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Diversity of Woody Plants in Dak Nong's Natural Forests, Vietnam

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Abstract

The objective of this study is to quantify the species composition and diversity of woody plant species (WPS) measured from six natural forests in Dak Nong province, which are managed in different ways. Additionally, the changes in WPS diversity according to topographic gradients (e.g., elevation and slope) were examined. The Hill number was applied to quantify the diversity of the WPS. The Jaccard coefficient and non-metric multidimensional scaling were used to compare the WPS among the forests. A total of 518 species representing 76 families were recorded in 181 sample plots (30m x 30m). The Fagaceae family is the most dominant in the forest with 45 species, followed by Lauraceae (40 species) and Euphorbiaceae (31 species). The lowest Hill number value was found in Dak R'Mang - Protection Forest Management Board (PFMB), whereas the highest value was observed in Nam Cat Tien PFMB and Ta Dung National Park (NP). The composition of the WPS varies among different forests and elevation gradients. Dak R'Mang PFMB presents the most significant difference in the diversity of woody species. A unimodal trend was found between tree species diversity and elevation gradients, which is consistent with natural expectations. Specifically, the diversity indices showed a trend of decreasing from H1 to H3 (<600m a.s.l (H1); 600 - 800m a.s.l (H2); 800 -1000m a.s.l) and increasing at higher elevations. The highest diversity index value was found at H6 (≥1400m a.s.l). This implies that species diversity may be influenced by human activities during the forest use history as well as microclimates.

Keywords: Woody plant species; diversity indices; elevational gradients; slope gradients

Introduction

Tropical forests are home to the majority of the Earth's terrestrial biodiversity . Unfortunately, activities such as deforestation, selective logging, and climate change have significantly degraded biodiversity (Phillips). The impact of tropical deforestation is profound, leading to population declines in many species and potentially driving some to extinction (Lewis).

Measuring biodiversity is crucial in ecology and conservation biology (Feroz, Enamul Kabir and Hagihara).The most frequently used metrics for assessing species diversity include the Shannon function, species richness (total number of species), and evenness (distribution of abundance among species, also known as equitability). Hill combined species richness and species abundance into a series of diversity measures, now known as Hill numbers (Hill).

One of the most fundamental and noticeable features of natural forest ecosystems is the spatial variation in botanical composition (Jost, Chao and Chazdon). Assessing the dissimilarity between forest communities is crucial for understanding changes in species composition due to various impacts. Jaccard (1900) introduced a method for measuring the similarity and dissimilarity of communities (Jaccard distance) based on the number of shared and distinct species in each community (Jaccard). In addition to the Jaccard index, the Sørensen index and Bray-Curtis index are widely used to evaluate the similarity and dissimilarity between forest communities (Curtis and McIntosh; Sørensen et al.).

Topography significantly influences the distribution of vegetation (Sebastiá). Numerous studies have investigated changes in species composition along elevational and slope gradients (Lovett, Marshall and Carr; Williams-Linera, Toledo-Garibaldi and Hernández; Dorji et al.), revealing various trends in species diversity. Song and Cao (2017) found that species richness exhibited a significant unimodal response to altitude (Song and Cao). Sinha, and Robinson observed a negative correlation between species richness and the Shannon H' index with elevational gradients, while the Simpson index showed a positive correlation with elevation (Sinha et al.; Robinson et al.). Conversely, Cui and Zheng reported a significant positive relationship between tree species diversity and altitude (Cui and Zheng). Liu et al. also noted significant changes in species composition and diversity along topographical gradients (Liu, Yunhong and Slik), though the relationship between slope and species diversity was not statistically significant according to Song and Cao and Robinson et al.

The Central Highlands of Vietnam are characterized by diverse environmental conditions that result in a wide variety of ecosystems, making this region one of the most biodiverse in Vietnam. Dak Nong, a province in the Central Highlands, is particularly notable for its biodiversity, housing many endemic species. However, past land use practices have led to the conversion of several large forested areas for agriculture and hydropower, causing a significant loss of species diversity and high CO2 emissions. The varying levels of human disturbance and land use history have resulted in the forests of Dak Nong becoming a mosaic of different plant communities, each with differing degrees of degradation. The remaining natural forests in this province are managed in various ways, including strictly protected areas (national parks and nature reserves), protection forest management boards (PFMBs), forestry enterprises, and community forests managed by local communities.

The diversity of woody species in the natural forests of Dak Nong province has attracted considerable interest. Most previous studies have primarily focused on determining species composition and distribution. Additionally, little attention has been given to exploring the effects of elevation, slope, and different forms of forest management on biodiversity in the region, with the exception of Nguyen and Chau. Therefore, this study aims (i) to quantify the composition and diversity of woody plant species using Hill numbers and (Jalli et al.) to analyze the impact of different topographic gradients (e.g., elevation, slope) and forest management forms on species composition using the Jaccard distance(Nguyen).

Materials and Methods

Study area

This study was conducted in the natural forests of Dak Nong province, a key region in the Central Highlands of Vietnam. Dak Nong is situated between 11°45' and 12°50' N latitude and 107°12' and 108°07' E longitude (Figure 1). WPS were collected from natural evergreen forests within six forest management units (FMUs): Ta Dung National Park (NP), three protected forest management boards (PFMBs) - Nam Cat Tien, Dak R'Mang, and Gia Nghia - and two state forestry enterprises (FEs) - Duc Hoa and Dak N'tao (Figure 1). All units were previously managed as forest enterprises 15-20 years ago. The elevation and slope gradients of each study site are shown in Table 1.

No	*Study site*	*Elevation gradient (m a.s.l)*	*Slope gradient (^{0})*
1	Duc Hoa FE	820 - 1255	6 - 26
2	Dak Ntao FE	841 - 1044	0 - 40
3	Gia Nghia PFMB	747 - 880	4 - 22
4	Dak Mang PFMB	785 - 1039	6 - 24
5	Nam Cat Tien PFMB	528 - 597	2 - 17
6	Ta Dung NP	674 - 1479	3 - 35

Table 1: The elevation and slope gradient of each study site.

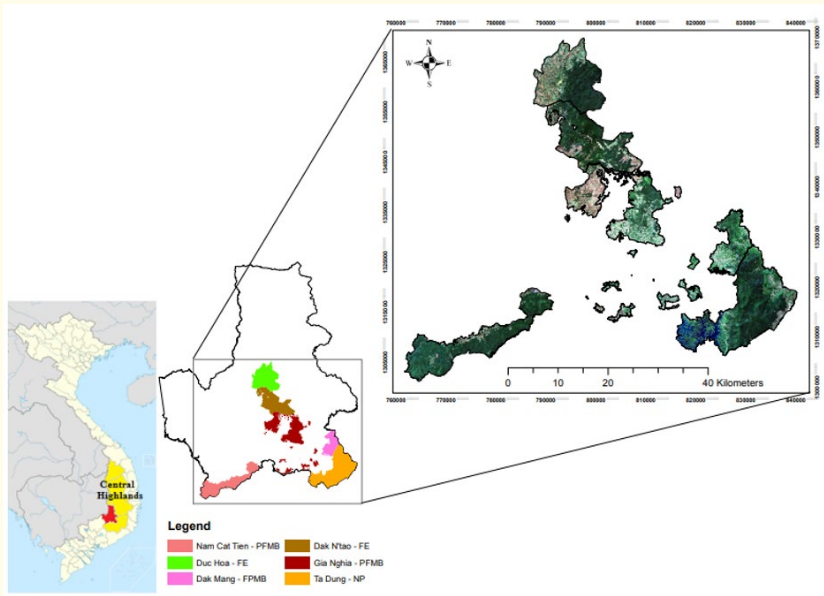

Figure 1: Location of the study area.

Topographic Data

A Digital Elevation Model (DEM) with a resolution of 30x30m was used to classify elevational gradients. Elevation was divided into six levels: H1 (<600m), H2 (600 - 800m), H3 (800 - 1000m), H4 (1000 - 1200m), H5 (1200 - 1400m), and H6 (≥1400m). Similarly, slope was divided into six levels: S1 (<5°), S2 (5 - 10°), S3 (10 - 15°), S4 (15 - 20°), S5 (20 - 25°), and S6 (≥25°). The elevation and slope maps of the study area were created from the DEM and are shown in Figure 2 and Figure 3.

Sampling design and data Collection

WPS data were collected from each square plot with an area of 900m^2. A total of 181 sample plots were arranged at different elevation and slope levels. Each sample plot was set in the East-West direction and divided into 9 cells (10mx10m). In each sample plot, all woody trees with a diameter at breast height greater than 6 cm were recorded by species, genus, and family name. The names of all tree species were checked to avoid synonyms using the plant list (http://www.worldfloraonline.org). The coordinates, elevation, and slope of all sample plots were recorded on-site with GPS and calibrated with the DEM using ArcGIS version 10.6. The number of sample plots at elevation gradients H1, H2, H3, H4, H5, and H6 were 33, 35, 76, 12, 17, and 8 respectively. The number of sample plots at slope gradients S1, S2, S3, S4, S5, and S6 were 26, 30, 60, 39, 19, and 7 respectively.

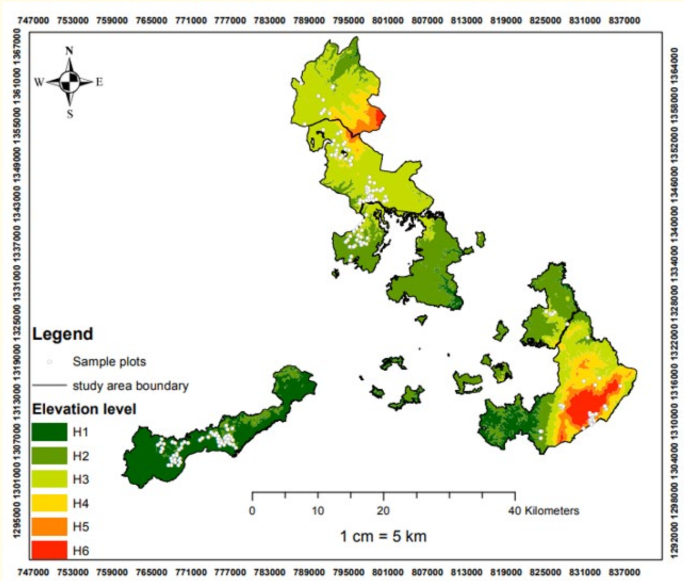

Figure 2: Elevation-levels and sample plots.

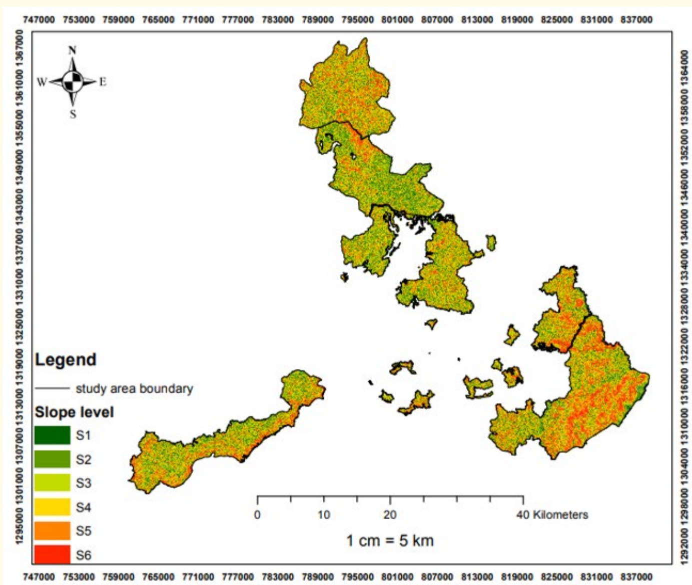

Figure 3: Slope-levels map of study area.

Data analysis
The Composition of WPS

The importance value index (IVI) was calculated for the WPS in each forest management unit based on relative abundance, frequency, and dominance.

The Diversity of WPS

The Hill numbers (Hill, 1973 [16]) were used to quantify the diversity of WPS, and their mean values were calculated for each forest management unit.

$$ {}^{q}D = \left(\sum_{i=1}^{S} p_i^q\right)^{1/(1-q)} \quad (1) $$

where, S is the number of species in the assemblage, and the *i*th species has relative abundance p_i, i =1, 2, ... , S.

Parameter *q* determines special situations of Hill numbers. When *q*=0, the species abundances do not contribute to equation (1), and ${}^{0}D$ is equal species richness (S). When q=1, ${}^{1}D$ as exponential Shannon entropy, which means the number of typical species in the community. When *q*=2, ${}^{2}D$ as reciprocal Simpson index, which means the number of dominant species in the community (Chao et al.; Simpson). The diversity profiles are plotted for all values (including non-integers) of q from q=0 to q = 3 or 4, beyond which it generally does not change much (Tóthmérész). In this study, we estimated Hill numbers until q=4, which includes species richness (q=0), exponential Shannon entropy (q=1), reciprocal Simpson index (q=2), and two diversity indices for q=3, and q=4. These indices were calculated using the vegan package in R software (Oksanen et al.).

Similarity and Dissimilarity

The similarity or dissimilarity of two samples (floristic sample) was defined based on the presence or absence of certain species in the two samples (Legendre and Legendre). In this study, Jaccard distance (Jaccard) was used to measure floristic dissimilarity between different elevation, slope gradients, and the forest management units. The Jaccard distance was defined by formula:

$$ d_J = \frac{(b+c) \times 100}{(a+b+c)} \quad (2) $$

Where a: number of common presences for both samples, b: number of presences in the first sample, c: number of presences in the second sample.

Additionally, non-metric multidimensional scaling (NMDS) was employed to explore the variability in species composition among the plots (Kruskal). NMDS utilizes a distance or dissimilarity matrix to analyze indirect gradients. This method is non-metric because stress, the measure of closeness of fit, is based on rankings rather than actual dissimilarity values. In this study, Jaccard distance was used for NMDS analysis using the *metaMDS* function from the *vegan* package in R software (Oksanen et al.). Stress was utilized to gauge the goodness-of-fit between predicted and actual distances. Kruskal suggested that stress values close to zero indicate excellent fit, while values above 0.2 should be considered poor (Kruskal).

Results and Discussions
Composition of woody plant species

In present study, we identified a total of 15,795 tree individuals belonging to 518 species across 182 genera and 76 families from 181 sample plots (162,500 m^2). Among the 76 families represented in the WPS, Fagaceae was the most dominant with 45 species, followed by Lauraceae with 40 species and Euphorbiaceae with 31 species. Euphorbiaceae had the highest number of genera (13), followed by Lauraceae (8), Meliaceae (8), Rubiaceae (8), and Fabaceae (8) (Table 2). Twenty-six families were found to be the least common, each represented by only one species. These families include Actinidiaceae, Altingiaceae, Asparagaceae, Boraginaceae, Calophyllaceae, Cardiopteridaceae, Chrysobalanaceae, Commelinaceae, Crypteroniaceae, Datiscaceae, Hamamelidaceae, Irvingiaceae, Iteaceae, Leeaceae, Loganiaceae, Lythraceae, Myrsinaceae, Ochnaceae, Pinaceae, Proteaceae, Rhamnaceae, Rhodoleiaceae, Schisandraceae, Stemonuraceae, Styracaceae, and Thymelaeaceae. Each of these families contributes only one species to the forest, making them particularly vulnerable to extinction due to human activities, unsuitable environmental conditions, or both (Kuma, 2016). Additionally, several species that were previously popular and had high commercial value, such as *Aquilaria crassna* Pierre ex Lecomte, *Pterocarpus macrocarpus*, *Dalbergia bariensis* Pierre, and *Afzelia xylocarpa* (Kurz) Craib, have become very rare. Therefore, strict protection measures for these species must be prioritized, not only in protected areas but also in forest ecosystems.

Family	***No. Species***	***No. Genus***	***Family***	***No. Species***	***No. Genus***
Fagaceae	45	3	Symplocaceae	5	1
Lauraceae	40	8	Aceraceae	4	1
Euphorbiaceae	31	13	Aquifoliaceae	4	1
Meliaceae	22	8	Bignoniaceae	4	3
Annonaceae	20	5	Ericaceae	4	4
Rubiaceae	20	8	Flacourtiaceae	4	2
Clusiaceae	19	2	Lamiaceae	4	3
Theaceae	19	7	Rosaceae	4	3
Moraceae	14	3	Araliaceae	3	3
Myrtaceae	13	2	Hypericaceae	3	2
Anacardiaceae	11	6	Lecythidaceae	3	2
Ebenaceae	11	1	Myristicaceae	3	2
Fabaceae	11	8	Rhizophoraceae	3	1
Magnoliaceae	10	4	Rutaceae	3	2
Elaeocarpaceae	9	1	Tiliaceae	3	2
Mimosaceae	9	3	Ulmaceae	3	2
Dipterocarpaceae	8	3	Caesalpiniaceae	2	2
Sapindaceae	8	5	Cardiopteridaceae	2	1
Sapotaceae	8	4	Juglandaceae	2	1
Sterculiaceae	8	4	Malvaceae	2	1
Apocynaceae	7	4	Phyllanthaceae	2	2
Burseraceae	6	2	Podocarpaceae	2	2
Combretaceae	5	1	Simaroubaceae	2	2
Dilleniaceae	5	1	Staphyleaceae	2	1
Melastomataceae	5	1	26 families, which has only one species	26	26

Table 2: The dominant family of woody tree species in study area.

Effect of different forms of forest management on floristic composition

Floristic composition and diversity of the forest management units

The study evaluated the composition of WPS across various forest management units (Table 3). WPS diversity ranged from 85 to 324 species, with the highest recorded in Ta Dung National Park (324 species). Nam Cat Tien PFMB had the highest number of genera (126) and families (62), reflecting effective conservation strategies.

Historically, all national parks (NPs) and PFMBs were established from former forest enterprises and have been impacted by historical logging, both legal and illegal (Daknong). Despite strict protection measures, these historical impacts are evident. For example, Dak Mang PFMB, which borders Ta Dung, has the lowest species (85), genera (58), and family counts (32), highlighting the long-term effects of past logging practices.

Tree density and basal area also varied: Dak N'tao Forest Enterprise (FE) had the highest tree density (1,121 stems), while Ta Dung NP had the highest basal area (43.26 m^2/ha). In contrast, Gia Nghĩa PFMB had the lowest tree density (802 stems) and basal area (25.01 m^2/ha). These differences reflect the varying impacts of management practices and historical exploitation. Generally, forestry enterprises had lower diversity indices than NPs and PFMBs, except for Dak Mang PFMB, due to past overexploitation for economic purposes. The decline in biodiversity in these areas underscores the need for stringent protection and sustainable management to restore and conserve forest ecosystems.

ID	*Forest manage unit*	*No. Sample plot*	*Tree density (stems/ha)*	*Tree basal area (m^2/ha)*	*No. Species*	*No. Genera*	*No. Family*	*No. Rare species*
1	Duc Hoa FE	10	863	27.39	123	68	37	10
2	Dak N'tao FE	48	1121	30.87	208	109	52	12
3	Gia Nghia PFMB	22	803	25.01	108	66	35	8
4	Dak Mang PFMB	6	881	31.99	85	58	32	4
5	Nam Cat Tien PFMB	58	968	29.21	289	126	62	15
6	Ta Dung NP	37	947	43.26	324	120	60	21

Table 3: Tree density, floristic composition by forest management unit.

Our study in Dak Nong province revealed the presence of 27 rare and precious woody species listed in the IUCN Red List 2024. Among these, 2 species were classified as critically endangered, 4 as endangered, 7 as vulnerable, 3 as near threatened, and 11 as least concern (Table 3). This diversity underscores the region's ecological significance but also highlights its vulnerability to species loss. Notably, Ta Dung National Park (NP) emerged as a critical hotspot with 21 threatened species, while Dak Mang Protected Forest Management Board (PFMB) exhibited the lowest count with 4 species (Table 5). These findings emphasize the need for tailored conservation strategies, particularly for species at risk of extinction.

STT	*Species*	*Ta Dung*	*Nam Cat Tien*	*Gia Nghia*	*Dak Mang*	*Dak N'tao*	*Duc Hoa*	*IUCN 2019*
1	Aquilaria crassna Pierre ex Lecomte	✓						CR
2	Dipterocarpus hasseltii Blume	✓	✓			✓		EN
3	Cinnamomum balansae Lecomte	✓	✓					EN
4	Hopea pierrei Hance		✓			✓	✓	VU
5	Mangifera dongnaiensis Pierre	✓	✓	✓		✓	✓	EN
6	Afzelia xylocarpa (Kurz) Craib		✓					EN
7	Dalbergia oliveri Gamble ex Prain	✓	✓					CR
8	Alstonia scholaris (L.) R.Br.	✓	✓	✓	✓	✓	✓	LC
9	Canarium littorale Blume	✓	✓	✓		✓		LC
10	Dacrycarpus imbricatus (Blume) de Laub.	✓			✓	✓	✓	LC
11	*Irvingia malayana* Oliv. ex A.W.Benn.		✓					LC
12	Knema globularia (Lam.) Warb.	✓	✓	✓		✓	✓	LC
13	Podocarpus neriifolius D.Don	✓				✓	✓	LC
14	Rhodoleia championii Hook.	✓		✓	✓	✓	✓	LC
15	Magnolia conifera (Dandy) V.S.Kumar.	✓					✓	LC
16	Altingia siamensis Craib	✓				✓		LC
17	Lithocarpus truncatus Rehder	✓						LC
18	*Scaphium macropodum* (Miq.) Beumée ex K.Heyne		✓					LC
19	Aglaia odorata Lour.	✓	✓	✓				NT
20	Dipterocarpus obtusifolius Teijsm. ex Miq.	✓		✓				NT
21	Dipterocarpus alatus Roxb. ex G.Don					✓		VU
22	Dipterocarpus costatus C.F.Gaertn.	✓						VU
23	*Hydnocarpus annamensis* (Gagnep.) Lescot & Sleumer	✓	✓				✓	VU
24	Knema pierrei Warb.	✓	✓					VU
25	Magnolia albosericea Chun & C.H.Tsoong						✓	VU
26	Phoebe poilanei Kosterm.	✓	✓	✓	✓	✓		VU
27	Xylopia pierrei Hance	✓						NT

CR: Critically Endangered, EN: Endangered, VU: Vulnerable, LC: Least concern, NT: Near threatened.

Table 4: Woody plant species in the study area belong to the IUCN Red List 2019.

The Hill numbers of WPS were calculated for each sample plot. The mean of Hill numbers of the 6 forests were shown in Figure 4.

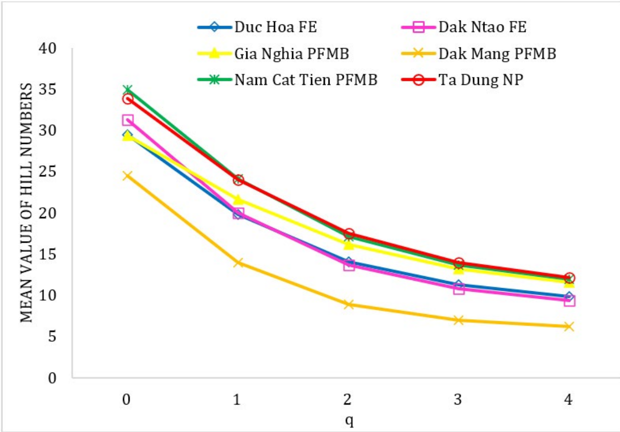

Figure 4: The Hill number of woody tree species according to the forest management unit.

Figure 4 presents Hill numbers of woody plant species diversity across forest management units. Nam Cat Tien PFMB and Ta Dung NP show the highest diversity, while Dak Mang PFMB exhibits the lowest. Forestry enterprises generally have lower diversity indices, except for Dak Mang PFMB, reflecting past extensive logging and encroachment. This highlights the significant biodiversity decline in areas previously managed for economic gain, underscoring the need for effective conservation strategies and sustainable management practices.

Disimilarly in WPS composition between forest management units

The Jaccard distance (Poorter et al.) was applied to measure the dissimilarity of the WPS composition between managed forest units. The difference in the WPS composition was found among forms of forest management by all dj was greater than 50%. Additionally, the difference in the WPS composition was found to be highest between PFMB and NP by dj = 60.04%. The lowest difference was found between FE and PFMB by dj = 57.49%.

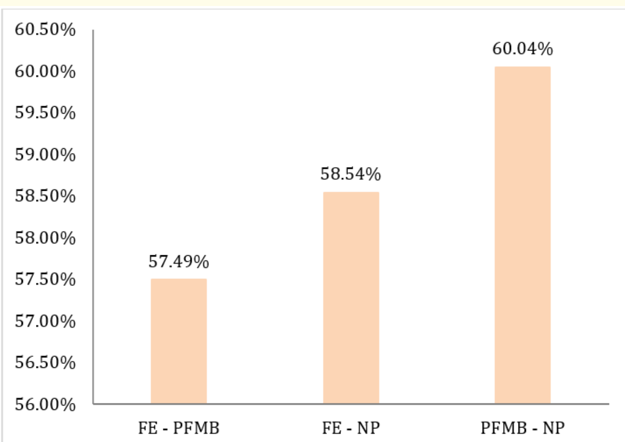

Figure 5: Jaccard distance (%) between forest management units.

The NMDS ordination in four dimensions had the stress of 0.171 with linear fit =0.781 and non-metric fit = 0.97. (Figure 6). The NMDS plots based on Jaccard distance, showing the distance between sample plots of forest management units on a two-dimensional scatter plot (Figure 7). Figure 7 shows the WPS composition is quite diverse, with changes throughout the region and between different forest management units.

Overall, these findings underscore the distinct ecological impacts of different forest management strategies, emphasizing the importance of understanding and managing WPS diversity for effective conservation and sustainable forest management.

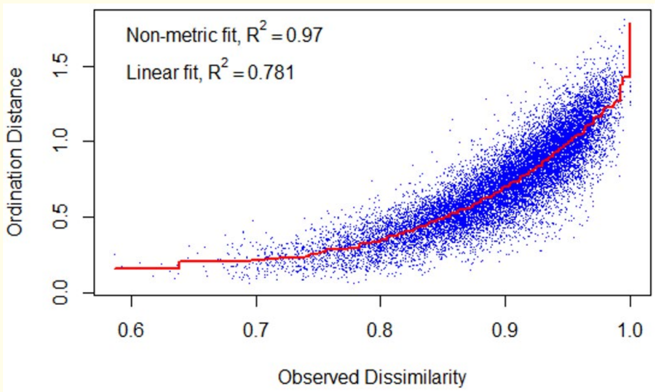

Figure 6: Linear fit and non-metric fit of NMDS.

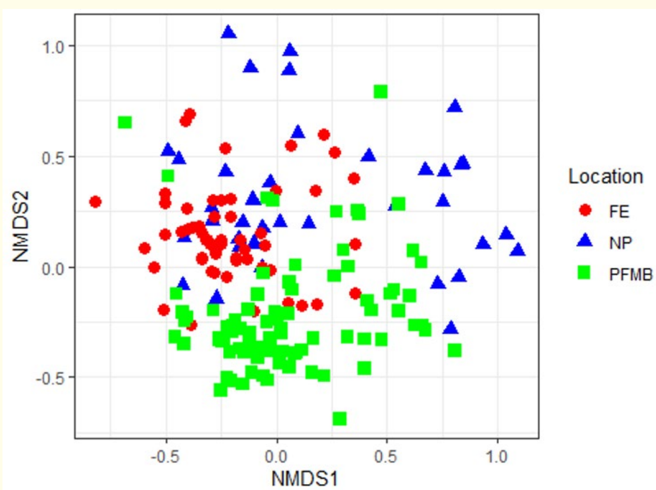

Figure 7: NMDS plot based on Jaccard distance matrix between sample plots according to forest management units.

Effect elevation and slope on floristic composition

The Jaccard distance was used to determine the dissimilarity in WPS composition between elevation and slope gradients. Figure 8 shows the differences in WPS composition between elevation levels, with all Jaccard distances (Poorter et al.) greater than 50%. In particular, H6 (>1400m a.s.l) exhibited the most significant differences, with Jaccard values ranging from 60.89% to 69.16%. The highest dissimilarity in WPS composition was observed between H1 and H6 (69.16%), while the lowest was recorded between H1 and H2 (51.79%). There are differences, but no consistent trend or rule; the differences are sometimes abrupt, possibly due to human impact. Historical land-use practices, such as logging and agricultural expansion, have significantly altered forest composition in the region, leading to variations that deviate from natural patterns (Beche et al.). This underscores the importance of considering both natural and anthropogenic factors when analyzing species diversity and composition for future studies (Kolbe et al.).

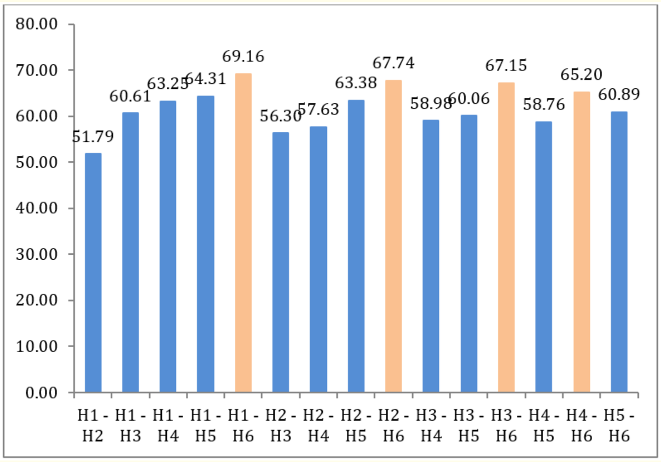

Figure 8: Jaccard distance (%) between elevation levels.

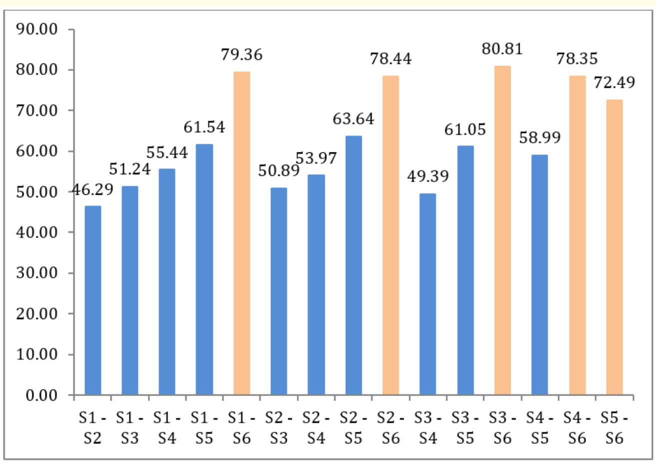

Figure 9: Jaccard distance (%) between slope levels.

Similarly, the composition of WPS exhibited significant differentiation across slope gradients in our study area, as demonstrated in Figure 9. Elevation level H6 (>1400m a.s.l) showed the greatest dissimilarity in WPS composition, with a Jaccard distance exceeding 70%. The most substantial difference in species composition occurred between slope gradients S1 and S6, with a Jaccard distance of 79.36%, while the least dissimilarity was observed between S1 and S2 at 46.29%. To further analyze the spatial distribution and clustering of WPS across elevation levels, non-metric multidimensional scaling (NMDS) was applied using abundance data and the Jaccard distance measure. Figure 10 illustrates the dispersion of sample plots across elevation levels on the NMDS graph, highlighting distinct clusters corresponding to each elevation level. This analysis underscores the variability in WPS composition within and between elevation gradients, emphasizing the ecological influence of elevation on plant community structure and diversity.

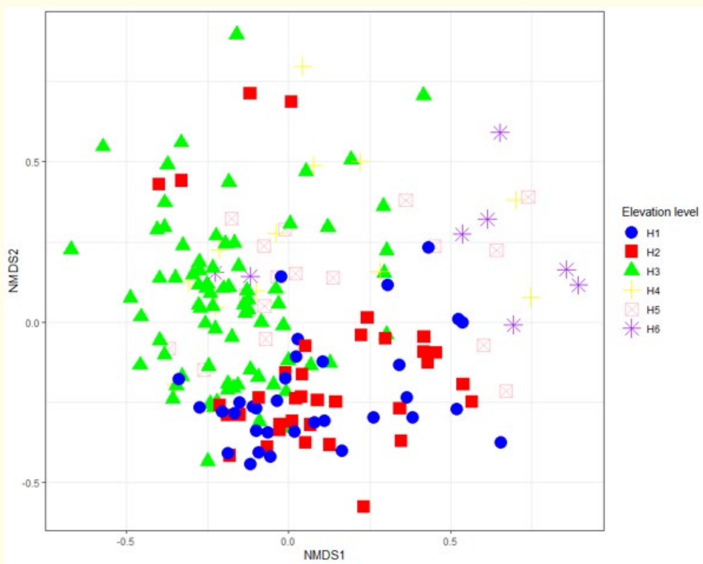

Figure 10: NMDS plot based on Jaccard distance matrix between sample plots according to elevation levels.

Contrary to traditional views, this study found that woody plant species (WPS) diversity in tropical forests does not decrease with altitude. Instead, WPS diversity tends to increase at higher elevations. Mean diversity indices showed a decrease from H1 to H3, followed by an increase from H3 to H4, with a slight decrease from H4 to H5 and a clear increase from H5 to H6 (Figure 12). Similar findings are reported in other studies (Grytnes and Vetaas; Oommen and Shanker; Song and Cao), while others noted a linear increase in species richness with elevation (Dorji et al.; Shimono et al.).

These results challenge traditional views and suggest that local factors such as microclimates and habitat diversity may influence biodiversity patterns. Furthermore, historical human impacts, such as logging and land use changes, likely contribute to shaping current biodiversity gradients along elevation. Understanding these dynamics is essential for effective biodiversity conservation in tropical mountain ecosystems.

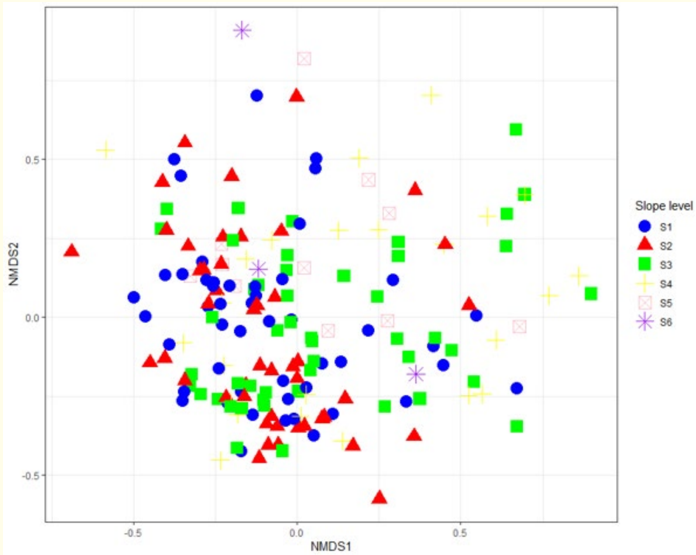

Figure 11: NMDS plot based on Jaccard distance matrix between sample plot according to slope levels.

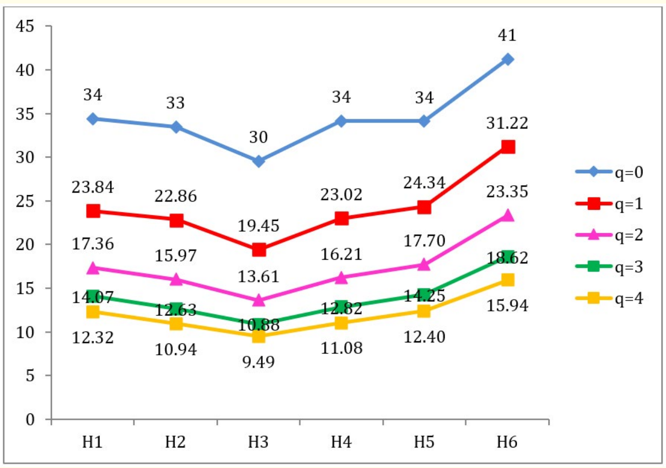

Figure 12: The average value of Hill number for elevation levels.

Conclusion

This study assessed WPS diversity across forest management units and elevation gradients in Dak Nong province, identifying 518 species from 181 plots. Ta Dung NP and Nam Cat Tien PFMB stood out with the highest species richness, reflecting effective conservation efforts compared to areas impacted by historical logging and land use changes. The presence of 27 rare and endangered species highlights conservation priorities. Analysis using Jaccard distances and NMDS ordination revealed significant WPS composition differences across management units and elevation gradients. Contrary to traditional views, WPS diversity did not uniformly decrease with altitude but varied, may influenced by microclimates and human activities. These findings underscore the need for tailored conservation strategies that integrate local ecological factors and historical contexts to preserve biodiversity and support sustainable forest management in Dak Nong province.

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Conflict

We don't have any conflicts of interest to disclose.

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Volume 7 Issue 2 August 2024