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The ecological interaction between endangered, precious and rare woody species in rich forest community of Tanphu protection forest, Vietnam

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Abstract. *Huong PV, Cuong LV. 2022. The ecological interaction between endangered, precious and rare woody species in rich forest community of Tanphu protection forest, Vietnam. Biodiversitas 23: 6119-6127.* The present study was conducted to explore the ecological relationship between endangered, precious, and rare tree species and other woody tree species in the rich forest in Tanphu protection forest, Southeastern region, Vietnam. Thirty 2500 m^2 study plots (50 × 50 m) were established in the rich forest in Tanphu protection forest. The results revealed that: the rich forest comprised 38 species of woody trees, in which *Dipterocarpus alatus* Roxb was the dominant species, *Shorea guiso* Blume, *Shorea roxburghii* G.Don and *Vitex ajugiflora* Dop were co-dominant species; *Afzelia xylocarpa* (Kurz) Craib, *Dalbergia oliveri* Gamble ex Prain, *Pterocarpus macrocarpus* Kurz and *Dalbergia cochinchinensis* Pierre were four endangered, precious and rare species. In the study area, the eight pairs of species viz. *D. oliveri* - *D. alatus*; *A. xylocarpa* - *D. alatus*; *A. xylocarpa* - *S. guiso*; *D. cochinchinensis* - *D. alatus*; *D. cochinchinensis* - *S. roxburghii*; *P. macrocarpus* - *D. alatus*; *P. macrocarpus* - *V. ajugiflora* and *P. macrocarpus* - *S. guiso* were positively correlated; while two pairs of species were negatively correlated viz. *S. guiso* - *D. oliveri*; *S. guiso* - *D. cochinchinensis*. Hence, the findings from this study suggested that when choosing plant combinations, the first priority has to be the species that were positively correlated with endangered, precious, and, rare species, and to avoid the selection of negatively associated species.

Keywords: Endangered, plant community group, precious and rare species, rich forest, Tanphu protection forest, Vietnam

INTRODUCTION

In nature, biomes are formed when certain types of organisms appear, exist, and thrive in the same environmental conditions at a specific time. Different forest plant communities evolve in forest ecosystems when populations of forest plants appear, coexist, and develop together. The plant species in the community always have a certain ecological relationship with each other, they were grouped together to form and create the characteristics of each forest type (Jin et al. 2015; Zhang et al. 2015; Huong et al. 2021). Community organisms often have three relationships: negative grouping, positive grouping, and no grouping (Li et al. 2008). Studies on ecological grouping and interspecific association of plant species in nature have brought significant application values in various scientific fields (Kunwar et al. 2012). Research on ecological groupings among forest plant populations is significant in forest development, forest restoration, forest management, and forest protection, etc. (Yang et al. 2016; Gu et al. 2017; Do et al. 2019). Understanding the mechanism and principles of grouping, the relationship between the forest plant species in the group, and the existence and correlation between the forest plant species in the community will be the basis for the selection and plant combination during afforestation. It is also crucial to apply silvicultural measures such as promoting regeneration, enrichment, reclamation, and care of forests (Lan et al. 2012; Liu et al. 2019). Those values are even more meaningful for woody species with economic and conservation value in use and sustainable development (Chai et al. 2016). Vietnam's forestry development strategy for the 2021-2030 period, with a vision toward 2050, identified solutions in sustainable forest development and the afforestation of large and indigenous timber trees as critical and essential solutions. This solution contributes to the restoration of degraded forests, forest enrichment, and sustainable forest development. On the other hand, studies have also highlighted the drawbacks of the pure-species afforestation process, including the less stable forest stand structure caused by the simple forest structure, the low production of the forest, and the high risk of disease (Drössler et al. 2015).

To ensure sustainable development of planted forest stands and overcome the limitations of the pure-species afforestation method, the mixed-species afforestation method is an inevitable solution (Drössler et al. 2015; Zhao et al. 2017; Semenyutina et al. 2018; Liu et al. 2018).

The rich forest in Tanphu protection forest at Dongnai Province has estimated over 64 species of woody species belonging to 45 genera of 33 families. The plant community has some dominant species such as *Shorea*

roxburghii G.Don, *Dipterocarpus alatus* Roxb. & G.Don, *Lagerstroemia speciosa* Pers., *Shorea guiso* Blume, etc. and some endangered, precious and rare woody species, including *Dalbergia cochinchinensis* Pierre, *Dalbergia oliveri* Gamble ex Prain, *Afzelia xylocarpa* (Kurz) Craib, *Pterocarpus macrocarpus* Kurz, etc. (Bao et al. 2021). These forest plant species have been included in the list of plantation tree species by the Government of Vietnam, serving to implement Vietnam's forestry development strategy. The rich forest of Tanphu Protection Forest in Southeast Vietnam is home to many endangered, precious, and rare tree species. As a result, information on the ecological grouping characteristics of these tree species with naturally dominant plant species is appropriate for conducting a study. The research will elucidate the mechanism, principles, and characteristics of ecological grouping between endangered, precious, rare tree species and dominant plant species. Thus far, however, existing knowledge and studies have offered limited information on the ecological grouping characteristics of endangered, precious and rare tree species (Calatayud et al. 2020), particularly in the Southeastern region of Vietnam. Therefore, the primary objective of the study presented in this paper was to explore the ecological relationship between endangered, precious and rare tree species and other woody tree species in the rich forest in Tanphu protection forest, Southeastern region, Vietnam. The present study aims to find species associated well with endangered, precious, and rare species or competitive exclusion associated with them as well as dominant species. Additionally, it will contribute to a scientific basis for improving the efficiency of combination tree species, forest rehabilitation, and forest care, as same as the management, conservation and development of endangered, precious, and rare tree species.

MATERIALS AND METHODS

Study site description

The study was conducted in Tanphu Protection Forest, Dongnai Province, Southeastern region, Vietnam (N11º08'55''-11º51'30", E106º90'73"-107º23'74") (Figure 1). The study area has a tropical monsoon climate where the rainy season usually occurs from May to November and the dry season occurs from December of the previous year to April of the following year. The mean annual temperature is 25ºC (21.9ºC in December and 35.1ºC in April, respectively), and the average annual precipitation is 2100 mm (most rainfall occurs from June to October). Annual mean humidity is 80%. The average elevation of this area ranges from 80 to 120 m a.s.l. There are two main soil types in the study area: (i) Grey soil derived from granite rocks; and (ii) Reddish brown soil derived from basaltic rocks (Bao et al. 2021). The research subjects of this study are endangered, precious and rare woody species and dominant species of rich forest in tropical moist evergreen closed forest and tropical moist semi-deciduous closed forest in Tanphu Protection Forest, Dongnai Province, Vietnam. The rich forest in the study area is accounted for 13.8% of the total area of the Tanphu Protection Forest. This state has timber volume ranging from 210 to 295 $m^{3.}$ ha^{-1}, averaging 248.3 $m^{3.}$ ha^{-1}; tree density is about 620 to 860 trees ha^{-1}, the average is 660 trees ha^{-1}; the average canopy cover is 0.65, the canopy competition index (CCI) of trees in the community is 0.63 and the coefficient of variation of the CCI is about 0.34-0.9; The Gini-Simpson diversity index is estimated at 0.85-0.9, Shannon (H') of the rich forest is about 2.7-2.9. The dominant tree species include some species of some families, such as Dipterocarpaceae, Meliaceae, Sapindaceae, Myrtaceae, Fabaceae, etc. There are some endangered, precious and rare species in the study area, such as *D. cochinchinensis*, *D. oliveri*, *A. xylocarpa*, *P. macrocarpus*, etc. (Viet et al. 2019).

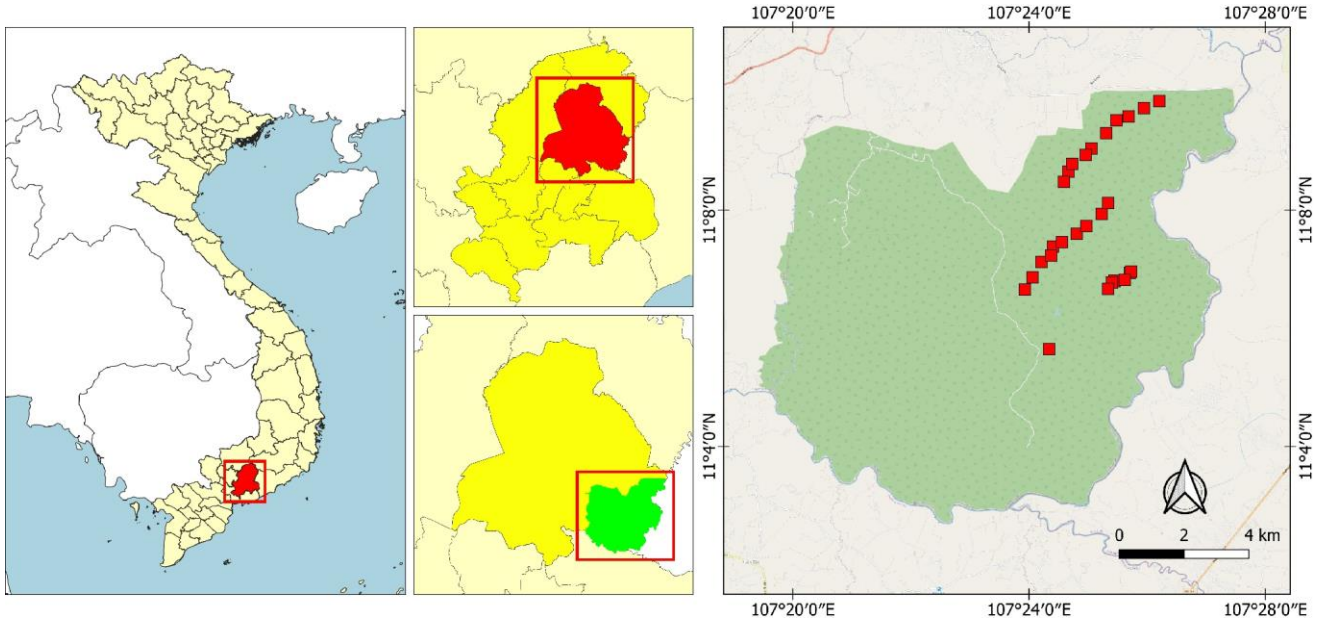

Figure 1. Map of experimental plots in Tanphu protection forest (Dongnai Province, Southeastern region, Viet Nam)

Data collection

Our research results highlight the method of analyzing ecological groupings of plant species in the community, which was proposed by Chahouki (2013) and used in the ecological analysis of forest plant communities. In the rich forest, three line transect surveys were established, each transect had a width of 50 m, and the length depended on the distribution width. On each transect, some sample plots with an area of 2500 m^2 (50m × 50m) were set up in the form of equidistant randomization, the distance between the two sample plots was 500 m. The total sample plots were 30. Each sample plot made a sub-plot (circular) with an area of 500 m^2 by rotating around the center with a radius r = 12.6m, the center of the circle is the intersection of 2 diagonals of sample plots (Figure 1).

All tree species with a diameter at the breast height (DBH) value greater than 6.0 cm were measured in each sample. The measurement indicators include species name, DBH, and the total height of tree (H). Measurement methods were carried out according to the guidelines in basic silvicultural research. In addition, some characteristics such as forest canopy cover, exposure direction, slope, and elevation above sea level were determined in the sample plot.

In the sub-plot, endangered, precious and rare tree species, as well as dominant and co-dominant tree species were identified. The probability of encountering tree species in the sub-plot used Nominal variables to calculate. If the species appeared in the sub-plot, then value "1" was assigned, if it wasn't, the value "0" was given.

Data analysis

Identification of tree species composition

The formula of species composition (SC) includes all species with an important value index (IVI, %) ≥ 5.0%. The IVI for each species in the sub-plot was calculated and the dominant species were selected according to their value of importance (Danilov et al. 2020). The IVI% was calculated as below:

$$IVI = (N\% + G\% + M\%)/3 \quad \text{eq. 1}$$

Where: N%, G% and V% are the relative density, relative trunk cross-section and relative trunk volume of tree species, respectively. The value M = g*H*F, where F = 0.45, H is the total height of tree (H, m), G is the trunk cross-sectional (G, $m^{2.}$ ha^{-1}). According to Danilov et al. (2020), The dominating tree species (with the highest IVI value) and the co-dominant species (other species with IVI values > 5%), where the overall value of the group is less than 50%, make up the species composition in tropical rainforests.

Identification of ecological groups of endangered, precious and rare plants with dominant trees species

Firstly, using the Cluster index, the Correlation Index (CI) and the Principal Component Analysis (PCA) to identify the plant groups. Next, using the method to study species-ecological relationships in tropical rainforests based on the criteria ρ and χ2 as formulas (2) and (3) (Liang et al. 2019):

$$\rho = \frac{P(AB) - P(A).P(B)}{\sqrt{P(A).(1-P(A)).P(B).(1-P(B))}} \quad \text{eq. 2}$$

$$(-1 \le \rho \le 1)$$

$$P(A) = \frac{(nA+nAB)}{n};\ P(B) = \frac{(nB+nAB)}{n};\ P(AB) = \frac{nAB}{n}$$

Where: *P(A)* is the probability of occurrence of species A; *P(B)* is the probability of occurrence of species B; *P(AB)* is the probability of occurrence of two species A and B simultaneously.

When ρ = 0, two species A and B are independent; 0 < ρ ≤ 1 then species A and B are positively associated (mutualism associated) and -1 ≤ ρ < 0 then species A and B are negatively associated (competitive exclusion associated). The direction and level of groups that are connected between the two species are indicated by ρ. When ρ value is less than 0, there is a negative relationship between the two species, and the higher the ρ value, the more competitive exclusion there is. In contrast, when ρ value > 0, two species are positively correlated, and the greater the value of |ρ|, the more the mutualism that exists between them. It is unknown whether the two species are truly associated in the case with |ρ| value roughly equal 0. At this point, the χ2 criterion must be used to test for independence. The χ2 criterion was defined in the following equation (Liang et al. 2019):

$$\chi^2 = \frac{(|ad-bc|-0.5)^2.n}{(a+b)(c+d)(a+c)(b+d)} \quad \text{eq. 3}$$

Where: a = nA is the number of sub-plots with only species A; b = nB is the number of sub-plots showing only species B; c = nAB is the number of sample plots where both species A and species B appear; d is the number of sub-plots that do not appear both species A and B and n is the total number of observation sub-plots.

The χ^2 calculated in formula (3) compares with $\chi^2_{(0.05,\ 1)}$ or $\chi^2_{(0.1,\ 1)}$ corresponding to degrees of freedom k=1. If χ^2 is smaller than $\chi^2_{(0.05,\ 1)}$ or $\chi^2_{(0.1,\ 1)}$, the relationship between the two species is Neutral. If $\chi^2 > \chi^2_{(0.05,\ 1)}$ or $\chi^2_{(0.1,\ 1)}$, then the two species are related. To consider the direction of the relationship between two species, using two criteria ρ and χ^2 simultaneously, then: between two species is positively related when $\chi^2 > \chi^2_{(0.05,\ 1)}$ or $\chi^2_{(0.1,\ 1)}$ and ρ > 0; between two species are negatively related when $\chi^2 > \chi^2_{(0.05,\ 1)}$ or $\chi^2_{(0.1,\ 1)}$ and ρ < 0 (Liang et al. 2019).

In the present study, both data processing and statistical analyses were performed using SPSS 25.0 and Primer 6 version 6.1.6 software packages.

RESULTS AND DISCUSSION

Structural and growth characteristics of tree species in rich forest

The structural features of the rich forest, such as density and volume, important value index of species, species composition and growth indicators are shown in Tables 1 and 2. The data in Table 1 demonstrates that: the average density of trees was 872 tree· ha^{-1} and the average volume was 279.7 m^{3}· ha^{-1}. There were total of 38 different species in the rich forest state, in which the species with IV% > 5.0% include *D. alatus*, *S. guiso*, *S. roxburghii*, *Vitex ajugiflora* Dop, *Syzygium wightianum* Wall., *L. speciosa*, *Cratoxylum prunifolium* (Wall.) Dyer. and *Gluta laccifera* (Pierre) Ding Hou. So, the formula of species composition of the rich forest status was: FOSC = 13.8 Dial + 12.9 Shgu + 10.4 Shro +8.6 Viaj + 7.7 Sywi + 6.6 Lasp + 6.1 Crpr + 5.5 Mela + 28.7 Others.

The average amount of individuals of the species was 23.0 tree· $species^{-1}$. *C. prunifolium* had the highest number of trees (88 tree· ha^{-1}) accounting for 10.6% of the total. However, *C. prunifolium* had a low growth index, and the ecological role (IVI% value) ranked only 7th in the community. Three species belonging to the family of Dipterocarpaceae which were *D. alatus*, *S. guiso* and *S. roxburghii* had high tree density and high growth index, so the IVI value of these three species was high. *D. alatus* was determined to be the dominant species with the highest IVI value (13.8%). In addition, all the species had IVI% > 5.0%, including four species *S. guiso*, *S. roxburghii*, *V. ajugiflora* and *S. wightianum* and the cumulative of this group was 45%. So, the total IVI value of these 5 species accounted for 53.4%. So, it can be clearly seen that, in the rich forest, the *D. alatus* was the dominant species, combined with co-dominant species such as *S. guiso*, *S. roxburghii* to form the dominant species of the Dipterocarpaceae family. It reflects the character of the rich forest in the study area, which is typical for tropical moist semi-deciduous forests. In particular, it had four endangered, precious and rare tree species, including *A. xylocarpa*, *D. oliveri*, *P. macrocarpus* and *D. cochinchinensis*. The tree density of these species was 96 tree· ha^{-1} (accounting for 11.0%), while the total IVI value of 4 species was 7.0%.

Table 2 shows that the dominant and co-dominant trees have quite good growth quality. The average DBH of these species ranges from 16.8 to 34.2 cm, the average H varies from 8.9 cm to 18.5 m depending on each species. However, the growth index of 4 endangered, precious and rare tree species is not high. Most of the individual trees of these species were in the growing stage, specifically *D. cochinchinensis* had an average density of 32 trees ha^{-1}, of which the biggest DBH was 15.6cm, the average DBH was 13.6 cm; *A. xylocarpa* had a density of 12 trees ha^{-1}, the biggest DBH was 32.5 cm, and the average DBH was 14.4 cm; *D. oliveri* had a density of 16 trees ha^{-1}, the biggest and average DBH was 19.6 cm and 12.3 cm respectively and *Pterocarpus macrocarpus* had a density of 36 trees ha^{-1}, the biggest DBH was 41.1 cm, the average DBH was 21.8 cm. These data show that most plants were low growth indexes and small trees. Some trees of four species with DBH size were quite small, indicating that these four species may have been heavily exploited in the past. Besides, it also reflects the effectiveness of forest management and protection in recent years, which has contributed to supporting these endangered, precious and rare trees to recover achieved growth as it is today.

Conservation and protection of tree species

The results of comparing tree species in the rich forest have determined the conservation and protection status of the species (Table 3).

Compared with the list of plant species in the Vietnam Red Book in 2007 (MOST 2007), four species have been identified with a conservation status of Endangered category in the rich forest including *P. macrocarpus*, *D. oliveri*, *D. cochinchinensis* and *A. xylocarpa*. According to the Vietnam Red Book, there are 10.5% of endangered species located in the rich forest in Tanphu protection forest, and this is quite a high proportion. Compared with the data of IUCN in 2022 (IUCN 2022), of the eight species found in the study area, three species are classified as Endangered category and five species are classified in the Vulnerable category. According to the IUCN (2022), the rich forest in Tanphu protection forest, Dongnai Province, Vietnam has very high conservation significance, as it has up to 21.1% of the total species which are classified as endangered and vulnerable.

Table 1. Structural characteristics of tree species in rich forest

Species name	Acronym	Density (tree· ha^{-1})	G (m^{2}· ha^{-1})	M (m^{3}· ha^{-1})	IVI (%)	Dominant level of species
Dipterocarpus alatus	Dial	68 ± 6	6.2 ± 0.4	52.0 ± 4.2	13.8	Dominant
Shorea guiso	Shgu	76 ± 6	5.9 ± 0.5	44.5 ± 4.3	12.9	Co-dominant
Shorea roxburghii	Shro	84 ± 8	4.4 ± 0.4	30.5 ± 2.8	10.4	Co-dominant
Vitex ajugiflora	Viaj	88 ± 9	3.4 ± 0.2	21.0 ± 1.9	8.6	Co-dominant
Syzygium wightianum	Sywi	72 ± 6	3.4 ± 0.3	18.2 ± 1.9	7.7	Co-dominant
Lagerstroemia speciosa	Lasp	48 ± 5	2.9 ± 0.3	20.4 ± 2.1	6.6	Co-dominant
Cratoxylum prunifolium	Crpr	92 ± 7	2.0 ± 0.2	8.2 ± 0.6	6.1	Co-dominant
Gluta laccifera	Mela	76 ± 6	1.8 ± 0.1	8.6 ± 0.7	5.4	Co-dominant
The 4 endangered, precious and rare species		96 ± 5	2.3 ± 0.2	11.9 ± 1.3	7.0	EN, V, R
Others (26 species)		172 ± 14	9.3 ± 0.7	64.6 ± 5.2	21.7	other
Total		87 ± 73	41.7 ± 3.5	279.7 ± 25.8	100	

Table 2. The growth characteristics of trees in rich forest

Species	Density (trees· plot^{-1})	Density (trees· ha^{-1})	DBH (cm)			H (m)		
			Max	Min	Average	Max	Min	Average
Dipterocarpus alatus	17	68	73.8	10.2	34.2±2.9	22.5	7.3	18.5±1.5
Shorea guiso	19	76	48.7	9.2	31.5±3.4	21.7	10.2	16.7±1.6
Shorea roxburghii	21	84	68.3	7.5	25.9±2.3	23.8	8.5	15.3±1.2
Vitex ajugiflora	22	88	36.2	7.1	22.1±1.6	16.7	5.3	13.8±1.0
Syzygium wightianum	18	72	45.2	6.4	24.7±2.1	16.7	5.6	11.7±1.0
Lagerstroemia speciosa	12	48	39.2	8.3	27.7±3.0	17.2	6.8	15.7±1.3
Cratoxylum prunifolium	23	92	27.1	6.3	16.8±1.3	13.5	4.6	8.9±0.6
Gluta laccifera	19	76	26.3	6.0	17.3±1.6	15.2	6.7	10.7±1.1
Pterocarpus macrocarpus	9	36	41.1	8.2	21.8±2.0	16.2	5.5	12.5±1.3
Dalbergia oliveri	4	16	19.6	8.3	13.5±1.1	12.3	5.6	11.5±1.0
Afzelia xylocarpa	3	12	32.5	7.2	18.2±1.5	14.4	4.5	9.7±0.6
Dalbergia cochinchinensis	8	32	15.6	6.5	13.6±1.4	10.5	4.7	8.4±0.5
Others (26 species)	43	172	103.7	6.0	26.2±2.4	23.5	4.8	15.5±1.6

Note. DBH, diameter at breast height (1.3 m); H, tree height

Table 3. Characteristics of endangered, precious and rare tree species

Species	Status of conservation and protection		
	Vietnam Red Book, 2007	IUCN, 2022	Decree No. 06
Pterocarpus macrocarpus Kurz	EN A1a,c,d	EN*	IIA
Dalbergia oliveri Gamble ex Prain	EN A1a,c,d	EN	IIA
Afzelia xylocarpa (Kurz) Craib	EN A1c,d	EN	IIA
Dalbergia cochinchinensis Pierre.	EN A1a,c,d	VU	IIA
Dipterocarpus alatus Roxb.		VU	
Shorea guiso Blume		VU	
Shorea roxburghii G.Don.		VU	
Vitex ajugiflora Dop		VU	

Note. (*) IUCN (2022): CR: Critically Endangered; EN: Endangered; VU: Vulnerable; DD: Data deficient; LR: Lower Risk; LC: Least concern; NT: Near-threatened. Vietnam Red Book (2007): CR: Critically Endangered, EN: Endangered, VU: Vulnerable. Decree No. 06 is No.06/NĐ-CP of Vietnam Government: IA: Prohibits commercial exploitation for commercial purposes; IIA: restrict exploitation for commercial purposes

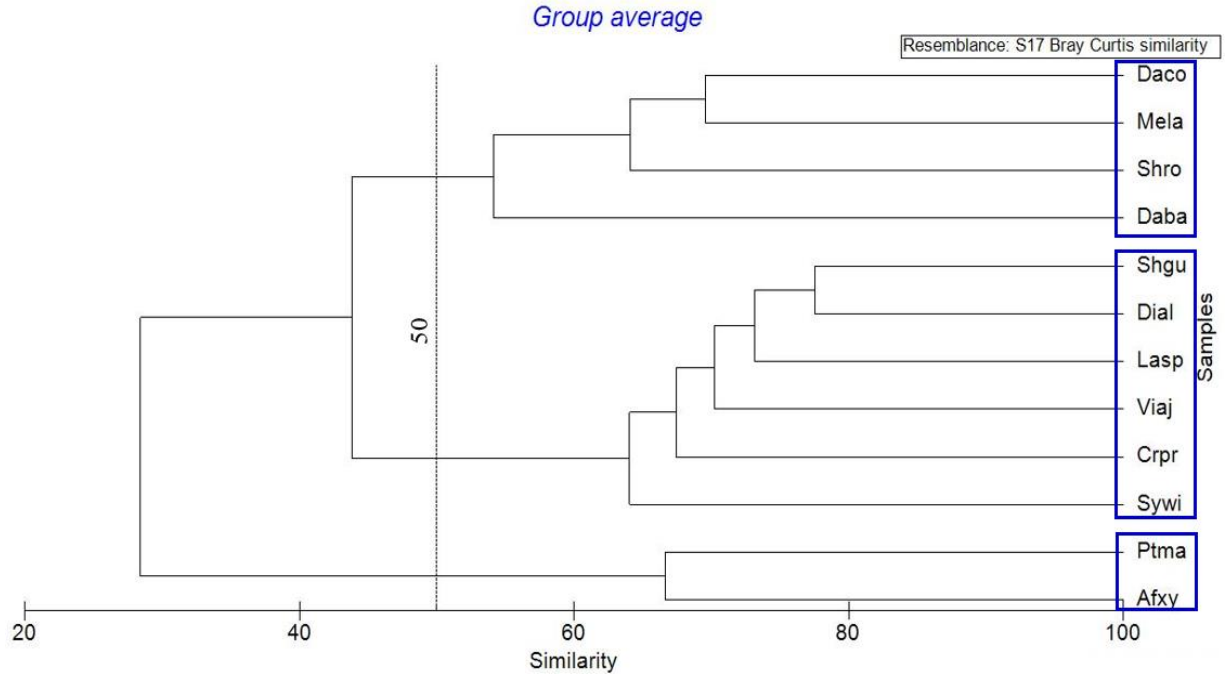

Figure 2. Dendongram showing the results of cluster analysis for plant communities

According to Decree No. 06/2019/ND-CP, dated January 22, 2019 of the Socialist Republic of Vietnam Government, it is found in a rich forest has four species listed in Appendix IIA class (restrict exploitation for commercial purposes). They are all belonging to The Fabaceae family, including *D. oliveri* Gamble ex Prain, *D. cochinchinensis*, *P. macrocarpus* and *A. xylocarpa*. They are in danger of becoming extinct if not managed strictly (GOV 2019).

Plant community groups in rich forest

Cluster analysis for plant communities

The results of clustering analysis for the plant community of the rich forest are shown in Table 4 and Figure 2.

A total of 12 species were analyzed with similarities ranging from 43% to 55%, then 4 groups of plants were identified. The first group, including *D. cochinchinensis*, *M. laccifera*, *S. roxburghii* and *D. oliveri*, this group had 2 endangered and rare species (accounting for 50%). The second group had 6 species, including: *S. guiso*, *D. alatus*, *L. speciosa*, *V. ajugiflora*, *C. prunifolium* and *S. wightianum*, this group was mostly the dominant and co-dominant species of the rich forest. The third group consisted of 2 species viz. *P. macrocarpus* and *A. xylocarpa*, which are endangered, precious and rare species.

In terms of the similarity correlation index (CI) of 12 species in Table 4, *D. alatus* was positively related with 5 species viz. as *M. laccifera*, *D. oliveri*, *A. xylocarpa*, *D. cochinchinensis* and *A. xylocarpa*. At the same time, it was negative relationship was observed with the species of *C. prunifolium*, *S. wightianum*, *S. guiso* and *L. speciosa* and it was neutral with *S. roxburghii*. Therefore *D. alatus* can be clustered with the most endangered, precious and rare species.

Shorea guiso had a positive interaction with four species: *C. prunifolium*, *S. wightianum*, *A. xylocarpa* and *P. macrocarpus*. Besides that, this species had negative plant interaction with some species, such as *D. alatus*, *M. laccifera*, *S. roxburghii*, *D. oliveri*, *D. cochinchinensis* and *L. speciosa*. The result indicates *S. guiso* had negative relationship with two endangered, valuable and rare species in community.

In addition, *V. ajugiflora* had positive relationship with species such as *P. macrocarpus* and *L. speciosa* and was neutral related to *C. prunifolium*, while other species *V. ajugiflora* was in negative plant interaction.

The data in Table 4 shows that the similarity correlation index between *M. laccifera* and *D. oliveri* has the highest value (0.60), followed by the *P. macrocarpus* - *A. xylocarpa* (0.56) and the next is *P. macrocarpus* - *D. oliveri* (0.51). These pairs with SCI value > 0.5 indicate that they have a strong ecological relationship with each other. Moreover, the pair of *D. oliveri* and *C. prunifolium* had a strong negative relationship (CI = - 0.5).

Clusters analysis of endangered, precious and rare species with dominant and co-dominant species

The cluster analysis of four endangered, precious and rare species with dominant and co-dominant species is shown in Table 5 and Figure 3.

The endangered, precious, and rare species were found in a plant community with four dominating and co-dominant species in the rich forest. *D. oliveri* had a positive correlation with *D. alatus* and a negative correlation with *S. guiso*, and was neutral with *S. roxburghii* or *V. ajugiflora*. *A. xylocarpa* had two types of interaction in the plant community which were positive with *S. guiso* and *D. alatus*; and neutral with *S. roxburghii* or *V. ajugiflora*. In contrast to *D. oliveri*, *A. xylocarpa* combines effectively with *S. guiso*, *D. alatus*, and *S. roxburghii*; nevertheless, the amount of interaction with *V. ajugiflora* is weak (= - 0.05), which is similar to neutral correlation.

Table 4. Characteristics of ecological relationships in plant community

Species	Dial	Crpr	Sywi	Mela	Shro	Viaj	Shgu	Daba	Afxy	Daco	Ptma	Lasp
Dial	1											
Crpr	-0.18	1										
Sywi	-0.18	0.03	1									
Mela	0.27	-0.41	-0.41	1								
Shro	0.00	-0.25	-0.11	0.27	1							
Viaj	-0.13	0.00	-0.29	-0.14	-0.29	1						
Shgu	-0.22	0.10	0.10	-0.17	-0.07	-0.18	1					
Daba	0.10	**-0.50**	-0.06	**0.51**	-0.06	-0.15	-0.22	1				
Afxy	0.27	0.18	0.03	-0.30	0.03	-0.05	0.11	-0.39	1			
Daco	0.07	-0.43	0.03	**0.60**	0.49	-0.21	-0.08	0.43	-0.36	1		
Ptma	0.04	-0.03	-0.03	-0.39	-0.03	0.22	0.08	-0.36	**0.56**	-0.33	1	
Lasp	-0.27	0.12	0.12	-0.30	-0.18	0.05	-0.11	-0.10	0.02	-0.32	-0.02	1

Note: Dial: *Dipterocarpus alatus*; Lasp: *Lagerstroemia speciosa*; Viaj: *Vitex ajugiflora*; Daba: *Dalbergia oliveri*; Shgu: *Shorea guiso*; Afxy: *Afzelia xylocarpa*; Ptma: *Pterocarpus macrocarpus*; Shro: *Shorea roxburghii*; Mela: *Gluta laccifera*; Crpr: *Cratoxylum prunifolium*; Daco: *Dalbergia cochinchinensis*; Sywi: *Syzygium wightianum.* Values in bold indicate strong ecological relationships between the two species

Table 5. The clusters analysis of endangered, precious and rare species (EPR) with dominant and co-dominant species (D-cD)

EPR species	D-cD species	β	χ^2	Type of grouping with level α			
				$\chi^2_{(0.05, 1)}$	α = 95%	$\chi^2_{(0.1, 1)}$	α = 90%
Dalbergia oliveri	Dial	0.10	12.90	3.84	Positive	2.71	Positive
	Shro	-0.06	0.81	3.84	Neutral	2.71	Neutral
	Viaj	-0.15	2.01	3.84	Neutral	2.71	Neutral
	Shgu	-0.22	8.31	3.84	Negative	2.71	Negative
Afzelia xylocarpa	Dial	0.27	14.37	3.84	Positive	2.71	Positive
	Shro	0.03	1.13	3.84	Neutral	2.71	Neutral
	Viaj	-0.05	2.34	3.84	Neutral	2.71	Neutral
	Shgu	0.11	10.35	3.84	Positive	2.71	Positive
Dalbergia cochinchinensis	Dial	0.07	12.24	3.84	Positive	2.71	Positive
	Shro	0.49	5.52	3.84	Positive	2.71	Positive
	Viaj	-0.08	2.12	3.84	Neutral	2.71	Neutral
	Shgu	-0.26	8.61	3.84	Negative	2.71	Negative
Pterocarpus macrocarpus	Dial	0.04	11.38	3.84	Positive	2.71	Positive
	Shro	-0.03	0.73	3.84	Neutral	2.71	Neutral
	Viaj	0.19	5.66	3.84	Positive	2.71	Positive
	Shgu	0.04	11.38	3.84	Positive	2.71	Positive

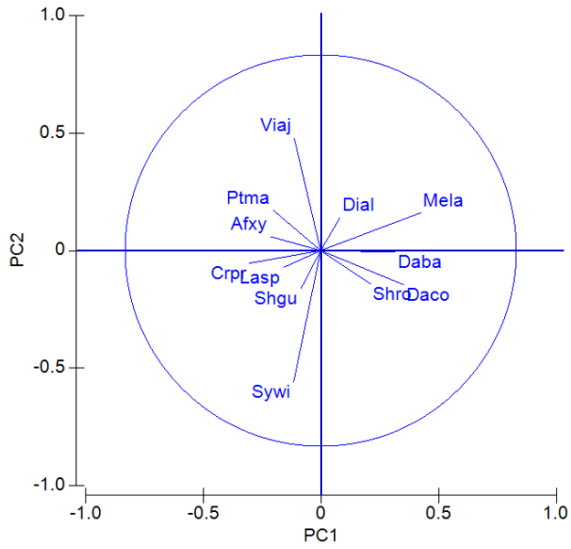

Figure 3. Grouping of 4 endangered, precious and rare species with dominant and co-dominant species

Pterocarpus macrocarpus is associated well with *S. guiso*, *V. ajugiflora*, *S. guiso* and neutrally with *S. roxburghii*. The results indicated eight pairs of positive correlations including: *D. oliveri* - *D. alatus*; *A. xylocarpa* - *D. alatus*; *A. xylocarpa* - *S. guiso*; *D. cochinchinensis* - *D. alatus*; *D. cochinchinensis* - *S. roxburghii*; *P. macrocarpus* - *D. alatus*; *P. macrocarpus* - *V. ajugiflora* and *P. macrocarpus* - *S. guiso*. It can be found that *D. alatus* is the dominant species with 100% positive association with four endangered and rare tree species; the next is *S. guiso*, which is grouped with three endangered, precious and rare species (accounting for 75%); *V. ajugiflora* and *S. roxburghii* have a positive association with only 1 endangered, precious and rare species (accounting for 25%). In combining trees in afforestation, it is necessary to avoid choosing pairs with negative correlated such as *S. guiso* - *D. oliveri*; *S. guiso* - *D. cochinchinensis*. It is possible to accept neutral correlated in a plant community, but it priority should be given to selecting pairs with positive probability ($\rho > 0$) as the pair of *A. xylocarpa* - *S. roxburghii*.

Discussion

Our study demonstrated that there were 38 woody plant species in the rich forest. The woody plant species richness in our study area is not high compared to the rich forest in the neighboring protected area of Cattien National Park (47 woody plant species in the rich forest) (Long 2020). The richness of woody plants in the study area is not high, because it may have been affected by intense selective harvesting (Silva et al. 2017; Bao et al. 2021). However, the present results also showed one dominant and seven co-dominant plant species, which represent the characteristics of tropical moist evergreen closed forest and tropical moist semi-deciduous forest in the Southeastern region of Vietnam. This finding is also congruent with the findings from previous studies (Bao et al. 2021).

In particular, the current study has identified four endangered, precious and rare plant species (*P. macrocarpus; D. oliveri*, *Afzelia xylocarpa* and *D. cochinchinensis*) in the rich forest under Tanphu Protection Forest in Southeast Vietnam. However, the number of individuals of these four tree species is still very low (ranging from 12 to 36 trees ha^{-1}), and the remaining individual trees have a rather low diameter and height. One of the important reasons for this situation is that these trees have high economic value, good wood, and are often used in handicrafts, etc., and this also attracts the attention of loggers. On the other hand, due to the effective management, protection and conservation capacity, the efficiency was not high, leading to widespread exploitation activities, thereby causing a rapid decrease in the number of individual species and only small individual trees that were not valuable for timber use (Bao et al. 2021). In the past 15 years, the Government, local authorities and forest

owners have applied drastic measures to protect and conserve endangered and rare plant species. Forest owners have also applied scientific and technical solutions to forest restoration. Therefore, endangered, precious and rare species are better protected. Although the growth index DBH and H of individual plants are not high, they are in the process of recovery and development (Ryan et al. 2013; Huong et al. 2014; Paula et al. 2014).

Our study has determined that in the plant community, there were ecological groupings among plant species with two main trends viz. positive and negative. However, when considering the relationship between the four endangered, rare, and endangered species, and the four dominant and co-dominant species, it showed that in addition to the positive and negative grouping patterns, there was also a random clustering pattern. This result is different from the study results of Souza et al. (2014) and Ruan et al. (2021, 2022) when analyzing ecological clustering in tropical evergreen broadleaved forest types. Compared with some previous studies in Vietnam, our study also indicated the degree of grouping between tree species (Nguyen et al. 2016, 2018). The current study's findings are very meaningful in the selection and combination of tree species in mixed afforestation. Based on the findings of this study, it suggested combining trees in afforestation, and it is necessary to avoid choosing pairs with negative correlation, such as *S. guiso* - *D. oliveri*; *S. guiso* - *D. cochinchinensis*. In the situation that it is possible to accept random tree groups, priority should be given to selecting pairs with positive grouping ($\rho > 0$) as the pair of *Afzelia xylocarpa* - *S. roxburghii*. Until now, the studies on selecting plant species for mixed forest plantations have been little researched or based on sentimental judgments. Therefore, in order for the research results to have higher scientific value, it is required to have an experiment to test the ecological grouping of these eight pairs of trees.

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