Interspecific association of dominant tree species in an evergreen broadleaved forest in Phu Quoc National Park, Vietnam

Nguyen Van Quy[1], Le Van Cuong[1], Nguyen Van Hop[1], Pham Thanh Ha[2], Nguyen Hong Hai[2*]
[1]*Vietnam National University of Forestry – Dong Nai Campus*
[2]*Vietnam National University of Forestry*

Mối quan hệ của các loài cây ưu thế trong rừng lá rộng thường xanh ở Vườn quốc gia Phú Quốc, Việt Nam

Nguyễn Văn Quý[1], Lê Văn Cường[1], Nguyễn Văn Hợp[1], Phạm Thanh Hà[2], Nguyễn Hồng Hải[2*]
[1]*Trường Đại học Lâm nghiệp – Phân hiệu Đồng Nai*
[2]*Trường Đại học Lâm nghiệp*
[*]*Corresponding author: hainh@vnuf.edu.vn*
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ABSTRACT
All species within a community either directly or indirectly interact with each other. Such interactions serve as the nucleus of both ecological and evolutionary processes. This study focused on dominant tree species' interspecific associations and the stability of evergreen broadleaved forest stands in Phu Quoc National Park in Kien Giang province of Vietnam. The data were analyzed using the variance ratio (VR), χ^2 test, association coefficient (AC), and the Godron stability method. At the end of 2022, we set up two 1-ha study plots (100 m × 100 m) in the strict protection zone within the national park to collect data. The results revealed that overall interspecific associations were significantly positive in medium and rich forests. The χ^2 and AC tests indicated that associations among dominant species pairs were predominantly independent. The tree communities in the study area exhibited a relatively stable succession state. However, stability levels differed among the variety of forests. As expected, the medium forest exhibited lower stability than the rich forest. Out of the seventy-eight pairs of thirteen dominant species in each study plot, eleven significantly associated pairs were found in the medium forest, and seven significantly associated were determined in the rich forest. These significant findings should be taken into consideration when planning new afforestation or forest enrichment initiatives in areas with soil and climate conditions similar to those of the study area.

Keywords:
Godron stability index, species interaction, succession stages, tropical forest, Yates's chi-squared test

TÓM TẮT
Các loài trong quần xã tương tác trực tiếp hoặc gián tiếp với nhau. Những tương tác như vậy được xem là cốt lõi của cả quá trình sinh thái và tiến hóa. Nghiên cứu này phân tích mối quan hệ của các loài cây ưu thế và sự ổn định của các lâm phần cây lá rộng thường xanh trong Vườn quốc gia Phú Quốc, tỉnh Kiên Giang, Việt Nam. Dữ liệu được phân tích thông qua các chỉ số bao gồm: tỷ lệ phương sai VR, kiểm định χ^2, hệ số liên kết AC và chỉ số Godron. Vào cuối năm 2022, hai ô tiêu chuẩn tạm thời có kích thước 1 ha (100 m × 100 m) đã được thiết lập trong phân khu bảo vệ nghiêm ngặt của Vườn quốc gia Phú Quốc để thu thập dữ liệu. Kết quả cho thấy sự tương tác tổng thể giữa các loài là tích cực trong cả trạng thái rừng trung bình và rừng giàu. Cả kiểm định χ^2 và hệ số liên kết AC đều chỉ ra rằng mối quan hệ giữa các cặp loài cây ưu thế chủ yếu là độc lập. Các quần xã thực vật trong khu vực nghiên cứu thể hiện trạng thái diễn thế tương đối ổn định. Tuy nhiên, mức độ ổn định là khác nhau giữa các trạng thái rừng khác nhau. Không khác với dự đoán ban đầu, rừng trung bình thể hiện mức độ ổn định thấp hơn so với rừng giàu. Trong số 78 cặp của 13 loài cây ưu thế xuất hiện ở mỗi ô nghiên cứu, 11 cặp có mối quan hệ có ý nghĩa thống kê trong rừng trung bình, trong khi con số này là 7 cặp ở rừng giàu. Mối quan hệ giữa những cặp loài cây này cần phải được xem xét cẩn thận khi thực hiện các chương trình trồng rừng mới hoặc làm giàu rừng ở những khu vực có điều kiện lập địa và khí hậu tương đồng so với khu vực nghiên cứu.

Từ khóa:
Các giai đoạn diễn thế, chỉ số Godron, kiểm định χ^2 của Yates, tương tác loài, rừng nhiệt đới

1. INTRODUCTION

Forest successional stages refer to plant species abundance and composition changes over time as they interact and adapt to changing environmental conditions [1, 2]. As a new species immigrate into a community, it competes with existing species for nutrients, light, and space [3, 4]. In some cases, certain species may facilitate the growth of others, such as nitrogen-fixing plant species that increase soil fertility and support neighbours' development [5].

Interspecific associations are the foundation for forming and evolving ecological communities [6]. They result from species interactions. These interactions can be positive (facilitation) or negative (competition) interactions, affecting the growth and survival of species in the community [7]. Various factors can influence interspecific associations, including the physical environment, resource availability, and each species' biological traits. Some species may compete for the same resources and limit each other's growth, while others may have complementary resource needs and support the development of companion species. Studying interspecific associations and their effects on forest successional stages is essential for understanding the dynamics of plant communities [8, 9]. This knowledge can inform management practices aimed at preserving or restoring forest ecosystems and biodiversity conservation efforts. For example, if certain species are facilitators of other plant species, efforts could be made to plant and protect them. This approach will promote establishing and growing vital species in forest stands.

Another critical aspect of forest plant community stability is its structure and function. This issue includes species richness, diversity, and evenness, as well as ecological functions such as nutrient cycling and carbon sequestration. Community stability and structure can be assessed through various methods, including environmental indicators, statistical models, and mathematical simulations, for example, the Godron stability index [10]. Understanding community stability and structure can inform management practices promoting forests' long-term health and sustainability.

Ecosystems in islands are characterized by an amalgamation of land and sea features, forming a unique ecological assemblage with distinct resources, environmental vulnerability, and system integrity [11]. The island's isolation reduces the external exchange of materials and energy and creates an ecosystem confined to its boundaries [12]. These features make island ecosystems an ecosystem archetype [11]. However, the rapid development of the marine economy and extensive urbanization in island ecosystems leads to increasing conflict between human activities and the environment [13]. The island vegetation plays a crucial role in maintaining the balance of such ecological systems [14]. Therefore, studying the association between plant species on islands is essential to preserving and sustaining these unique ecosystems.

In 2022, two study plots with 1 ha each were established within the evergreen broadleaved forest in Phu Quoc National Park, Phu Quoc Island, Kien Giang province, Vietnam. Our objectives are to collect data to answer the following research inquiries: (i) What are the interspecific associations and interactions among dominant tree species in the evergreen broadleaved forest in Phu Quoc Island? (ii) Do the plant communities exhibit various levels of stability across different evergreen broadleaved forests? (We anticipated that the medium forest displayed lower stability than the rich forest) (iii) What is the current succession stage of plant communities in the study area?

2. RESEARCH METHODOLOGY

2.1. Study area

The study was conducted in Phu Quoc National Park, Phu Quoc Island, Phu Quoc district, Kien Giang province, Vietnam. The Phu Quoc National Park manages a total forest land area of about 29,135.9 hectares. This park is situated between 10°12'7" to 10°27'2" North latitude and 103°50'4" to 104°04'40" East longitude. Phu Quoc Island belongs to the tropical monsoon climate zone, equatorial and influenced by ocean dynamics. The area experiences two distinct seasons - the rainy season from May to October and the dry season from November to April. The average temperature is 27.1°C, and the average rainfall is 3,037 mm. The terrain elevation declines from north to south and west to east, ranging from 20-603 m *a.s.l* with slopes varying from 5-45° [15].

Two 1-ha study plots were set up inside the Phu Quoc National Park's strict protection zone to collect data. The first plot, P1, was situated at 10°23'2.80" N latitude and 104° 0'47.03" E longitude. The second one, P2, was situated at 10°20'50.43" N latitude and 104° 3'17.40" E longitude. The dominant tree species in the study region include *Hopea pierrei*, *Diospyros venosa*, *Syzygium cuminii*, *Memecylon ligustrinum*, *Garcinia delpyana*, *Olea dioica*, *Garcinia vilersiana*, *Syzygium zeylanicum*, and

Diospyros sylvatica [15].

2.2. Field measurements

Surveys spanned from August to December 2022 and consisted of four field trips. The grid-based sampling method was used to ensure the accuracy and completeness of data collection. The 1-ha study plot was divided into 100 subplots, each measuring 10 m long, resulting in a total area of 100 m^2 per subplot. Within each subplot, all trees with a diameter at breast height (dbh) ≥ 5 cm were collected information. A comparative morphology method and reference materials like Plants of Vietnam and Vietnam Forest Trees [16, 17] were used to determine the species name of each tree in the subplots. The scientific names of trees were standardized using Kew Royal Botanic Gardens [18] and World Flora Online [19] information. A diameter calliper was used to measure tree dbh, and the total height of each tree was measured by a Blume-Leiss meter. The reference system's origin was established at the intersection point of the two edges of the study plot in the north and south directions. A laser distance meter (Leica Disto-D2) and a compass were used to record the relative coordinates of each tree within the study plot.

2.3. Data analysis

2.3.1. Importance values

The importance value index (IVI) was used to assess the status and role of each species in a community. This index was computed as the mean of the relative abundance (RA), relative frequency (RF), and relative dominance (RD) of a species. We employed the IVI to identify the dominant tree species in the present study. The IVI was determined using the following equations [8].

$$IVI = (RA + RD + RF)\,/\,3 \qquad (1)$$

$$RA = a_i \,/\, \sum_{i=1}^{S} a_i \qquad RD = d_i \,/\, \sum_{i=1}^{S} d_i \qquad RF = f_i \,/\, \sum_{i=1}^{S} f_i \qquad (2)$$

where,

a_i is the number of individuals of species i;

d_i is the basal area at the height of 1.3 m of species I;

f_i is the number of subplots in which the species i appears;

and S is the total number of species.

Species interaction occurs only when the presence of one species affects another's presence. In simpler terms, for species to interact, they must inhabit the same area [3]. With this premise in mind, we selected the species for the species association analysis in our study based on their IVI and utilizing the hierarchical clustering method. Hierarchical clustering is a technique that groups similar objects into clusters by their similarities. These similarities include species abundance, distribution, size, or ecological role. Hierarchical clustering was implemented for our study by applying the Bray-Curtis similarity index to species based on their varying abundance across different subplots [20]. Creating a dendrogram—a tree-like diagram representing the hierarchical clustering—will determine groups of tree species that often co-occur or share similar ecological characteristics in the study plot.

2.3.2. Classification of evergreen broadleaved forests

The classification of evergreen broadleaved forests in the study area was based on the stand volumes and Circular No. 33/2018 issued by the Vietnam Ministry of Agriculture and Rural Development. According to this classification, the rich forest is defined as having a volume of over 200 m^3 ha^{-1}, the medium forest has a volume ranging from 100-200 m^3 ha^{-1}, and the poor forest has a volume of less than 100 m^3 ha^{-1} [21].

2.3.3. Overall species association (multiple-species case)

We employed the variance ratio (VR) test to examine the overall association among the various species, and the significance of this relationship was assessed using the W statistic value [22]. The formulas used for these calculations are presented below:

$$VR = S_T^2 \,/\, \delta_T^2 = \left[\frac{1}{N}\sum_{i=1}^{N}\left(T_j \quad t\right)^2\right] \Big/ \sum_{i=1}^{S} P_i \times (1 \quad P_i)$$
$$P_i = \frac{n_i}{N} \qquad W = VR \times N \qquad (3)$$

where,

n_i is the number of subplots that contain species i;

N is the total number of subplots;

S is the total number of species;

T_j is the number of species occurring in subplot j;

and t is the average number of species in subplots.

If VR > 1, species have a positive association; if VR < 1, species have a negative association. VR = 1 indicates that species have no associations since they are assumed independent. The overall interspecific association is not considered significant (P > 0.05) if $\chi^2_{0.95(N)}$ < W < $\chi^2_{0.05(N)}$, where W is the VR of all species. If W is less than $\chi^2_{0.95(N)}$ or greater than $\chi^2_{0.05(N)}$, then the association is significant (P < 0.05).

2.3.4. Test of species association (two-species case)

A null hypothesis was employed to assess interspecific associations, assuming that the species under investigation are independent of one another. We used a corrected χ^2 test to test this null hypothesis and applied Yates's correction formula to the 2×2 contingency table [23]. This approach allowed the study to determine whether any observed associations among the species were statistically significant or could have arisen by chance alone.

$$\chi^2 = \frac{n\,(|ad-bc|-0.5n)^2}{(a+b)\,(a+c)\,(b+d)\,(c+d)} \qquad (4)$$

where,

n represents the total number of subplots examined;

a represents the number of subplots in which both species A and B co-occurred;

b represents the number of subplots containing only species A;

c represents the number of subplots containing only species B;

and d represents the number of subplots without either species A or B.

If χ^2 < 3.841, the two species exhibit independent associations. If the value of χ^2 is between 3.841 and 6.635, species A and B exhibit a certain degree of association. If χ^2 > 6.635, species A and B demonstrate a significant association. The interspecific association between species A and B can also be identified by comparing the values of ad and bc. If ad > bc, species A and B interact positively. Conversely, if ad < bc, species A and B interact negatively.

2.3.5. Measures of species association (two-species case)

The association coefficient (AC) index was utilized to validate the results of the χ2 test further and determine the strength of associations [22].

$$AC = \begin{cases} (ad\text{-}bc)/[(a+b)(b+d)] & (ad \geq bc) \\ (ad\text{-}bc)/[(a+b)(a+c)] & (ad < bc,\ d \geq a) \\ (ad\text{-}bc)/[(b+d)(d+c)] & (bc > ad,\ d < a) \end{cases} \qquad (5)$$

The AC value ranges between 0 and 1 and estimates the strength of the association among the species. The AC = 1 represents a complete positive association where species A and B are present in all subplots, and no subplot contains only one of the two species. Conversely, when the AC = -1, there is a complete negative association between the two species, implying that no subplots contain both species together. The AC = 0 indicates that species have no association whatsoever.

2.3.6. Community's stability

The Godron stability index was employed to evaluate the community's stability [8]. Firstly, all tree species in each subplot were arranged in ascending order of frequency. Then, the relative frequency of each species was computed by dividing its frequency by the total frequency of all species. Besides, the reciprocal of the total species was determined by dividing one by the total number of species. The accumulative relative frequency was utilized as the dependent variable, while the accumulative reciprocal frequency was the independent variable. Next, a binomial equation was simulated using the smoothed scatter plot curve. The coordinates of the intersection points were obtained by finding where this simulation equation intersected the equation y = -x + 100. Finally, the stability of the community was evaluated based on the Godron stability judgment method by comparing the obtained coordinates with the coordinate of the community stability point (20, 80). The greater the proximity of the obtained coordinates to this point (20, 80), the greater the stability of the community.

All statistical analyses in this study were performed using R version 4.3.0. The species association indexes were calculated using two

R packages, '*spaa*' and '*corrplot*'.

3. RESULTS

3.1. Basic characteristics of the stands

A total of sixty-four tree species were identified on two 1-ha study plots (Table 1). Forty-eight species were recorded in Plot P1 (medium forest), while fifty-one were found in Plot P2 (rich forest). Thirty-five species appeared in both study plots. Only six out of the forty-eight species in Plot P1 had an IVI > 5% and were considered ecologically significant. These six species were: *A. quocense, H. pierrei, H. ferrea, S. roxburghii, G. delpiana,* and *S. cinereum*. In Plot P2, nine out of fifty-one species were considered ecologically significant, with an IVI > 5%. These nine species were: *A. quocense, H. pierrei, H. ferrea, S. roxburghii, D. sylvatica, S. saman, D. crumenata, S. cuminii,* and *S. superba*.

Table 1. Basic information on the study plots

No.	Scientific name	Code	P1			P2		
			N	IVI	V	N	IVI	V
1	*Archidendron quocense*	AQU	267	14.8	37.41	105	9.3	37.02
2	*Hopea pierrei*	HPI	199	7.8	9.98	297	12.1	17.15
3	*Hopea ferrea*	HFE	152	6.8	8.84	91	5.1	9.02
4	*Shorea roxburghii*	SRO	129	6.3	6.52	109	7	16.96
5	*Garcinia delpiana*	GDE	125	5.8	4.12	73	4	3.32
6	*Diospyros sylvatica*	DSY	111	4.9	4.07	78	5.3	11.56
7	*Samanea saman*	SSA	85	4.5	5.33	73	5.7	19.85
8	*Memecylon edule*	MED	102	4.4	3.71	62	3.5	3.43
9	*Diospyros crumenata*	DCR	94	4.2	3.07	117	5.6	4.10
10	*Syzygium cuminii*	SCU	65	3.7	4.80	129	6.9	12.21
11	*Schima superba*	SSU	48	3.6	8.12	63	6.6	29.16
12	*Syzygium cinereum*	SCI	300	11.9	15.80	-	-	-
13	*Syzygium zeylanicum*	SZE	57	3.5	7.02	-	-	-
14	*Vatica cinerea*	VCI	-	-	-	63	3.8	7.33
15	*Garcinia vilersiana*	GVI	-	-	-	71	3.5	1.64
16	Thirteen co-dominant species		1734	82.2	118.79	1331	78.6	172.75
17	Others		315	17.8	25.24	340	21.4	30.42
18	All		2049	100	144.04	1671	100	203.17

Note: Code - Abbreviation of species name; N - Density (number of individuals ha^{-1}); IVI - importance value index (%); V - stand volume (m^3 ha^{-1}).

The species within the two study plots were analyzed using the IVI of species and hierarchical clustering technique. The result indicated that the species in plots P1 and P2 were separated into two branches at 53% and 51% similarity degrees on the dendrogram, respectively. We are drawn towards examining the association of species belonging to the same branch with an IVI > 3%. The outcomes of the hierarchical clustering analysis are displayed in Figure 1.

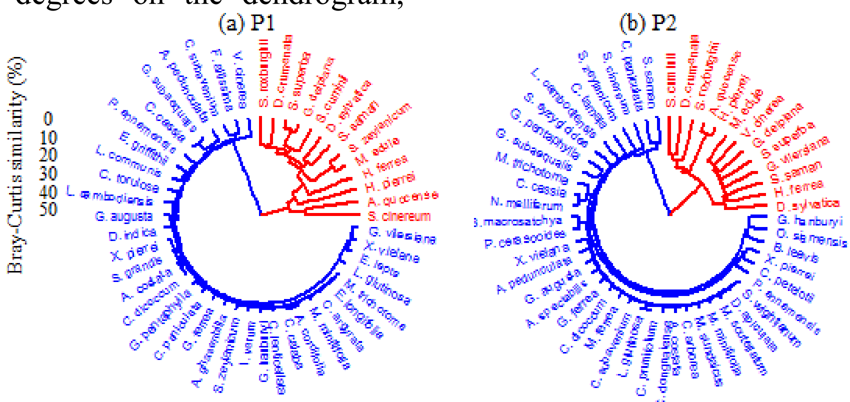

Figure 1. The dendrogram illustrating the results of hierarchical clustering for tree species surveyed in the study plots

(The dendrogram displays thirteen tree species with an IVI > 3% forming a separate branch at a similarity threshold of 53% in Plot P1(a) and 51% in Plot P2 (b); species on the dendrogram sharing the same color belong to the same branch)

3.2. Overall interspecific association

Table 2 presents the overall interspecific association among dominant species in the stands. The results showed that the overall interspecific association in medium (P1) and rich (P2) forests was positively associated with a VR > 1. The χ^2 test further confirmed the significant overall interspecific association. This finding suggested that the tree species in medium and rich forests maintain a relatively stable stage and seem to exist in a mutually beneficial symbiotic relationship.

Table 2. Overall association among dominant species

Study plots	Variance ratio (VR)	Test statistics (W)	$\chi^2_{0.95(100)}, \chi^2_{0.05(100)}$	Test results
P1	1.58	158.31	77.92, 124.34	a significant association
P2	1.54	154.69	77.92, 124.34	a significant association

3.3. Associations between dominant species pairs

The χ2 test was used to determine the significance of interspecific associations among dominant species. The result revealed that a higher proportion of positive associations was observed among the seventy-eight species pairs of thirteen dominant species in each study plot than independent and negative ones (Fig. 2). For instance, in Plot P1, the proportion of positive, independent, and negative association pairs was 1.45:1.09:1. Meanwhile, in Plot P2, it was 1.57:1.14:1. Moreover, significant differences were noted between the two study plots concerning the number of species pairs with a significant association. In Plot P1 (Fig. 2a), eleven species pairs were found to have significant associations, including ten pairs with positive associations (*S. superba – D. crumenata*, *M. edule – S. roxburghii*, *S. superba - S. roxburghii*, *G. delpiana - S. roxburghii*, *D. crumenata – D. sylvatica*, *D. crumenata – S. cuminii*, *S. cuminii – S. cinereum*, *G. delpiana – S. cinereum*, *D. crumenata – A. queens*, and *H. pierrei - A. queens*) and one pair with a negative association (*D. sylvatica – S. zeylanicum*). Meanwhile, in Plot P2 (Fig. 2b), seven species pairs demonstrated significant associations. Specifically, five species pairs displayed positive (*S. superba – H. ferrea*, *V. cinerea – D. sylvatica*, *D. crumenata – S. cuminii*, *S. cuminii – A. queens*, and *M. edule – G. vilersiana*), and two had negative associations (*S. saman – V. cinerea*, and *H. pierrei – M. edule*). Most dominant species pairs did not show significant associations, indicating primarily independent interspecific associations of dominant species. Specifically, there were no significant associations between sixty-seven of the seventy-eight species pairs in Plot P1 and seventy-one of the seventy-eight species pairs in Plot P2.

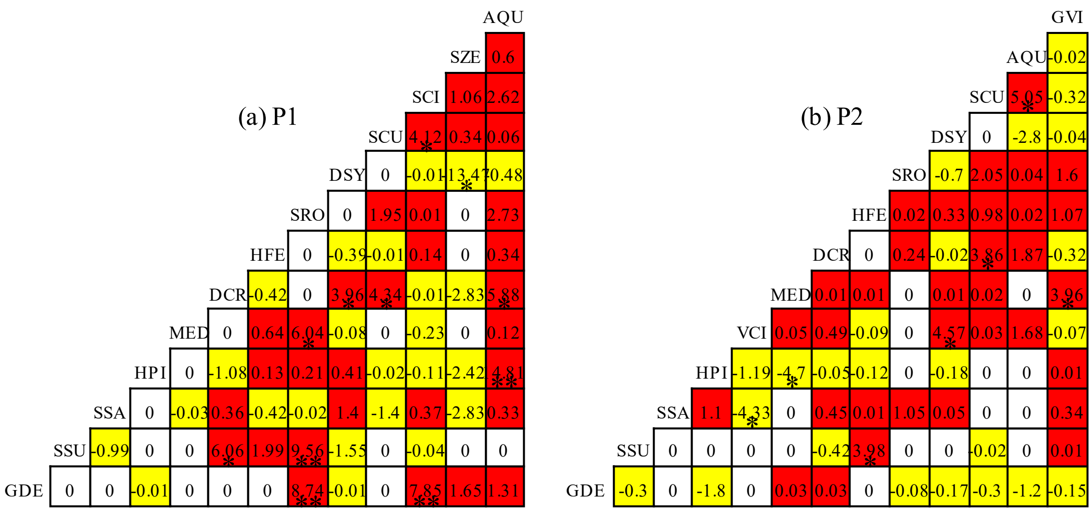

Figure 2. Half matrix diagrams of χ^2 test for the association of dominant tree species in the study plots
*(Positive (VR >0), negative (VR <0), and no associations (VR =0) are represented in red, yellow, and white, respectively; species codes correspond to those in Table 1; *: P < 0.05; **: P < 0.01)*

The analysis of the AC index revealed that in Plot P1, among a total of seventy-eight pairs of thirteen dominant species, eleven pairs exhibited a strong association with an AC value ranging from -0.5 to 0.5 (Fig. 3a). Conversely, there were seven species pairs strongly associated in Plot P2 (Fig. 3b). These findings align with the results obtained from the χ^2 test, suggesting that most associations among dominant species are independent of each other.

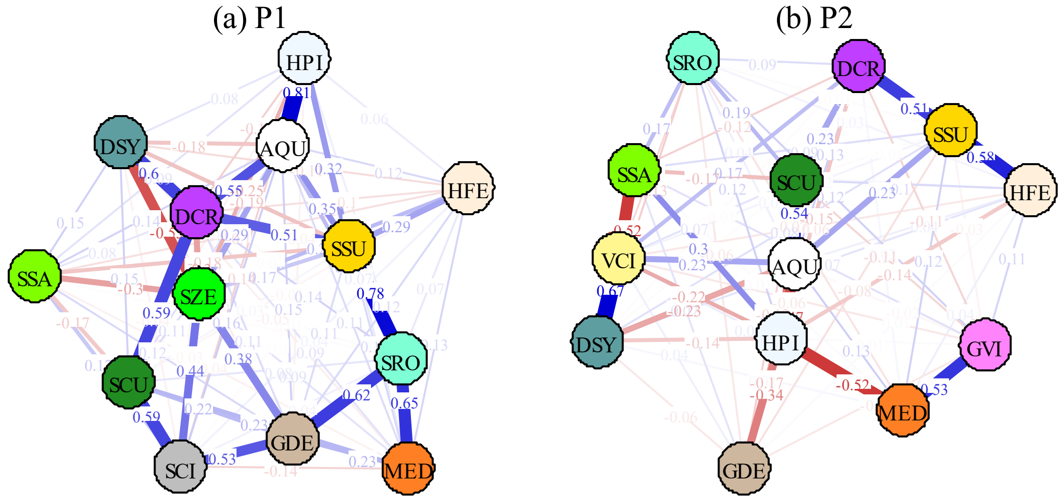

Figure 3. Association network of the AC index among dominant tree species in the study plots

(Positive and negative associations appear in blue and red, respectively. Species codes match those in Table 1. The intensity of the green and red lines reflects the absolute value of the AC index)

3.4. Stability of the community

The scatter plots of Godron and the calculated results of communities in different forests are presented in Figure 4. The analysis revealed that the distances between the intersection point of the two regression models and the stable point (20, 80) were 9.65 for the medium forest (See Fig. 4a) and 7.49 for the rich forest (Refer to Fig. 4b). Based on the Godron stability assessment method, it could be inferred that the medium forest exhibited a lower level of community stability than the rich forest.

Based on the analytical results of the Godron stability index and the overall interspecific association among the dominant tree species in the stands, it is evident that the forest communities in the study area are at a relatively stable succession stage.

4. DISCUSSION

4.1. Associations among the dominant species

Studying the overall association of tree species is essential in determining community stability, a crucial aspect of ecology [24]. Previous studies have demonstrated that tree species engage in competition and facilitative interactions as a community undergoes succession to optimize resource utilization [25]. This process contributes to changes in tree species composition, leading to a more stable community structure [8]. Ultimately, the coexisting species within the community tend to exhibit a positive overall association [26]. However, it is noteworthy that while the overall association is positive, the association between species pairs tends to be independent [27]. The association between species reflects the reciprocal interactions among species within the same habitat. Numerous studies in forest ecology utilizing species co-occurrence data have suggested that species pairs with a positive association exhibit similar responses to changes in habitat or demonstrate similarities in resource utilization [25]. On the other hand, species pairs with a negative association typically exhibit varying responses to changing environmental conditions [22]. In the independent association case, species interactions are negative or facilitating remains unclear [7].

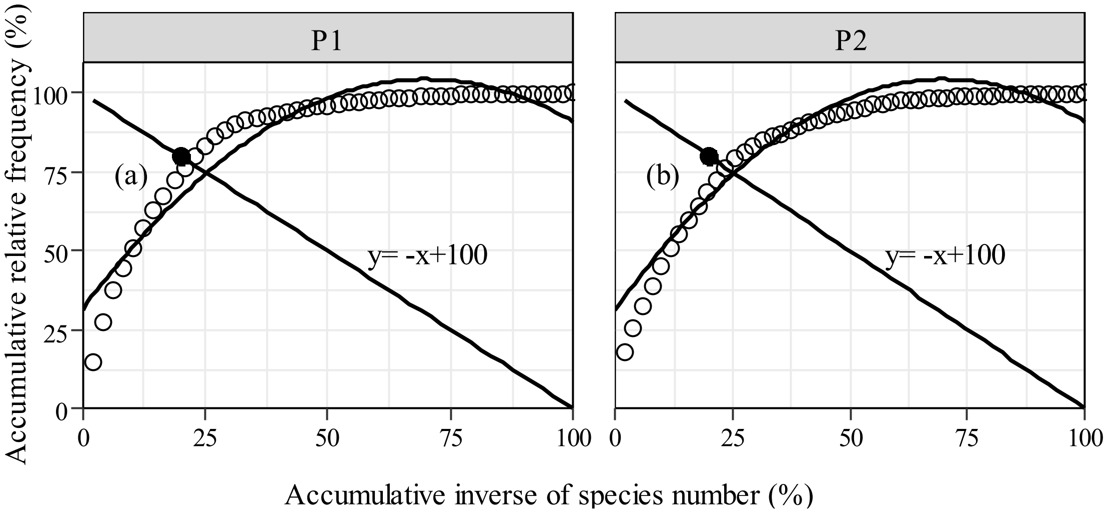

Figure 4. Community stability diagrams of dominant tree species in the study plots
(The black symbol is a stable point (20, 80) according to the Godron stability method)

The χ^2 test in our study examines whether the associations between species pairs are significant. Concurrently, we employed the AC index to evaluate the strength of these associations. Our analytical results using χ^2 and AC showed that positive species associations have accounted for a higher proportion than negative associations. However, most of them were statistically insignificant. These findings suggested that dominant species in the medium and rich forests exhibit positive interactions, but interaction intensity was weak. To explain the prevalence of independent associations between species pairs compared to significant positive and negative associations in our study, we support the viewpoint of Li *et al.* [28]. These authors suggested that the high proportion of independent associations in tropical forest ecosystems results from the highly diverse community and complex structure. The high diversity of tropical forests leads to a low probability of encounters between species, making non-associations between species common. Many other authors have obtained similar results to our study using other techniques for analyzing interspecific associations, such as spatial point pattern analysis or the nearest neighbour method. For instance, Nguyen Hong Hai *et al.* [29] found that independent associations accounted for a high proportion (> 50%) among 420 tree species pairs in the evergreen broadleaved forests of Central Vietnam, compared to attracted and repulsed patterns. Velázquez et al. [30] discovered that nearly 50% of the 64 species had no significant associations within a 50-ha study plot in tropical forests on Barro Colorado Island. Together with previous studies, our study once and again confirmed that independent associations among species are common in tropical forests.

Although employing the same method to study the interspecific associations of tree species in the evergreen broadleaved forest, our study yielded different results from those conducted by Pham Van Huong *et al.* [31] and Pham Van Huong & Le Van Cuong [32]. These authors discovered higher proportions of positive and negative associations than no associations. The discrepancies between our study and these authors can be explained as follows: Firstly, our study analyzed species associations within subplots of the same study plot, whereas the two studies mentioned above-collected data from scattered subplots. Secondly, our study utilized the Yates-corrected χ^2 test, while the two studies above used the uncorrected χ^2 test. Recent studies have demonstrated the effectiveness of grid-based sampling in studying the interspecific associations of plant species or less mobile organisms. Blanchet *et al.* [33] maintained that the simultaneous occurrence of species in scattered subplots does not necessarily indicate species interaction. Barner *et al.* [34] also criticized studies that equate species interactions and their occurrence across scattered quadrats. It is relatively easy to observe that most plant species are not moving throughout their life stages, except the seed dispersal stage.

Consequently, species interactions primarily occur within neighboring scales of approximately 30 m, as numerous studies have acknowledged [29]. The presence-absence data of species within scattered subplots can interfere with detecting species interactions. In addition, when examining species associations by a checkerboard distribution, using the χ^2 test to evaluate the significance of associations is crucial. The uncorrected χ^2 test is often less rigorous and may result in more rejected null hypotheses. In contrast, the Yates-corrected χ^2 test is more rigorous, reducing the likelihood of Type I errors in hypothesis testing and has gained increased recognition in recent years. Hence, we can confidently assert the reliability of our study results by employing the Yates-corrected χ^2 test and utilizing a grid-based sampling method for data collection.

4.2. Stability of tree communities

Previous studies assessing community stability relied on the VR index. These studies suggested that if VR >1, the community would be relatively stable, whereas if VR < 1, the community would be unstable [10]. Based on the calculated VR values for two medium and rich forest stands in our study, it can be observed that both forest stands exhibited stability. However, we found that the VR index alone could not compare the level of stability between the two different stands. This issue prompted the need for an additional index to compare the stands' stability, and it led us to insert the Godron stability index into this study. The results showed that the medium forest exhibited lower stability than the rich forest. This could be attributed to the lower species complexity in the medium forest compared to the rich forest. Specifically, the medium forest recorded only forty-eight species in the 1-ha study plot, whereas the rich forest had fifty-one species. Our findings align with previous studies, such as the study by Jin *et al.* [8], which suggested that communities with complex species compositions tend to form dominant species groups and exhibit higher stability than communities with more straightforward species compositions. Li *et al.* [28] also argued that higher species diversity within a community promotes the ecological niche differentiation of species and enhances plant community stability.

When it comes to restoring vegetation or forest enrichment, mimicking the laws of natural forests can minimize unforeseen risks. However, according to the findings of this study, proposing a comprehensive list of tree species suitable for restoring forest areas with similar soil conditions and climates to the study area is not feasible due to the requirement for further analysis regarding species relationships across various spatial scales. This limitation makes it impossible to know a reasonable planting hole distance. Nevertheless, this does not undermine the scientific value of the present study. Assessing the stability of the stands forms the basis for planning the management and conservation of forest biodiversity. Moreover, the association between dominant species in this study is a valuable reference for planting or enriching the forest programs in the study area.

5. CONCLUSIONS

Our analyses revealed a significant positive overall interspecific association between the dominant tree species in the evergreen broadleaved forest on Phu Quoc Island, Vietnam. However, the interspecies associations among dominant species pairs mainly showed independence. Currently, the plant communities in the study area demonstrate relative stability regarding species composition and interactions, known as the climax community state. The stability level varies among forests, with the rich forest exhibiting higher stability than the medium. Out of the seventy-eight dominant species pairs examined, eleven pairs displayed significant associations in the medium forest, while seven were observed in the rich forest. It is crucial to carefully consider the associations among these species pairs when implementing afforestation or enrichment programs in areas with similar soil and climatic conditions as the study area. Further investigation of interspecies associations at different spatial scales is recommended for future studies. This approach will determine appropriate planting hole distances, enhancing the effectiveness of afforestation and enrichment programs.

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