUCTION

Understanding ecological mechanisms and underlying processes that influence species assemblages is critical to getting deep insights into species associations and community structure. Analyzing the spatial patterns of species is therefore of primary interest in community ecology to figure out the underlying mechanisms and test different ecological theories [1, 2]. Several processes-such as competition or facilitation, dispersal limitation, habitat preference, and the Janzen-Connell hypothesis-have been proposed for explaining community structure.

At present, there are several methods available to describe and compare forest spatial structure, including classic methods, nearest neighbor analysis methods, point pattern analysis, and marked second-order characteristics methods [3-7]. These methods have been widely applied in forestry and ecology. The spatial structure of a forest refers to the spatial relationships among different individuals within the same community. The spatial structure is determined by using tree positions and their attributes and provides a more detailed description of a forest [8]. The spatial structure has advantages compared to the non-spatial structure as it provides detailed descriptions and largely determines competition and niches among trees, as well as reflects the health status, growth potential, and stability of the stands [9].

The nearest neighbor analysis method has been used to analyze forest spatial structure, dominance, and species composition [10]. The assessment techniques include structural parameters that reflect the nearest-neighbor relationships between a target tree and its four nearest neighbors [11]. These parameters have many applications, such as analyzing spatial structure and composition, identifying dominance and species diversity, adjusting structure, and guiding good forestry practices [8]. The spatial structure parameter consists of four indices: the uniform angle index (W), mingling (M), dominant (U), and crowding (C) [12]. The W index reflects the degree of spatial distribution regularity; M measures the similarity probability of tree species; U indicates the relationships of tree size; and C

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measures the degree of crowding of the neighbors surrounding the target tree. Nearest neighbor statistics techniques allow for determining the relationships within groups of trees in terms of species diversity and size class at small scales [13].

The objective of this study is to analyze the spatial characteristics of trees using nearest-neighbor statistical techniques. The data was collected from three forest types, including dry evergreen forest, mixed deciduous forest, and mixed coniferous forest, in Phou Khao Khouay National Park, Laos. Four main questions have been raised: (1) How are the spatial distribution patterns of what or where? (2) How are tree species compositions in space? (3) Can tree size dominance show the competition among tree species? (4) Do individual trees adjust nutrient space via the crowding index of different species in these forest types?

2. RESEARCH METHODOLOGY

2.1. Study area

This study was conducted in Phou Khao Khouay (PKK) National Park, Laos. PKK national park has a total area of 191,942 ha [14] and is located between 18°14'–18°32' N and 102°38'–102°59' E (Fig. 1). Forest types in the study area were classified as dry evergreen forest (DEF), mainly by the Dipterocarpaceae family, mixed deciduous forest (MDF), mainly by the Fabaceae, and mixed coniferous forest (MCF), mainly by the Pinaceae [15].

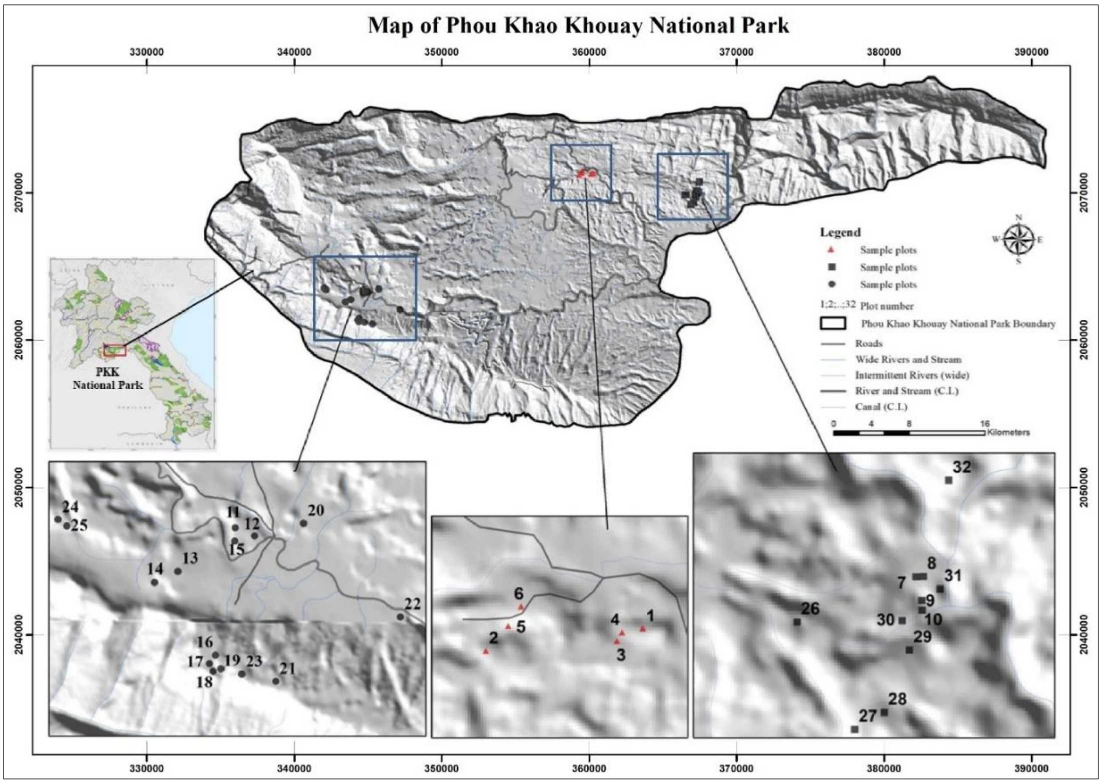

Figure 1. Maps of the study region and locations of the study plots

The elevation of the study area varies from 100 m to nearly 1,700 m above sea level. The national park is covered by typical tropical red to brown soils of organic acrisols and lithosols with textures ranging from sandy to sandy loam and poorly organic matter [15]. The average annual rainfall in PKK is about 1,769 mm and is divided into two seasons. The rainy season is from April to October, with the highest rainfall usually in August of about 494.2 mm, and the average temperature is from 16.6°C to 31.8°C. The dry season is from November to March, with the lowest rainfall of about 2.5 mm in February, and the average temperature is from 16.8°C to 24.6°C [16].

2.2. Data collection

Data was collected in permanent plots established by the Institut Recherche Pour le

Development (IRD) in France and the Faculty of Forestry Science (FFS) at the National University of Laos (NUoL) in 2009 [15, 17]. The first and second sites were located in Thaphabat district, Bolikhamxay province, with the former site called Tad Leuk containing six plots at an elevation of 569 m (Fig. 1) and the latter site named Tad Xay containing 11 sample plots at an elevation of 390 m. The third site was located in Thoulakhom district, Vientiane province, near Vang Heua village, with 15 plots at an elevation of 816m (Lucas et al., 2013). In total, there were 32 plots, each of 2500 m^2 (50 m × 50 m) and divided into 25 subplots of 10 m × 10 m.

Individuals with a diameter at breast height (DBH) greater than or equal to 5 cm were labeled, identified, and measured by using a diameter tape. The tree height was measured using a Blumme-Leiss hypsometer, while the tree coordinates and crown diameter were measured using a laser distance measurer (Leica Disto D2) within the subplots. Specimens were collected and sent to the herbarium of the Faculty of Forestry Science (FFS), National University of Laos (NUoL), for species identification confirmation.

2.3. Data analysis

Stand structural parameters were based on neighborhood relationships; current techniques of nearest neighbor statistics were applied based on the assumption that the spatial structure of a forest stand is determined by the distribution of specific structural relationships within neighborhood groups of trees. A forest stand is composed of neighboring structural units of an n-tree. We used four structural indices proposed by [8, 18-21], such as species mingling, dominance, crowding, and the uniform angle index, to describe the homogeneity or heterogeneity of a tree through a variety of species, diameter classes, and spatial arrangements.

The mingling index (M) refers to both the spatial arrangement and composition of trees in a forest. This index measures the ratio of non-identical species present among the four nearest neighbors of a reference tree (as shown in Fig. 2):

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

where, $v_{ij} = 1$ if the j^{th} neighboring tree is not the same species as the i^{th} reference tree, and $v_{ij} = 0$ otherwise.

The uniform angle index (W) measures the regularity of the four closest neighbors to the reference tree. To determine W, the proportion of angles (α) less than the standard angle α_o (72°) (as shown in Figure 2) is computed using the following formula:

$$W_i = \frac{1}{4}\sum_{j=1}^{4} z_{ij} \qquad (2)$$

where, $z_{ij} = 1$ if $\alpha < \alpha_o$, and $z_{ij} = 0$ otherwise.

The crowding index (C) reflects the relationship between the canopy of the reference tree and its four nearest neighbors and can be expressed (Fig. 2) as follows:

$$C_i = \frac{1}{4}\sum_{j=1}^{4} y_{ij} \qquad (3)$$

where, $y_{ij} = 1$ if the canopy projection of the jth neighboring tree overlaps that of the ith reference tree, and $y_{ij} = 0$ otherwise. The C index reflects not only the degree of crowding of trees and their four nearest neighbors with competition but also whether the forest canopy layer covers the woodland continuously. The greater the cumulative value of C, the higher the stand density and the more continuous the coverage of the canopy.

The dominance index for height (U) refers to the degree of variation in size between a given tree and its four closest neighboring trees. This index is determined by calculating the proportion of the four nearest neighbors that have a smaller height than the reference tree (as illustrated in Figure 2):

$$U_i = \frac{1}{4}\sum_{j=1}^{4} k_{ij} \qquad (4)$$

where, $k_{ij} = 1$ if the jth neighboring tree is smaller than the i^{th} reference tree, and $k_{ij} = 0$ otherwise.

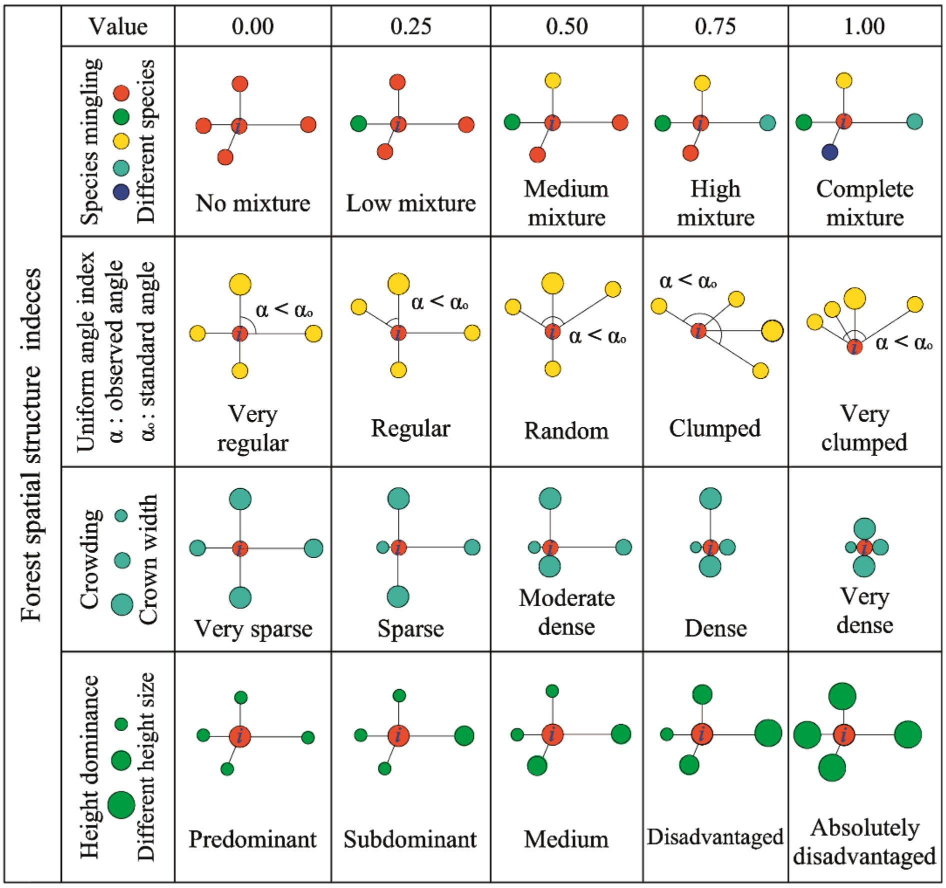

Figure 2. Definition of the spatial indices: species mingling (M), uniform angle index (W), crowding (C), and dominance (U)

The stand structural parameters of the ten most dominant tree species were selected for structural analysis of these communities. The methods described above were implemented using the software Crancord (*http://crancord.org*). To eliminate the edge effect of the estimate, we used four structural indices such as Mingling - M_i, Uniform angle index - W_i, Crowding - C_i, and Dominance - U_i, and we applied the nearest neighbor edge correction method proposed by [22].

3. RESULTS

3.1. Forest stand properties

The survey recorded a total of 5,477 individuals of 188 tree species from 57 families across three forest types (Table 1). In the dry evergreen forest (DEF), 138 tree species from 52 families were identified, with 10 dominant species accounting for 45.76% of tree abundance and an IVI coverage of 38.39%. The other 128 species contributed 54.24% of tree abundance and had an IVI coverage of 61.61%. The density of trees in the DEF was 705.11±9.14 trees ha^{-1}, with a DBH mean of 19.07±14.33 cm. In the mixed deciduous forest (MDF), a total of 1,509 individuals of 126 species from 51 families were identified, with 10 dominant species accounting for 33.73% of tree abundance and an IVI coverage of 31.10%. The remaining 116 species contributed 66.27% of tree abundance and had an IVI coverage of 68.90%. The density of trees in the MDF was 754.50±7.18 trees ha^{-1}, with a DBH mean of 17.86±11.31 cm. In the mixed coniferous forest (MCF), a total of 795 individuals of 54 species from 36 families were identified, with 10 dominant species accounting for 68.81% of tree abundance and an IVI coverage of 62.74%. The other 44 species contributed 31.19% of tree abundance and had an IVI coverage of 37.26%. The density of trees in the MCF was 530.00±16.7 trees ha^{-1}, with a DBH mean of 20.34±14.20 cm.

Table 1. Characteristics of tree species in the three forest types

Forest type	Dominant species	Code	Density	IVI (%)
Dry evergreen forest	*Hopea pierrei*	HOPE	278	10.92
	Hydnocarpus ilicifolia	HYDN	213	4.65
	Alphonsea gaudichaudiana	ALPH	178	3.87
	Cratoxylum formosum	CRAT	170	2.75
	Aporasa planchoniana	APOR	147	2.37
	Schima wallichii	SCHI	129	2.70
	Gironniera nervosa	GIRO	114	3.15
	Syzygium syzygioides	SYZY	95	3.19
	Nephelium hypoleucum	NEPH	83	2.21
	Xanthophyllum lanceatum	XANT	45	2.58
	128 other species	DEF	1,721	61.61
Mixed deciduous forest	*Aglaia grandis*	AGLA	61	4.92
	Lithocarpus fenestratus	LITH	87	4.43
	Xanthophyllum lanceatum	XANT	24	3.54
	Syzygium cinereum	SYZYG	49	2.91
	Schima wallichii	SCHI	60	2.83
	Gironniera nervosa	GIRO	48	2.71
	Vatica harmandiana	VATI	29	2.46
	Lagerstroemia calyculata	LAGE	62	2.46
	Elaeocarpus tectorius	ELAE	42	2.43
	Alphonsea gaudichaudiana	ALPH	47	2.41
	116 other species	MDF	1,000	68.90
Mixed coniferous forest	*Pinus merkusii*	PINU	123	20.02
	Dacrydium elatum	DARC	96	7.80
	Schima wallichii	SCHI	77	8.28
	Dipterocarpus obtusifolius	DIPT	75	7.75
	Syzygium cinereum	SYZYG	55	5.41
	Schima noronhae	SCHIN	52	4.41
	Lithocarpus fenestratus	LITH	24	3.09
	Garcinia multiflora	GARC	18	2.11
	Parinari anamensis	PARI	16	2.09
	Syzygium lineatum	SYXYL	11	1.78
	44 other species	MCF	248	37.26

3.2. Spatial structural characteristics of three forest types

3.2.1. Dry evergreen forest (DEF)

Overall, 138 DEF tree species showed a total of 87% high to complete mixture; height dominance presented 41% from predominance to sub-dominance and 39% disadvantage to absolute disadvantage (Fig. 3). In addition, these tree species distributed at random (56%), clumped to very clumped (27%), and very regular to regular (17%); their crowdings were mostly dense to very dense (50%) and very sparse to sparse (27%), with only 23% in moderately dense.

Most of the dominant tree species were highly (M = 0.75) to completely mixed (M = 1.0) with other species (Fig. 3), including *A. gaudichaudiana* (89%), *C. formosum* (74%), *A. planchoniana* (77%), *S. wallichii* (77%), *G. nervosa* (94%), *S. syzygioides* (99%), *N. hypoleucum* (96%), and *X. lanceatum* (96%). Only two tree species were in the lower mixture, with interspecific species containing *H. pierrei* (69%) and *H. ilicifolia* (67%).

The ten dominant tree species were balanced in dominance (U = 0.0–0.25) and disadvantage (U = 0.75–1.0) of tree height, such as *H. ilicifolia* (41 vs. 40%), *C. formosum* (36 vs. 41%), *A. planchoniana* (41 vs. 43%), *G. nervosa* (43 vs. 33%), *S. syzygioides* (40 vs. 35%), *N. hypoleucum* (40 vs. 34%), and *X. lanceatum* (43 vs. 38%) (Fig. 3). Two tree species were dominant to subdominant with neighboring species, including *H. pierrei* (55%), and *S. wallichii* (48%). In addition, only *A. gaudichaudiana* was disadvantaged compared to neighboring species (51%).

In relation to the spatial distribution (Fig. 3), all dominant tree species were clumped to very clumped (W = 0.75–1.0) with high frequency containing *H. pierrei* (62%), *H. ilicifolia* (46%), *A. gaudichaudiana* (44%), *C. formosum* (57%), *A. planchoniana* (48%), *S. wallichii* (64%), *G. nervosa* (46%), *S. syzygioides* (47%), *N. hypoleucum* (53%), and *X. lanceatum* (48%). In addition, those species were balanced from regular (W = 0-0.25) to random (W = 0.5) distributions.

Most of the dominant species are highly concentrated in the moderately dense (C = 0.5) zone of crowding, with frequencies ranging from 50 to 63% and a balance between sparce and dense with a lower percentage.

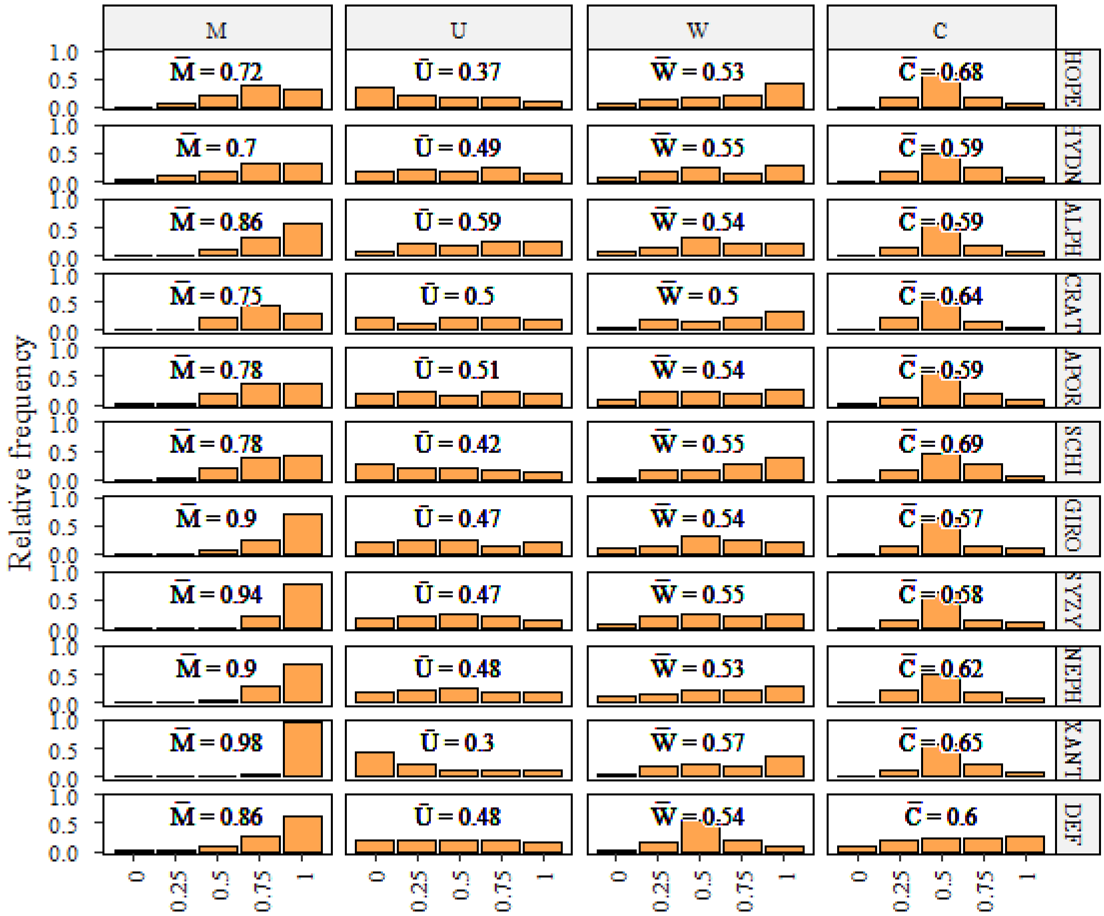

Figure 3. M-U-W-C distributions of tree species in DEF

3.2.2. Mixed deciduous forest (MDF)

In general, 126 tree species identified in MDF were mixed with neighboring species from high (M = 0.75) to complete mixture (M = 1.00 (90%); balanced between dominant (U = 0-0.25, 46%) and disadvantage (U = 0.75–1, 33%); 56% tree species were distributed in random distribution (W = 0.5); and 53% tree species were dense (C = 0.75) to very dense (C = 1.0) of crowding (Fig. 4).

Nine dominant tree species (Fig. 4), including *A. grandis* (96%), *L. fenestratus*

(100%), *X. lanceatum* (96%), *S. cinereum* (92%), *S. wallichii* (95%), *G. nervosa* (95%), *V. harmandiana* (86%), E. tectorius (100%), and A. gaudichaudiana (90%), were mixing from highly (M = 0.75) to completely mixed (M = 1.0) with other species. Only *L. calyculata* mixed in medium (M = 0.5, 32%) and high mixtures (M = 0.75–1.0, 53%) with interspecific species.

Eight dominant tree species dominated (U = 0-0.25) interspecific neibourgh trees with high frequency, containing *A. grandis* (48%), *L. fenestratus* (54%), *X. lanceatum* (75%), *S. cinereum* (43%), *S. wallichii* (50%), *G. nervosa* (50%), *V. harmandiana* (45%), and *L. calyculata* (47%) (Fig. 4). The two species were disadvantaged (U = 0.75) to absolutely disadvantaged (U = 1) with high frequency, including *E. tectorius* (41%), and *A. gaudichaudiana* (44%).

Nine dominant tree species are distributed from clumped (W = 0.75) to very clumped (W = 1.0) with high frequency, containing *A. grandis* (44%), *L. fenestratus* (61%), *X. lanceatum* (79%), *S. cinereum* (47%), *S. wallichii* (62%), *G. nervosa* (62%), *V. harmandiana* (62%), *E. tectorius* (67%), and *A. gaudichaudiana* (51%) (Fig. 4). Only *L. calyculata* distributed from very regular (W = 0) to regular (W = 0.25) with 40% frequency.

Regarding the crown width, all ten dominant tree species were moderately dense (C = 0.5) with high frequency, such as *A. grandis* (52%), *L. fenestratus* (54%), *X. lanceatum* (54%), *S. cinereum* (61%), *S. wallichii* (47%), *G. nervosa* (47%), *V. harmandiana* (52%), *L. calyculata* (55%), *E. tectorius* (62%), and *A. gaudichaudiana* (62%).

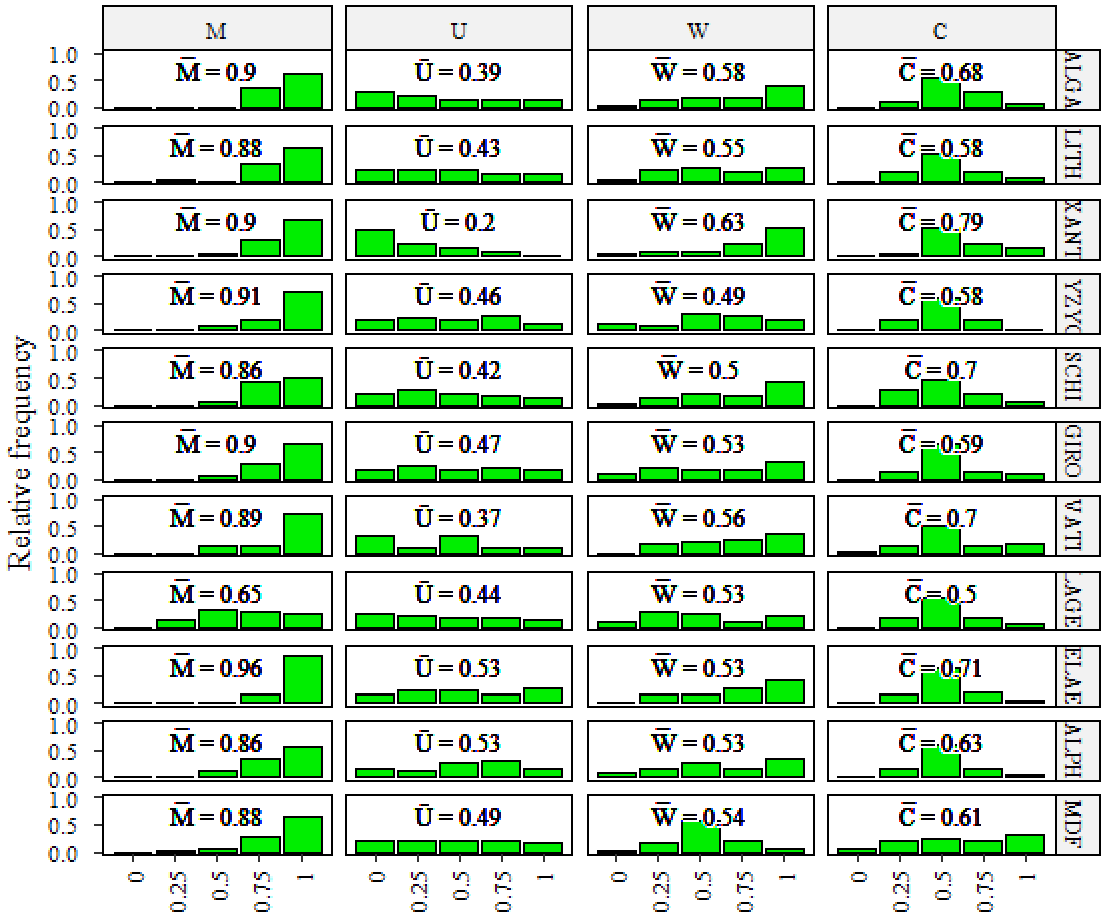

Figure 4. M-U-W-C distributions of tree species in MDF

3.2.3. Mixed coniferous forest (MCF)

Generally, 54 MCF tree species were mixed with neighbor species from high (M = 0.75) to complete mixture (M = 1.00 (71%)); dominanted neighbors from predominant (U = 0) to subdominant (U = 0.25) with 47% of frequency; 57% individuals distributed in random distribution (W = 0.5); and 43%

individuals were dense to very dense (C = 0.75–1.0) of crowding (Fig. 5).

High to complete mixtures (M = 0.75–1.0) with other species were revealed among nine abundant tree species (Fig. 5), including *P. merkusii* (76%), *S. wallichii* (69%), *D. obtusifolius* (70%), *S. cinereum* (78%), *S. noronhae* (77%), *L. fenestratus* (100%), *G. multiflora* (100%), *P. anamensis* (100%), and *S. lineatum* (100%). Only *D. elatum* was found in balance between the medium mixture (35%) and the high mixture (40%).

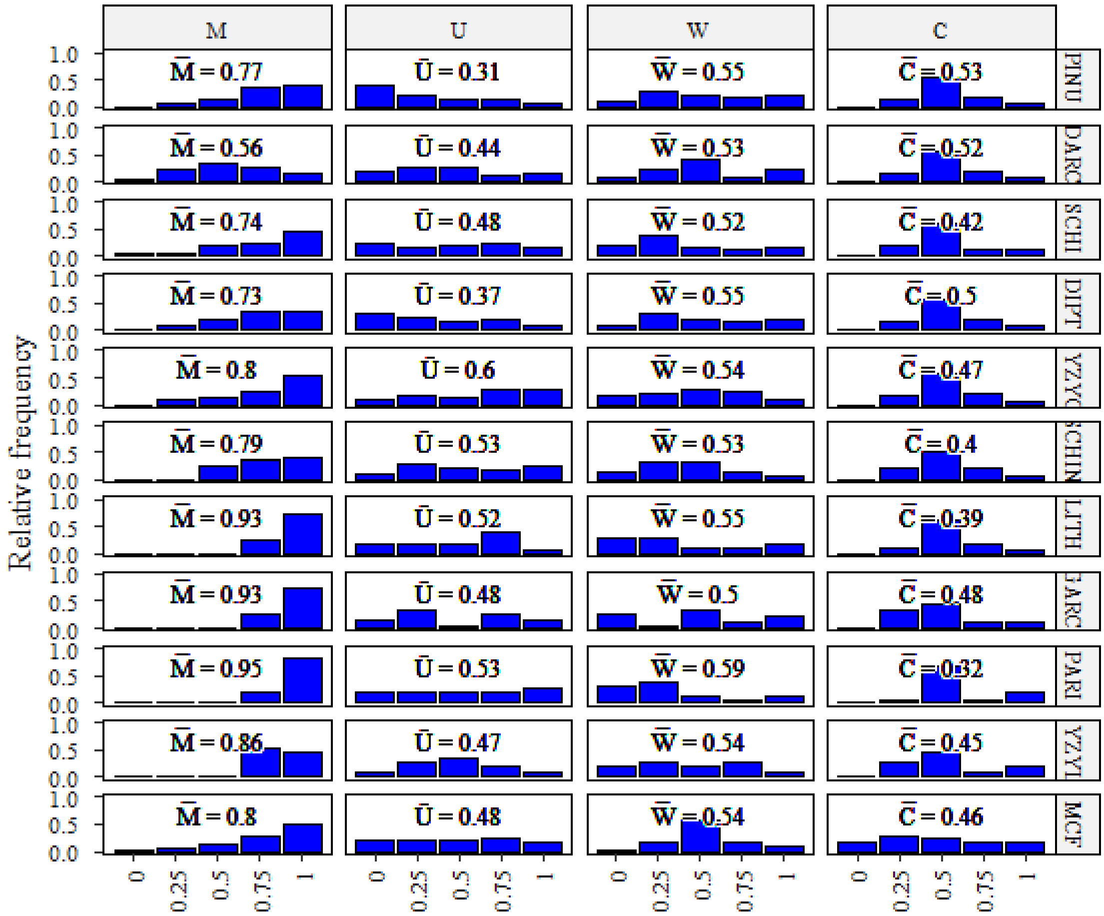

Figure 5. M-U-W-C distributions of tree species in MCF

Predominant to subdominant heights (U = 0 - 0.25) with neighbors were recorded in *P. merkusii* (63%), *D. elatum* (47%), *D. obtusifolius* (55%), and *G. multiflora* (50%), while the remaining species containing *S. wallichii* (41%), *S. cinereum* (56%), *S. noronhae* (41%), *L. fenestratus* (50%), *P. anamensis* (43%), and *S. lineatum* (28%) presented disadvantaged to completely disadvantaged heights.

All dominant species with high frequencies, including *P. merkusii* (39%), *D. elatum* (30%), *S. wallichii* (56%), *D. obtusifolius* (43%), *S. cinereum* (38%), *S. noronhae* (48%), *L. fenestratus* (58%), *G. multiflora* (33%), *P. anamensis* (69%), and *S. lineatum* (45%), indicated a very regular to regular (W = 0 - 0.25) spatial distribution. While clumped to very clumped (W = 0.75 - 1), spatial distributions were found at lower frequencies in species such as *P. merkusii* (41%), *D. obtusifolius* (36%), *S. cinereum* (35%), *G. multiflora* (34%), and *S. lineatum* (37%).

Crown width of all ten dominant tree species was measured at moderate density (C = 0.5) with high frequency, such as *P. merkusii* (56%), *D. elatum* (57%), *S. wallichii* (60%), *D. obtusifolius* (59%), *S. cinereum* (56%), *S. noronhae* (50%), *L. fenestratus* (63%), *G. multiflora* (44%), *P. anamensis* (67%), and *S. lineatum* (45%).

4. DISCUSSION

The relationship between individual trees and their nearest neighbors is considered to have high potential to elucidate interactions for limited environmental resources, mutual dependence, and species coexistence [4]. In this study, structural parameters such as mingling, uniform angle index, crowding, and height dominance were used to explore species associations between each specific individual and its four nearest neighbors in the three forest types consisting of dry evergreen forest, mixed deciduous forest, and mixed coniferous forest in Phou Khao Khouay national park, Laos.

The species mingling index of the forest types is above average, and most of their dominant species indicate a high to complete mixture (Figs. 3–5). The species mingling is affected by the species richness and abundance of the tree population [23]. A species population with low abundance always has heterospecific neighbors surrounding it, while species with high abundance usually show a low degree of mixing with other species. Moreover, species mingling is also affected by the tree distribution pattern [24]. With a random or regular distribution pattern, species with fewer individuals are more likely to be surrounded by heterospecifics, while the nearest neighbors of species with high abundance are more likely to be of the same species. With a clumped pattern, the probability that the nearest neighbors of a tree species will be of the same species is greater than the average probability for the entire forest [25]. This is similar to a finding of Hubbell và Foster [26] that, in species-rich communities, two individuals of the same species may share only a few common species among their nearest neighbors. Moreover, high-diversity species, meaning high mixture, may also involve neutral theory [27], in which functionally similar species may produce ecological equivalence, reduce interspecific competition, and therefore facilitate more diverse species in their neighborhood.

The average W values of forest types and most of the abundant species show spatial distributions from clumped to very clumped in DEF and MDF, but regular to very regular patterns in MCF (Figs. 3-5). The clumped pattern is a common distribution of tropical tree species that is mainly driven by dispersal limitation and habitat preference mechanisms [19]. While regular distribution can result in competitive interaction between tree individuals for limited natural resources including light, moisture, and nutrients [28, 29]. In our study, there are light-demanding species as strong competitors for light, such as Hopea pierrei, Vatica harmandiana, Dipterocarpus obtusifolius (Dipterocarpaceae), and Pinus merkusii (Pinaceae). Moreover, during the successional process to the climax state, the forest community gradually shifts from clumped to regular, and the process is constantly accompanied by the random weakening of interspecific associations among dominant species [30].

In our study, most individuals of dominant species in three forest types are dominant in tree height, with their nearest neighbors indicating that they are strong competitors. These characteristics may facilitate the maintenance of species diversity in line with niche differentiation theory [31]. Each species' population differed in dominance, thus maximizing the use of three-dimensional spatial resources by the forest stand. Most individuals of dominant species also showed crowding as moderately dense in all three forest types. This indicates that individual trees balance their space well. Crowding index, which is used to adjust the individual tree nutrient space of the object tree species so that the object tree has sufficient growth space.

5. CONCLUSION

The approach used in this research has practical benefits, as it allows for the precise determination of stand spatial attributes by evaluating the immediate neighborhoods of target trees. The mixture, size differentiation, distribution patterns, and crowding between a single individual and the four adjacent neighboring trees are closely associated with the structural parameters, which can be strongly adjusted, as previous studies have shown [5, 32, 33]. Target-tree management can scientifically and accurately quantify the description of forest structures, reveal the relationship between forest structure and forest competition, reveal the spatial diversity of tree species, and help formulate target management measures to guide quantitative adjustments of forest structure. From the information about the spatial structure characteristics of the dominant species in our study, managers can also select the ideal tree species to optimize management goals in forest stands where silviculture techniques are permitted.

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MÔ HÌNH CÂY LÂN CẬN GẦN NHẤT CỦA CÁC LOÀI ƯU THẾ TRONG RỪNG NHIỆT ĐỚI, VƯỜN QUỐC GIA PHOU KHAO KHOUAY, LÀO

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TÓM TẮT

Quản lý cây mục tiêu là một kỹ thuật lâm sinh hiện đại trong quản lý rừng bền vững dựa trên sự hiểu biết về cấu trúc không gian rừng. Nghiên cứu này đã áp dụng một phương pháp mới để phân tích định lượng cấu trúc không gian của các lâm phần tự nhiên dựa trên khoảng cách giữa các cây lân cận. Chúng tôi đã thiết lập 32 ô tiêu chuẩn có kích thước 50 m × 50 m thuộc ba trạng thái rừng khác nhau trong vườn quốc gia Phou Khao Khouay ở Lào bao gồm rừng khô thường xanh, rừng thường xanh hỗn giao rụng lá và rừng thường xanh hỗn giao cây lá kim. Tất cả cây thân gỗ có đường kính ngang ngực (DBH) ≥ 5 cm được định vị, đo DBH, đường kính tán lá và xác định loài. Bốn chỉ số cấu trúc không gian rừng là hệ số đồng góc, độ hỗn loài, độ ưu thế và độ tập trung tán đã được sử dụng để phân tích dữ liệu. Kết quả cho thấy: (1) hầu hết các loài ưu thế trong 3 kiểu rừng đều thể hiện sự hỗn giao từ mức trung bình đến hoàn toàn; (2) các cây mục tiêu có sự ưu thế về chiều cao so với các cây lân cận gần nhất; (3) mô hình phân bố của cây trong lâm phần biểu hiện từ phân bố đều đến phân bố cụm; (4) độ tập trung tán chỉ ra rằng cây trong lâm phần phân bố từ thưa thớt đến dày đặc. Kết quả nghiên cứu cũng cho thấy phát tán bị giới hạn và sự cạnh tranh giữa các cây lân cận là những cơ chế chính đã điều chỉnh cấu trúc không gian rừng ở khu vực nghiên cứu. Những thông tin được cung cấp trong nghiên cứu này rất hữu ích cho việc đề xuất các biện pháp lâm sinh nhằm quản lý rừng bền vững ở Vườn quốc gia Phou Khao Khouay.

Từ khóa: cây mục tiêu, chỉ số đồng góc, độ tập trung tán, loài ưu thế, phần mềm Crancord.

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