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Vegetation diversity in the Geumpang Protected Forest Area, Pidie District, Aceh, Indonesia

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Abstract. *Anhar A, Erida G, Siregar AW, Rahmah H, Muslih AM, Hanafi I, Hayati D. 2025. Vegetation diversity in the Geumpang Protected Forest Area, Pidie District, Aceh, Indonesia. Biodiversitas 26: 4490-4499.* Forests, as complex ecosystems, play a vital role in maintaining global environmental balance by providing critical ecosystem services such as biodiversity conservation, climate regulation, and water management. The Geumpang Protected Forest Area (PFA) in Pidie District, Aceh, Indonesia, is a key area for ecological stability and community benefits, making biodiversity research essential to inform conservation efforts and sustainable forest management policies. The research was conducted in the Geumpang PFA. This study employed vegetation analysis techniques with 63 plots of varying sizes established to collect data on species, individual counts, stem diameters, and tree heights. Data analysis included indices for diameter distribution, Importance Value Index (IVI), species dominance (C), species diversity (H'), evenness (E), and richness (R) to assess forest composition and structure. The results highlighted species composition across growth stages, with indices providing insights into dominance, diversity, and distribution patterns within the forest ecosystem. The Geumpang PFA contains a wide variety of vegetation diversity, comprising 14 species at the seedling stage, 30 species at the sapling stage, 32 species at the pole stage, and 39 species at the tree stage, with a total of 46 vegetation species across all growth stages. The tree diameter distribution in the Geumpang PFA forms an inverted J-shaped curve. The highest IVI is recorded for *Lithocarpus* sp. in tree (77.18%) and pole (32.92%) stages, *Ficus hispida* in sapling stage (24.83%), and *Coffea canephora* in seedling stage (65.43%). In general, the C in Geumpang PFA is low across all growth stages, with values approaching 0. The H' ranges from medium to high, with a high value in the pole stage (3.12) and medium values in the tree, sapling, and seedling stages (2.94, 2.89, and 2.10, respectively). The E shows the pole stage with the highest value (0.90) and the seedling stage with the lowest (0.79). The R shows high species richness at the tree (R: 6.31), pole (R: 5.77), and sapling stages (R: 5.28), while the seedling stage has low richness (R: 2.86). The high vegetation diversity and early-stage regeneration challenges in the Geumpang PFA underscore the urgent need for conservation succession, ecosystem resilience, and local community benefits.

Keywords: Diversity, dominance, evenness, IVI, richness

INTRODUCTION

Forests are complex ecosystems that support biodiversity and provide important services for human well-being and environmental balance (Brockerhoff et al. 2017; Mori et al. 2017). They manage water cycles by capturing rainfall with tree canopies, reducing flood risks, and maintaining groundwater supplies. Forests also absorb carbon dioxide through photosynthesis, helping to reduce greenhouse gases that trigger climate change (Weiskopf et al. 2020). Additionally, forests stabilize the climate by regulating temperatures and supporting nutrient cycles, which are crucial for food security and resilient ecosystems (Dlamini 2019). However, forests worldwide face serious threats from deforestation, land-use changes, and climate impacts, with about 10 million hectares lost each year (FAO 2020). These threats weaken forest functions, highlighting the urgent need for sustainable management to protect their ecological and social benefits. Studying forest diversity and structure is essential for developing effective conservation strategies to address these challenges and ensure forests remain ecologically stable for the future.

Biodiversity is critical for maintaining forest ecosystem processes, such as pollination, seed dispersal, nutrient cycling, and carbon storage. These processes strengthen forests' ability to withstand disturbances like climate change and natural disasters (Law et al. 2021; Nuryanti et al. 2023). Protected Forest Areas (PFAs) are key to conserving rare, endemic, and threatened species while supporting these processes. Globally, PFAs cover nearly 15% of the earth's surface and are a major strategy to prevent the loss of tropical forests and biodiversity (Geldmann et al. 2018; Mackinnon et al. 2020). PFAs are designed to restrict or reduce the anthropogenic pressures in areas of high biological diversity (Venter et al. 2014; Watson et al. 2014), which helps maintain ecosystem stability and provides benefits like clean water, disaster protection, and climate regulation. However, PFAs face challenges such as illegal logging, land encroachment, and limited management resources, which reduce their effectiveness (Ullah et al. 2022; Sattraburut et al. 2024). High biodiversity in PFAs is essential for maintaining ecological stability, particularly in tropical regions where species diversity is rich but increasingly at risk from human activities.

PFAs in Indonesia is critical for biodiversity protection and supporting ecosystem services both at national and global levels. Indonesia has 125.76 million hectares of forest, categorized into several types: permanent production forests (29.22 million hectares), limited production forests (26.77 million hectares), and protected forests (29.58 million hectares) (KLHK 2022). In Aceh, protected forests cover 1,781,448 hectares (BPS Aceh 2021) and are known as biodiversity hotspots, supporting many plants and animals essential for regional ecological stability. However, Aceh's forests are threatened by activities like logging, land conversion for agriculture, and infrastructure development, which reduce forest cover and disrupt ecosystem services. Although many studies have explored tropical forest biodiversity in Indonesia, detailed information about vegetation diversity and ecological succession in the Geumpang PFA, Pidie District, Aceh, Indonesia, is scarce, especially on regeneration patterns across growth stages. This lack of data makes it difficult to create conservation plans tailored to the unique ecological and social needs of this area, emphasizing the need for thorough biodiversity studies.

The Geumpang PFA is a valuable ecological resource, providing clean water, preventing floods and landslides, and storing carbon, all of which directly benefit local communities (Erida et al. 2025). Its rich biodiversity supports ecosystem processes like nutrient cycling and habitat provision, contributing to regional ecosystem stability. However, human activities, such as illegal logging and land-use changes, threaten the forest's ecological integrity and the well-being of nearby communities. The Geumpang PFA is located within the Ulu Masen ecosystem, intersected by the Geumpang-Meulaboh provincial road linking Pidie and Meulaboh Districts, which increases the potential for habitat fragmentation. Illegal gold mining by local communities poses a significant threat, potentially leading to vegetation loss and ecosystem degradation, while the absence of detailed forest stand inventory underscores the necessity of this study to document vegetation diversity and address these anthropogenic impacts. Studying the vegetation diversity and ecological succession in the Geumpang PFA is essential for creating baseline data to guide sustainable forest management and biodiversity conservation. This research is important because it addresses the knowledge gap about the Geumpang PFA's ecological patterns, supporting the development of evidence-based policies that strengthen ecosystem stability, sustain local livelihoods through services like water supply and disaster prevention, and raise community awareness about conservation. Additionally, this study contributes to global conservation efforts by offering insights into tropical forest succession, which can guide similar initiatives in other biodiversity-rich regions.

This study aims to identify and analyze vegetation diversity in the Geumpang PFA to address the identified research gap and support conservation efforts. By examining species composition, diversity indices, and regeneration patterns, this research seeks to provide a scientific foundation for sustainable forest management, enhance public awareness, and inform policy-making for protected forests in Pidie District, ultimately contributing to ecological stability and community well-being.

MATERIALS AND METHODS

Study area

The research was conducted in the Geumpang PFA, Pidie District, Aceh, Indonesia. The map of the research location is shown in Figure 1.

Procedures

Instruments and materials

The instruments and materials used in this study included a work plot map, Global Positioning System (GPS), clinometer, plastic rope, stakes, measuring tape/field band, digital camera, stationery, tally sheets, and forest vegetation.

Data collection techniques

Vegetation data were collected using a systematic sampling approach, establishing 63 plots, each measuring 20x20 m^2, systematically distributed across the study area at regular intervals to capture vegetation across four growth stages: seedling, sapling, pole, and tree. Within each plot, subplots were created with specific dimensions: 20x20 m^2 for the tree stage, 10x10 m^2 for the pole stage, 5x5 m^2 for the sapling stage, and 2x2 m^2 for the seedling stage. Data collected included species, number of individuals, stem Diameter at Breast Height (DBH: 1.3 m), and tree height for the tree and pole stages, while species and number of individuals were recorded for the sapling and seedling stages. Species identification was conducted using field guides and taxonomic references, and consultation with local botanists.

The study of tree diameter class distribution examines the horizontal structure of forest stands (Wiharto et al. 2008). This study was conducted by measuring the diameter of each tree (DBH>10 cm) within observation plots and assigning them to specific diameter classes. These classes include Class I (10-19 cm), Class II (20-29 cm), Class III (30-39 cm), Clas IV (40-49 cm), Class V (50-59 cm), Class VI (60-69 cm), Class VII (70-79 cm), Class VIII (80-89 cm), Class IX (90-99 cm), and Class X (>100cm).

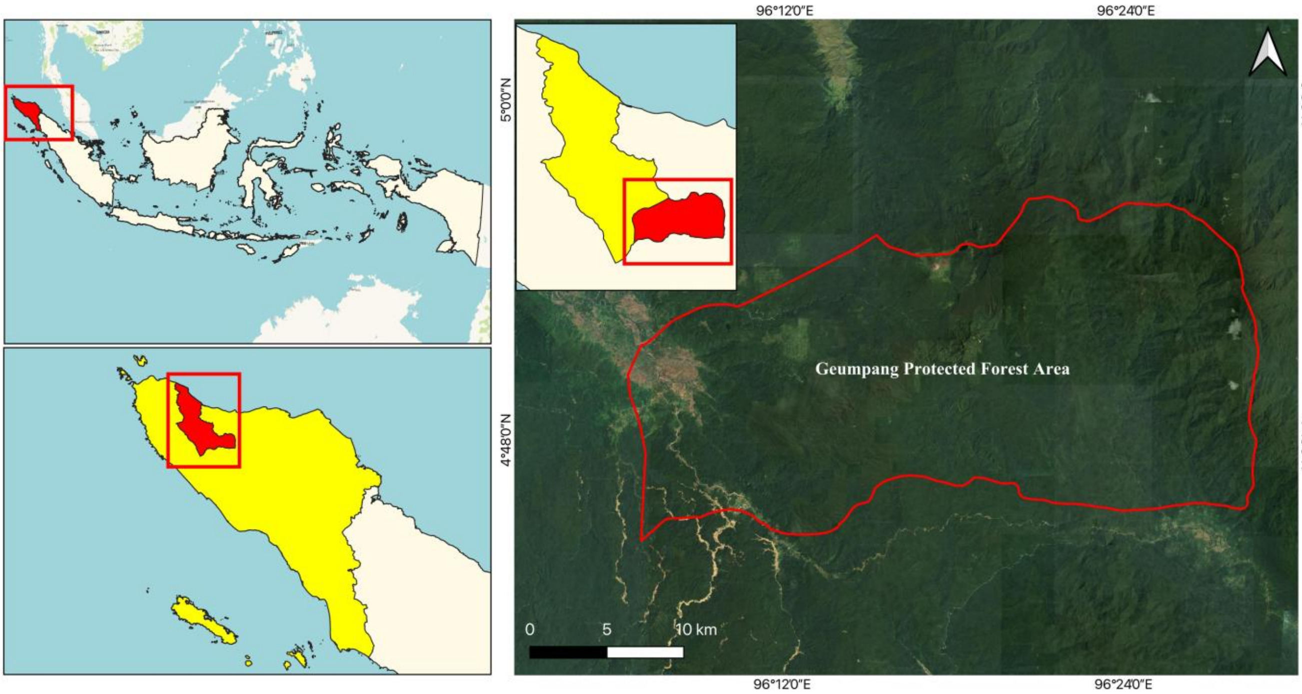

Figure 1. Study site of vegetation diversity in Geumpang Protected Forest Area, Pidie District, Aceh, Indonesia

Data analysis

To understand the composition and structure of vegetation in Geumpang PFA, an analysis of research parameters is required. The analyses conducted include Important Value Index (IVI), species dominance index (C), species diversity index (H'), species evenness index (E), and species richness index (R) (Kusmana and Melyanti 2017).

Species composition

The vegetation species data collected in the field are presented in a table, displaying information on local names, scientific names, and species occurrence at each growth stage of the trees.

Diameter distribution

The number of individual trees in each diameter class range was then plotted on a two-dimensional graph, with the x-axis representing the tree diameter class distribution and the y-axis indicating the number of individual trees (Wiharto et al. 2008)

Importance Value Index (IVI)

The Importance Value Index (IVI) is used to analyze the dominance of a species within a specific community (Kusmana and Susanti 2015). The mathematical formula for calculating IVI is as follows (Mueller-Dombois and Ellenberg 1974):

$$Density\ (D) = \frac{Number\ of\ individuals\ of\ a\ species\ (N)}{Sample\ plot\ area\ (ha)}$$

$$Relative\ Density\ (RD) = \frac{Density\ of\ a\ species}{Density\ of\ all\ species}\ x\ 100$$

$$Frequency\ (F) = \frac{Number\ of\ plots\ where\ a\ species\ found}{Total\ number\ of\ plots}$$

$$Relative\ Frequency\ (RF) = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species}\ x\ 100$$

$$Dominance\ (Dom) = \frac{Total\ basal\ area\ of\ a\ species}{Sample\ plot\ area}$$

$$Relative\ Dominance\ (RDom) = \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species}\ x\ 100$$

$$IVI\ for\ seedlings\ and\ saplings\ (\%) = RD + RF$$

$$IVI\ for\ poles\ and\ trees\ (\%) = RD + RF + RDom$$

Species dominance index (C)

The Species Dominance Index is used to determine the concentration and grouping of a particular species within a specific community (Kusmana and Melyanti 2017). The formula for its calculation is as follows:

$$C = \sum_{i=1}^{n} \left(\frac{ni}{N}\right)^2$$

Description: C: Species dominance indeks, ni: Number of individuals of species i, N: Total number of individuals

The value of the Species Dominance Index ranges between $0<C<10<C<1$. If a stand is dominated by a single species, the value of C approaches 1, indicating the presence of species grouping or concentration. Conversely, if the value of C approaches 0, it suggests no species concentration, where multiple species dominate simultaneously (Ghufrona et al. 2015).

Diversity index (H')

The species diversity index is a parameter used to assess the stability of a community or its ability to maintain equilibrium despite disturbances to its components. The diversity of species was calculated using the formula Shannon and Wiener (1949) as follows:

$$H' = -\sum_{i=1}^{n}\left[\left(\frac{ni}{N}\right)ln\left(\frac{ni}{N}\right)\right]$$

Description: H': Shannon-Wiener diversity index, ni: Number of individuals of species i, N: Number of individuals of all species. Criteria: If $H'<1$: Low diversity, If $1<H'<3$: Medium diversity, If $H'>3$: High diversity.

Species evenness index (E)

The species evenness index indicates the distribution of individuals across species within a forest area (Kusmana and Melyanti 2017). The formula for its calculation is as follows (Magurran 1988):

$$E = \frac{H'}{\ln(S)}$$

Description: E: Species evenness index, H': Shannon-Wiener diversity index, ln: Natural logarithm, S: Number of species.

Species richness index (R)

The species richness index (R) reflects the diversity of species within a region by calculating the number of species present. The formula is as follows (Magurran 1988):

$$R = \frac{(S-1)}{\ln(N)}$$

Description: R: Species richness index, S: Total number of species identified, N: Total number of individuals. Criteria (Magurran 1988): $R<3.5$: Low richness, $3.5\leq R\leq 5.0$: Moderate richness, $R>5.0$: High richness.

RESULTS AND DISCUSSION

Species composition

The collected data reveal significant variation in the number of species and individuals across different tree growth stages in the Geumpang PFA. As shown in Table 1, the tree exhibits the highest species richness (39 species) and the largest number of individuals (413 individuals), followed by the pole stage with 32 species and 215 individuals, the sapling stage with 30 species and 243 individuals, and the seedling stage with the lowest species count (14 species) and fewest individuals (94 individuals).

The high species richness and number of individuals at the tree stage in the Geumpang PFA stem from a near-climax successional process, where species resilient to environmental pressures, such as competition and predation, have accumulated over time. Fast-growing pioneer species, as noted by Dodo and Hidayat (2020), contribute to this diversity through abundant seed banks on the forest floor. Additionally, the large number of individuals at the tree stage reflects successful reproduction and regeneration from past generations, with many species in the Geumpang PFA reaching maturity.

In contrast, the low species richness and number of individuals at the seedling stage result from environmental constraints, such as limited light availability and anthropogenic pressures from local community activities. Besides that, study from Mammo et al. (2024) further suggests that low seedling numbers may also be driven by overgrazing, browsing by animals, seed predation, low disease resistance, moisture and temperature stress, insufficient sheltered spaces for seedling growth, and limited seed dispersal mechanisms.

According to Birhanu et al. (2025), good regeneration is indicated by a higher number of seedlings compared to trees, supported by a diverse and abundant soil seed bank that ensures a continuous seed supply. The low species and individual counts at the seedling stage compared to other strata in the Geumpang PFA signal regeneration pose challenges that could threaten long-term biodiversity. Thus, conservation interventions, such as canopy management to enhance light availability or community-based approaches engaging local residents, are critical to sustaining the ecological health of the Geumpang PFA.

Diameter distribution

Tree diameter distribution serves as a key indicator for understanding the complexity of forest structure (Kara 2021). In the Geumpang PFA, measurements of tree diameter distribution reveal a dominance of certain diameter classes. As shown in Figure 2, three diameter classes have the highest number of individuals (>100 ind): Class I (10-19 cm) with 215 ind, Class II (20-29 cm) with 179 ind, and Class III (30-39 cm) with 139 ind. In contrast, Classes IV to X have fewer individuals (<50 ind), with the lowest counts in Class VII (70-79 cm) and Class VIII (80-89 cm), each with only 4 ind/ha.

The tree diameter distribution in the Geumpang PFA forms an inverted J-shaped curve (Figure 2), indicating robust regeneration with a high number of small-diameter individuals and a gradual decline in larger-diameter mature trees. This pattern aligns with Susanto's (2019) findings, which suggest that an inverted J-shaped curve reflects a relatively stable and healthy forest ecosystem with strong regeneration. Rubin et al. (2006) further emphasizes that diameter distribution can indicate whether the density of small trees is sufficient to replace existing mature trees, serving as a tool to assess forest sustainability. However, the low number of individuals in larger diameter classes may result from the selective logging of mature trees for various purposes, as reported by Mekonnen and Mola (2016). These findings highlight the need for conservation strategies to balance regeneration and the preservation of mature trees in the Geumpang PFA.

Table 1. Number of species and individuals at each vegetation growth stage in the Geumpang PFA, Pidie District, Aceh, Indonesia

Growth stage	Number of species	Number of individuals
Seedling	14	94
Sapling	30	243
Pole	32	215
Tree	39	413

Note: The number of species and individuals refers to the total count of species and individual trees across all sampling plots (63 plots)

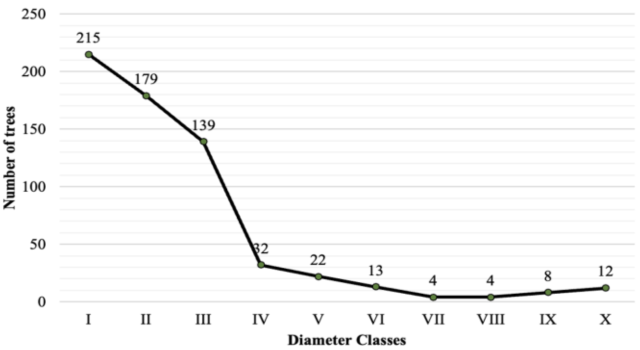

Figure 2. Diameter distribution in the Geumpang PFA, Pidie District, Aceh, Indonesia. Diameter Class I: 10-19 cm, Diameter Class II: 20-29 cm, Diameter Class III: 30-39 cm, Diameter Class IV: 40-49 cm, Diameter Class V: 50-59 cm, Diameter Class VI: 60-69 cm, Diameter Class VII: 70-79 cm, Diameter Class VIII: 80-89 cm, Diameter Class IX: 90-99 cm, and Diameter Class X: >100 cm. Number of trees refers to the total count of individual trees (DBH>10 cm) across all sampling plots (63 plots)

Important Value Index (IVI)

To illustrate the role of each vegetation species found in the Geumpang PFA, the IVI was calculated, as described by Ismaini et al. (2015). The IVI of a species in a plant community reflects the extent to which the species contributes or plays a crucial role within that community. Species with significant dominance in the community typically exhibit a high IVI value (Martono et al. 2019). The IVI values indicate the ecological relevance of tree species in community structure (Aye and Shibata 2023), where a high IVI value indicates a strong social structure of a species within the community, revealing its position in the ecological hierarchy. Information on IVI is crucial as it allows for the comparison of ecological significance between different species (Ayele et al. 2024). Therefore, the species with the highest IVI value is dominant and exerts a major influence on the structure and function of the ecosystem, in contrast to species with lower IVI values (Darmawati et al. 2021).

At the seedling stage (Table 2), the five species with the highest IVI identified in the Geumpang PFA are *Coffea canephora* (65.43%), *Bischofia javanica* (29.43%), *Archidendron pauciflorum* (14.72%), *Mangifera* sp. (14.72%), and *Macaranga diepenhorstii* (14.72%). The dominance of *C. canephora* at the seedling stage may reflect anthropogenic influences from surrounding coffee plantation activities, such as unintentional seed release or seed dispersal facilitated by animal vectors like birds and small mammals (Landim et al. 2025). However, seed dispersal by animals is influenced by various factors, including plant traits, disperser behavior, and environmental conditions (Côrtes and Uriarte 2013). In addition, natural factors such as wind and water (Wunderle 1997; Liu 2025) also contribute to seed dispersal and may explain the presence of the other four species at the seedling stage. Seed dispersal plays a vital role in shaping plant community composition (Soomers et al. 2013) and is essential for maintaining and restoring biodiversity.

At the sapling stage (Table 3), the five species with the highest IVI identified in the Geumpang PFA are *Ficus hispida* (24.83%), *C. canephora* (22.66%), *Vitex pinnata* (13.19%), *Ulmus* sp. (13.08%), and *Lithocarpus* sp. (11.84%). The dominance of *F. hispida* at the sapling stage suggests its ecological importance in the successional dynamics of the forest, likely due to its resilience and adaptability to suboptimal environmental conditions (Hendrayana et al. 2021). Similarly, the consistently high IVI of *C. canephora* from the seedling to the sapling stage indicates this species' strong capacity for establishment and adaptation within the protected forest ecosystem. This pattern supports the hypothesis that *C. canephora's* success is not solely due to proximity to seed sources from nearby coffee plantations, but also due to its inherent regenerative capability under potentially disturbed or stressed conditions. Moreover, *C. canephora* is known for its tolerance to drought and heat, as well as its natural resistance to several major pests and diseases, such as coffee leaf rust and the coffee berry borer, which may enhance its survival in challenging environments (Campuzano-Duque and Blair 2022). Beyond the dominance of *F. hispida* and *C. canephora*, the relatively high IVI values of *V. pinnata*, *Ulmus* sp., and *Lithocarpus* sp. at the sapling stage indicate that these species also possess considerable regenerative potential and may play important roles in maintaining forest structure and biodiversity in the Geumpang PFA.

At the pole stage (Table 4), the five species with the highest IVI are *Lithocarpus* sp. (32.92%), *F. hispida* (27.44%), *Hibiscus tiliaceus* (21.53%), *V. pinnata* (19.86%), and *Eugenia grandis* (18,18%). At the tree stage (Table 5), *Lithocarpus* sp. dominates with an IVI of 77.18%, followed by *Vatica* sp. (21.15%), *V. pinnata* (19.62%), *Ficus benjamina* (19.31%), and *M. diepenhorstii* (15.37%), The marked dominance of *Lithocarpus* sp. across the pole and tree stages highlights its significant role in the vegetation community of the area, likely supported by its large basal area and high density.

The IVI of a species is directly correlated with its dominance or prevalence within a plant community (Rangkuti et al. 2023). In this study, *Lithocarpus* sp. demonstrates significant dominance across multiple growth stages, ranking among the top five species with the highest IVI at the sapling (11.84%), pole (32.92%), and tree (77.18%) stages, reflecting its strong adaptation to local ecosystem conditions and its ability to persist and grow across various developmental phases. *V. pinnata* also shows notable presence, appearing in the top five with the highest IVI at the sapling (13.19%), pole (19.86%), and tree (19.62%) stages, indicating its adaptability to the forest environment. However, neither species consistently ranks in the top five across all stages, as *V. pinnata* is absent from the seedling stage (Table 2), where *C. canephora* (65.43%) dominates. The exceptionally high IVI of *Lithocarpus* sp. at tree stage underscores its substantial influence in the vegetation community of the Geumpang PFA, largely due to its large basal area, which supports the development of large trees with high density. Vegetation species with high dominance tend to have larger average stem diameters and greater individual numbers (Ali and Yan 2017; Darmawati et al. 2021). The high IVI of *C. canephora* at the seedling stage suggests strong regenerative potential, a pattern consistent with studies on early-stage dominance of *Coffea* species in disturbed areas, where seed availability and dispersal mechanisms drive initial establishment (Campuzano-Duque and Blair 2022). This dominance may also indicate the influence of nearby agricultural sources, a factor that enhances seedling recruitment but could limit long-term persistence, as noted in regeneration studies where early dominance does not always translate to later stages due to competitive pressures. The persistence of *C. canephora* into the sapling stage with a high IVI (22.66%) reinforces its adaptability, a trait observed in other *Coffea* species under varying environmental conditions, where tolerance to stress supports mid-successional presence (Campuzano-Duque and Blair 2022). The emergence of *Lithocarpus* sp. at the sapling stage (11.84%) aligns with findings on *Lithocarpus* species in montane forests, where early growth indicates potential for canopy dominance, though its progression depends on competitive dynamics (Culmsee et al. 2011). The role of *F. hispida* in successional stages is supported by its adaptability, a characteristic noted in similar environments where early resilience facilitates ecological recovery. The increasing IVI of *Lithocarpus* sp. from pole (32.92%) to tree stage (77.18%) reflects a pattern of canopy dominance seen in other *Lithocarpus* species in undisturbed montane forests, where large basal area and density contribute to structural stability (Kessler 2001; Culmsee et al. 2011). This suggests that *Lithocarpus* sp. in Geumpang may be a key species in forest maturation, though its high IVI at the tree stage could indicate limited regeneration pressure, a factor influenced by canopy closure and light availability. The dominance of *Lithocarpus* sp. across stages, peaking at the tree stage, is consistent with observations of *Lithocarpus* species in other tropical forests, where high IVI reflects their role in maintaining canopy structure (Culmsee et al. 2011). The absence of *C. canephora* in later stages, despite its seedling dominance, may be influenced by competitive exclusion or environmental constraints, a pattern noted in regeneration studies where early-stage species face challenges in progressing due to canopy effects. The adaptability of *V. pinnata* across mid to late stages suggests a successional role, potentially enhanced by light availability, a factor that affects species distribution in regenerating forests.

Table 2. Five species with the highest IVI at the seedling stage in the Geumpang PFA, Pidie District, Aceh, Indonesia

Species	Local name	RD (%)	RF (%)	IVI (%)
Coffea canephora	*Kopi robusta*	40.43	25.00	65.43
Bischofia javanica	*Tingkem*	12.77	16.67	29.43
Archidendron pauciflorum	*Jengkol*	6.38	8.33	14.72
Mangifera sp.	*Mangga Hutan*	6.38	8.33	14.72
Macaranga diepenhorstii	*Tampui*	6.38	8.33	14.72

Note: RD: Relative Density, RF: Relative Frequency, IVI: Importance Value Index

Table 3. Five species with the highest IVI at the sapling stage in the Geumpang PFA, Pidie District, Aceh, Indonesia

Species	Local name	RD (%)	RF (%)	IVI (%)
Ficus hispida	*Rasi*	16.05	8.78	24.83
Coffea canephora	*Kopi robusta*	15.23	7.43	22.66
Vitex pinnata	*Gleum*	5.76	7.43	13.19
Ulmus sp.	*Pungkeh*	7.00	6.08	13.08
Lithocarpus sp.	*Mentarek*	5.76	6.08	11.84

Note: RD: Relative Density, RF: Relative Frequency, IVI: Importance Value Index

Table 4. Five species with the highest IVI at the pole stage in the Geumpang PFA, Pidie District, Aceh, Indonesia

Species	Local name	RD (%)	RF (%)	RDom (%)	IVI (%)
Lithocarpus sp.	*Mentarek*	12.09	7.58	13.25	32.92
Ficus hispida	*Rasi*	10.70	6.06	10.68	27.44
Hibiscus tiliaceus	*Waru*	8.37	6.06	7.10	21.53
Vitex pinnata	*Gleum*	5.58	7.58	6.70	19.86
Eugenia grandis	*Jambu Hutan*	6.05	6.06	6.07	18.18

Note: RD: Relative Density, RF: Relative Frequency, RDom: Relative Dominance, IVI: Importance Value Index

Table 5. Five species with the highest IVI at the tree stage in the Geumpang PFA, Pidie District, Aceh, Indonesia

Species	Local name	RD (%)	RF (%)	RDom (%)	IVI (%)
Lithocarpus sp.	*Mentarek*	28.57	14.29	34.33	77.18
Vatica sp.	*Bak Reusak*	5.57	4.15	11.43	21.15
Vitex pinnata	*Gleum*	8.96	6.45	4.21	19.62
Ficus benjamina	*Beringin*	2.18	3.23	13.91	19.31
Macaranga diepenhorstii	*Tampui*	6.30	5.07	4.01	15.37

Note: RD: Relative Density, RF: Relative Frequency, RDom: Relative Dominance, IVI: Importance Value Index

The vegetation structure in Geumpang, as indicated by IVI trends, may be shaped by regeneration dynamics, where high seedling density transitions to selective dominance at later stages. This pattern aligns with studies showing that regeneration success depends on seed dispersal and light conditions, with disturbed sites often exhibiting strong early recruitment followed by competitive thinning (Purwaningsih 2006; Chamagne et al. 2016; Hakkenberg et al. 2020). Additionally, the influence of human activities, such as agricultural encroachment, likely contributes to the initial dominance of *C. canephora*, a factor that can alter forest composition over time, as observed in regions with high anthropogenic pressure (Wekesa et al. 2018). The high IVI of *Lithocarpus* sp. at the tree stage suggests a mature component, potentially indicating recovery potential if disturbance is minimized, a process supported by stable forest structures in less disturbed areas (Aye et al. 2014).

Species dominance index

The species dominance index (C), a comprehensive tool for assessing the concentration or dominance of a species at a given site (Ghufrona et al. 2015), was rigorously applied in this study. The highest dominance index (Figure 3) was found at the seedling stage with a value of 0.20, and the lowest at the pole stage with a value of 0.06. However, in general, the species dominance index (C) in the Geumpang PFA was low at all growth stages, with values approaching 0. This comprehensive analysis indicates that there is no concentration of certain species within the plant community, thus providing an adequate understanding of the ecosystem. The Species Dominance Index is related to species diversity; the higher the species diversity, the lower the dominance index. According to Noviady and Siwi (2015), species dominance in a community is associated with the Important Value Index (IVI), a quantitative parameter used to express the dominance of a species in the plant community. Dominant species in a community will have a higher IVI compared to others.

Species diversity index

The species diversity index provides valuable insights into the composition and status of each vegetation type, which is crucial for understanding the community structure of natural forests (Mustapha et al. 2022). High species diversity plays a critical role in maintaining ecosystem stability (Martono et al. 2019), as it helps buffer the ecosystem against external disturbances. In the Geumpang PFA, the species diversity index values indicate a trend where the pole stage exhibits the highest diversity compared to the sapling and seedling stages (Figure 4). Specifically, the pole stage has the highest diversity index (H': 3.12), followed by the tree stage (H': 2.94), the sapling stage (H': 2.89), and the seedling stage (H': 2.10). These values reflect the community's capacity to remain stable against disturbances, as higher diversity suggests a more resilient and balanced ecosystem.

Species diversity is a critical factor in assessing the growth status of an ecosystem and plays a key role in determining its stability (Deb et al. 2015). The trend observed in the Geumpang PFA, where the pole stage has the highest diversity index, supports the idea that as forests mature and progress through stages of ecological succession, species richness tends to increase. This increase in diversity aligns with the ongoing succession processes, where more species are able to establish themselves as the forest progresses towards a more stable, mature state. Additionally, if a specific species dominates the area while others show low dominance, this typically indicates lower species diversity, suggesting a less balanced ecosystem (Arrijani 2008). In contrast, the relatively uniform dominance of species at the pole and tree stages in the Geumpang PFA suggests a higher level of stability and maturity, with the ecosystem nearing a climax stage.

The increase in species diversity at the tree stage is consistent with the ongoing processes of community succession (Yang et al. 2025). The variation in tree species diversity across the study area may be influenced by several factors, such as altitude, accessibility for human exploitation, and proximity to settlements (Kothandaraman and Sundarapandian 2017; Aye and Shibata 2023). For example, areas that are more difficult for humans to reach, such as those far from settlements or located at higher altitudes, tend to have higher levels of species diversity and better conservation of natural resources.

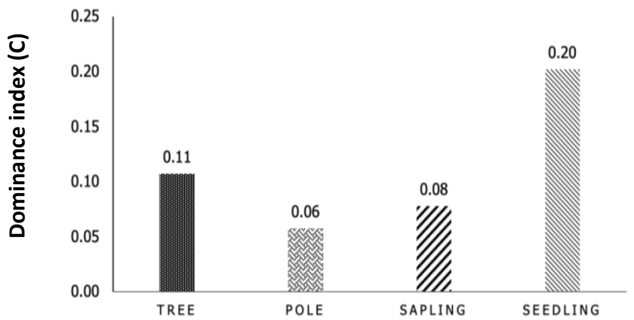

Figure 3. Dominance index (C) values across all growth stages (seedling, sapling, pole, and tree) in the Geumpang PFA, Pidie District, Aceh, Indonesia

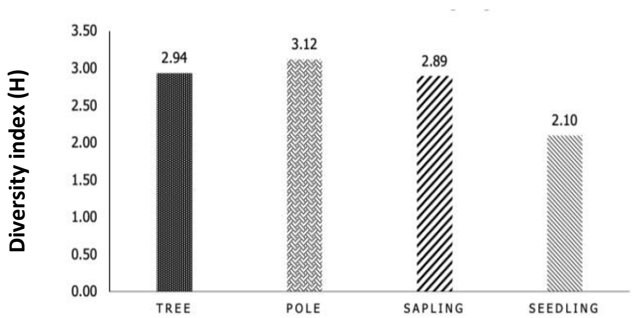

Figure 4. Diversity Index (H’) values for all growth stages (seedling, sapling, pole, and tree) in the Geumpang PFA, Pidie District, Aceh, Indonesia

Species evenness index

The evenness index of a species reflects the degree of evenness of a species within a community. If the number of individuals found is the same in each measured plot, the species is evenly distributed within the community. The species evenness index ranges from 0 to 1, and if the index value approaches 1, it indicates that the distribution of a species is nearly even within the community (Ismaini et al. 2015). An increase in species richness and community evenness can indicate an improvement in the stability of the community structure (Yang et al. 2025), meaning the community is better able to withstand external disturbances and environmental changes.

Based on the evenness index (E) graph (Figure 5), the pole category has the highest evenness index value, which is 0.90, indicating that the distribution of species is nearly uniform compared to other growth stages. In contrast, the seedling stage has the lowest evenness value, 0.79, indicating uneven distribution. According to Mebrat et al. (2014), a decrease in seedling evenness indicates an increased vulnerability of seedlings to animals and humans, such as being cut down while still young for community use, preventing the seedlings from reaching the next growth stages.

For the sapling and tree categories, the evenness indices are 0.85 and 0.80, respectively. Although both categories have relatively high evenness values, they are still lower than the pole stage. This suggests that at the sapling and tree stages, there is a tendency for some species to be more dominant.

Species richness index

The species richness index and vegetation diversity are crucial indicators of forest biodiversity, as trees provide essential resources and habitats for a wide range of other plant species (Malik et al. 2016). The species richness index (R) at various growth stages reflects the level of species diversity in a given area, highlighting the ecological health of the forest. Based on the data (Figure 6), the tree growth stage has an R value of 6.31, indicating high species richness. Similarly, the pole stage shows an R value of 5.77, also reflecting a high level of species richness. The sapling stage has an R value of 5.28, which remains relatively high, indicating a diverse range of species at this stage as well. However, at the seedling stage, the R value drops to 2.86, which falls into the low richness category. This indicates that the seedling stage is less diverse, likely due to environmental conditions that limit species establishment and survival.

The higher species richness observed at the tree, pole, and sapling stages is influenced by various factors, including soil conditions, environmental factors, and human disturbances (Susilowati et al. 2020). In particular, the higher the species richness and diversity at the tree and sapling stages, the more heterogeneous the species composition in those habitats (Myklestad 2004). On the other hand, the lower species richness at the seedling stage can be attributed to local extinction events, the prevalence of short-lived species, which underscores the need for long-term conservation strategies, early successional dynamics, and limited shade tolerance, which are common challenges for species at this stage (Chen and Popadiouk 2002; Luo and Chen 2011).

In general, forests that experience minimal disturbance tend to have higher species richness. This finding is supported by Reang et al. (2025), who linked variations in species richness to several key factors, including deforestation, harvesting of forest products, land clearing, development activities, expansion of settlements, and ecological connectivity. These disturbances can disrupt natural successional processes and reduce biodiversity, especially in more vulnerable stages of forest growth, such as the seedling stage. Therefore, protecting forests from excessive human interference is essential for maintaining high species richness and promoting ecological stability.

In conclusion, the Geumpang PFA exhibits high vegetation diversity across growth stages, with species richness increasing from 14 species at the seedling stage to 39 species at the tree stage. The highest species diversity occurs at the pole stage (H': 3.12), with high evenness (E: 0.900) and low dominance (C approaching 0), indicating a balanced and stable ecosystem. The lower species richness at the seedling stage (R: 2.86) compared to tree (R: 6.47), pole (R: 5.96), and sapling (R: 5.46) stages suggests typical challenges in early ecological succession. This pattern underscores the Geumpang PFA's ecological significance and its progression toward a mature forest community.

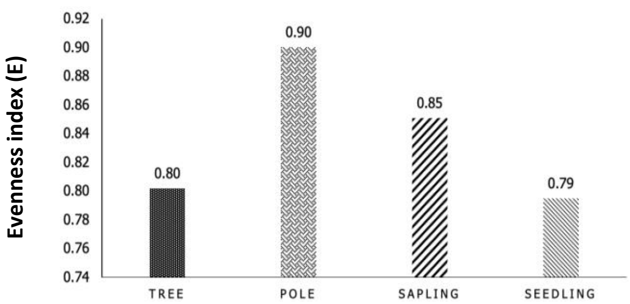

Figure 5. Evenness index (E) values across all growth stages (seedling, sapling, pole, and tree) in the Geumpang PFA, Pidie District, Aceh, Indonesia

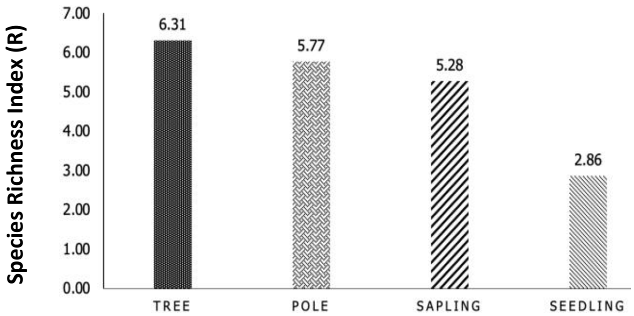

Figure 6. Species richness index (R) values across all growth stages (seedling, sapling, pole, and tree) in the Geumpang PFA, Pidie District, Aceh, Indonesia

To sustain ecological succession and biodiversity in the Geumpang PFA, conservation efforts should prioritize protecting mature forest stages and supporting seedling regeneration. Reducing human disturbances, such as deforestation and land-use changes, and promoting sustainable forest management practices are essential. Engaging local communities in these initiatives is crucial to enhance ecosystem resilience and ensure long-term ecological and social benefits. Moving forward, we recommend implementing selective canopy thinning to improve light availability, which could enhance regeneration in the seedling stage where species richness is lower. Regular monitoring of seedling growth and recruitment through systematic plot assessments will help track progress and detect stressors like overgrazing or moisture stress. Additionally, conservation priorities should focus on supporting vulnerable seedling stages through community-led efforts, such as restricting human access and encouraging natural regeneration processes, to secure the forest's biodiversity and stability for the future.

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