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STRUCTURE CHARACTERISTICS AND BIODIVERSITY OF POOR NATURAL EVERGREEN BROADLEAF PRODUCTION FORESTS IN LAO CAI PROVINCE, VIETNAM

Nguyen Toan Thang[1*], Nguyen Trong Minh[2], Trinh Ngoc Bon[1],
Dao Trung Duc[1], Nguyen Huu Hiep[3], Tran Van Do[1]

[1]Silviculture Research Institute, Vietnamese Academy of Forest Sciences, Hanoi, Vietnam.

[2] Vietnam National University of Forestry, Hanoi, Vietnam.

[3]Nguyen Huu Hiep, Joint Vietnam-Russia Tropical Science and Technology Research
Center, Institute of Tropical Ecology, Hanoi, Vietnam.

*Corresponding Author

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ABSTRACT

This study aimed to evaluate the structural characteristics and biodiversity of poor natural evergreen broadleaf production forests in Lao Cai province. Three temporary sample plots of 2,500 m² each were established randomly across different altitudinal zones to collect data. Results showed that tree density ranged from 416 to 616 trees/ha, average diameter from 13.3 to 15.8 cm, and average height from 10.3 to 11.4 m. Wood volume ranged from 55.4 to 68.9 m³/ha, and biomass from 46.2 to 57.7 tons/ha. The Shannon index varied from 2.42 to 3.16 and the Simpson index from 0.80 to 0.94, indicating medium to high biodiversity. Elevation significantly influenced forest structure and species composition, with mid-altitude plots showing better structure and diversity. The diameter distribution followed a Reverse-J shape, indicating strong natural regeneration. The study provides a scientific basis for proposing appropriate strategies for sustainable forest management and biodiversity conservation in similar ecological regions.

Keywords: Biodiversity, Biomass, Forest Structure, Natural Forest, Lao Cai

1. INTRODUCTION

Evergreen broadleaf forests in Southeast Asia represent one of the most biologically diverse terrestrial ecosystems globally, playing crucial roles in carbon sequestration, watershed protection, and biodiversity conservation (Ohtsuka, 2010; Kueh and Lim, 1999). In Vietnam, these forests form part of the South China-Vietnam tropical evergreen forest ecoregion, which extends from northern Vietnam into southeastern China and is characterized by high levels of endemic and threatened species. However, rapid economic development, agricultural expansion, and unsustainable forest exploitation have led to significant degradation of these ecosystems, resulting in widespread conversion of primary forests to secondary and degraded forest types.

Poor natural production forests, characterized by discontinuous canopy cover (0.3-0.6), average tree height below 20 m, and low timber volume, represent a significant proportion of Vietnam's forest estate. These forests are particularly important in mountainous regions where they provide essential ecosystem services to local communities while maintaining residual biodiversity (Do et al., 2011). Understanding the structural characteristics and biodiversity patterns of these degraded forests is fundamental for developing effective restoration and sustainable management strategies.

Previous studies have documented substantial variation in forest structure and species diversity across environmental gradients in tropical and subtropical Asia. Altitude has been identified as a primary driver influencing species composition, forest structure, and biomass accumulation (Aiba & Kitayama, 1999). In Vietnam, research on evergreen broadleaf forests has primarily focused on protected areas and high-quality forests, while poor production forests, despite their extensive coverage, remain understudied. This knowledge gap limits our ability to assess their ecological value and develop appropriate management interventions.

Forest structural attributes, including tree density, diameter distribution, and height structure, provide important indicators of forest condition, successional stage, and management history (Do et al., 2016). The diameter distribution pattern, particularly the Reverse-J shape characteristic of uneven-aged natural forests, reflects regeneration capacity and long-term population stability (Condit et al., 1998). Biomass estimation in tropical forests has advanced significantly through the development of region-specific allometric equations, which improve accuracy compared to pan-tropical models (Huy et al., 2016).

Biodiversity assessment using diversity indices such as the Shannon-Wiener and Simpson indices provides quantitative measures for comparing ecological communities and evaluating conservation priorities (Magurran, 1988). These indices integrate both species richness and evenness, offering complementary perspectives on community structure. In degraded forests, biodiversity assessment is particularly important for understanding resilience and recovery potential following disturbance (Gibson et al., 2011).

Lao Cai province, located in northeastern Vietnam, contains extensive areas of poor natural evergreen broadleaf production forests distributed across varied topographic and climatic conditions. These forests face multiple pressures including agricultural encroachment, illegal logging, and climate change, yet their structural characteristics and biodiversity remain poorly documented. This study addresses this gap by providing a comprehensive assessment of forest structure and biodiversity across an altitudinal gradient.

The objectives of this study were to: (1) characterize the structural attributes of poor natural evergreen broadleaf production forests, including tree density, diameter and height distributions, wood volume, and biomass and (2) assess species diversity using Shannon-Wiener and Simpson indices. The findings will contribute to the scientific basis for sustainable forest management and biodiversity conservation strategies in degraded forest landscapes of northern Vietnam.

2. STUDY SITE AND METHODS

2.1. Study Site

The study was conducted in Lao Cai province in northeastern Vietnam. The study area features hilly and mountainous terrain with moderate to steep slopes, at elevations ranging from 451 m to 1,038 m above sea level. The climate is tropical monsoon with a dry season from November to April and a rainy season from May to October. Annual rainfall ranges from 1,400 to 1,800 mm. Mean annual temperature ranges from 18 to 22°C. Soils are predominantly yellow-red ferralitic developed on sandstone and shale bedrock.

The study focused on poor natural evergreen broadleaf production forests. These forests are characterized by discontinuous canopy cover (0.3-0.6), average tree height below 20 m, and species composition dominated by native trees capable of growing under nutrient-poor soil conditions. In the site, soil pH ranges from 4.2 to 4.8, organic matter content of 2.1-3.4%, and total nitrogen of 0.12-0.18%, reflecting typical nutrient-poor conditions of degraded forests in the region. Microclimate shows that relative humidity varies from 75-85% during the growing season, with canopy openness ranging from 35-55% across plots, influencing light availability and understory regeneration patterns.

2.2. Data Collection Methods

Temporary random sampling plots were used to collect data. Plot locations were identified on the 2023 forest map within areas classified as poor natural evergreen broadleaf production forests. A handheld GPS was used to locate plots in the field, ensuring deviation from mapped locations did not exceed 10 m. Temporary square plots of 2,500 m² (50 m × 50 m) were established in the field.

All trees within plots were surveyed, with species identified according to Vietnam's plant taxonomy system. Growth parameters measured included: diameter at breast height ($DBH_{1.3}$) measured at 1.3 m height, total height (H) for all trees with $DBH_{1.3} \geq 6$ cm, height to live crown base (Huc), and crown diameter (Dc). Diameter was measured using callipers with 0.1 cm precision, and height was measured using a Vertex hypsometer with 0.1 m precision.

Tree quality was assessed using three classes: (1) Good quality trees (Grade A): straight stem, good growth vigour, balanced crown, no pests or diseases. (2) Medium quality trees (Grade B): crooked stem, moderate growth vigour, slightly asymmetric crown, showing signs of pests or diseases. (3) Poor quality trees (Grade C): severely crooked stem, poor growth vigour, highly asymmetric crown, affected by pests and diseases.

2.3. Data Analysis

Aboveground biomass (B) was calculated using equation (1) from Vu et al. (2012):

$$B = \sum_{i=1}^{n} B_i \times 4 \qquad (1)$$

Where: $B_i = 0.1277 \times D_i^{2.3947}$, D_i is diameter at 1.3 m height ($DBH_{1.3}$) of tree i.

Standing timber volume was calculated using equation (2):

$$M\ (m^3/ha) = M_0 \times 4 \qquad (2)$$

Where: M_0 = primary plot volume, calculated using equation (3):

$$M_0 = \sum_{i=1}^{n} D_i^2 \times \pi/40{,}000 \times H_i \times f \qquad (3)$$

Where:

- D_i (cm): diameter at breast height ($DBH_{1.3}$) of tree i
- H_i (m): total height of tree i
- f: form factor = 0.48

Species composition was calculated using equation (4):

$$IV_i\ (\%) = (N_i\ (\%) + G_i\ (\%))/2 \qquad (4)$$

Where:

- IV %: importance value
- N_i (%): percentage of stems by species
- G_i (%): percentage of basal area by species

The Shannon-Wiener index (H', Magurran 1988) was calculated using equation (5):

$$H' = -\sum_{i=1}^{s} P_i \ln(P_i) \qquad (5)$$

Where: Pi is the relative abundance of species i (Pi = ni/N, ni is the number of individuals of species i); S is the total number of species and N is the total number of individuals surveyed.

Higher H' values indicate greater species diversity. When H' = 0, the community contains only one species, representing the lowest diversity level.

The Simpson diversity index (Cd) was calculated using equation (6):

$$Cd = 1 - \sum_{i=1}^{s} (ni/N)^2 \quad (6)$$

Where: ni = number of individuals of species i; N = total number of individuals of all species.

3. RESULTS

3.1. Stand Characteristics

Analysis of stand characteristics across the three study plots revealed notable differences among altitudinal zones (Table 1). Tree density ranged from 416 to 616 trees/ha, with plot YB4 having the highest density (616 trees/ha) at 807 m elevation, followed by plot YB3 with 428 trees/ha at 1,038 m elevation, and plot YB6 having the lowest at 416 trees/ha at 451 m elevation.

Mean diameter ($DBH_{1.3}$) ranged from 13.3 to 15.8 cm. There were differences among altitudinal zones, with plots at elevations above 500 m (YB3 and YB6) having larger mean diameters than the plot below 500 m (YB4). Specifically, plot YB3 had the largest mean diameter (15.8 ±0.8 cm), followed by plot YB6 (15.1 ±0.6 cm), and YB4 had the smallest (13.3 ±0.5 cm).

Total height (H) showed a similar trend to diameter. Plots at elevations above 500 m had significantly greater mean heights than the lower elevation plot. Plot YB6 had the highest mean height (11.4 ±0.3 m), followed by plot YB3 (11.0 ±0.4 m), and YB4 had the lowest (10.3 ±0.2 m).

Height to live crown base (Huc) ranged from 4.9 to 5.4 m. Plots at elevations above 500 m had greater heights to crown base, indicating longer branch-free stem sections, which may be due to light conditions and competition among trees.

Crown diameter (Dc) ranged from 3.2 to 3.7 m. Plot YB6 had the largest crown diameter (3.7 ±0.2 m), plot YB4 had a Dc of 3.2 ±0.1 m, while plot YB3 had a Dc of 3.4 ±0.2 m.

In terms of volume and biomass, plot YB3 at the highest elevation had the best indices with a basal area of 10.4 m^2/ha, timber volume of 68.9 m^3/ha, and biomass of 57.7 tons/ha. This was followed by plot YB4 with corresponding values of 10.1 m^2/ha, 58.2 m^3/ha, and 51.3 tons/ha. Plot YB6 had the lowest values at 8.7 m^2/ha, 55.4 m^3/ha, and 46.2 tons/ha.

Regarding tree quality (Fig. 1) in the stands, results showed that plot YB3 had the highest proportion of good quality trees (Grade A) at 46.5%, followed by medium quality trees (Grade B) at 37.6%, and poor-quality trees (Grade C) at 15.9%. Plot YB4 had a relatively balanced quality structure with Grade A, B, and C trees accounting for 35.2%, 41.4%, and 23.4%, respectively. Plot

YB6 had the lowest proportion of good quality trees (31.7%) but a high proportion of medium quality trees (45.8%) and poor-quality trees at 22.5%.

Table 1: Stand characteristics of study forests

Plot	Elevation (m)	Density (trees/ha)	DBH$_{1.3}$ (cm)	H (m)	Huc (m)	Dc (m)	G (m^2/ha)	M (m^3/ha)	B (tons/ha)
YB3	1,038	428	15.8^{a} ±0.8	11.0^{a} ±0.4	5.4^{a} ±0.3	3.4^{ab} ±0.2	10.4	68.9	57.7
YB4	807	616	13.3^{b} ±0.5	10.3^{b} ±0.2	4.9^{b} ±0.2	3.2^{a} ±0.1	10.1	58.2	51.3
YB6	451	416	15.1^{a} ±0.6	11.4^{a} ±0.3	5.2^{a} ±0.2	3.7^{b} ±0.2	8.7	55.4	46.2

Different letters (^{a,b}) in the same column indicate significant differences in mean values among plots.

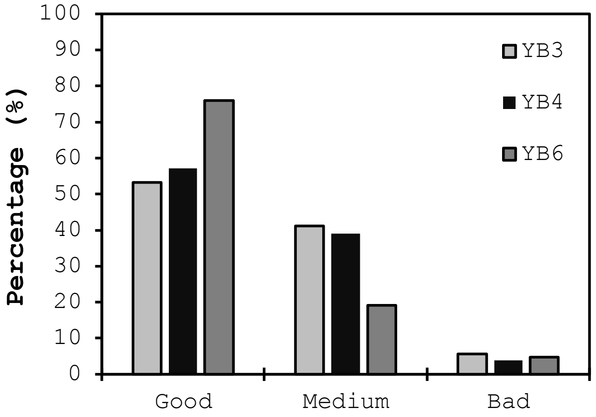

Figure 1: Tree quality distribution in the stands

3.2. Biodiversity

Species composition across the study plots demonstrated high diversity, with species numbers ranging from 29 to 45 (Table 2). Plot YB4 had the highest species diversity with 45 species belonging to 28 plant families, followed by plot YB6 with 33 species in 22 families, and plot YB3 with 29 species in 23 families.

The Shannon diversity index (H') ranged from 2.42 to 3.16, indicating medium to high levels of species diversity. Plot YB6 had the highest Shannon index (3.16), followed by plot YB4 (3.07), and YB3 had the lowest (2.42). This suggests that although plot YB4 had the most species, the evenness of species distribution was not as high as in plot YB6.

The Simpson index (Cd) ranged from 0.80 to 0.94, corresponding to high to very high diversity levels. Plot YB6 had the highest Simpson index (0.94), followed by plot YB4 (0.91), and YB3 had the lowest (0.80). These results align with the Shannon index, confirming that plot YB6 had the highest biodiversity among the study plots.

Differences in biodiversity among plots can be explained by ecological factors such as elevation, slope, aspect, and soil conditions. At mid-elevation (plot YB6, 451 m), more favourable ecological conditions support the development of more diverse species, while at higher elevation (plot YB3, 1,038 m), harsher conditions lead to dominance by a few well-adapted species.

Table 2: Biodiversity characteristics of study forests

Plot	Number of species	Number of families	Simpson index	Shannon index
YB3	29	23	0.80	2.42
YB4	45	28	0.91	3.07
YB6	33	22	0.94	3.16

3.3. Tree Distribution Patterns in Study Forests

3.3.1. Tree Distribution by Diameter Class (n/DBH$_{1.3}$)

Tree distribution by diameter class showed the characteristic pattern of natural forests, with tree numbers decreasing as diameter class increased (Fig. 2). All plots exhibited a Reverse-J distribution pattern, typical of uneven-aged forest structure with good regeneration capacity.

The 6-10 cm diameter class (midpoint 7.5 cm) had the highest proportion in all plots. Plot YB4 had the most trees in this class (224 trees), followed by plot YB3 (136 trees) and plot YB6 (92 trees). This reflects good regeneration and recovery capacity of forests in the study areas.

The 10-15 cm diameter class (midpoint 12.5 cm) contained substantial numbers of trees in all plots, with plot YB4 having 200 trees, plot YB6 having 136 trees, and plot YB3 having 100 trees. This variation may be due to different ecological conditions and harvesting histories among areas.

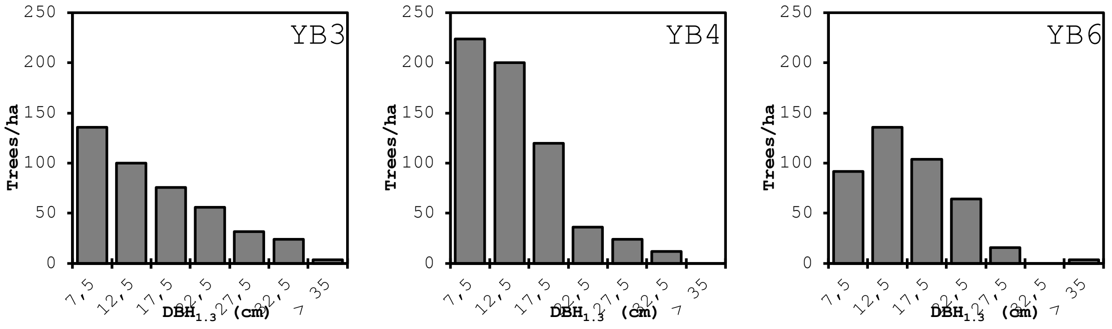

Figure 2: Tree distribution by diameter class

Large diameter classes (>25 cm) had few trees, especially the >35 cm class which was present only in plots YB3 and YB6 with very small numbers (4 trees). This indicates that forests are in a recovery stage following past impacts, with few large-diameter trees yet present.

3.3.2. Tree Distribution by Height Class (n/H)

Tree distribution by height class also exhibited characteristics of uneven-aged forests (Fig. 3). Notably, no trees with heights below 5 m were found in any study plots.

The 10-12.5 m height class contained the most trees in plot YB4 (216 trees) and plot YB6 (136 trees), while in plot YB3 this class had only 76 trees. Conversely, plot YB3 had a relatively even distribution across height classes from 7.5 m to 17.5 m, indicating more diverse canopy structure.

The >17.5 m height class was present only in plot YB3 (12 trees) and plot YB6 (16 trees), while plot YB4 had no trees in this height class. This reflects differences in growth potential and ecological conditions among areas.

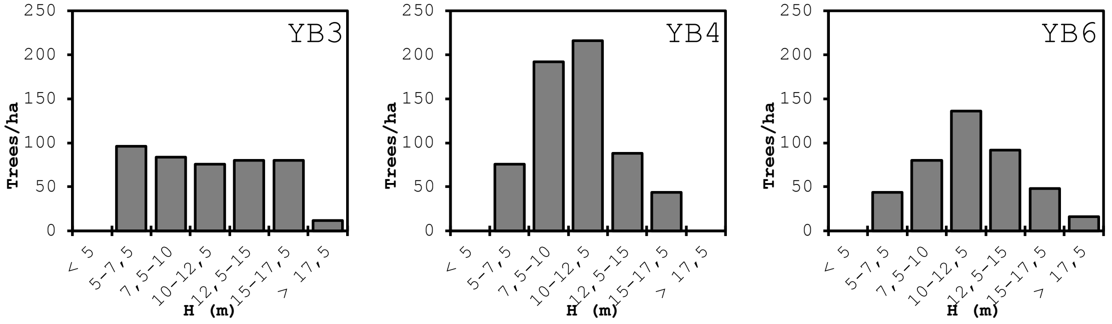

Figure 3: Tree distribution by height class

3.3.3. Tree Distribution by Height to Crown Base Class (n/Huc)

Height to crown base reflects wood quality and trees' light competition capacity (Fig. 4). Most trees had heights to crown base of 2-8 m, concentrated mainly in the 2-4 m and 4-6 m classes.

Plot YB4 had the most trees in the 4-6 m class (276 trees), indicating fairly intense light competition. Plot YB6 also had high numbers in this class (144 trees) and in the 2-4 m class (116 trees). Plot YB3 had relatively even distribution across classes from 2-10 m, reflecting complex forest structure with multiple canopy layers.

The number of trees with height to crown base >12 m was very small in all plots, indicating that wood quality is not yet high and forests have not achieved the complete structure of primary forests.

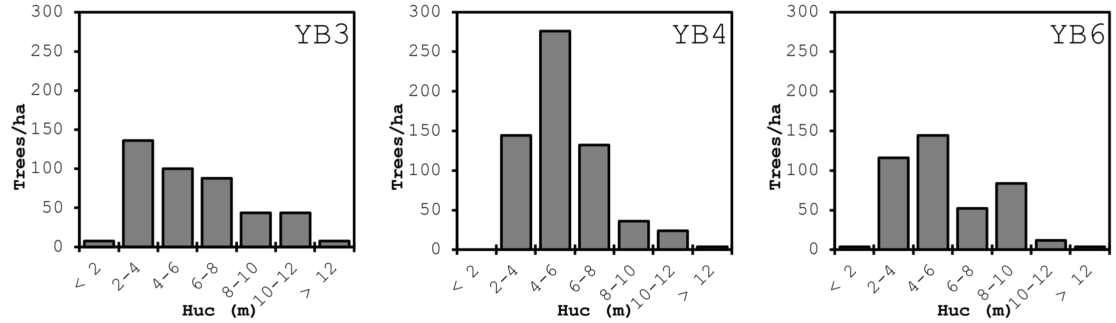

Figure 4: Tree distribution by height to crown base class

3.3.4. Tree Distribution by Crown Diameter Class (n/Dc)

Crown diameter reflects trees' spatial and light competition capacity (Fig. 5). Most trees had crown diameters of 2-6 m, concentrated mainly in the 2-3 m, 3-4 m, and 4-5 m classes.

Plot YB4 had high numbers of trees in small crown diameter classes (2-5 m), indicating high density and intense competition for growing space. Plot YB6 had relatively even distribution across classes from 2-6 m, while plot YB3 had significant numbers of trees in the 5-6 m class (96 trees), reflecting better crown development capacity due to lower density.

Large crown diameter classes (>8 m) had very few trees, present only in plot YB6 in small numbers. This indicates that in poor forest conditions with relatively high density, trees have difficulty developing wide crowns.

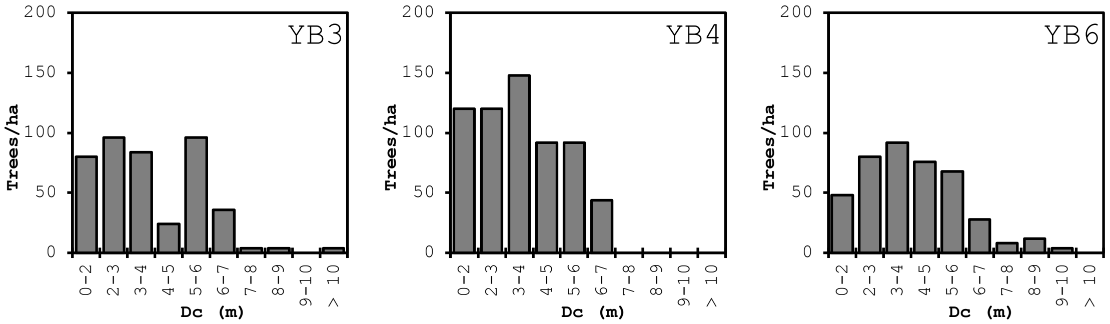

Figure 5: Tree distribution by crown diameter class

3.4. Species Composition Formula

Species composition formulas reflect species dominance in communities (Table 3). Results showed quite diverse species composition with clear differences among study plots and tree size groups.

For large trees ($DBH_{1.3} \geq 6$ cm), plot YB3 was dominated by *Clethra faberi* Hance at 44.2%, combined with *Toxicodendron succedanea* (L.) Moldenke at 7% and 27 other species comprising 48.4%. This indicates that at high elevation, some species adapted to harsh conditions can develop into large trees.

Plot YB4 had more diverse large tree species composition with Barringtonia macrostachya (Jack) Kurz accounting for 23.2%, *Schefflera heptaphylla* (L.) Frodin 16.9%, *Canarium album* (Lour.) DC.5.9%, *Prunus arborea var. densa* (King) Kalkm 5.4%, and 41 other species comprising 47.8%. This diversity reflects favorable ecological conditions at mid-elevation.

Plot YB6 was dominated by *Allospondias lakonensis* Stapf at 15.8%, followed by *Barringtonia macrostachya* (Jack) Kurz 9.9%, *Gironniera nervosa* Planch 9.8%, and other species. This relatively even distribution indicates community stability.

Table 3: Species composition

Plot	Species composition
YB3	44,2 *Clethra faberi* + 7 *Toxicodendron succedanea* + 48,4 others (27/29 species)
YB4	23,2 *Barringtonia macrostachya* + 16,9 *Schefflera heptaphylla* + 5,9 *Canarium album* + 5,4 *Prunus arborea var. densa* + 47,8 others (41/45 species)
YB6	15,8 *Allospondias lakonensis* Stapf + 9,9 *Barringtonia macrostachya* + 9,8 *Gironniera nervosa* + 5,4 *Artocarpus chama* + 4,9 *Pterospermum grewiaefolium* + 4,8 *Lithocarpus bacgiangensis* + 49,7 others (27/33 species)

4. DISCUSSION

The results demonstrate that poor natural evergreen broadleaf production forests in Lao Cai province exhibit considerable variation in structural characteristics and biodiversity, depending on ecological conditions, particularly topographic elevation. Statistically significant differences among altitudinal zones in growth parameters such as diameter, height, and height to crown base reveal the pronounced impact of topographic factors on forest development.

Tree density ranged from 416-616 trees/ha, relatively high compared to other studies on poor natural evergreen broadleaf forests in Vietnam. Tran et al. (2022) reported densities of 380-520 trees/ha at Dong Son - Ky Thuong Nature Reserve, Quang Ninh. These differences may be attributed to varying ecological conditions and levels of human disturbance.

Mean diameter of 13.3-15.8 cm and mean height of 10.3-11.4 m reflect characteristics of forests in recovery stages following past disturbances. While these values are lower than those of primary forests, they demonstrate good recovery potential. Timber volume of 55.4-68.9 m³/ha and biomass of 46.2-57.7 tons/ha fall within the moderate range compared to other studies. Huy et al. (2016) reported biomass ranging from 40-80 tons/ha for evergreen broadleaf forests in Vietnam, depending on ecological conditions and conservation status. These values are consistent with expectations for degraded forests undergoing natural regeneration in mountainous regions of northern Vietnam.

The Shannon diversity index of 2.42-3.16 indicates medium to high species diversity. Magurran (1988) suggested that Shannon index values from 1.5-3.5 correspond to medium to high diversity in tropical forest ecosystems. The Simpson index of 0.80-0.94 also confirms high diversity levels, particularly in plots YB4 and YB6. These biodiversity values are encouraging for degraded production forests and suggest substantial conservation value despite past disturbance. The relatively high diversity may reflect the resilience of evergreen broadleaf forests in this region and the effectiveness of reduced exploitation pressure in recent years.

Differences in biodiversity among altitudinal zones can be explained by ecological gradient theory. According to this theory, mid-elevations typically provide the most favourable conditions for development of diverse species assemblages, while at very low or very high elevations, harsher conditions lead to reduced diversity (Rahbek, 1995). However, in this study, plot YB6 at the lowest elevation (451 m) had the highest diversity, which may be due to other factors such as soil moisture, aspect, and land use history. The higher diversity at lower elevation may also reflect proximity to seed sources from adjacent valleys or more favourable temperature and moisture regimes.

The relationship between stand structure and biodiversity is further illuminated by examining height distribution patterns (Fig. 3). Plot YB3 showed more even distribution across height classes from 7.5 m to 17.5 m, creating a multi-layered canopy structure that, despite lower overall species richness (Table 2), may provide diverse microhabitats for fauna and epiphytes. In contrast, plot YB4's trees in the 10-12.5 m height class (216 trees) suggests more uniform canopy structure despite having the highest species count (45 species). This discrepancy between species richness and structural complexity highlights the importance of considering multiple dimensions of biodiversity in forest assessment and management planning.

The Reverse-J shaped diameter distribution is a positive characteristic of natural forests, indicating regeneration capacity and population stability (Condit et al., 1998). As shown in Figure 2, all three plots exhibited this characteristic pattern, with the 6-15 cm diameter class containing 54-69% of total stems across sites. This pattern, observed consistently across all plots, suggests that despite past degradation, these forests maintain essential ecological processes including seed production, germination, and sapling establishment. The abundance of small diameter trees provides a cohort for future stand development, though the relative scarcity of very large trees (>35 cm DBH) indicates incomplete recovery from historical disturbance. Notably, Table 1 reveals that plot YB3, despite having lower density (428 trees/ha), achieved the highest volume (68.9 m^3/ha) and biomass (57.7 tons/ha), suggesting that mid-sized trees (15-25 cm DBH) contribute disproportionately to stand productivity. The tree quality distribution (Fig. 1) further supports this, with plot YB3 having 46.5% Grade A trees compared to only 31.7% in plot YB6, indicating that elevation and management history interact to influence both structure and quality. The diameter structure observed is typical of secondary forests in Southeast Asia that have been subject to selective logging followed by natural regeneration (Berry et al., 2010).

Species composition formulas revealed no absolute dominance by any single species, which is advantageous for ecosystem stability and resilience. The diversity of dominant species among plots reflects species adaptation to specific ecological conditions. At higher elevations (plot YB3), the dominance of *Clethra faberi* (44.2%) suggests this species is particularly well-adapted to cooler temperatures and possibly higher rainfall characteristic of upper montane zones. In contrast, at lower elevations, more diverse species dominance patterns indicate more heterogeneous environmental conditions or different successional trajectories following disturbance.

The relatively high proportion of medium to poor quality trees (Grade B and C) across all plots reflects the degraded status of these forests. However, the presence of substantial numbers of good quality trees (Grade A), particularly in plot YB3 (46.5%), indicates potential for future timber production with appropriate silvicultural management. The lower quality in plots YB4 and YB6 may result from more intensive past exploitation or less favourable growing conditions. Improving stand quality through selective thinning and protection from disturbance should be a management priority.

The variation in forest structure and biodiversity across the altitudinal gradient has important implications for conservation and management planning. The higher diversity observed at mid-elevations (plot YB6) suggests these areas may serve as important refugia for species diversity and should be prioritized for conservation. However, higher elevation forests (plot YB3), despite lower diversity, harbour species specifically adapted to montane conditions and represent distinct conservation values. A landscape-level approach that protects forests across the full elevational gradient would best preserve the region's biodiversity.

The study's findings contribute to growing evidence that degraded tropical forests retain significant ecological value and recovery potential (Chazdon et al., 2009). The combination of reasonable biodiversity levels, natural regeneration capacity indicated by Reverse-J diameter distributions, and substantial biomass accumulation suggests this poor production forests provide important ecosystem services including carbon storage, watershed protection, and biodiversity conservation. These values should be recognized in forest management policies and practices.

However, several limitations of this study should be acknowledged. The sample size of three plots, while providing valuable insights, may not fully capture the heterogeneity of poor production forests across Lao Cai province. Future research should expand spatial coverage and include additional environmental variables such as soil properties, microclimate conditions, and disturbance history to better understand drivers of forest structure and diversity patterns. Long-term monitoring would provide insights into successional trajectories and recovery rates, informing adaptive management strategies.

Based on these findings, several practical management recommendations can be proposed for poor natural evergreen broadleaf production forests in Lao Cai province. First, selective thinning should be implemented in high-density plots (>600 trees/ha) by removing Grade C trees from the 6-15 cm diameter classes to reduce competition and promote growth of better-quality stems. Second, all trees >25 cm DBH should be protected as seed sources given their current scarcity. Third, mid-elevation areas (400-600 m) exhibiting highest biodiversity (Table 2) should be designated as conservation priority zones with strict protection measures to maintain seed sources for landscape-level regeneration. Fourth, enrichment planting with high-value native species such as *Barringtonia macrostachya* and *Canarium album* should be considered in area with >20% Grade C trees (Fig. 1) to accelerate stand improvement. Finally, a 5-year monitoring cycle should be established to track diameter distribution changes, species composition shifts, and stand quality improvement, enabling adaptive management adjustments based on forest response to interventions. These targeted strategies can enhance both timber production and ecosystem services while maintaining the natural regeneration.

5. CONCLUSION

This study characterized the structure and biodiversity of poor natural evergreen broadleaf production forests in Lao Cai province through investigation of three sample plots across different altitudinal zones. Results showed that forests had densities of 416-616 trees/ha, mean diameters of 13.3-15.8 cm, and mean heights of 10.3-11.4 m. Timber volume reached 55.4-68.9 m³/ha, and biomass ranged from 46.2-57.7 tons/ha. Forests exhibited Reverse-J diameter distributions, indicating good natural regeneration capacity and stable recovery-oriented structure. Shannon diversity indices of 2.42-3.16 and Simpson indices of 0.80-0.94 reflected medium to high biodiversity levels. The sample plot at mid-elevation (451 m) had the highest species diversity, demonstrating the pronounced influence of topographic factors on growth and forest structure. The documented natural regeneration capacity and biodiversity levels indicate these degraded forests retain substantial recovery potential, justifying restoration investments through selective thinning and protection measures rather than plantation conversion. Management strategies should account for pronounced elevational effects on structure and diversity. Future research priorities include expanding spatial coverage, establishing permanent monitoring plots, and evaluating climate change impacts on species distribution. The research findings provide a scientific basis for proposing management, conservation, and sustainable use solutions for natural forests in the context of environmental change and increasingly diminishing resources.

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REFERENCES

[1]. Aiba, S., & Kitayama, K. (1999). Structure, composition and species diversity in an altitude-substrate matrix of rain forest tree communities on Mount Kinabalu, Borneo. *Plant Ecology*, 140(2), 139-157.

[2]. Berry, N. J., Phillips, O. L., Lewis, S. L., Hill, J. K., Edwards, D. P., Tawatao, N. B., ... & Hamer, K. C. (2010). The high value of logged tropical forests: lessons from northern Borneo. *Biodiversity and Conservation*, 19(4), 985-997.

[3]. Chazdon, R. L., Peres, C. A., Dent, D., Sheil, D., Lugo, A. E., Lamb, D., ... & Miller, S. E.

(2009). The potential for species conservation in tropical secondary forests. *Conservation Biology*, 23(6), 1406-1417.

[4]. Condit, R., Sukumar, R., Hubbell, S. P., & Foster, R. B. (1998). Predicting population trends from size distributions: a direct test in a tropical tree community. *The American Naturalist*, 152(4), 495-509.

[5]. Do, T. V., Osawa, A., & Thang, N. T. (2011). Recovery of vegetation structure and species diversity after shifting cultivation in Northwestern Vietnam, with special reference to commercially valuable tree species. *ISRN Ecology* 2011:12 pages.

[6]. Do, T. V., Osawa, A., & Thang, N. T. (2016). Post-logging regeneration and growth of commercially valuable tree species in evergreen broadleaf forest, Vietnam. *Journal of Tropical Forest Science*, 28(4), 426-435.

[7]. Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., ... & Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, 478(7369), 378-381.

[8]. Huy, B., Kralicek, K., Poudel, K. P., Phuong, V. T., Khoa, P. V., Hung, N. D., & Temesgen, H. (2016). Allometric equations for estimating tree aboveground biomass in evergreen broadleaf forests of Vietnam. *Forest Ecology and Management*, 382, 193-205.

[9]. Kueh, R.J.H., & Lim, M.T. (2019). Forest biomass estimation in Air Hitam Forest Reserve. Seminar Pengurusan dan Ekologi Hutan Simpan Air Hitam, Puchong, Selangor, Malaysia, p. 7.

[10]. Magurran, A.E. (1988). Ecological Diversity and Its Measurement. Princeton University Press, Princeton, NJ, p. 192.

[11]. Ohtsuka, T. (2010). Biomass changes in yearly tropical succession on a large-scale shifting cultivation area, Northeast Borneo Island. *Tropics* 10, 529-537.

[12]. Rahbek, C. (1995). The elevational gradient of species richness: a uniform pattern? *Ecography*, 18(2), 200-205.

[13]. Tran, V.D., Nguyen, T.T., Vu, T.L., et al. (2022). Biomass and structure of natural forest in Dong Son - Ky Thuong Natural Reserve Area, Quangr Ninh. *Vietnam Journal of Forest Science*, 6/2022:114-120.

[14]. Vu, T.P., Nguyen, V.X., Dang, T.T., Phung, D.T., Nguyen, X.G., & Pham N.T. (2012). Tree allometric equation development for estimation of forest above-ground biomass in Viet Nam - Evergreen broadleaf, Deciduous, and Bamboo Forest in the Central Highland region. UN-REDD Programme Vietnam, 2012.