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Assessment of Stand Structure Characteristics in Forest Compartments Containing Cinnamomum Balansae in Ta Dung National Park, Dak Nong Province, Viet Nam

Phan Thi Hang[1], Nguyen Thi Thanh Huong[2], Nguyen Thi Thu[3]
[1,2]*Faculty of Agriculture and Forestry, Tay Nguyen University, VietNam*
[3]*Nong Lam University Ho Chi Minh City- Campus in Gia Lai, Viet Nam*

Abstract: Understanding forest structure is essential for sustainable forest management, particularly in the context of climate change and increasing anthropogenic pressures. This study aims to analyze the stand structure and biodiversity characteristics of forest communities with the presence of *Cinnamomum balansae*in Ta Dung National Park, Vietnam. A total of 50 sampling plots (900 m² each, 30 × 30 m) were surveyed, and data were analyzed using RStudio 4.4.0.Results indicate that *Cinnamomum balansae*is among the 10 species with the highest Importance Value Index (IVI%), reflecting its significant ecological role in the studied forest stand. Biodiversity indices (Margalef, Shannon-Wiener, Simpson) revealed a highly stable community structure, with Simpson's index (D = 0.98) indicating no single species dominance. Diameter distribution exhibited a reverse J-shaped curve, with small-diameter trees (6–10 cm DBH) dominating, characteristic of an uneven-aged forest with active natural regeneration. Similarly, height distribution analysis showed that medium-height trees (8–16 m) accounted for the largest proportion, suggesting that the forest is in a regeneration and recovery phase.

These findings provide crucial scientific insights for sustainable forest management and biodiversity conservation, especially in developing climate-resilient forest policies. Future research should focus on the role of large trees in carbon sequestration, the impact of climate change on forest dynamics, and the application of remote sensing technologies in long-term forest monitoring.

Keywords: IVI%, N/D, N/H, R Studio, Biodiversity indices, Ta dung National Park

I. INTRODUCTION

Sustainable forest management is an inevitable trend in modern forestry, aiming to balance ecological resource conservation with socio-economic development (FAO, 2020). Understanding forest stand structure plays a vital role in formulating forest management strategies, as it provides essential information on species composition, tree density, height distribution, and the number of trees by diameter (N/D) and height classes (N/H) (Anderegg *et al.*, 2020). These data serve as a scientific foundation for proposing appropriate silvicultural measures, thereby contributing to biodiversity conservation and enhancing forest resilience to the impacts of climate change (IPCC, 2021).

Cinnamomum balansae Lecomte is a rare and valuable tree species with significant economic and medicinal importance due to its distinctive aromatic essential oils. However, excessive exploitation and habitat degradation have led to a sharp decline in its population, resulting in its classification as a Group IIA species under Decree No. 84/2021/NĐ-CP of the Vietnamese Government and listing as Critically Endangered (CR) in the Vietnam Red Data Book (http://www.vncreatures.net). This situation underscores the urgent need to investigate the stand structural characteristics of C. balansae to support its conservation and sustainable development.

Ta Dung National Park, located in Dak Nong Province, is recognized for its high biodiversity, harboring numerous rare plant species, including *C. balansae* (Ta Dung National Park Biodiversity Report, 2022). However, to date, no in-depth study has been conducted on the stand structure of this species within the park. Therefore, this study aims to evaluate the forest stand characteristics of *C. balansae* in Ta Dung National Park through a combination of field surveys and data analysis using R Studio software. The study focuses on analyzing the Important Value Index (IVI), biodiversity indices (Simpson, Shannon, Margalef), and the distribution structure of tree number by diameter (N/D) and height classes (N/H). The research findings are expected to provide a scientific basis for quantifying the ecological value of the forest and proposing appropriate management, conservation, and sustainable development strategies for this species in the study area (IPCC, 2021).

II. MATERIAL AND METHOD

Research area

Ta Dung National Park is located on the administrative boundary of Dak Som commune, Dak G'long district, Dak Nong province, Viet Nam.

Coordinates: From 11047'27" to 11059'20" North latitude; From 107053'10" to 10806'32" East longitude (**Figure 1**)

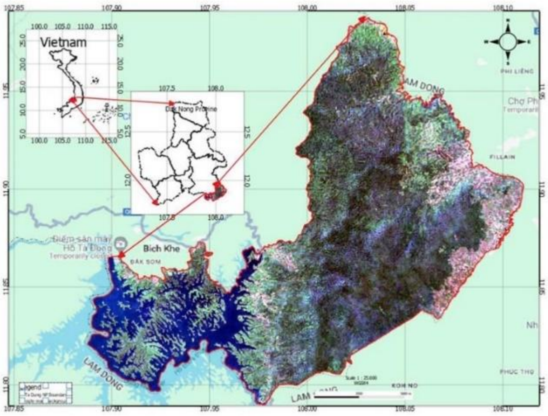

Figure 1. Location of Ta Dung National Park area

Data Collection

In this study, 50 standard plots (900 m² each; 30 m × 30 m) were established following the methodology of Condit and Richard (1995). These plots were systematically distributed from areas with low frequency to high-density occurrence of *C. balansae*. Each standard plot was subdivided into nine subplots (10 m × 10 m; 100 m²) to facilitate detailed surveys (**Figure 2**). Terrain slope corrections were applied within each 10 m × 10 m subplot to ensure measurement accuracy and analytical consistency (Henttonen & Kangas, 2015).

Within the subplots, all woody individuals with a diameter at breast height (DBH) ≥ 6 cm were recorded. The collected parameters included species name, tree height, DBH, tree quality, and other variables specified in pre-designed field survey forms (Chave *et al.,* 2005).

To record the geographical coordinates of each tree and plot, a Global Positioning System (GPS) device was used. The spatial data were standardized using the UTM Zone 48N coordinate system and the WGS84 geodetic reference system. GPS coordinates were verified for accuracy and integrated into base maps for spatial analysis (Zhang *et al.,* 2014).

Standard forestry measurement tools were used during the surveys, including a Sunto clinometer and a laser rangefinder for measuring tree height, slope, and distance; a diameter tape for DBH measurement; and a 30-meter measuring tape for establishing plot boundaries (Tang, 2010).

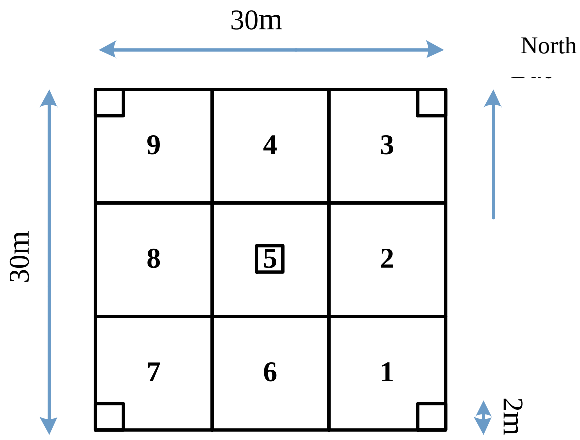

Figure 2. Layout diagram of standard plots (OTCs) in the field.

Data Analyzis

Determination of dominant species and species composition

Dominant species and species composition were determined based on the Important Value Index (IVI%), calculated using the number of individuals, basal area, and stem volume of each species.Species composition and IVI were determined according to the formula proposed by Curtis and McIntosh (1950).

$$IVI\%=(N(\%)+F(\%)+G(\%))/3 \quad (1)$$

The IVI% for each species was calculated using species-specific coefficients, including relative density (N%), relative frequency (F%), and relative basal area (G%).

N% represents the relative density of a species compared to the total tree density of the stand.

F% is the relative frequency, calculated as the ratio of the number of plots where the species occurs to the total number of plots.

G% refers to the relative basal area of the species in comparison with the total basal area of all species within the stand.

According to Daniel Marmillod, species with an IVI% greater than 5% are considered ecologically significant within a forest stand.

The study employed RStudio (version 4.4.0) to analyze field data and compute IVI%. Field data were first organized in an Excel file containing detailed information on sample plots, individual trees, and species lists. The data processing workflow included the calculation of tree basal area and classification of trees into diameter classes. Descriptive statistics were used to determine key stand characteristics such as total number of trees, species richness, and species distribution across plant families. The results generated in RStudio were exported into Excel format for interpretation and reporting(Nguyen, 2024). The following R packages were utilized throughout the study:

Data processing: tidyverse, openxlsx

Ecological analysis: vegan, abdiv

Data visualization: ggplot2 (from tidyverse), ggrepel, ggpubr

Exporting results: openxlsx

Biodiversity indices analysis

Margalef's Species Richness Index (d) was employed to quantify the richness of rare and valuable tree species in the study area. The Margalef index is calculated using the formula:

$$d = (S-1)/\ln N \quad (2)$$

where:

S is the total number of species, and N is the total number of individuals in the sample plot.

Shannon–Weiner Diversity Index (H') is a widely used diversity metric that incorporates both species richness and evenness within a community. The index is calculated as:

$$H' = -\sum_{i=1}^{s} p_i(\ln p_i) \; hay \; H' = -\sum_{i=1}^{s} \frac{ni}{N} \ln \frac{ni}{N} \quad (3)$$

where:

S is the total number of species,

$p_1 = n_i/N$ is the proportion of individuals of species i,

n_i is the number of individuals of species i,

and N is the total number of individuals in the sample.

Simpson's Diversity Index (D) was used to assess species diversity in the study area. It is calculated as:

$$D = 1 - \sum_{i=1}^{S} {p_i}^2 \quad (4)$$

where:

p_i is the proportion of individuals of species

i,and S is the total number of species.

All biodiversity indices were calculated using the vegan package in RStudio (version 4.4.0), based on field survey data collected from the sample plots (Nguyen, 2024).

Analysis of tree density and diameter structure (N/D)

The tree density and diameter structure were constructed to illustrate the distribution of individual trees across diameter classes. In natural tropical forests, such distributions typically follow a reverse-J or negative exponential pattern, often modeled by the Mayer function. This structure can be compared with stable forest models to adjust or supplement tree densities within appropriate diameter classes, following ecological succession principles (Renato *et al.*, 2015).

Diameter classes were determined by grouping trees into equal intervals based on collected DBH data. The number of diameter classes was calculated using the following formula:

$$\text{Number of classes} = (DBHmax - DBHmin)/d \quad (5)$$

where:

DBH_{max} is the maximum diameter at breast height (cm),

DBH_{min} is the minimum diameter at breast height (cm),

d is the class width (e.g., 4, 5, 10, or 20 cm). Smaller class widths allow for more detailed structural representation (Arshad, 2019).

The distribution function of tree density by diameter was modeled using the exponential Mayer equation:

$$y = \alpha . e^{-\beta x} \quad (6)$$

where:

y is the number of trees in each diameter class

x is the midpoint value of each diameter class

α and β are model parameters

Analysis of tree density and height structure (N/H)

Natural tropical forests are typically characterized by a multi-layered structure including emergent, dominant (canopy), sub-canopy, understory, and ground layers. Analyzing the distribution of tree numbers across height classes allows for accurate identification of vertical stratification and optimal tree density, particularly important for regeneration analysis (Tao *et al.*, 2020).

A left-skewed N/H distribution graph indicates higher density of juvenile or shorter trees, whereas a right-skewed graph suggests dominance of mature individuals and strong competition for resources such as light and nutrients. A bell-shaped distribution reflects a relatively stable and well-developing forest with most individuals clustered around the mean height (Cao *et al.*, 2019).

Height class categorization was performed in a similar manner to diameter classing. Data analysis was carried out using RStudio (4.4.0), based on field data imported from Excel. The main analytical steps included:

Data initialization and preprocessing: Excel files containing plot data, species lists, and individual tree measurements were cleaned and structured.

Variable processing: Key variables such as DBH (DBH_cm) and tree height (H_m) were grouped into defined classes.

Density structure analysis: Trees were grouped into size classes (e.g., DBH: [6–10], [10–15] cm; Height: <4, [4–8], [8–12] m), and the number of individuals per class was visualized using bar charts.

Visualization and export: Outputs, including diameter and height class distributions, biodiversity indices, and tree densities, were visualized and exported as PDF or CSV files.

The RStudio environment, with support from the dplyr package and related tools, was instrumental in ensuring accurate, efficient analysis of forest structure and species distribution within the study area (https://github.com/tidyverse/dplyr).

III. RESULTS AND DISCUSSION

3.1. Species composition structure in forest stands containing *Cinnamomum balansae*

Analyzing the structural composition of forest stands helps clarify the ecological roles and interrelationships among tree species within the forest ecosystem. The results of this study are presented in **Table 1** and **Figure 3**, which display the top 10 species with the highest Important Value Index (IVI%) recorded across the sample plots.

Table 1. List of the top 10 species with the highest IVI% in the study area

Scientific Name	n	sG	F	MD	UT	TS	IVI	Ranking
Dysoxylum poilanei	81	14,6	0,51	2,62	8,72	2,02	13,37	1
Cinnamomum balansae	69	13,04	0,75	2,23	7,79	2,96	12,98	2
Dacrycarpus imbricatus	32	13,14	0,39	1,03	7,85	1,56	10,44	3
Walsura elata	141	5,89	0,55	4,56	3,52	2,18	10,26	4
Neolitsea poilanei	156	5,38	0,41	5,04	3,21	1,64	9,89	5
Baccaurea ramiflora	141	2,94	0,49	4,56	1,76	1,95	8,26	6
Michelia mediocris	76	4,9	0,47	2,46	2,93	1,87	7,25	7

Scientific Name	n	sG	F	MD	UT	TS	IVI	Ranking
Syzygium wightianum	56	5,49	0,47	1,81	3,28	1,87	6,96	8
Endospermum chinense	53	4,96	0,43	1,71	2,96	1,71	6,39	9
Elaeocarpus bojeri	75	3,3	0,43	2,42	1,97	1,71	6,11	10

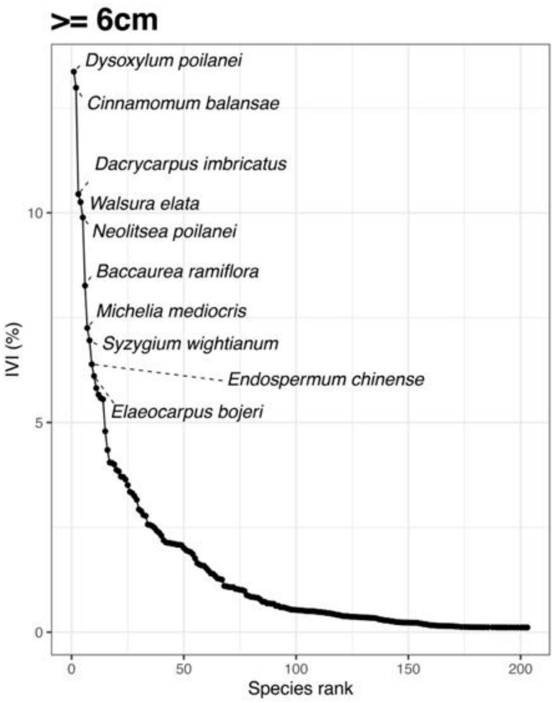

Figure 3 IVI% distribution of the top 10 species in the study area

The results indicated that *Dysoxylum poilanei* had the highest Important Value Index (IVI) at 13.37%, highlighting its dominant role in the forest structure within the study area. With a substantial number of individuals (n = 81) and the largest total basal area (G = 14.6%), this species likely plays a crucial role in maintaining ecosystem stability and regulatory functions.*Cinnamomum balansae*, ranking second with an IVI of 12.98%, also showed biomass dominance, supported by a high frequency of occurrence (f = 0.75).

Other species with relatively high IVI values included *Dacrycarpus imbricatus* (IVI = 10.44%), *Walsura elata* (IVI = 10.26%), and *Neolitsea poilanei* (IVI = 9.89%). These species displayed distinct stratification in terms of biomass and occurrence within the forest community. Notably, *Neolitsea poilanei* had the highest number of individuals (n = 156), yet a lower IVI compared to some other species, reflecting a common pattern among widely distributed but biomass-scarce species. This phenomenon was also documented by Ashton *et al.*,1988in studies of Dipterocarpaceae forest structure in Southeast Asia, where species with high density did not necessarily dominate the canopy structure.

Disparities in IVI values suggest divergent ecological strategies. For instance, *Dacrycarpus imbricatus*, though less abundant (n = 32), had a high total basal area (G = 13.14%), characteristic of long-lived, large-statured tree species aligned with K-strategist ecological traits (Pianka, 1970). This strategy has also been observed among dominant biomass species in Amazonian rainforests (Phillips *et al.*, 2003), where slow growing yet stable species shape long-term forest structure.

In contrast, species like *Baccaurea ramiflora* and *Endospermum chinense*, which occur in large numbers but have lower IVI values, may function as pioneer species. These are essential during natural regeneration phases, consistent with findings by Nguyen &Tran (2021) in the Dong Nai Nature Reserve.

These findings carry practical implications for forest planning, conservation, and management. Species with high IVI values, such as *Dysoxylum poilanei* and *Cinnamomum balansae*, should be prioritized in conservation and ecological restoration strategies. At the same time, identifying supportive species with medium to low IVI helps maintain species diversity—an essential factor for ecological resilience and long-term stability (Tilman *et al.*, 1997). In this regard, sustainable forest management approaches such as close-to-nature forestry or controlled natural regeneration represent promising and feasible solutions (Schütz, 2001; Nguyen *et al.*, 2020).

3.2. Biodiversity Indices Analysis

Assessing biodiversity indices plays a crucial role in understanding population structure, evaluating ecosystem stability, and proposing sustainable conservation strategies (Magurran, 2004). The results of the Margalef, Shannon, and Simpson indices calculated for tree groups with different diameter at breast height (DBH) classes in Ta Dung National Park are presented in **Figure 4.**

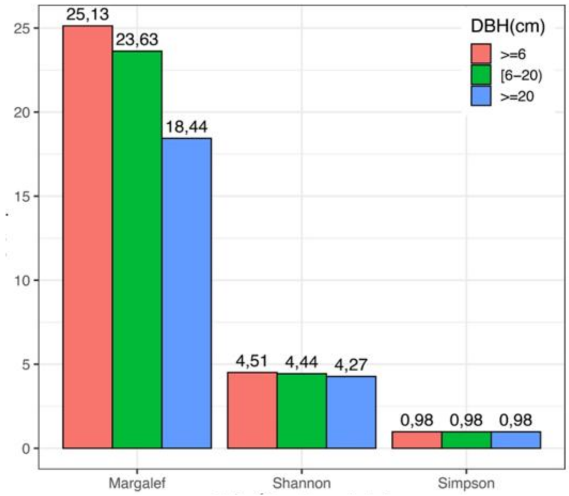

Figure 4 Biodiversity Indices in Ta Dung National Park

The Margalef index (*d*) reflects species richness within a community. The results revealed the following patterns:

Tree group with DBH ≥ 6 cm had the highest Margalef index (25.13), indicating the greatest species richness.

The 6–20 cm DBH group showed a slightly lower value (23.63) but still reflected high diversity.

Trees with DBH ≥ 20 cm had the lowest Margalef index (18.44), suggesting a decline in species richness as tree size increases.

This decreasing trend is common in tropical forest ecosystems, where small to medium-sized tree species tend to dominate in number, while larger trees are less frequent due to ecological competition and environmental pressures (Poorter *et al.*, 2015).

The Shannon–Weiner index *(H′)* measures the evenness of species distribution. Analysis results showed minor differences across DBH classes:

DBH ≥ 6 cm: *H′* = 4.51

DBH 6–20 cm: *H′* = 4.44

DBH ≥ 20 cm: *H′* = 4.27

The slight decline in *H′* suggests that as tree size increases, species distribution becomes less even—likely due to the ecological dominance of a few key species. This trend is consistent with findings by Nguyen *et al.*, 2021, who noted that large tree species typically occur less frequently but play a significant role in maintaining spatial structure and ecological stability.

The Simpson index (*D*) evaluates species dominance, with values ranging from 0 to 1; higher values indicate greater dominance by a few species. In this study, Simpson's index values for all DBH groups were approximately 0.98, indicating a well-balanced species distribution with no single species showing absolute dominance.

This level of evenness is ecologically important, as it suggests a high potential for ecosystem resilience against external disturbances (Phillips *et al.*, 2004).

These findings highlight the high biodiversity and structural stability of forest communities in Ta Dung National Park. However, the decreasing trends of the Margalef and Shannon indices in larger DBH groups suggest a decline in dominant species richness, potentially due to ecological competition, logging activities, or climate change (Hui *et al.*, 2019).

These results are consistent with the study by Chau, T. N. Q. (2019) in Ta Dung National Park, where similar levels of biodiversity indices were recorded. That study also emphasized the ecological significance of

Ta Dung's forests and the urgent need for prioritized conservation efforts to maintain ecosystem stability and protect ecologically important plant species.

Therefore, sustainable forest management strategies should prioritize the conservation of large, ecologically dominant tree species to maintain population balance and ecosystem functioning. These findings not only contribute to conservation planning in Ta Dung but also offer practical implications for forest management in other protected areas across Vietnam.

3.3. Tree Density and Diameter Structure Analysis (N/D)

Analysis of tree density and diameter distribution (N/D) serves as an important ecological indicator reflecting the dynamics and developmental stage of plant populations within forest ecosystems (Pretzsch, 2009). **Figure 5** illustrates the distribution of tree counts across 20 diameter classes, each with a 5 cm interval, ranging from juvenile to mature trees.

The results show that the N/D structure in Ta Dung National Park exhibits a declining distribution pattern across diameter classes. The highest number of individuals is concentrated in the smaller diameter classes (5–15 cm), with a sharp decrease as diameter increases. This pattern reflects an actively regenerating forest community, characteristic of natural forests in a stable development phase. The dominance of smaller trees indicates that the population is successfully replenishing younger generations, an essential factor for ensuring long-term forest ecosystem sustainability (Nguyen & Le, 2020).

This trend is consistent with previous studies conducted in tropical forests of Vietnam and Southeast Asia, where diameter–density distributions typically follow a log-normal or reverse-J curve (Ashton *et al.*, 1988; Nguyen *et al.*, 2021). Specifically, research by Nguyen, T. T. (2020) and Le *et al.*, 2020 in Vietnamese nature reserves reported similar structures, with high densities in smaller diameter groups, indicating strong natural regeneration potential under minimally disturbed conditions.

The observed declining distribution is not only a typical structural feature of natural forests but also a useful ecological indicator for evaluating the effectiveness of forest management and conservation practices—particularly relevant in the context of increasing impacts of climate change on forest dynamics (Phillips *et al.*, 2004).

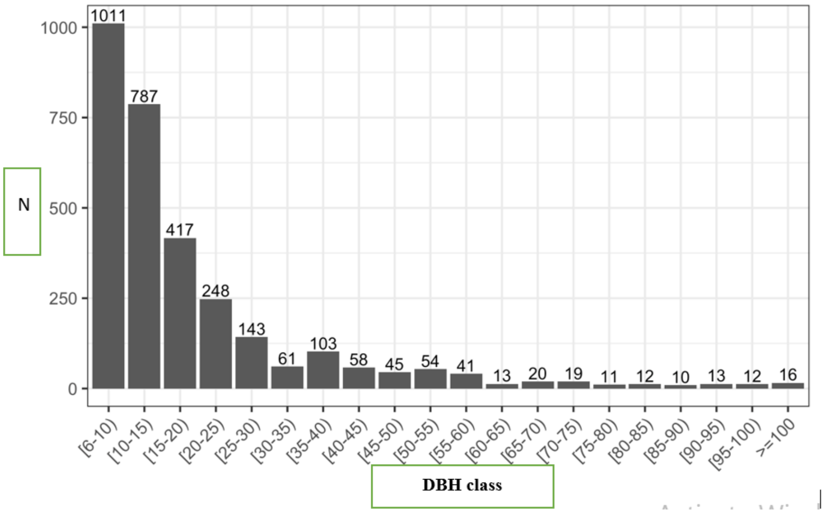

Figure 5. Number of trees by diameter class surveyed across the sample plot system

The diameter class distribution of trees in Ta Dung National Park clearly reflects the characteristics of a natural forest stand undergoing stable regeneration. Field data show that trees in the smallest diameter class (6–10 cm) dominate, with a total of 1,011 individuals, while the number of trees sharply declines in the larger diameter classes. This pattern follows a reverse-J shaped distribution, commonly found in primary tropical forests, where juvenile trees predominate due to strong natural regeneration and minimal anthropogenic disturbance (Ashton *et al.*, 1988; Phillips *et al.*, 2004).

In contrast, trees with large diameters (DBH ≥ 100 cm) accounted for only 16 individuals, indicating a limited presence of mature trees. This may be a consequence of prolonged competition for light and nutrients in a closed-canopy environment, coupled with external factors such as selective logging, shifting cultivation, and unregulated ecotourism development (Nguyen *et al.*, 2021).

The dominance of small-diameter trees highlights active regeneration and forest resilience. However, the low proportion of large trees raises concerns about long-term canopy structure and ecosystem functioning, which largely depend on the presence of ecologically dominant and mature individuals (Pretzsch, 2009; Poorter *et al.,* 2015). As such, forest management strategies in the area should prioritize the conservation of large trees to maintain ecological balance and protect key environmental services, including climate regulation, soil stabilization, and water retention.

The N/D distribution was modeled using the Meyer distribution function, a widely applied model in the study of natural forest dynamics (Meyer, 1952; Pretzsch, 2009). The model simulation results, presented in **Figure 6** yielded parameter estimates of $\alpha = 625.99$ and $\beta = 0.046$, with a coefficient of determination $R^2 = 0.89$, indicating a high degree of model fit. This confirms the effectiveness of the Meyer function in describing the tree diameter distribution in the study area.

The resulting curve illustrates a typical declining trend in tree numbers with increasing diameter, characteristic of forests undergoing strong natural regeneration. Small trees (DBH < 20 cm) dominate in number, while trees above 40 cm decline substantially and become nearly absent at DBH > 100 cm. This decline can be attributed to intra-stand resource competition in closed-canopy environments and the impacts of logging or slash-and-burn agriculture (Hui *et al.,* 2019; Poorter *et al.,* 2015).

This pattern is consistent with findings by Pham *et al.,* 2021 in Ta Dung National Park, who also reported that small-diameter trees dominate in number, while large trees, though few—play a crucial ecological role in carbon storage, canopy structure maintenance, and regeneration support.

These findings reinforce the conclusion that the natural forest in the area is in a regeneration phase. However, sustainable forest management measures are still essential. Such strategies must recognize the dual importance of small trees—for maintaining population numbers and recovery capacity—and large trees—for ensuring ecological functions, spatial structure stability, and biomass storage. Therefore, silvicultural planning should promote natural regeneration while implementing effective conservation mechanisms for mature tree cohorts (Hui *et al.,* 2019; Pretzsch, 2009).

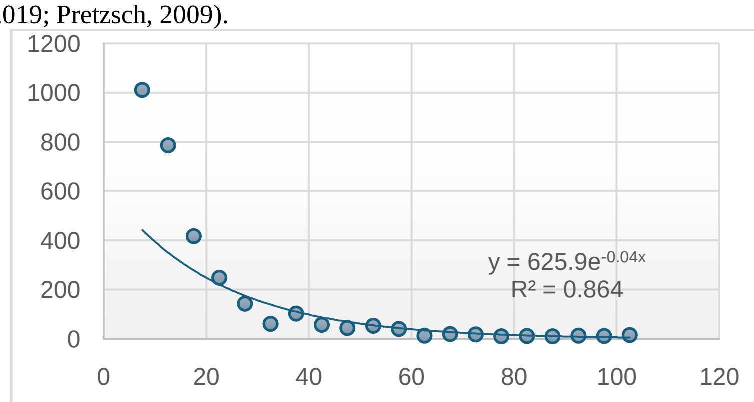

Figure 6. Simulation of treediameter distribution using the Meyer function

3.4. Tree height and density structure analysis (N/H)

The analysis of tree number distribution by height class (N/H) provides critical insights into canopy development, vertical biodiversity structure, and the ecological succession stage of the forest community (Pretzsch, 2009). **Figure 7** illustrates the N/H distribution results obtained from the sample plot system in Ta Dung National Park, reflecting the characteristic canopy structure of tropical moist closed forests.

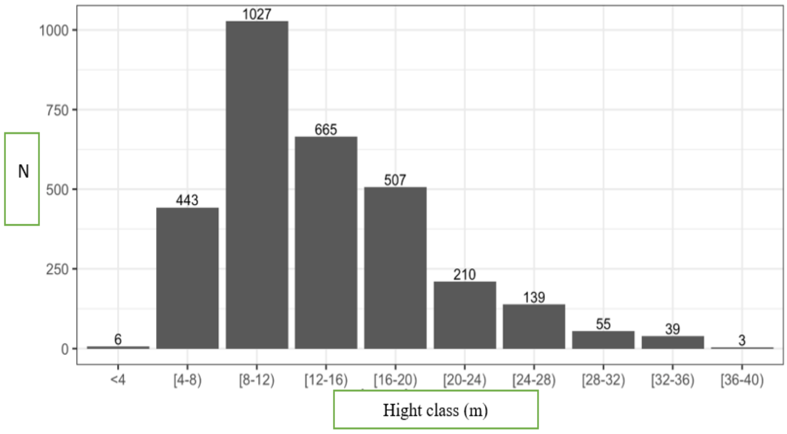

Figure 7. Tree count distribution by height class in Ta Dung National Park

The analysis of canopy structure based on tree number distribution across height classes (N/H) in Ta Dung National Park reflects the typical characteristics of a tropical forest ecosystem undergoing regeneration. The distribution graph shows a left-skewed pattern, with the highest number of individuals occurring in the 8–12 m height class (1,027 individuals), followed by the 12–16 m (665 individuals), and 16–20 m (507 individuals) classes. The dominance of mid-height tree groups suggests strong natural regeneration and indicates positive vegetation development within the natural forest ecosystem.

In contrast, the number of trees taller than 24 meters decreases significantly, with only three individuals recorded in the 36–40 m class. This reflects a limited presence of emergent trees, which may result from growth competition—particularly for light and nutrients—within the closed-canopy environment, alongside external pressures such as logging, shifting cultivation, or microclimatic alterations due to canopy thinning (Nguyen *et al.,* 2021; Hui *et al.,* 2019). This trend aligns with previous studies in Vietnam, which have also found high tree densities in the middle canopy layer, with only a few emergent individuals possessing ecological dominance (Poorter *et al.,* 2015; Phillips *et al.,* 2004).

This N/H distribution structure conforms to typical canopy stratification models observed in tropical rainforests, as reported by Chave *et al.,*2005 and Cao *et al.,*2019 in forest dynamics studies in Vietnam. Both studies emphasized that canopy imbalance can affect ecological stability—especially under the pressures of climate change and anthropogenic disturbances.

These findings underscore the importance of conserving large trees—not only to maintain structural diversity but also to ensure carbon storage capacity and the continued provision of ecosystem services. Sustainable forest management strategies should prioritize minimizing the harvesting of large trees, protecting ecologically dominant species, and enhancing natural regeneration to restore forest ecosystems over the long term (Hui *et al.,* 2019). Additionally, the results of this study provide a valuable scientific basis for forest conservation planning in Ta Dung National Park and offer potential applications for silvicultural research in other tropical forest regions.

IV. CONCLUSION

The study conducted in Ta Dung National Park provides scientific insights into forest structure, biodiversity, and the dynamics of forest stands where *Cinnamomum balansae* is distributed. The findings revealed that no single species holds absolute dominance (IVI < 15%), though species such as Dysoxylum poilanei, Cinnamomum balansae, and Walsura elata play a significant role in maintaining forest structure and ecosystem stability.

Biodiversity analysis indicates a high level of species richness in the park, with the Margalef index being highest in the small-diameter group (DBH ≥ 6 cm), reflecting rich species diversity and active natural regeneration. However, decreasing trends in the Margalef and Shannon indices among larger tree groups suggest a potential decline of large-sized species—likely due to growth competition, anthropogenic disturbances, or climate change. The Simpson index remained stable at 0.98, indicating a well-balanced forest structure with no single species dominating, which is vital for biodiversity maintenance and ecological resilience.

Forest structure was also reflected in the distribution of tree numbers across diameter and height classes, with small trees (DBH 6–10 cm) being overwhelmingly dominant. This highlights robust regeneration processes, though the scarcity of large trees (DBH ≥ 100 cm) presents a challenge for long-term ecosystem conservation. Height distribution analysis showed a dominance of mid-sized trees (8–16 m), reflecting characteristics of a regenerating and recovering forest community.

To enhance the applicability of these findings and support sustainable forest management strategies, the study proposes several directions for future experimental research:

Employ remote sensing and GIS technologies to monitor forest structural changes over time.

Integrate AI models with spatial data to predict regeneration trends and deforestation risk.

Analyze climate change scenarios and their impacts on the growth of ecologically dominant tree species.

Develop adaptive forest management models to mitigate the effects of changing temperature and precipitation regimes.

Quantify carbon storage potential of large tree individuals to better understand their ecological value.

Pursuing these directions will not only deepen the understanding of the ecological mechanisms within forest stands containing *C. balansae* butalso contribute to the advancement of sustainable forest conservation models, laying a foundation for more effective resource management in the context of globalization and climate change.

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Data availability statement

The datasets generated during this study are available from the corresponding author upon reasonable request.

Conflict of interest: The authors declare no conflict of interest

REFERENCES

[1]. Anderegg, W. R., Trugman, A. T., Badgley, G., Konings, A. G., & Shaw, J. (2020). Drought stress limits tree growth and reduces forest carbon uptake. *Proceedings of the National Academy of Sciences*, 117(40), 24753-24760.

[2]. Arshad Ali.(2019). Forest stand structure and functioning: Current knowledge and future challenges. *Ecological Indicators*, 98, 665–677. DOI: 10.1016/j.ecolind.2018.11.017

[3]. Ashton, P. S., Givnish, T. J., & Appanah, S. (1988). Staggered flowering in the Dipterocarpaceae: new insights into floral induction and the evolution of mast fruiting in the aseasonal tropics. *The American Naturalist*, 132(1), 44–66.

[4]. Booth, T. H., Nix, H. A., Busby, J. R., & Hutchinson, M. F. (2014). BIOCLIM: The first species distribution modelling package, its early applications and relevance to most current MaxEnt studies. *Diversity and Distributions*, 20, 1–9. DOI:10.1111/ddi.12144

[5]. Cao, T. T. H., Nguyen, D. C., Bui, M. H., & Nguyen, V. B. (2019). Some structural characteristics and tree species diversity of the evergreen broad-leaved forest in Ba Be National Park. *Journal of Forest Science and Technology*, 3(2019), 35–45.

[6]. Chave, J., Andalo, C., Brown, S., et al. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145, 87–99. DOI: 10.1007/s00442-005-0100-x

[7]. Chau, T. N. Q. (2019). The application of remote sensing and GIS for assessing woody plant species diversity in evergreen broad-leaved forests in Ta Dung National Park, Dak Nong Province. *Master's thesis, Tay Nguyen University*.

[8]. Condit, R. S. (1995). Research in large, long-term tropical forest plots. *Trends in Ecology and Evolution*, 10(1), 18–22. DOI:10.1016/0169-5347(95)90263-1

[9]. Curtis, J. T., & McIntosh, R. P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, 31(3), 434–455. DOI:10.2307/1931497

[10]. Daniel Marmillod. (1977). Études Phytoécologiques Appliquées aux Forêts Claires du Cambodge. *Bois et Forêts des Tropiques*, 175(1), 41–59.

[11]. Dinh, T. T., Pham, M. P., Nguyen, Q. K., Bui, T. T. X., Nguyen, V. S., Vu, D. D., Tran, Q. B., Nguyen, V., & Tuan, N. T. (2020). Neighbor trees and habitat suitability of Cinnamomum balansae Lecomte in North Central Coast and Northern Vietnam. *Springer*. DOI:10.1007/s40808-022-01378-7

[12]. FAO (Food and Agriculture Organization). (2020). Global Forest Resources Assessment 2020: Main Report. *FAO*.

[13]. Henttonen, H. M., & Kangas, A. (2015). Optimal plot design in a multipurpose forest inventory. *Forest Ecosystems*, 2, 31. DOI:10.1186/s40663-015-0055-2.

[14]. Hui, D., Luo, Y., & Katul, G. (2019). Detecting gradients of ecosystem function: The role of large trees in forest structure and carbon storage. *Ecological Indicators*, 101, 470–480.

[15]. Hui, G., Zhang, G., Zhao, Z., et al. (2019). Methods of forest structure research: A review. *Current Forestry Reports*, 5, 142–154. DOI:10.1007/s40725-019-00090-7.

[16]. IPCC (Intergovernmental Panel on Climate Change). (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press.*

[17]. Jeff W. Atkins, Atticus E.L. Stovall, Carlos Alberto Silva.(2022). Open-Source tools in R for forestry and forest ecology. *Forest Ecology and Management*. Volume 503, 119813. DOI:10.1016/j.foreco.2021.119813.

[18]. Le, H. V., Nguyen, H. H., Tran, Q. B., Nguyen, V. T., & Le, N. H. (2020). Spatial structural characteristics of dominant tree species in tropical moist evergreen closed forests in Tan Phu, Dong Nai. *Journal of Forest Science and Technology*, (1), 072–083.

[19]. Magurran, A. E. (2004). Measuring biological diversity. *Blackwell Science*.

[20]. Meyer, H. A. (1952). Structure, growth, and drain in balanced, uneven-aged forests. Journal of Forestry, 50(2), 85–92.

[21]. Nguyen, T. L., & Tran, M. H. (2021). Structural characteristics and tree species diversity in natural forests of the Dong Nai Culture and Nature Reserve. *Journal of Forest Science*, 4, 67–75.

[22]. Nguyen, T. T., & Le, H. V. (2020). Analysis of natural forest structure in southern Vietnam. *Journal of Forest Science*, 4, 45–52.

[23]. Nguyen, V. H., Tran, T. M., & Dang, Q. A. (2021). Forest structure dynamics and regeneration in tropical forests of central Vietnam. *Forest Ecology and Management*, 496, 119–130.

[24]. Nguyen, L. X. B. (2024). Basic ecological data analysis with R. Retrieved from https://nlxbach.github.io/ECOR

[25]. Nguyen, T. T. (2020). Study on structure and diversity of woody species in regenerating forests after swidden cultivation in Ta Dung National Park, Dak Nong Province. *Journal of Agriculture and Rural Development*, 16. ISSN 1859-4581.

[26]. Phillips, O. L., et al. (2004). Pattern and process in Amazon tree turnover, 1976–2001. Philosophical Transactions of the Royal Society B: *Biological Sciences*, 359(1443), 381–407.

[27]. Pham, V. H., Nguyen, V. H., & Le, T. H. (2021). Structural characteristics and regeneration of natural forests in Ta Dung National Park. *Vietnam Journal of Forest Science*, 2, 56–65.

[28]. Pham, V. H., Tran, T. B. N., Kieu, P. A., & Pham, T. L. (2021). Structural characteristics and vertical diversity of woody layers in subtropical moist evergreen broad-leaved forests in Ta Dung National Park. *Journal of Forest Science and Forestry*, 01-2021.

[29]. Pianka, E. R. (1970). On r- and K-selection. *The American Naturalist*, 104(940), 592–597.

[30]. Poorter, L., et al. (2015). Diversity enhances carbon storage in tropical forests. *Global Ecology and Biogeography*, 24(11), 1314–1328.

[31]. Pretzsch, H. (2009). Forest dynamics, growth and yield: From measurement to model. *Springer Science & Business Media*.

[32]. RStudio Team. (2023). RStudio: Integrated Development Environment for R. Posit PBC.

[33]. Renato Augusto Ferreira de Lima, João Luís Ferreira Batista, & Paulo Inácio Prado (2015). Modeling tree diameter distributions in natural forests: An evaluation of 10 statistical models. *Forest Science*, 61(2), 320–327. DOI:10.5849/forsci.14-070

[34]. Schütz, J. P. (2001). Opportunities and strategies of transforming regular forests to irregular forests. *Forest Ecology and Management*, 151(1–3), 87–94.

[35]. Tang, M. P. (2010). Advances in study of forest spatial structure. *Scientia Silvae Sinicae*, 46(1), 117–122.

[36]. Tao, G. H., Bu, Y. K., Xue, W. P., Zuo, M. M., Lu, R., & Li, W. Z. (2020). Relationship between understory diversity and stand spatial structure in air-drilled Pinus tabulaeformis forests of different densities. *Journal of Forest and Environment*, 40(2), 171–177.

[37]. Teimouri, M., Doser, J. W., & Finley, A. O. (2019). ForestFit: An R package for modeling tree diameter distributions. Retrieved from https://arxiv.org/abs/1911.11002.

[38]. Thanh Huong Nguyen Thi, The Hien Nguyen, Hang Thi Phan, Hoai Thi Cao, and Bao Dinh Ho. (2024). Classification of forest cover of Ta Dung National Park, Vietnam using optical satellite images. *IOP Conf. Ser.: Earth Environ.* Sci. 1391. 012018. SCOPUS. DOI:10.1088/1755-1315/1391/1/012018.

[39]. Tilman, D., et al. (1997). The influence of functional diversity and composition on ecosystem processes. *Science*, 277(5330), 1300–1302.

[40]. Yan, H., Sun, F. F., Ma, S. M., Wang, C. C., Zhang, D., & Zhang, Y. L. (2021). Population structure and spatial distribution pattern of Haloxylon ammodendron and Haloxylon persicum. *Southwest China Journal of Agricultural Sciences*, 34(8), 1781–1787.

[41]. Zhang, H., Zheng, J., Dorr, G., et al. (2014). Testing of GPS accuracy for precision forestry applications. *Arabian Journal for Science and Engineering*, 39, 237–245. DOI:10.1007/s13369-013-0861-1