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SPECIES AND TREE QUALITY SPATIAL DISTRIBUTION PATTERNS AND ASSOCIATIONS IN TUYEN QUANG, VIETNAM

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Spatial distribution patterns of trees are important keys to understanding forest structure and for proposing forest management solutions. Management of rainforests in Vietnam is constrained by a shortage of spatial forest data. Therefore, research was conducted in an upland secondary forest in Tuyen Quang, Vietnam to assess spatial distributions of species and quality levels, and associations between them. Tree diameter, height, coordinates and quality (good, medium and bad) were recorded in three one-hectare plots. Tree density ranged from 920–1050 trees ha^{-1}, and there were 61–69 species ha^{-1}. The highest percentages of good and bad trees were 25.1 and 42.9%, respectively. The habitat was determined as heterogeneous to homogeneous. The spatial distribution of all species and ecological important species was mostly random and clustered. Associations among ecological important species was mainly independent. Tree qualities were randomly distributed, but bad trees were more abundant in the understorey. Associations between tree qualities were mostly independent. The results on spatial distribution patterns and associations between species and qualities will be useful in helping to eliminate competition of trees in clusters, assist regeneration in gaps and determine options for reducing the frequency of bad trees in the future.

Keywords: Association, spatial distribution, tree quality, tropical secondary forest

INTRODUCTION

Spatial patterns of species and individuals is extremely important and meaningful in ecological research (Martínez et al. 2010, Wang et al. 2010, Fatma et al. 2020, Houdanon et al. 2019). The spatial distribution of species influences the formation and development of plant communities, and changes in forest structure can be explained through the spatial distribution of individuals on the ground (Martínez et al. 2010, Liu et al. 2021, Pham et al. 2022). Species associations are affected by spatial patterns of individuals and the co-existences of species is promoted more strongly when species are clustered (Liu et al. 2021). Random and regular distributions tend to reduce tree density at short distances, leading to negative interactions between species (Martínez et al. 2010, Liu et al. 2021). Characteristics of the spatial distribution of species can reflect species competition intensity, seed dispersal features and the homogeneity of habitats in the study area (Barot et al. 1999, Pham et al. 2022). Ecological correlations among species and species composition at different sites can be elucidated by studies of species associations, especially among ecological important species in the stand (Wang et al. 2016, Liu et al. 2021). The spatial distribution characteristics along with associations between species are an essential basis for foresters to apply appropriate silvicultural techniques such as thinning, enrichment planting and maximum biodiversity (Hung 2016).

Many studies have been conducted on the spatial distribution of forest trees for different forest types, tree species and life stages. The spatial distribution of individuals on the ground has three types: cluster, random and regular distribution (Illian et al. 2008, Higuchi et al. 2010, Baddeley et al. 2015). However, spatial distribution patterns are influenced by many biological, environmental and human factors. Therefore, the spatial patterns can be very diverse between regions and species (Wang et al. 2010, Shin et al. 2017). Examples include aggregation in the Changbaisan forests in China, random and clustered distribution in old-growth forest in South Korea, and regular and random distribution of dominant tree species in Amazon forests (Wang et al. 2010), Shin et al. 2017, Costa-Cysneiros et al. 2018). Associations between species and different life stages have also been analysed in many locations. Usually, there are 3 types of relationships: attractive, independent and repulsive. These interactions also vary widely across regions, between species and life stages (Lan et al. 2012, Costa-Cysneiros et al. 2018, Wédjangnon et al. 2020). However, less is known of the spatial distribution and associations among forest trees that differ in qualities such as canopy condition, growth and tree form. This knowledge is necessary for developing solutions to improve forest quality.

In Vietnam, a small number of studies have been conducted in Dong Nai, Nghe An, Phu Quoc and Ninh Binh provinces on the spatial distribution of tree species and life stages (Quy et al. 2021, Pham et al. 2022, Quy et al. 2022). These studies revealed that spatial distribution patterns showed both similarities and differences between regions. Forest trees were randomly distributed in Dong Nai, but in Nghe An, species were clustered at distances less than 15 m, and had random or uniform distributions at distances greater than 15 m (Quy et al. 2021, Pham et al. 2022). Therefore, further field investigations are essential across a wider range of forest types in Vietnam to inform future forest management. Tuyen Quang province was chosen to analyse the spatial distribution characteristics of species as well as the relationships between ecological important species as there are no similar studies in this part of Vietnam. Furthermore, in Vietnam, no studies have analysed the spatial distribution of tree quality as well as the associations between them based on point pattern analysis supported by R. Therefore, this research was carried out: i) to understand and compare floristic community and tree quality characteristics among forest plots, ii) to analyse habitat homogeneity within plots, iii) to assess and compare the spatial distribution characteristics of all species and ecological important species, and iv) to analyse distribution patterns and associations between tree qualities. The results of this study will help generate a scientific basis for more sustainable and effective forest management in the study area.

MATERIALS AND METHODS

Study site

The forest in the study area is an evergreen, tropical, secondary natural forest. This is the common forest type across the uplands of northern Vietnam. The forest is managed by the Tuyen Quang Forest Protection Department. Khau Tinh commune, Na Hang district, Tuyen Quang province was selected for establishing plots (Figure 1). The terrain in the study area is mountainous and complex, with many caves. The average altitude is 439 m and the average slope is 30–35 ^{o}. The climate in the study area is tropical monsoon. Each year has two distinct seasons: the wet and hot season from April to September, and the dry and cold season from October to March (Luc et al. 2019). The average annual temperature is 23.5 ^{o}C. The annual rainfall is 1390–1600 mm, with about 80% of the annual rainfall occurring in July and August. The annual average humidity is 75%, the highest in March and April is up to 85% and the lowest is 60% in January and February. In the area, there are two prevailing winds: northeast wind in the dry season, and southeast wind in the rainy season. Most of the region is covered by a yellow-red oxisol (Luc et al. 2019).

Establishment of plots and data collection methods

Three representative plots of the forest type were established in the study area at an altitude of 450 m in 2019. The selected locations for the plots were natural tropical forests, representing the region. Each plot had an area of 1 ha (100 × 100 m) (Figure 2). The distance between the plots was more than 200 m. Each plot was divided into 25 sub-plots for ease of collection of data.

All trees with a diameter at breast height (DBH) greater than 6 cm were included in

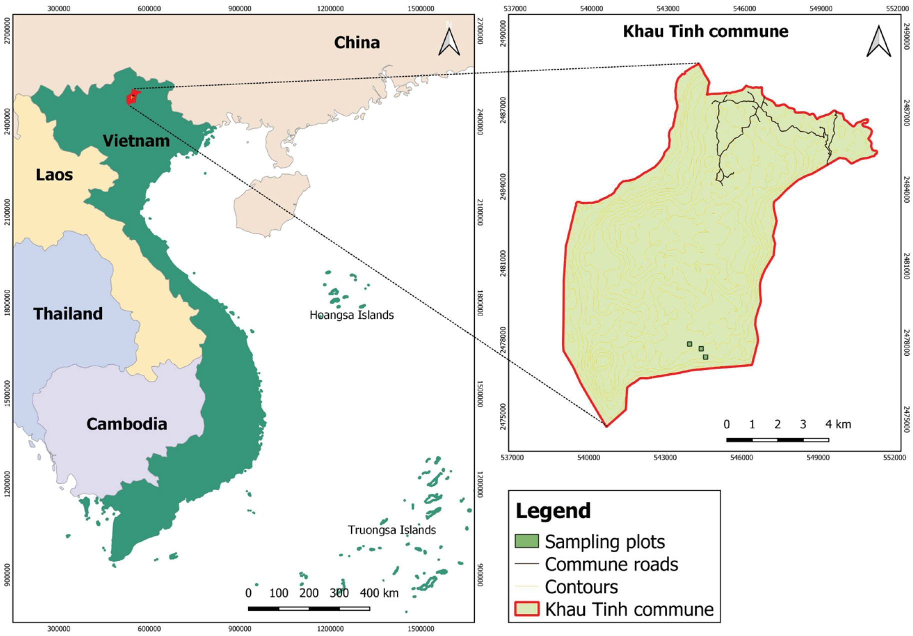


Figure 1 Study area, maps of Vietnam (left) and Khau Tinh commune (right)

the study (Hoan & Ngu 2003). Diameter was obtained using calipers, and the height to the top of the crown was measured using Blumleiss model BL7. The X and Y coordinates of each tree (Figure 2) were obtained using measurement tapes and compasses (Philip 1998). Trees were identified to species. First, Vietnamese names were determined based on comparison with reference documents and species identification experts (Ho 2007). Next, scientific names were determined and verified using the Royal Botanic Gardens' online sources (POWO 2022).

Tree quality information was collected and each tree was classified as good, medium or bad. Good trees had straight boles, strong growth, well-developed crowns without truncation, and no obvious disease. Bad trees had crooked boles, poor growth, weakly-developed crowns or topless boles, and obvious disease. Medium trees had some combined traits of good and bad trees (Hoan & Ngu 2003, Zawieja & Kazmierczak 2015, Trieu 2017, Hung et al. 2022).

Statistical analysis

Descriptive statistics and importance value

Arithmetic mean and standard deviation (SD) were calculated for the diameter variable of species in plots. The mean showed the magnitude of the calculated quantity and the SD indicated the variability of the diameter values of species (Zar 1999).

To understand the importance of species, species importance value index (IVI) was calculated. The IVI was a sum of relative density and relative dominance (Cottam & Curtis 1956, Bormann 2005).

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Total number of all individuals in the plot}} \quad (1)$$

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species in the plot}} \quad (2)$$

$$\text{IVI} = \text{Relative density} + \text{Relative dominance} \quad (3)$$

In this study, ecological important (EI) species were those with IVI greater than or equal to 5% (Hoan & Ngu 2003, Trieu 2017).

Biodiversity and quality comparison between plots

Differences in the number of species and the number of individuals of each species between plots were examined using non-metric multidimensional scaling (NMDS). This is a

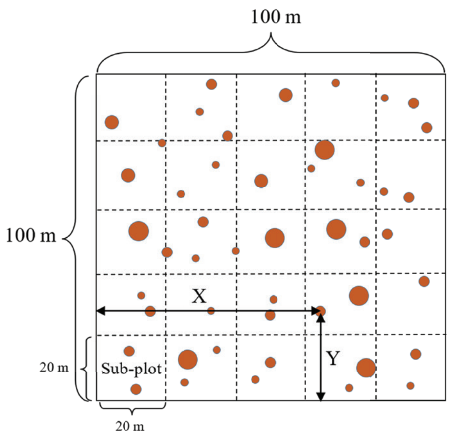


Figure 2 Plot and sub-plot design, X and Y present coordinates of trees, red circles represent forest trees and their size indicates tree diameter

multivariate analysis based on a matrix between plots and species. The number of tree species in tropical forests is often very large, so their frequency distributions are often very complex, not following the normal distribution. Therefore, NMDS is suitable to be applied to tree species data, since it does not require assumptions (McCune et al. 2002, Holland 2008). Detrended correspondence analysis (DCA) was used to test for differences in tree quality between plots. The DCA is a multivariate analysis based on a matrix between plots and quality levels, and used to remove the arch effect from correspondence analysis (CA). The DCA is suitable for analysing the relationship between two categorised variables. In this study, DCA was used to overcome the distortions inherent to CA (Jansons et al. 2016, Holland 2019).

Habitat heterogeneity analysis

Spatial distribution characteristics of mature trees with diameters greater than or equal to 15 cm were used to explore the homogeneity of environmental conditions in the plots. The distribution of mature trees is greatly influenced by environmental conditions. They can exist in any area in the plots. Therefore, they could be used to indicate the homogeneity of environmental conditions. If the distribution of these mature trees were clustered, the environmental conditions would have been very heterogeneous. If their distribution was random, then the conditions were heterogeneous. Lastly, if their distribution pattern was regular, then the environmental conditions were homogeneous in the plots (Pham et al. 2022).

Species and tree qualities spatial patterns analysis

The spatial distribution characteristics of tree species, ecological important species and tree quality were analysed by the univariate pair correlation [$G_{11}^{(r)}$] (Houdanon et al. 2019, Fatma et al. 2020). This function relies on the tree position to calculate distances between any two trees. Then a ratio between the probability of getting 2 trees divided by the probability of the Poisson process is calculated. The formula of the $G_{11}(r)$ function used is as follows (Illian et al. 2008):

$$G_{11}^{(r)} = \frac{K'(r)}{2\pi r} \qquad (4)$$

where K'(r) is the first derivative of the tree density probability at distance r.

The study used the Monte Carlo test with 199 simulations to generate confidence envelopes. If $G_{11}(r)$ was greater than the confidence envelope, then the distribution was clustered. If $G_{11}(r)$ was in the confidence envelope, then the distribution was random. The distribution was regular if $G_{11}(r)$ was less than the confidence envelope (Illian et al. 2008, Hung 2016).

Ecological species and tree qualities association analysis

Associations between ecological species and tree qualities were analysed by the cross-type pair correlation function ($G_{ij}(r)$). This function calculates a ratio between the probabilities of encountering a point of different types (species or qualities) at a given distance r. The study also used the Monte Carlo test with 199 simulations to create confidence envelopes. If $G_{ij}(r)$ was greater than the confidence envelope, then the association was attraction. If $G_{ij}(r)$ was within the confidence envelope, then the association was independence. Otherwise, the association was repulsion, if $G_{ij}(r)$ was less than the confidence envelope (Illian et al. 2008, Pham et al. 2022).

The study used R software version 4.0.2 to run all analyses in the study (Team 2021).

RESULTS

Floristic community and tree quality characteristics in the plots

Floristic composition in plots

A total of 2993 individuals of forest trees, belonging to 91 species and 37 families, were measured in this study. More specifically, plot 1 had 1050 individuals, belonging to 62 species and 29 families, plot 2 had 920 individuals, belonging to 61 species and 29 families, and plot 3 had 1023 individuals belonging to 69 species and 33 families. The diameter mean was smallest in plot 1 (12.22 ± 4.88 cm) and largest in plot 3 (15.19 ± 6.09). In plot 1, there were seven EI species (IVI > 5%), in order of their IVI values: *Machilus bonii*, *Diospyros sylvatica*, *Symplocos cochinchinensis*, *Syzygium chanlos*, *Streblus ilicifolius*, *Phoebe cuneata* and *Deutzianthus tonkinensis.* There were 5 EI species in plot 2, namely *Streblus ilicifolius*, *Machilus bonii*, *Syzygium samarangense*, *Symplocos cochinchinensis* and *Vitex pariflora.* Plot 3 had four EI species, *Saraca dives*, *Machilus bonii*, *Diospyros eriantha* and *Syzygium chanlos.* The IVI of EI species was largest in plot 1 (51.84%), and lowest in plot 3 (33.27%) (Table 1). These species were selected for further analysis of spatial distribution characteristics.

Differences in the number of species and frequencies of each species between the three plots were analysed by NMDS. The results illustrated that species biodiversity was statistically different between plots (goodness of fit, p-value < 0.001) and this is visualised in Figure 3.

Tree quality in plots

The calculated results showed that the medium tree ratio was always the largest in all plots. In plot 1, the percentage of bad trees was the lowest (22.1%), while the percentage of good trees was the lowest in plot 2 and plot 3 (22.7% and 14.7%, respectively). Details of the proportion and number of individual forest trees according to the quality levels of the plots are provided in Table 2.

Comparison by DCA showed that the percentages of forest trees in the good, medium and bad classes were significantly different between plots (goodness of fit, p-value < 0.001). The quality allocation of forest trees in plot 3 was very different from that of plot 1 and plot 2 (Figure 4).

Habitat heterogeneity in the plots

Spatial distribution of trees larger than 15 cm in diameter was used to examine habitat heterogeneity in plots. The pair correlation function was applied to reveal the spatial distribution characteristics of these trees at different distances. The results showed that the mature trees were only distributed aggregately at distances of 0–1, 3–5 and 7–11 m in plot 1. In plot 2, the mature trees only had a clear clustering distribution at the distance of 4.5–6.5 m. In plot 3 and at other distances in plot 1 and plot 2, the mature trees had a random distribution. Spatial distribution patterns were statistically different between plot 1 and plot 2 (Mann-Whitney U = -12,427, p-value < 0.001), and plot 1 and plot 3 (Mann-Whitney U = -13,934, p-value < 0.001). However, the spatial distribution characteristics were similar between plot 2 and plot 3 (Mann-Whitney U = -0.409, p-value = 0.682) (Figure 5). The calculated results also indicated that in plot 1 there were several gaps without mature trees. There were fewer gaps in plot 2 and no gaps in plot 3. The difference between the observational model and the null model of SCR was most pronounced in plot 1, less in plot 2 and similar in plot 3. Thus, it can be concluded that habitat was very heterogeneous in plot 1, less heterogeneous in plot 2 and homogeneous in plot 3.

Table 1 Floristic composition in plots, the ecological important species are named and presented on their IVI ranking

Plot	Species	Family	N (trees ha^{-1})	DBH mean (cm)	SD	IVI (%)
Plot 1	*Machilus bonii*	Lauraceae	89	11.97	7.39	9.38
	Diospyros sylvatica	Ebenaceae	112	9.68	3.40	8.78
	Symplocos cochinchinensis	Symplocaceae	64	13.89	8.62	8.04
	Syzygium chanlos	Myrtaceae	79	11.04	4.59	7.07
	Streblus ilicifolius	Moraceae	83	10.54	3.43	6.94
	Phoebe cuneata	Lauraceae	70	9.96	5.37	5.95
	Deutzianthus tonkinensis	Euphorbiaceae	56	12.21	5.89	5.67
	Seven dominant species		553	11.42	5.53	51.84
	Other species (55 species)		497	12.33	4.78	48.16
	All species (62 species)		1050	12.22	4.88	100.00
Plot 2	*Streblus ilicifolius*	Moraceae	190	10.74	3.71	16.15
	Machilus bonii	Lauraceae	127	14.56	8.26	15.34
	Syzygium samarangense	Myrtaceae	77	8.96	2.90	5.81
	Symplocos cochinchinensis	Symplocaceae	32	18.13	10.68	5.08
	Vitex pariflora	Lamiaceae	40	15.29	8.40	5.05
	Five dominant species		466	13.54	6.79	47.42
	Other species (56 species)		454	14.28	5.73	52.58
	All species (61 species)		920	14.21	5.84	100.00
Plot 3	*Saraca dives*	Fabaceae	69	18.61	8.70	9.93
	Machilus bonii	Lauraceae	96	12.84	7.62	9.51
	Diospyros eriantha	Ebenaceae	120	9.66	3.94	8.81
	Syzygium chanlos	Myrtaceae	66	9.85	4.82	5.01
	Four dominant species		351	12.74	6.27	33.27
	Other species (65 species)		672	15.34	6.07	66.73
	All species (69 species)		1023	15.19	6.09	100.00

N = number of trees, DBH = diameter at breast height mean (cm), SD = standard deviation of DBH (cm), IVI (%) = importance value index

Table 2 Number and percentage of all forest trees according to quality classes

	Tree quality					
	Good		Medium		Bad	
Plot	N	N %	N	N %	N	N %
Plot 1	264	25.1%	554	52.8%	232	22.1%
Plot 2	209	22.7%	478	52.0%	233	25.3%
Plot 3	150	14.7%	434	42.4%	439	42.9%

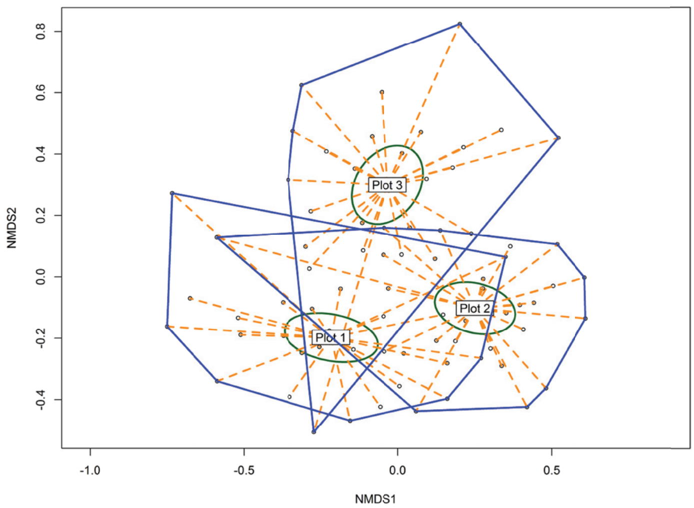


Figure 3 Species biodiversity comparison between plots determined by non-metric multidimensional scaling, dots are sub-plots, and the green lines are 95% estimation

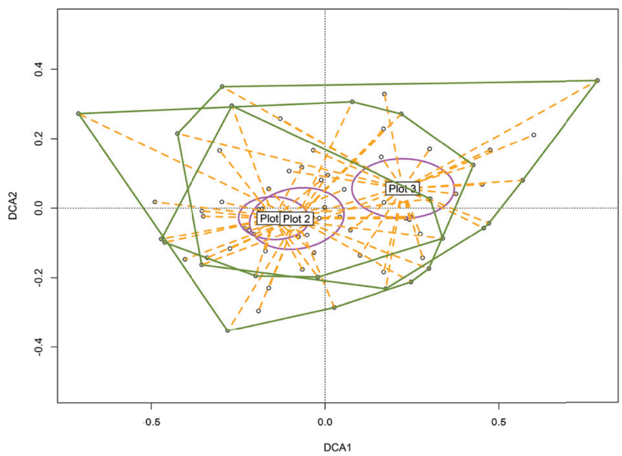


Figure 4 Tree quality comparison between plots, dots are sub-plots, and the pink lines are 95% estimation

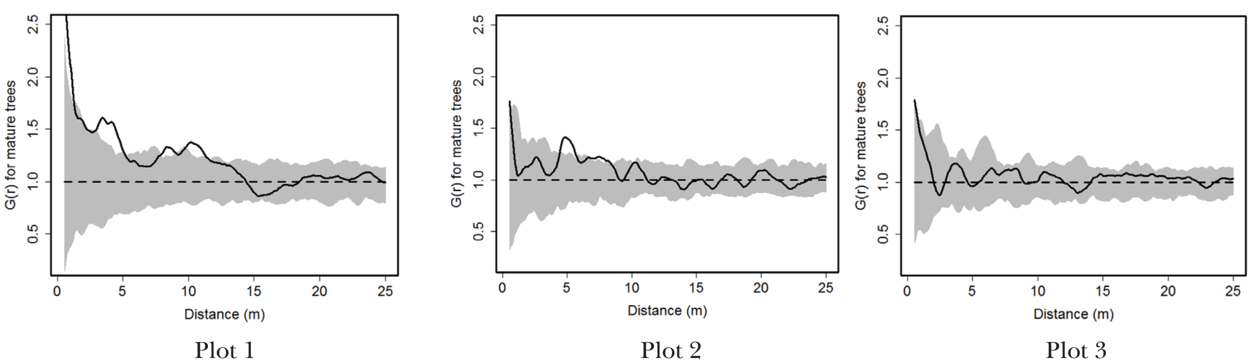


Figure 5 Distribution characteristics of mature trees in plots, the data were analysed by the G(r) function

Spatial distribution patterns of species

Spatial distribution patterns of all species

The distribution characteristics of all tree species in plots are visualised in Figures 6a–6c. The comparison results showed that forest tree density was significantly different between plot 1 and plot 2 (t-test = -2.115, p-value = 0.034), and between plot 1 and plot 3 (t-test = -0.428, p-value = 0.668). There was no significant difference in the density of forest trees between plot 2 and plot 3.

Trees had aggregated distribution at most distances in plot 1 such as 2.5–4.5, 6–12, 15.5–17 m, etc. In plot 2, the trees were mostly randomly distributed, except for a distance of 5 m. However, plot 3 had several distances at which forest trees had clustered distribution, such as 6–7, 8–9 and 15–17 m. At other distances in the plots, the trees were randomly distributed. Regular distribution was not observed in the studied stands (Figure 6). Spatial distribution patterns of trees were statistically different between plots: plot 1 and plot 2 (Mann-Whitney U = -14,889, p-value < 0.001), plot 2 and plot 3 (Mann-Whitney U = -4.432, p-value < 0.001), and plot 1 and plot 3 (Mann-Whitney U = -10.048, p-value < 0.001).

Spatial distribution patterns of ecological important species

Ecological important tree species were selected for further analysis of spatial distribution characteristics. In plot 1, about 85% of EI species were randomly distributed over many distances. Only about 15% had clustered distribution at distances of 2–7 and 9–11 m. In Plot 2, at 0–19 m, about half of the EI species were randomly distributed and half were clustered. In plot 2, at distances greater than 19 m, up to 80% of these species were distributed randomly, and only 10% aggregately. Plot 3 showed a few differences. At distances of 0–4 and 20–25 m, 75% of the EI species had random distribution, and only 25% of the species were clustered. At a distance of 4–20 m, 50% of the species had random distribution and 50% were clustered. In all three plots, EI species were not regularly distributed (Figure 7).

Associations between EI species were also examined. The results indicated that these species had independent associations in plot 1

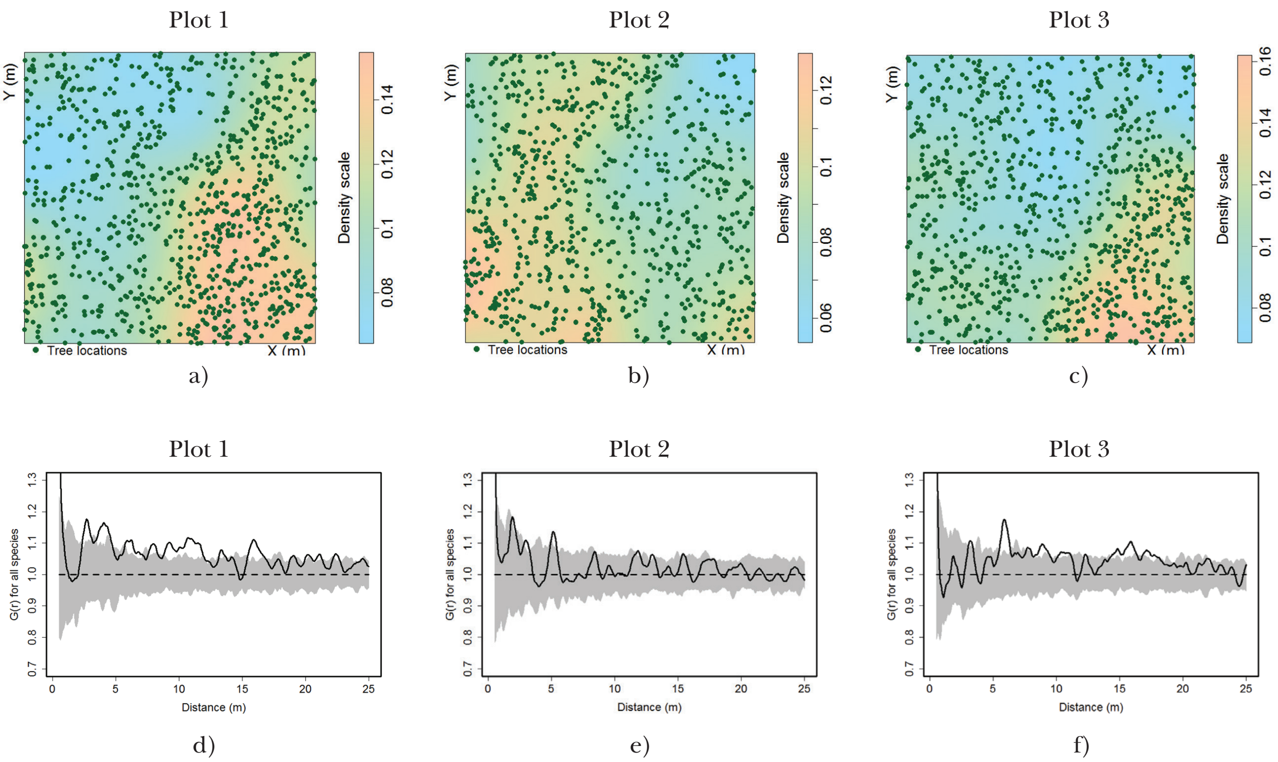


Figure 6 Density and tree location map in plots (a–c) and spatial distribution characteristics of all species in plots (d–f)

and plot 2 at all distances. In plot 3, associations of EI species were attraction at distances of 3–6 and 7–9.5 m. At the remaining distances, these associations were independent (Figure 8).

Tree quality distribution patterns and associations

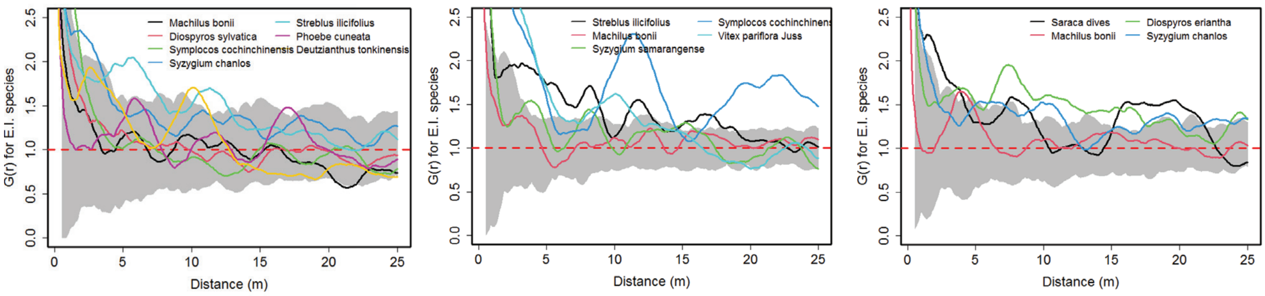
Tree quality distribution characteristics

Three-dimensional graphs of forest tree distribution according to quality and tree height levels are provided (Figure 9). Good, medium and bad trees were distributed across all height layers, from low to high storeys. However, there was a prominent feature in all three plots that trees with bad quality were often concentrated in the lower layers, especially in plot 1.

Regarding the horizontal distribution of quality levels, in general, all good, medium and bad trees had random distributions across all scales in all plots (Figure 10). Only a few distances, such as, 3–7 m for good trees in plot 1, 3–4 m for bad trees in plot 2 or 10–12 m for good trees in plot 3 had clustered distributions.

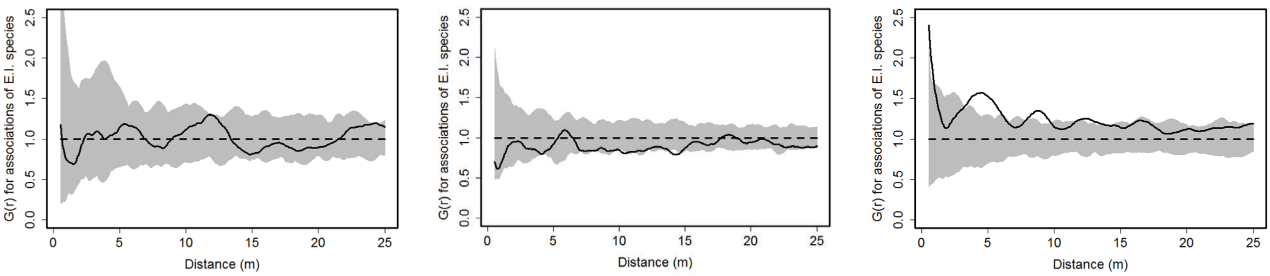
Associations of tree qualities

In plot 1, the quality pairs, good vs bad and medium vs bad were independent for most distances. However, the attractive relationship between good trees and medium trees appeared at many distances, such as, 2.5–4 m, 6–7.5, 10–12 m, 11–12 m and 20–21 m. In plot 2, all quality pairs were independently related at all distances. The associations between the qualities were most complex in plot 3. The association between the good trees and the medium trees was independent at all scales. However, the relationship between the good trees and the bad trees was repulsion at many distances, including: 1–4 m, 10.5–14 m, 17–22 m and 22.5–25 m. In contrast, medium and bad trees were attracted to each other at many scales, such as, 6–7 m, 10–12 m and 13–20.5 m (Figure 11).



Plot 1 Plot 2 Plot 3

Figure 7 Spatial distribution characteristics of ecological important species in plots



Plot 1 Plot 2 Plot 3

Figure 8 Associations among ecological important species in plots

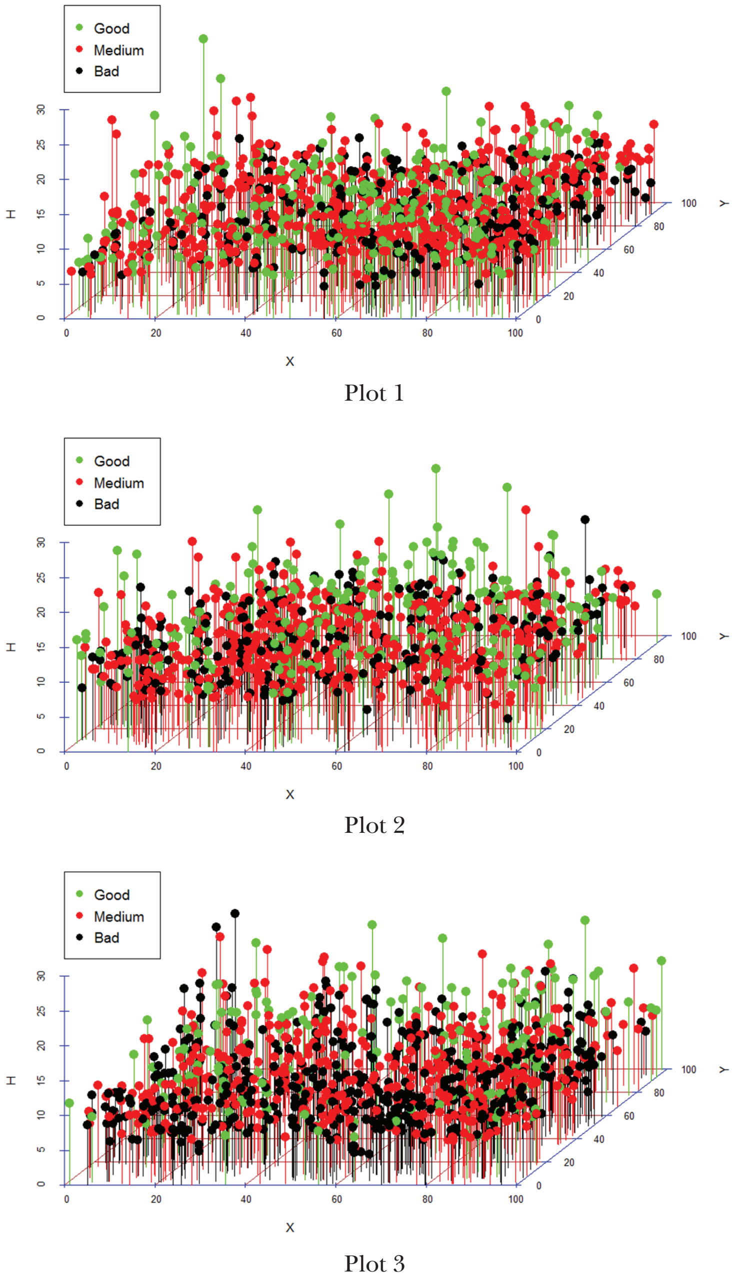


Figure 9 Vertical distribution of trees by qualities, green = good, red = medium, black = bad

DISCUSSION

Floristic community and tree quality properties

The tree density in the study area was similar to a study using the same plot size in upland tropical rain forest in Nghe An province where there were 862–1052 individuals ha^{-1} (Pham et al. 2022). However, the density was lower than in Phu Quoc Island (1671–2049 individuals ha^{-1}) and in Dong Nai province (1371 individuals ha^{-1}) (Quy et al. 2021, Quy et al. 2022). This could be due to less favorable soil and climatic conditions in the North of Vietnam or greater anthropogenic effects in the study area. The number of species in the study (61–69 species ha^{-1}) was lower than in the Dong Nai (111 species ha^{-1}) and Nghe An (81–94 species ha^{-1}) studies, but higher than in Phu Quoc (45–51 species ha^{-1}) (Quy et al. 2021, Pham et al. 2022, Quy et al. 2022). The number of EI species in the study area (4–7 species) was

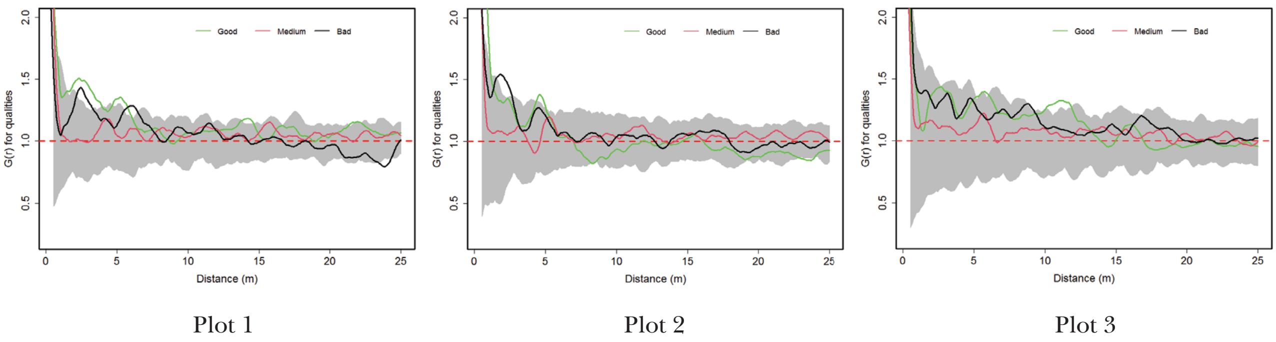


Figure 10 Horizontal distribution patterns of trees by qualities in plots

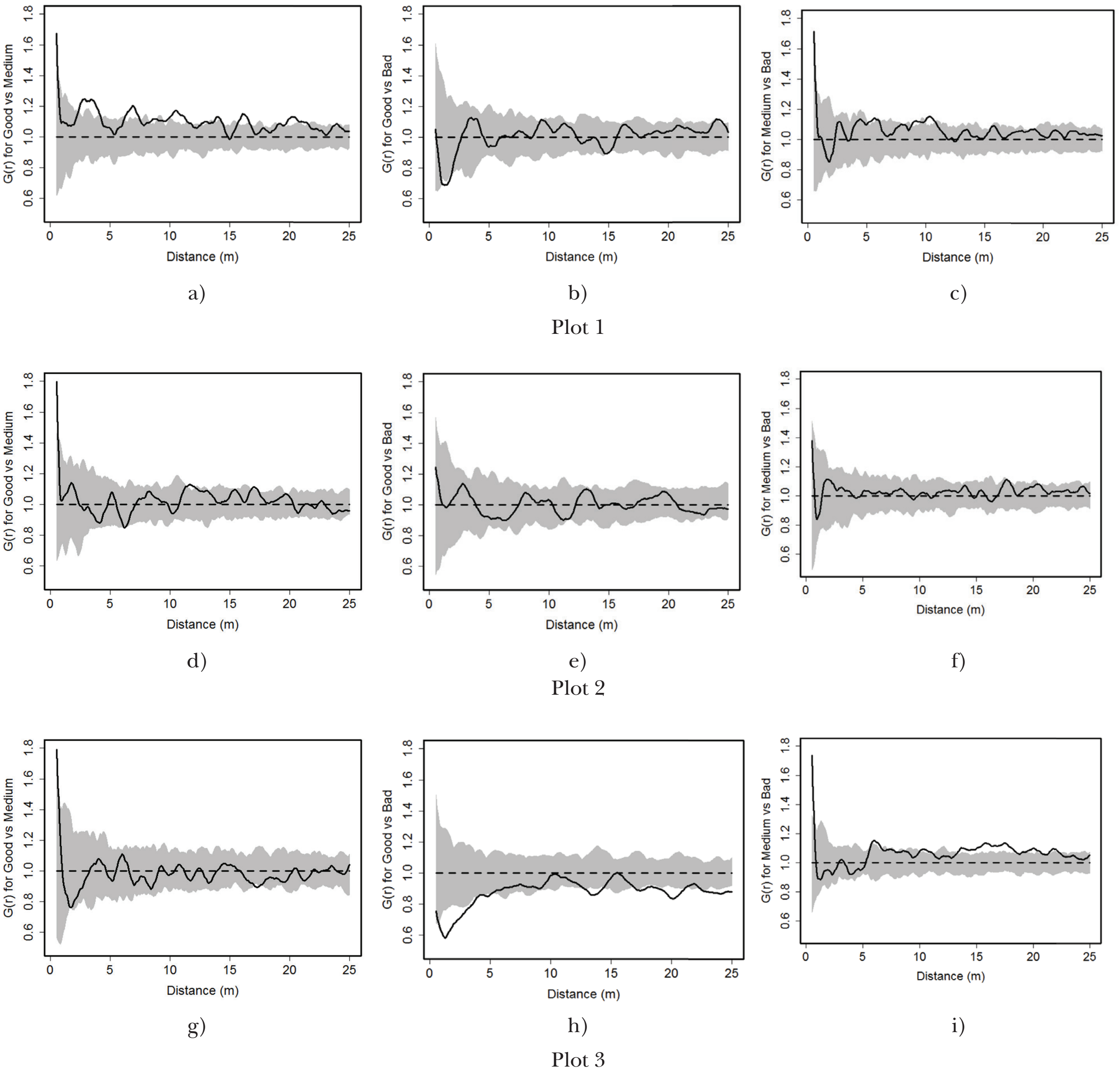


Figure 11 Tree quality associations in plots, plot 1 (a–c), plot 2 (d–f) and plot 3 (g–i)

comparable to Dong Nai (4 species) and Phu Quoc (10–13 species) (Quy et al. 2021, Pham et al. 2022, Quy et al. 2022). However, the EI taxa varied widely from region to region. This study established that the area of interest has its own characteristics in terms of ecological conditions. In order to improve forest biodiversity, attention should be paid to ecological important species, endemic species and any missing keystone tree species.

This is the first study to evaluate tree quality structure characteristics in forests in Vietnam. Trees classified as bad comprised 22.1 to 42.9% of the population. This proportion is higher than observations in rainforest in Gia Lai (12.4–16.35%), Bac Kan (9.4–11.54%) and Ba Vi (9.8–12.3%) (Hung & Hai 2018, Hung et al. 2019, Phong & Hung 2019). Therefore, foresters who want to improve the quality of forests in the study area need to focus on individuals with bad quality. Some management options might include clearing invasive vines and competing shrubs around recruitment seedlings and saplings, and improving the availability of mineral nutrients and light for early growth. The extent of disease in the bad trees is a concern and research should be undertaken to identify the causal agents and to investigate how disease incidence and impact might be mitigated in the future.

Habitat homogeneity among forest communities

The spatial distribution of mature trees can be the basis for concluding about habitat homogeneity in forest communities (Getzin et al. 2008, Pham et al. 2022). The habitat was relatively homogeneous in two plots, but heterogeneous in the third. Similar findings have been found in a number of other studies using one-hectare plots. For example, authors concluded that the habitat was homogeneous in two plots but heterogeneous in one plot in Nghe An (Pham et al. 2022). Another study conducted on Vancouver Island, Canada concluded that the habitat was homogeneous in the northern plot (0.9 ha) and heterogeneous in the southern plot (0.7 ha) (Getzin et al. 2008). Heterogeneity in habitats, including traits such as microclimate, soil type, soil depth, aspect and slope, will greatly affect the growth of forest trees, forest structure and especially the spatial patterns of forest trees (Tateno & Takeda 2003, Liu et al. 2021, Yao et al. 2022). When tending forests, foresters need to pay more attention to areas where the habitat is not homogeneous or spaces where the trees are clustered. Management options include stimulating regeneration in areas that are sparsely populated and regulating competition in areas of high tree density (Hoan & Ngu 2003).

Spatial distribution patterns of species

The spatial distribution patterns were either random or clustered. Random and cluster distributions of tree species, especially mature trees, also occur in forests in Dong Nai , Gia Lai, Nghe An and other Asian countries (Condit et al. 2000, Hung 2016, Quy et al. 2021, Pham et al. 2022). The EI species in this study showed cluster or random distributions, while regular distribution was not observed. Differences in spatial distribution patterns between plots, between forest types and between species are the result of many different causes (Condit et al. 2000, Liu et al. 2021, Yao et al. 2022). The development process from germination to maturity is influenced by environmental factors such as light, nutrient availability and competition (Mabberley 1992, Fangliang et al. 1997, Barnes et al. 1998, Wagner et al. 2011). Competition, natural thinning, dead trees and gap forming processes can lead to changes in the spatial distribution patterns of tree species. Therefore, the spatial distribution of forest trees is difficult to predict and changes over time. Some authors have concluded that limited dispersal capacity of parent plants, especially pioneer species, can lead to clustering of plants at scales smaller than 20 m because seed density is usually higher in the area near the mother plant (Fibich et al. 2016, Quy et al. 2021). Environmental heterogeneity can lead to the aggregation of species at greater distances (Wiegand et al. 2007, Quy et al. 2021). Species composition is also a cause of changes and differences in spatial distribution characteristics. Areas with a lot of shade-tolerant tree species tend to have clustered distribution, as they survive near and under crowns of other trees (Hoan & Ngu 2003). Sample plot size and sampling location can influence the findings because the distribution of forest trees is often not uniform on the ground (Hung 2016). In future studies, environmental factors can be investigated in more detail to analyse their correlations with spatial distribution properties of forest trees, especially for EI species.

Most associations between EI species were independent on most scales. This result confirms findings of the study in Nghe An and Sri Lanka (Pham et al. 2022, Wiegand et al. 2007). The relatively low number of EI species (4–7 species) and individuals (351 to 553 trees ha^{-1}), and clustering reduces the opportunity for these species having favorable neighbors, thus, they cannot build specific interactions (Wiegand et al. 2007). For this reason, the interaction between them is often independent.

Spatial distribution patterns and associations of tree qualities

Vertically, the good, medium and bad forest trees occured at all height layers but the bad trees were concentrated in the understorey. In a study in Gia Lai, the authors showed that bad quality trees were more concentrated in the lower layers of secondary forests. However, in the old-growth forest, the bad trees were evenly distributed at all height layers (Hung & Truong 2017). This trend was also found in secondary rainforest in Bac Kan (Tuan & Hung 2018). The cause of this phenomenon may be that trees in lower layers receive less light, and the available nutrient pools are more limited, leading to poorer growth (Hoan & Ngu 2003, Tuan & Hung 2018). The approach taken to analyse interactions between quality pairs should be extended to other forest types in the region as it can provide valuable information to those engaged in forest protection and forest management. For example, in plot 1, special attention should be paid when applying silvicultural measures for medium and good trees, because there is a supportive relationship between them. However, in plot 2, the removal of bad trees can be undertaken without affecting the good and medium trees. By contrast, in plot 3, forest managers need to be careful as bad trees have an attractive relationship with medium trees at many distances.

CONCLUSIONS

The number of species and frequencies was significantly different between plots. The number of ecological important species was similar, but their species names were quite different between plots. The proportion of trees by quality was similar between plot 1 and plot 2, but different from plot 3. The habitat was heterogeneous in plot 1 and very homogeneous in plot 3. The spatial distribution of all species and ecological important species was mostly random and clustered. Associations among ecological important species were mainly independent. Although bad trees were more concentrated in the lower layers, good, medium and bad trees were all randomly distributed on the ground, and their associations were mainly independent. Therefore, in order to improve forest quality in the study area, foresters should focus on improving environmental conditions for bad trees. When undertaking silvicultural measures, foresters need to be careful with the relationship between bad and medium trees. In future studies, permanent plots should be established and measurements should be carried out more frequently so that spatial variations of species and qualities can be obtained in a timely manner. At the same time, environmental information such as climate, soil, light and nutrients should be investigated and analysed along with the spatial distribution characteristics of individuals to understand the causes of these spatial structure variations. From there, it is possible to propose and apply appropriate silvicultural measures so as to manage forest resources effectively and sustainably in the region.

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