BIOTROPIA ISSN: 0215-6334 | e-ISSN: 1907-770X
The Southeast Asian Journal of Tropical Biology
Vol. 31 No. 2, 2024: 202 - 216
DOI: 10.11598/btb.2024.31.2.2042

Research Article

COMPOSITION, STRUCTURE, AND CARBON SEQUESTRATION OF DIFFERENT RAINFOREST ECOSYSTEMS IN THE GUNUNG GEDE PANGRANGO NATIONAL PARK, INDONESIA

Agus Sunyata, Isna Rakhmi Zulhida, Nike Triwahyuningsih, Kanda Raharja*

Forestry Study Program, Faculty of Forestry, Agricultural Institute (INTAN) Yogyakarta, Sleman, Yogyakarta 55284, Indonesia

ARTICLE HIGLIGHTS

- High demand for environmental services makes the park vulnerable to human activities.
- Both ecosystems are well regenerated; seedling > sapling > pole > tree (inverted J)
- Both ecosystems show normal diversity conditions and stable species distribution.
- Growth of *Maesopsis eminii* needs monitoring to preserve forest purity.
- Montane forests have greater biomass, carbon stocks, less anthropogenic disturbance

Article Information

Received 18 June 2023
Revised 9 December 2023
Accepted 28 May 2024

***Corresponding author, e-mail:**
kanda.raharja@gmail.com

ABSTRACT

The Gunung Gede Pangrango National Park (GGPNP) area is one of the vital ecosystems that support the environment in West Java Province, Indonesia. It is a unique area that has multiple forest ecosystems, including lowland rainforest and montane rainforest ecosystems. Despite the GGPNP's status as a conservation area, the high demand for the GGPNP's environmental services makes the region vulnerable to disturbances from human activities. Several studies have been conducted in the GGPNP area (lowland and montane forest ecosystems), however, the results of this study are still necessary to explain the forest dynamics and forest carbon sequestration in this location. The objective of this research was to analyze the structure, composition, and carbon sequestration of stands in the lowland and montane rainforest ecosystems in the GGPNP area. Data processing and analyses were conducted using diversity indices, biomass-carbon stock estimation, and carbon dioxide sequestration estimation. The results showed that the GGPNP lowland and montane rainforest ecosystems were well regenerated. The number of seedlings > saplings > poles > trees and the graph showed a reverse "J" pattern. The GGPNP lowland rainforest ecosystem was dominated by Neonauclea lanceolata and had relatively higher species diversity. The GGPNP montane rainforest ecosystem was dominated by Castanopsis acuminatissima with a higher individual density, denser canopy, and more complex canopy strata. The lack of regeneration in several species of trees heightens the threat to these species' existence in the future. Biomass, carbon stocks, and carbon sequestration in the GGPNP montane rainforest were greater than those in the GGPNP lowland rainforest. The GGPNP montane rainforest ecosystem had older forest stands, a larger average tree diameter, and lower potential for anthropogenic disturbances.

Keywords:
biomass, carbon sequestration, important value index, similarity index, tnggp

INTRODUCTION

The Gunung Gede Pangrango National Park (GGPNP) or Taman Nasional Gunung Gede Pangrango (TNGGP) area is among vital ecosystems supporting the environment in West Java Province, Indonesia. These ecosystems provide habitats for flora and fauna, deliver biodiversity and community livelihoods, maintain the balance of the hydrological cycle and soil fertility, function as carbon pools (Arrijani 2008; Helmi et al. 2009; Saefrudin 2013; Dendang & Handayani 2015), supply drinking water resources, and serve the agriculture and tourism sectors (Rushayati 2006; Siswantoro et al. 2021). Despite the GGPNP's status as a conservation area, the high demand for GGPNP's environmental services makes the region vulnerable to disturbances from human activities (Saefrudin 2013).

Anthropogenic factors are an important issue in conservation area management. This issue occurs not only in developing countries or around tropical forests (FAO 2005), but also in developed countries with subtropical forests (Nowacki *et al.* 2015). The need for land and environmental services from forest ecosystems is driving the decline of forest areas, including conservation areas (Popradit *et al.* 2015; Meer *et al*. 2023). In addition, biodiversity in conservation areas has also diminished due to human activities (Oladeji *et al*. 2012; Fetene *et al.* 2019).

The GGPNNP has as much problem complexity regarding human activities as diversity due to the ecosystems' uniqueness. The GGPNP area is a unique area that has multiple forest ecosystems, including lowland rainforest and montane rainforest ecosystems. Differences in climate and weather conditions in the two adjacent ecosystems result in high biodiversity (Yamada 1975; Gotsch *et al.* 2016). Rainfall in this location is quite high with an average of 3,000-4,200 mm per year, causing this area to be one of the wettest in Java Island.

In the montane rainforest ecosystem, *Schima wallichii* (Arrijani *et al*. 2006; Arrijani 2008; Helmi *et al*. 2009) and *Altingia excelsa* (Arrijani *et al*. 2006; Arrijani 2008; Dendang & Handayani 2015) are the two most dominant tree species. The diversity index of the montane rainforest ecosystem of the GGPNP is relatively high, but the species evenness is low (Dendang & Handayani 2015). This condition is due to the dominance of both aforementioned species (Arrijani *et al.* 2006; Arrijani 2008) and the disturbances of forest regeneration. (Dendang & Handayani 2015).

In the lowland rainforest ecosystems, *Schima wallichii, Pternandra caerulescens* (Helmi et al. 2009), and *Altingia excelsa* (in the *Altingia excelsa* forest) (Sadili 2013) are the most dominant tree species. Sadili et al. (2023) also mentioned *Maesopsis eminii, Syzygium acuminatissimum*, and *Lithocarpus korthalsii* as the most dominant species in this ecosystem of GGPNP. Unlike those in the montane rainforest ecosystem, the structure and composition of stands in the lowland rainforest ecosystem of the GGPNP are still understudied (Helmi et al. 2009; Sadili et al. 2023). Therefore, forest structure (horizontal and vertical) and composition (density of vegetation growth level, basal area, species abundance, biodiversity indices, etc.) need to be studied to obtain information about forest regeneration (Gatica-Saavedra *et al.* 2017) in the two forest ecosystems in the GGPNP.

Research on forest dynamics and carbon sequestration in the GGPNP is lacking compared to the high pressure and demand on this national park. Very little study exists about the structure and composition of the montane and lowland forests in the GGPNP. To date, only Arrijani (2008) and Dendang and Handayani (2015) studied the montane forest in the GGPNP, while studies on lowland forest were only conducted by Helmi *et al.* (2009) and Sadili *et al.* (2023). Therefore, more studies on both forest ecosystems are necessary to enrich data for better scientifically-based management of the GGPNP (Brearley *et al.* 2019). Research on carbon sequestration in the GGPNP can also explain the function of carbon stock conservation in forest ecosystems in the GGPNP. This is particularly relevant as in Indonesia, conservation areas are among those areas expected to increase carbon stocks according to REDD+ program (Indonesia Ministry of Forestry 2012).

The objective of this research was to analyze the structure, composition, and carbon sequestration of stands in the lowland rainforest and montane rainforest ecosystems in the GGPNP area. The results of this research are expected to help in policy-making and contribute to the improvement of conservation efforts and the management of conservation areas in the GGPNP. Appropriate policies can reduce or even protect conservation areas (national parks) from the threats of degradation due to human activities (Myga-Piątek *et al*. 2022).

MATERIALS AND METHODS

This research was conducted from August to October 2021 in the Gunung Gede Pangrango National Park, West Java Province, Indonesia. Data collection was carried out in the lowland rainforests at Bodogol Resort (106°51'57" E; 06°46'49" S) and the montane rainforest at Gunung Putri Resort (106°59'42'" E; 06°44'16" S). The locations are presented in Figure 1.

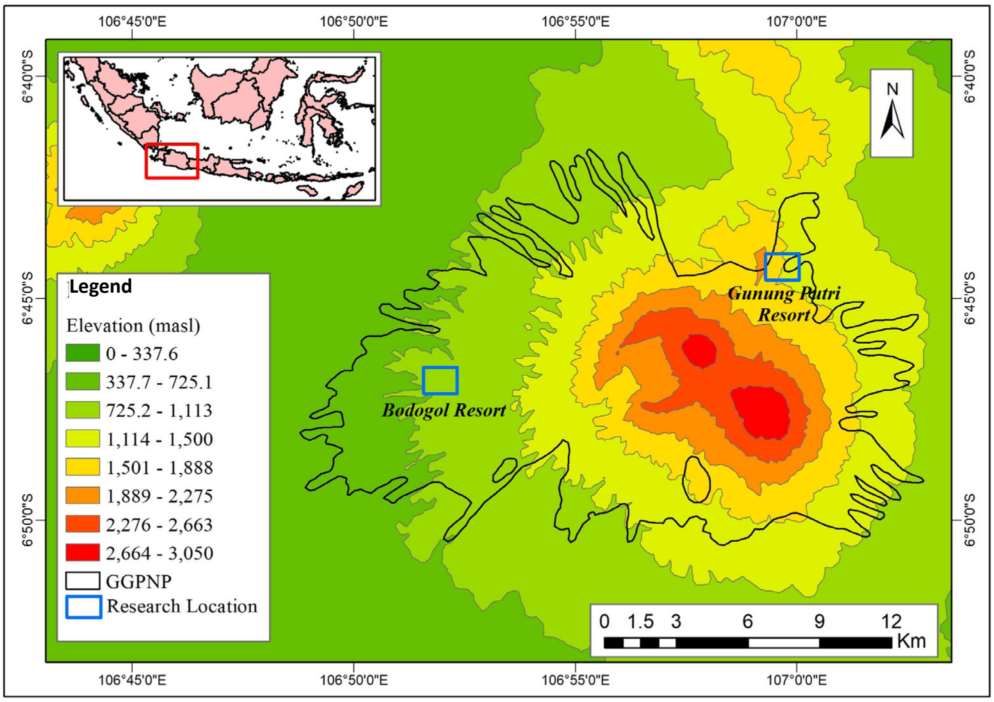

Figure 1 Gunung Gede Pangrango area and research location

Bodogol Resort has natural forest stands on the Cisuren and Cipadaranten hills. The forest extends from the lowland area on the western side of the GGPNP toward the top of Mt. Pangrango. Formerly a plantation forest, the forest includes stands of *Altingia excelsa, Agathis dammara*, and *Pinus merkusii*. The area has a hilly topography with steep slopes. The soils belong to the Red–Yellow Podsolic Soil type. A more detailed description of the research location in Bodogol Resort can be read in full at Soepraptohardjo (1975); Helmi et al. (2009); Sadili (2013); and Sadili et al. (2023).

Gunung Putri Resort, at an altitude of 1,600-1,800 meters above sea level (masl), is a rehabilitation zone of the GGPNP. This area was previously a Perhutani plantation forest area for *Altingia excels*. It is directly adjacent to farmland. At an altitude of 1,800-2,000 masl lies a secondary forest at Gunung Putri Resort that was also a Perhutani plantation forest or *Altingia excels* species. At an altitude of >2000 masl, a primary forest is perched at Gunung Putri Resort. A more detailed description of the research location in Gunung Putri Resort can be read in full in Putra et al. (2020). Both Bodogol and Gunung Putri Resorts are bordered by agricultural areas, which makes them highly vulnerable to anthropogenic activities.

Data Collection and Processing

Sampling locations were determined using purposive sampling based on the altitudes of the sites to represent different ecosystems, i.e., lowland forest and montane forest ecosystems. Purposive sampling or non-probability allows for efficient quantification of ecological characteristics (Araújo & Souza 2022). This technique can be very useful, even if only to describe a particular sample, and much environmental data can only be collected with this technique in spite of difficult sampling processes, access and safety issues, or time and expense constraints (Speak *et al.* 2018). Data collection was carried out in permanent plots at Bodogol and Gunung Putri Resorts. Permanent plots at Bodogol Resort were set at an altitude of 399 masl representing the lowland rainforest ecosystem and permanent plots at Gunung Putri Resort were set at an altitude of 1,824 masl representing the montane rainforest ecosystem. Permanent plots at these locations are usually used by the GGPNP management to observe forest dynamics and succession in the national park area (Herben 1996). Data were collected using the same plot design used by the GGPNP management. A total of 32 plots of samples were used (16 plots in the lowland rainforest ecosystem and 16 plots in the montane rainforest ecosystem). This activity was conducted in parallel with annual measurement activities by the GGPNP management.

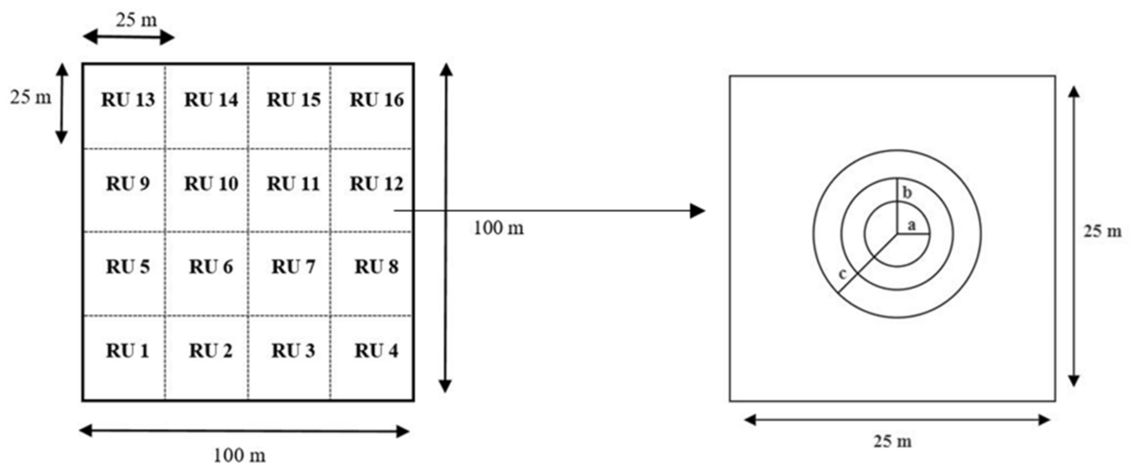

Figure 2 Designs of plots and subplots for measuring stand parameters in the forest.
Notes: a = 1 m; b = 2 m; c = 5 m.

The total plot area in each forest ecosystem was 10,000 m^2 (1 ha). According to Helmi *et al.* (2009) and Sadili *et al.* (2023), the minimum plot area for a vegetation study in the lowland tropical rainforest ecosystem of the GGPNP is 1 ha, while according to Richard (1952) in Meijer (1959) and Yamada (1975), the minimum plot area for a vegetation study in the montane tropical rainforest ecosystem of the GGPNP is also 1 ha. The designs of plots and subplots (Forestry Department of Indonesia 1992) is presented in Figure 2.

The parameters measured were: (1) the number of seedling species in subplot a; (2) the number of sapling species in subplot b; (3) the number of species and diameter of breast height (dbh) of poles (dbh = 10–20 cm) in subplot c; (4) number of species, dbh of tree (dbh > 20 cm); crown diameter, total height, free branch height, and widest crown height of trees in a 25 m × 25 m square plot. Data processing and analyses were carried out using Microsoft Excel.

Data Analysis

Important Value Index (IVI)

The IVI was used to determine the composition of tree species dominating the forest stand communities. The index was calculated using the Cottam and Curtis (1956) formula as follows:

$$\text{IVI (Important Value Index)} = \text{RD} + \text{RDc} + \text{RF}$$

$$\text{RD (Relative Density)} = \frac{\text{number of individuals of species}}{\text{total number of individuals}} \times 100\%$$

$$\text{RDc (Relative Dominance)} = \frac{\text{dominance of species}}{\text{dominance of all species}} \times 100\%$$

$$\text{RF(Relative Frequency)} = \frac{\text{frequency of species}}{\text{sum frequency of all species}} \times 100\%$$

Similarity Index (SI)

SI was used to determine the similarity between compared vegetation communities. The index used in this study was the Jaccard and Sorensen Similarity Index (Krebs 2014) and was calculated using the formula as follows:

$$\text{IS} = \frac{\text{C}}{\text{a} + \text{b} + \text{c}}$$

where:
IS = Jaccard and Sorensen Similarity Index
a = number of species in sample A and sample B (joint occurrences)
b = number of species in sample B but not in sample A
c = number of species in sample A but not in sample B

Biodiversity Index (H')

The Biodiversity Index was calculated using the Shannon-Wiener Diversity Index formula (Krebs 2014) as follows:

$$H' = -\Sigma\,[(ni/N)\ \ln\,(ni/N)]$$

where:
E = Evenness Index
H' = Shannon-Wiener Diversity Index
S = Total Species

Species Evenness Index (E)

The Evenness Index was used to determine the structure of the forest community in the study locations. The formula of Evenness Index (E) (Odum 1996) is as follows:

$$E = H'/\ln S$$

where:
E = Evenness Index
H' = Shannon-Wiener Diversity Index
S = Total species

Biomass and Carbon Stock Estimation, Carbon Dioxide Sequestration

Aboveground biomass (AGB) was estimated using the allometric biomass model developed by Chave *et al.* (2005). The model used was for a wet forest stand without a tree height predictor. Allometric models using height predictors can provide more accurate biomass estimates, but if used for tropical rainforest estimations, the results can be overestimated (Rutishauser *et al.* 2013). The model is as follows:

$$AGB = \rho \times \exp(-1.239 + 1.980 \ln(D) + 0.207 (\ln(D))^2 - 0.0281 (\ln(D))^3)$$

where:
AGB = Aboveground biomass (Mg)
ρ = wood gravity (g/cm^3)
D = diameter at breast height (cm)

Belowground biomass (BGB) was estimated using a model developed by Cairns *et al.* (1997), which is as follows:

$$BGB = \exp(-1.0587 + 0.8836 \ln AGB)$$

where:
BGB = Belowground biomass (Mg)
AGB = Aboveground biomass (Mg)

Carbon dioxide sequestration was calculated based on the mass ratio of the photosynthesis reaction equation (Muthmainnah *et al.* 2021):

$$\underset{(264)}{6CO_2} + \underset{(108)}{6H_2O} \rightarrow \underset{(180)}{C_6H_{12}O_6} + \underset{(192)}{6O_2}$$

Based on the photosynthesis reaction equation above, 180 grams of biomass ($C_6H_{12}O_6$) is produced from the reaction of about 264 grams of CO_2. CO_2 sequestration can be determined by the formula:

$$CO_2\ sqr = (264/180) \times TABGB$$
$$\text{or } CO_2\ sqr = 1.4667 \times \text{Biomass}$$

where:
CO_2 *sqr* = CO_2 Sequestration (Mg/ha/year)
TABGB = total above and below ground biomass (Mg).

RESULTS AND DISCUSSION

Forest Composition

In both lowland and montane rainforests, the highest densities occurred on the lowest growth level (Fig. 3a, Table 2) and diameter class (20-30 cm) (Fig. 4) showing that the density decreased as the growth level and diameter increased. The number of seedlings > saplings > poles > trees and the graph showed a reverse "J" (Fig. 3a) pattern. This pattern is typical for tropical rainforests that the forests regenerate well and are in a dynamic state (Ogawa *et al.* 1965; McLaren *et al.* 2005; Mirmanto 2014; Gonçalves 2017; Sadili *et al.* 2023). However, this result did not guarantee that every species could regenerate due to the possibility of species turnover dominating at each growth stage.

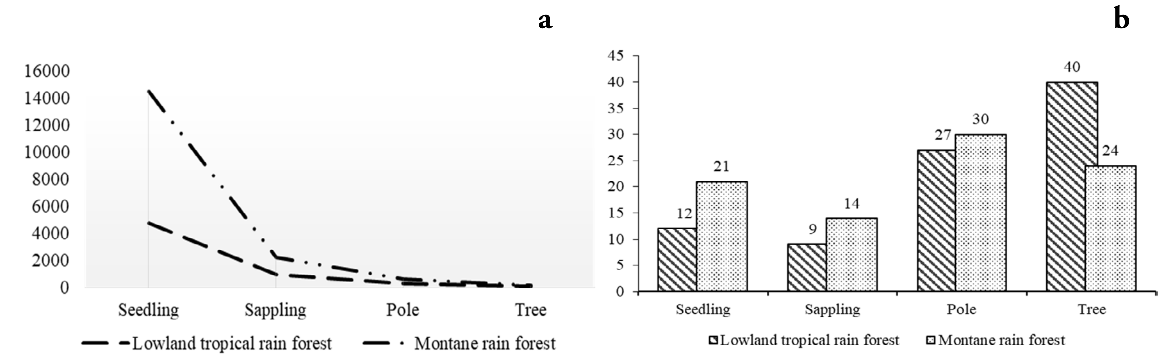

Figure 3 (a) Distribution of the number of individuals at each growth level; (b) Species diversity at various growth levels

The lowland rainforest ecosystem in the GGPNP had more tree species than in the montane rainforest ecosystem. In the lowland rainforest, 40 tree species (dbh > 20 cm) were recorded with a Basal Area (BA) of 8.85 m^2/ha and a Density (D) of 60 trees/ha. In the montane rainforest, 24 tree species were recorded with a BA of 18.85 m^2/ha and a Density of 130 trees/ha. The species richness and tree density (dbh > 10 cm) in our plots, at the lowland forest ecosystem (55 species and 339 tree/ha) were lower than those mentioned in other studies in the lowland forest of the GGPNP (66 species and 348 tree/ha) (Sadili *et al.* 2023), in the Gunung Halimun National Park in West Java (64-69 species and 405-441 tree/ha) (Yusuf 2004; Suryanti 2006), in Malinau, North Kalimantan (205 species and 759 tree/ha) (Sheil *et al.* 2010), in the Batang Gadis National Park (182 species and 583 tree/ha) (Kartawinata *et al.* 2004) and Bukit lawang, North Sumatra (216 species and 453 tree/ha) (Polosakan 2001). The species richness and tree density (dbh >10 cm) in our plots, at the montane rain forest ecosystem, (40 species and 775 tree/ha) were lower than those in previous studies in GGPNP montane forests by Arrijani (2008) (63 species and 966 tree/ha) but higher when compared to the results of Dendang and Handayani (2015) (25 species and 320 tree/ha). The number of species in our plots (40 species) was also lower than the results of Yamada *et al.* (1975) (57 species) in the GGPNP montane forest and Sadili *et al.* (2018) (59 species) in the Foja mountains of Papua but the density was higher (775 tree/ha) than their results (527 tree/ha and 693 tree/ha, respectively).

In the lowland rainforest ecosystem plots, there was the exotic species *Maesopsis eminii* (BA = 0.39 m^2/ha, D = 1/ha, Absolute Frequency (F) = 6%) (Helmi *et al.* 2009; Sadili *et al.* 2023) but it was not the dominating species as was stated by Sadili *et al.* (2023). This species had a seedling density of almost 200 seedlings/ha and a sapling density of almost 50 saplings/ha. *Neonauclea lanceolata, Pometia pinnata, and Aleurites moluccana* were the species with the highest species densities of 6 trees/ha, 6 trees/ha, and 4 trees/ha, respectively. *Castanopsis acuminatissima, Schima wallichii, and Turpinia sphaerocarpa* were the species with the highest species densities in the montane rainforest ecosystem. The tree densities were 33 trees/ha (BA = 5.78 m^2/ha), 22 trees/ha (BA= 4.05 m^2/ha), and 10 trees/ha (BA = 1. 14 m^2/ha), respectively. The studies by Arrijani *et al.* (2006), Arrijani (2008), and Rozak *et al.* 2016, *Schima wallichii* was found to be a dominant species in the GGPNP montane forest ecosystem.

Table 1 List of tree species without seedlings and saplings at different growth levels

	Lowland Rainforest	Montane Rainforest
1	*Durio zibethinus*	*Elaeocarpus angustifolius*
2	*Melaleuca leucadendron*	*Vernonia arborea*
3	*Vernonia arborea*	*Acer laurinum*
4	*Bridelia insulana*	*Litsea resinosa*
5	*Acer laurinum*	*Persea declinata*
6	*Litsea vulva*	*Astronia spectabilis*
7	*Horsfieldia sp.*	*Acronychia laurifolia*
8	*Phoebe declinata*	*Macaranga rhizinoides*
9	*Terminalia sp.*	*Manglietia glauca*
10	*Phoebe opaca*	*Quercus sundaica*
11	*Sandoricum koetjape*	*Quercus pseudomolucca*
12	*Michelia velutina*	*Toona sureni*
13	*Syzygium antisepticum*	
14	*Litsea angulata*	
15	*Machilus rimosa*	
16	*Myristica fragrans*	
17	*Gnetum gnemon*	
18	*Turpinia sphaerocarpa*	
19	*Crypteronia paniculata*	
20	*Dysoxylum macrocarpum*	
21	*Evodia aromatica*	
22	*Quercus sundaica*	
23	*Quercus pseudomolucca*	
24	*Nephelium lappaceum*	

The abundance and regeneration of forests in the GGPNP were relatively sufficient, and no additional artificial regeneration was required. This was indicated by the much greater seedling density than the next growth level (seedling to sapling) (Fig. 3a, Table 2). However, the regeneration of some species at the forests was disrupted at certain growth levels. In the lowland rainforest and montane rainforest, 24 out of 40 (60%) and 12 out of 24 (50%) tree species, respectively, had no seedling and sapling growth. Further research is needed to clarify this phenomenon. Few or no seedlings or saplings may indicate that the species is poorly regenerated. This leads to reduced populations of certain species at the seedling or sapling levels, driving widespread regeneration debts that can potentially lead to the extinction of the species (Ameja *et al.* 2022; Miller *et al.* 2023).

Table 2 Vegetation densities in two forest ecosystems in the GGPNP

Growth level	Vegetation Density (individuals/ha)	
	Lowland rainforest ecosystem	Montane rainforest ecosystem
Seedling	4,777	14,530
Sapling	945	2,239
Pole	279	645
Tree	60	130

The seedling and sapling densities (945 individuals/ha) in the lowland rainforest ecosystem were higher than those recorded in the lowland forests of the Mount Halimun National Park (815 individuls/ha) but lower than those recorded in Cikepuh Game Reserve (1298 individuals/ha) and the Batang Gadis National Park (2265 individuals/ha) (Kartawinata *et al.* 2004) (Table 2). In the montane rainforest ecosystem, the seedling and sapling densities (16,769 individuals/ha) were higher than those recorded in the previous study by Dendang and Handayani (2015) (13,720 individuals/ha) in the same forest ecosystem (Table 2). Table 2 shows that seedling and sapling densities in the lowland forest were lower (seedlings 0.33 times and saplings 0.42 times) than those in the montane forest. The plot site in the lowland rainforest ecosystem is in the utilization zone of the GGPNP in which human activities are allowed. In addition, Bodogol Resort is an area in the GGPNP National Park that is relatively closest to settlements in which most cases of human interventions or forest encroachment occur (Sudomo & Sairudin 2008). Sarkar and Devi (2014) stated that individuals in the juvenile phase are more vulnerable to all environmental pressures and anthropogenic disturbances.

Botzat *et al.* 2015 stated that the success of a tree species' regeneration depends on its ability to produce seedlings and the ability of these seedlings to survive and grow. Species that are vulnerable to extinction have populations with low levels of seedlings and saplings. They went on saying that the low rate of natural regeneration of a certain species indicates that the population is in a degradation phase, which can threaten its sustainability in the future. A very small number of seedlings will not be enough to replace dead trees (from old age, diseases, or other factors).

Forest Stand Structure

Horizontal Structure

The most abundant individual trees in the lowland rainforest ecosystem were in the diameter classes 20-30 cm (17 trees) and 30-40 cm (17 trees) (Fig. 4). The most abundant tree species in the 20-30 cm diameter class was *Pometia pinnata* (D = 4 trees/ha) and the most abundant tree species in the 30-40 cm diameter class were *Pometia pinnata* (D = 2 trees/ha) and *Mallotus paniculatus* (D=2 trees/ha) (Fig. 4). *Maesopsis eminii*, which was previously discussed, has a quite large diameter. Sadili *et al.* (2023) found this exotic species the most abundant in the GGPNP lowland forest ecosystem. *Maesopsis eminii* was included in the 70-80 cm diameter class with D = 1 tree/ha and BA = 0.39 m^2/ha. The largest diameter class was 80-90 cm, consisting of the tree species *Crypteronia paniculata* (D = 1 tree/ha, BA= 0.62 m^2/ha). Other studies in the GGPNP lowland forest by Sadilli *et al.* (2023) and in the Gunung Halimun National Park by Yusuf (2004) showed that *Maesopsis eminii* was the species with the largest basal area. With a growth rate of 1.5-5.5 cm per year in diameter and 1-3 m per year in height, this fast-growing species rapidly invaded the lowland forest (Schabel & Latiff 1997). It can grow well at altitudes of 100-900 masl within full sunshine and can be dispersed by birds, rodents, and monkeys (Schabel & Latiff 1997). With such characteristics, this exotic species has the potential to cause negative impacts because it can invade the GGPNP area quickly and aggressively while reducing the purity of natural forest stands in the GGPNP (Sadili *et al.* 2023).

In the montane rainforest ecosystem, the most abundant individual trees were in the 20-30 cm diameter class (47 trees) (Fig. 4), and the most abundant species in this class was *Castanopsis acuminatissima* (D = 11 trees/ha, BA= 0.5 m^2/ha). This species is common in the montane forests ecosystem of the GGPNP and is one of the most dominant species (Arrijani 2008; Helmi *et al.* 2009; Rozak *et al.* 2016). The largest diameter class in this forest ecosystem was 110-120 cm, and the largest tree species was *Quercus sundaica*. Arrijani (2008) explained that this species can be found in the montane forests of GGPNP and bears bowl-shaped fruit. Further information about the horizontal structure can be seen in Figure 4.

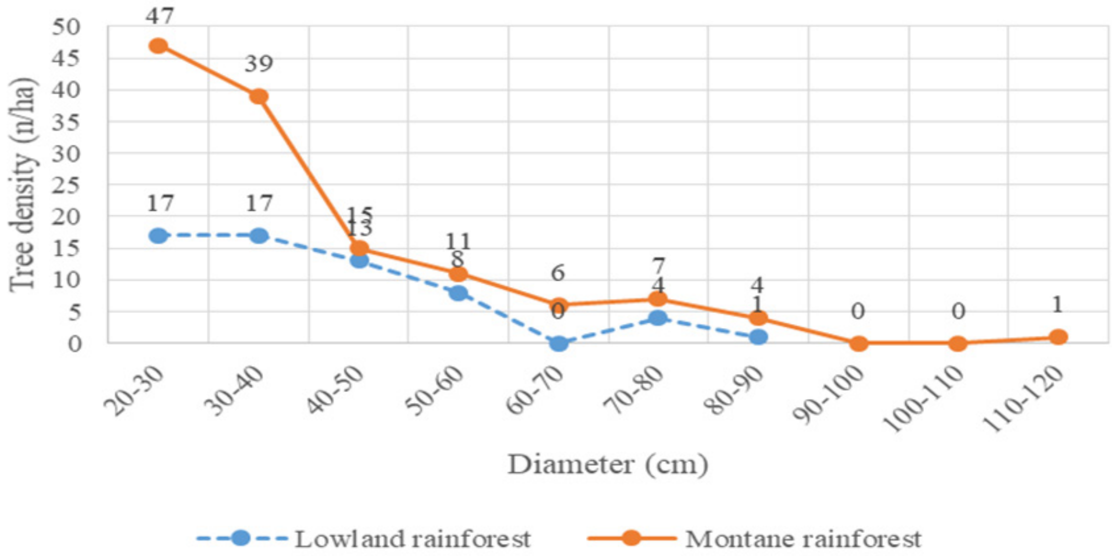

Figure 4 Horizontal structure in two forest ecosystems in the GGPNP

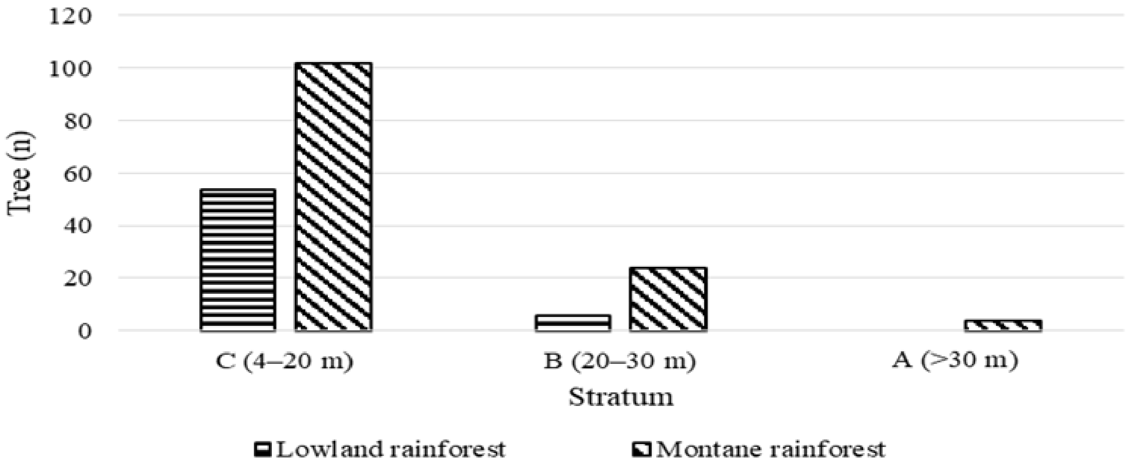

Figure 5 Vertical structure in two forest ecosystems in the GGPNP

Overall, the results of this study showed that the larger the tree diameter, the smaller the number of individual trees (Fig. 4). Similar patterns were also reported in the research by Arrijani (2008) and Dendang and Handayani (2015) in the montane rainforest ecosystems, and by Sadili *et al.* (2023) in the lowland rainforest ecosystem, indicating that only a few individual trees are successful in the competitive process during growth. Over time, individuals encounter interspecies or intraspecies competition. Naturally, this competition results in a reduction in the number of surviving individuals in each diameter class. However, Meyer (1961) observed that a normal stand of an uneven aged natural forest has a constant ratio of the number of trees per unit area to diameter class even though there is always a reduction in the number of individuals in each diameter class.

Vertical Structure

The vertical forest structure for all species refers to the relationship between tree density and height class (stratum). The strata in both forest ecosystems are presented below. In lowland rainforest ecosystem plots, no trees emerged at Stratum A (height > 30 m) (Fig. 5). Sadili *et al.* (2023) reported that in their research plots, *Chisocheton ceramicus*, *Lithocarpus korthalsii*, *Lithocarpus pallidus*, *Schima wallichii*, *Dalrympelea sphaerocarpa*, and *Maesopsis eminii* occupied stratum A). Stratum B was occupied by young trees with a height of 20-30 m. Usually it takes a shorter time to reach stratum B compared to the time needed to reach stratum A. Stratum C was occupied by young trees of more diverse species. *Syzygium acuminatissimum, Pometia pinnata, Lithocarpus pseudomoluccus, and Myristica sp*. were found both in this study and the study by Sadili *et al.* (2023) at stratum C.

In montane rainforest plots, four trees of three species constituted stratum A (Fig. 5). The Species were *Acer laurinum* (1 tree), *Castanopsis acuminatissima* (2 trees) and *Quercus sundaica* (1 tree). Strata B and C in the montane forest were also occupied by younger trees in the same pattern as the pattern in lowland rainforest plots. *Schima wallichii* was found both in this research and the research by Dendang and Handayani (2015) at stratum B. Diameters were found to be correlated with tree height (< 20 m for tratum C and 20-30 m for stratum B, which case the bigger the diameters the taller the trees (Dendang & Handayani 2015; Sadili *et al.* 2023). This forest condition guarantees the sustainability of the forest in the future because the number of individual seedlings is much greater than the number of individual mature trees (Denslow 1987).

Biodiversity Indices

Importance Value Index (IVI)

The species with the highest IVI scores were considered as the most important species in a community (plot). Respectively, in the lowland rainforest ecosystem, the seedling, sapling, pole, and tree growth stages, were dominated by *Syzygium polyanthum*, *Dysoxylum caulostachyum*, *Pometia pinnata,* and *Neonauclea lanceolata* (Table 3). As reported by Helmi *et al.* (2009), *Neonauclea lanceolata* trees were easily found in the lowland forest ecosystem of the GGPNP. The montane rainforest ecosystem of the GGPNP was dominated by *Acer laurinum* (seedlings and saplings), *Turpinia sphaerocarp* (poles), and *Castanopsis acuminatissima* (trees) (Table 3). *Castanopsis acuminatissima* was the dominant tree species and was easily found in the montane rainforest ecosystem of the GGPNP (Arrijani 2008; Rozak *et al.* 2016). It could even be found in the lowland rainforest ecosystem below (Helmi *et al.* 2009). IVI is the sum of the relative density, relative frequency, and relative dominance parameters. IVI is one of the parameters that can provide an overview of the role of species in the community, but a high IVI value does not always reflect a high level of dominance.

The greater the RD value of a species, the greater the number of individuals in the area. However, the RD value cannot provide an overview of the vegetation distribution at the research location. The distribution of vegetation in a particular community is limited by environmental conditions. Some species in tropical forest ecosystems are adapted to canopy conditions that vary in sunlight intensity (Balakrishnan *et al.* 1994) and their success in occupying an area is influenced by their ability to adapt to all physical environmental factors, biotic factors, and chemical factors (Krebs 1994).

Crypteronia paniculata trees, in the lowland rainforest ecosystem, had a higher RDc compared to *Pometia pinnata* trees. The BA of *Crypteronia paniculata* (BA = 1.26 m^2/ha) was larger than the BA of *Pometia pinnata* (BA = 0.73 m^2/ha). The greater the BA value of a species, the greater the absolute dominance and relative dominance values. Conversely, the RF of *Pometia pinnata* trees was higher than the RF of *Crypteronia paniculata* trees. *Pometia pinnata* trees were found in 4 out of 16 plots (F = 25%), while *Crypteronia paniculata* trees were only found in 3 out of 16 plots (F = 19%). The more frequently a species was found in some plots, the higher its Absolute Frequency and Relative Frequency values. Similar conditions were observered in *Polyosma illicifolia* and *Villebrumea rubescens* poles in the montane rainforest ecosystem.

Table 3 Species with the highest IVI scores in the lowland rainforest and montane rainforest ecosystems in the GGPNP

Growth Level	lowland rainforest					montane rainforest				
	Species	RD	RDc	RF	IVI	Species	RD	RDc	RF	IVI
Seedling	*Syzygium polyanthum*	16.67	-	12.50	29.17	*Acer laurinum*	42.47	-	18.52	60.98
	Dysoxylum caulostachyum	12.50	-	12.50	25.00	*Castanopsis argentea*	6.85	-	7.41	14.26
	Aglaia elliptica	8.22	-	12.50	20.83	*Antidesma tetrandum*	5.48	-	7.41	12.89
Sapling	*Dysoxylum caulostachyum*	21.05	-	18.75	39.80	*Acer laurinum*	20.00	-	20.00	40.00
	Syzygium polyanthum	15.79	-	18.75	34.54	*Turpinia sphaerocarpa*	13.33	-	13.33	26.67
	Aglaia elliptica	10.53	-	12.50	23.03	*Mimusops elengi*	13.33	-	10.00	23.33
Pole	*Pometia pinnata*	11.43	11.64	12.12	35.19	*Turpinia sphaerocarpa*	17.28	17.02	12.50	46.81
	Neonauclea lanceolata	5.71	9.63	6.06	21.41	*Villebrumea rubescens*	8.64	10.24	4.69	23.57
	Saurauria pendula	5.71	7.87	6.06	19.64	*Polyosma illicifolia*	7.41	7.73	7.81	22.95
Tree	*Neonauclea lanceolata*	10.00	15.92	7.41	33.33	*Castanopsis acuminatissima*	25.38	30.69	12.20	68.27
	Pometia pinnata	10.00	8.29	7.41	25.70	*Schima wallichii*	16.92	21.47	13.41	51.81
	Crypteronia paniculata	5.00	14.21	5.56	24.76	*Turpinia sphaerocarpa*	7.69	6.03	9.76	23.48

Notes: RD = Relative Density; RDc = Relative Dominance; RF = Relative Frequency.

Similarity Index (SI)

SI is useful for analyzing several different vegetation communities and is sensitive to differences in species diversity (Furusawa *et al.* 2014). Table 4 shows that the vegetation community in the GGPNP at each growth level was relatively different, hence its high biodiversity. The results of this study were in accordance with the research of Rozak *et al.* (2016), which showed that elevation influenced the presence of species in certain zones in the GGPNP.

The results of this study also showed that the forest ecosystem in the GGPNP area were in the transition phase in the succession process. Otherwise, they had yet to reach a climax. Some tree species, such as *Castanopsis* spp. (montane rainforest), *Ficus* spp. (lowland rainforest and montane rainforest), *Knema* spp. (lowland rainforest), *Litsea* spp. (lowland rainforest and montane rainforest), *Maesopsis eminii* (lowland rainforest), *Mallotus paniculatus* (lowland rainforest) *Pometia pinata* (lowland rainforest), *Schima walichii* (lowland rainforest), *Vernonia arborea* (lowland rainforest and montane rainforest), and *Villebrunea rubescens* (lowland rainforest and montane rainforest) are characteristic of secondary forests based on Sadili *et al.* (2023).

Species Diversity Index (H') and Species Evenness Index (E)

The results showed that the composition and structure of vegetation in each forest ecosystem varied in index values due to differences in each tree character. Table 5 shows that the montane rainforest ecosystem had lower diversity values than the lowland rainforest, except at the sapling growth level. Furthermore, the diversity index for all growth stages had normal conditions in both the lowland and montane forest ecosystems (1.5 < H' < 3.5) (Ortiz-Burgos 2016). A community will be more stable and more resilient to disturbances with higher diversity of species (McGlade 1988).

The E index has an interval value of 0-1. Both ecosystems in the GGPNP had even or stable species distribution (Table 5). Krebs (2001) explained that E > 0.75 indicates an even distribution or stable species, 0.5 ≤ E ≤ 0.75 indicates an unstable distribution, and ≤ 0.50 species indicates an uneven distribution or depressed species. A high Evenness index value (E > 7.5) indicates that no one species dominates in a community. The Evenness Index value is maximal when all species have equal abundance in the community (Krebs 1989) and the species is in an even distribution (Krebs 2001).

Table 4 Index of similarity scores in the lowland rainforest and montane rainforest ecosystems in the GGPNP

SI		Montane rainforest			
		Seedling	Sapling	Pole	Tree
lowland rainforest	Seedling	6.06 %			
	Sapling		0%		
	Pole			10.53%	
	Tree				9.38%

Table 5 H' and E index values in two different forest ecosystems in the GGPNP

	Lowland rainforest		Montane rainforest	
	H'	E	H'	E
Seedling	2.38	0.96	2.31	0.76
Sapling	2.26	0.94	2.5	0.9
Pole	3.2	0.97	3.06	0.9
Tree	3.47	0.94	2.63	0.83

Table 6 Biomass, carbon stock, and carbon sequestration in two forest ecosystems in the GPPNP

	AGB (Mg/ha)	BGB (Mg/ha)	TABGB (Mg/ha)	Carbon Stock (Mg/ha)	CO_2 sqr (Mg/ha/year)
Lowland rainforest	103.90	14.90	118.80	55.84	174.25
Montane rainforest	181.41	25.66	207.06	97.32	303.70

Carbon Sequestration

Tropical rainforest ecosystems have an important role in regulating carbon and biomass cycles. The results of this study showed that the GGPNP montane rainforest ecosystem had a greater carbon stock than the lowland rainforest ecosystem (Table 6).

The amount of forest biomass is determined by tree density, soil fertility, and the diameter, height, and specific gravity of wood. In general, the GGPNP montane rainforest had a greater tree density (Table 2). In addition, the composition of trees with a horizontal structure in the montane forest was greater than that in the lowland rainforest. There were old trees (stratum A) that were not found in the lowland rainforests (Fig. 5). Forests with older trees can store more carbon forests with younger ones (Baker *et al.* 2022). In addition, montane rainforests are located at relatively higher elevations (1842 masl) than lowland rainforests (< 400 masl) (Fig. 1), thus facing a less potential for anthropogenic threats (Sarkar & Devi 2014, Myga-Piątek *et al.* 2022).

The biomass stock in the montane rainforest of the GGPNP (207.60 M/ha) was relatively larger when compared to the montane rainforest of Mount Rinjani, with an average biomass stock of 195 tonnes/ha (Dossa *et al.* 2013), but lower than the montane forests of Mount Ciremai, with an average biomass stock of 258 tonnes/ha (Rozak & Gunawan 2015). The Mount Rinjani montane forest had a lower basal area and a lower tree density (BA < 15 m^2/ha, D < 125 trees/ha) (Dossa *et al.* 2013) compared to the GGPNP montane rainforest (BA = 18.85 m^2/ha; D = 130 trees/ha). Conversely, the Mount Ciremai montane forest had a larger basal area and a larger tree density (BA = 35 m^2/ha; D = 900 trees/ha) (Rozak & Gunawan 2015) compared to the GGPNP montane forest. The biomass stock in the GGPNP lowland rainforest (118.80 tonnes/ha) was lower than the biomass stocks of lowland rainforests in Sumatra (384 tonnes/ha) (Kotowska *et al.* 2015), but higher than the biomass stick of secondary lowland rainforests in South Kalimantan (43.11-72.99 tonnes/ha) (Suyanto *et al.* 2022). Lowland rainforests in Sumatra had a basal area of 27-32 m^2/ha and a tree density of 440-684 trees/ha (Kotowska *et al.* 2015) compared to GGPNP lowland rainforest had basal area of 8.85 m^2/ha and tree density of 60 trees/ha. The biomass stocks in secondary rainforests in South Kalimantan were lower due to timber harvesting (Suyanto *et al.* 2022).

CONCLUSION

The number of seedlings > saplings > poles > trees and the graph shows a reverse "J" pattern. It is typical for tropical rainforests, and indicating that, generally, the forests well regenerated and are in a dynamic state. Unfortunately, the finding of only a few species with a few or no seedlings or saplings may indicate that the species poorly regenerated. This leads to reduced populations of certain species at the seedling or sapling level, and driving widespread regeneration debts that could potentially lead to the extinction of the species. It is importanr that the GGPNP management also pay attention to the growth of Maesopsis eminii so as not to reduce the purity of natural forests in the GGPNP.

The horizontal structure of the GGPNP lowland and montane rainforest ecosystem was dominated by trees with diameters of 20-40 cm. It follows that the density decreased as the growth level and diameter increased. The vertical structure of the GGPNP lowland rainforests was occupied by stratum C (4-20 m) and B (20-30 m) trees with an absence of stratum A trees, while the GGPNP montane rainforests was occupied by trees of all strata (stratum C, 4-20 m; stratum B, 20-30 m; and stratum A, > 30 m).

The GGPNP lowland forest ecosystem was dominated by *Neonauclea lanceolata* and had a relatively higher species diversity. The GGPNP montane rainforest ecosystem was dominated by *Castanopsis acuminatissima*, with a higher individual density, denser canopy, and more complex canopy strata.

Biomass, carbon stocks, and carbon sequestration in the montane rainforest in the GGPNP were larger than those in the GGPNP lowland rainforest. Although there used to be plantation forests in the GGPNP lowland forest, these ecosystems had larger biomass and carbon stocks than logged-over forest area. The GGPNP montane rainforest had older forest stands, alarger average tree diameter, and lower potential for anthropogenic disturbances compared to GGPNP lowland rainforest.

REFERENCES

Ameja LG, Ribeiro N, Sitoe AA, Guillot B. 2022. Regeneration and restoration status of Miombo woodland following land use land cover changes at the buffer zone of Gile National Park, Central Mozambique. Trees For People [Internet]. [Cited 2024 May 25]; 9(2022):100290. DOI: 10.1016/j.tfp.2022.100290

Arrijani. 2008. Struktur dan komposisi vegetasi zona montana Taman Nasional Gunung Gede Pangrango. [Vegetation structure and composition of the montane zone of Mount Gede National Park Pangrango]. Biodiversitas [internet]. [Cited 2023 May 15]; 9(2):134-41. DOI: 10.13057/biodiv/d090212

Araújo JS, Souza JLP. 2022. Sampling techniques and environmental variables influence the distribution of pseudoscorpions in urban forest fragments in the central Amazon. Acta Amazonica [Internet]. [Cited 2024 May 23]; 52 (3):199-207. DOI: 10.1590/1809-4392202200441

Baker MG, Roviello V, Beresford-Kroeger D, Roviello GN. 2022. Old growth forests and large old trees as critical organisms connecting ecosystems and human health, a review. Environ Chem Lett 20 [Internet]. [Cited 2023 May 24]; 20(2022):1529-38. DOI: 10.1007/s10311-021-01372-y

Brearley FQ, Adinugroho WC, Cámara-Leret R, Krisnawati H, Alicia Ledo A, Qie L, …, Webb CO. 2019. Opportunities and challenges for an Indonesian forest monitoring network. Annal For Sci [Internet]. [Cited 2024 May 22]; 76 (2019):54. DOI: 10.1007/s13595-019-0840-0.

Balakrishnan M, Borgstrom R, Bie SW. 1994. Tropical Ecosystem, a synthesis of tropical ecology and conservation. New York (US): International Science Publisher.

Botzat A, Fischer L, Farwig N. Regeneration potential in South African forest fragments: extinction debt paid off or hampered by contemporary matrix modification?. Plant Ecol [Internet]. [Cited 2023 Apr 10]; 216 (2015):535-51. DOI: 10.1007/s11258-015-0457-9

Cairns M, Brown S, Helmer EH, Baumgradner GA. 1997. Root biomass allocation in the world's upland forests. Oecologia [Internet]. [Cited 2023 Apr 30]; 111 (1997):1-11. DOI: 10.1007/s004420050201

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, …, Yamakura T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia [Internet]. [Cited 2023 May 3]; 145 (2005):87-99. DOI: 10.1007/s00442-005-0100-x

Cottam G, Curtis JT. 1956. The use of distance measures in phytosociological sampling. Ecol [Internet]. [Cited 2023 May 9]; 37(3):451-60. DOI: 10.2307/1930167

Dendang B, Handayani W. 2015. Struktur dan komposisi tegakan hutan di Taman Nasional Gunung Gede Pangrango. [Jawa Barat Structure and composition of forest stands in Mount Gede Pangrango National Park, West Java]. Biodiversitas [Internet]. [Cited 2023 May 4]; 1(4):691-5. DOI: 10.13057/psnmbi/m010401

Denslow JS. 1987. Tropical rainforest gaps and tree species diversity. Ann Rev Ecol and Syst [Internet]. [Cited 2023 May 27]; 18 (1987):431-52. Available from: https://www.jstor.org/stable/2097139

Dossa GGO, Paudel E, Fujinuma J, Yu H, Chutipong W, Zhang Y, …, Harrison RD. 2013. Factors determining forest diversity and biomass on a tropical volcano, Mt. Rinjani, Lombok, Indonesia. PLoS ONE [Internet]. [Cited 2023 May 24]; 8(7):e67720. DOI: 10.1371/journal.pone.0067720

FAO. 2005. FAO Statistical Databases. Rome (IT): Food and Agriculture Organization.

Fetene A, Yeshitela K, Gebremariam E. 2019. The effects of anthropogenic landscape change on the abundance and habitat use of terrestrial large mammals of Nech Sar National Park. Environ Syst Res [Internet] [Cited 2024 May 18]; 8 (19):1-16. DOI: 10.1186/s40068-019-0147-z

Forestry Department of Indonesia. 1992. Forestry Manual. Jakarta (ID): Forestry Department of Indonesia.

Furusawa T, Sirikolo MQ, Sasaoka M, Othsuka R. 2014. Interaction between forest biodiversity and people's use of forest resources in Roviana, Solomon Islands: implications for biocultural conservation under socioeconomic changes. J Ethnobiol Ethnomed [Internet]. [Cited 2023 May 23]; 10 (2014):1-20. DOI: 10.1186/1746-4269-10-10

Gatica-Saavedra P, Echeverría C, Nelson CR. 2017. Ecological indicators for assessing ecological success of forest restoration: a world review. Res Ecol [internet]. [Cited 2023 Oct 15]; 25(6):850-7. DOI: 10.1111/rec.12586

Gonçalves FMP, Revermann R, Gomes AL, Aidar MPM, Finckh M, Juergens N. 2017. Tree species diversity and composition of Miombo woodlands in South-Central Angola: a chronosequence of forest recovery after shifting cultivation. Int J For Res [Internet]. [Cited 2023 May 5]; (2017):1-13. DOI: 10.1155/2017/6202093

Gotsch S, Asbjornsen H, Goldsmith G. 2016. Plant carbon and water fluxes in tropical montane cloud forests. J Trop Ecol [Internet]. [Cited 2023 May 5]; 32(5):404-20. DOI: 10.1017/S0266467416000341

Helmi N, Kartawinata K, Samsoedin I. 2009. An undescribed lowland natural forest at Bodogol, the Gunung Gede Pangrango National Park, Cibodas Biosphere Reserve, West Jawa, Indonesia. REINWARDTIA [Internet]. [Cited 2023 May 2012]; 13(1):33-44. DOI: 10.14203/reinwardtia.v13i1.11

Indonesia Ministry of Forestry. 2012. The Republic of Indonesia Minister of Forestry Regulation Number: P. 20/Menhut-II/2012 about Forest Carbon Organization. Jakarta (ID): Indonesia Ministry of Forestry.

Kotowska MM, Leuschner C, Triadiati T, Meriem S, Hertel D. 2015, Quantifying above- and belowground biomass carbon loss with forest conversion in tropical lowlands of Sumatra (Indonesia). Glob Change Biol [Internet]. [Cited 2023 May 24]; 21 (2005):3620-34. DOI: 10.1111/gcb.12979

Krebs CJ. 1989. Ecological metodology. New York (US): Harper & Row Publishers.

Krebs CJ. 1994. Ecology, the experimental analysis of distribution and abundance. New York (US): Addison-Wesley Educational Publishers.

Krebs CJ. 2001. Ecology, the experimental analysis of distribution and abundance, Fifth Edition. San Fransisco (US): Benyamin Cumming, an imprint of Addition Wesley Longman, Inc.

Krebs CJ. 2014. Ecology, the experimental analysis of distribution and abundance, Sixth Edition. Edinburgh (UK): Pearson Education Limited.

McGlade J. 1988. Advanced Ecology Theory: Principles and Application. London (UK): Blackwell Science Ltd.

McLaren KP, McDonald MA, Hall JB, Healey JR. 2005. Predicting species response to disturbance from size class distributions of adults and saplings in a Jamaican tropical dry forest. Plant Ecol [Internet]. [Cited 2023 May 11]; 181(2005):69-84. DOI: 10.1007/s11258-005-3497-8

Meer BB, Julius PY, Ikima DI, Manyam HI, Adedotun A, Vangervihi DM, Kajo D. 2023. Implications of anthropogenic induced perturbations on Nigerian National Park rangelands. J Res For Wildl & Environ [Internet]. [Cited 2024 May 18]; 14(2):68-77. Available from: https://www.ajol.info/index.php/jrfwe/article/view/258525

Meijer W. Plantsociological analysis of montane rainforest near Tjibodas, West Java. Acta Botanica Neerlandica 8(3):277-91.

Meyer HA, Stevensonand D. 1961. Forest management 2nd edition. New York (US): The Ronald Press Company

Miller KM, Perles SJ, Schmit JP, Matthews ER, Weed AS, Comiskey JA, …, Fisichelli NA. 2023. Overabundant deer and invasive plants drive widespread regeneration debt in eastern United States national parks. Ecol Appl [Internet]. [Cited 2024 May 25]; 33(4):e2837. DOI: 10.1002/eap.2837.

Mirmanto E. 2014. Fitososiologi hutan pegunungan di lereng tenggara Gunung Salak. [Phytosociology of a Montane Forest at the South-East Slope of Mount Salak]. Jurnal Biologi Indonesia. 10(1):27-38

Muthmainnah, Abdullah A, Ridha A, Rusyidi S. 2021. Estimation of biomass potential, carbon stocks, and carbon sequestration of Trigona sp honey bees feed. In: 2nd Biennial Conference of Tropical Biodiversity 2021. Proceeding: 2021 Aug 4-5; Indonesia. Makassar (ID): IOP Conference Series: Earth and Environmental Science. p. 1-7.

Nowacki GJ Abrams MD. 2015. Is climate an important driver of post-European vegetation change in the Eastern United States?. Global Change Biol [Internet]. [Cited 2024 May 5]; 21 (2015):314-34. DOI: 10.1111/gcb.12663

Oladeji SO, Agbelusi EA, Trevelyan R. 2012. Anthropogenic activities threatening the management of ecotourism resources in Old Oyo National Park, Nigeria. J Res For Wildl & Environ [Internet]. [Cited 2024 May 18]; 5 (1):100-10. Available from: https://www.ajol.info/index.php/ejesm/article/view/74191

Odum EP. 1996. Fundamentals of ecology. Philadelphia (US): W.B. Saunders Company

Ogawa H, Yoda K, Ogino T, Shidei D, Ratnawongse, Apa Sutaya C. 1965. Comparative ecological study on three main types of forest vegetation in Thailand. I: structure and floristic composition. Nat Life Southeast Asia 4:13-48.

Ortiz-Burgos S. 2016. Shannon-Weaver Diversity Index. In: Kennish MJ, editor. Encyclopedia of Estuaries. Encyclopedia of Earth Sciences Series. Dordrecht (NL): Springer. p. 572-3.

Myga-Piątek U, Sobala M, Szypuła B. 2022. Do national parks protect natural landscapes?. J Nat Conserv [Internet]. [Cited 2024 May 19]; 68(2022):126229 DOI: 10.1016/j.jnc.2022.126229

Popradit A, Srisatit T, Kiratiprayoon S, Yoshimura J, Ishida A, Shiyomi M, …, Phromma I. 2015. Anthropogenic effects on a tropical forest according to the distance from human settlements. Sci Rep [Internet]. [Cited 2024 May 5]; 5 (14689). DOI: 10.1038/srep14689

Putra GG, Mardiastuti A, Mulyani YA. 2020. Mixed flock of insectivorous birds in Gunung Gede-Pangrango National Park, West Java, Indonesia. In: The 3rd International Conference on Biosciences. Proceeding: 2019 Aug 8; Indonesia. Bogor (ID): IOP Conference Series: Earth and Environmental Science. p. 1-6.

Rozak AH, Astutik S, Mutaqien Z, Widyatmoko D, Sulistyawati E. 2016. Kekayaan jenis pohon di hutan Taman Nasional Gunung Gede Pangrango, Jawa Barat. [Tree species richness in forest of Mount Gede-Pangrango National Park, West Java]. Jurnal Penelitian Hutan dan Konservasi Alam [Internet]. [Cited 2023 May 2]; 13(1):1-14. DOI: 10.20886/jphka.2016.13.1.1-14

Rozak AH, Gunawan H. 2015. Altitudinal gradient affects on trees and stand attributes in Mount Ciremai National Park, West Java, Indonesia. Jurnal Penelitian Kehutanan Wallacea [Internet]. [Cited 2023 May 24]; 4(2):93-9. DOI: 10.18330/jwallacea.2015.vol4iss2pp93-99

Rushayati SB. 2006. Ketersediaan air kawasan Taman Nasional Gunung Gede Pangrango. [Water Availability in Gunung Gede Pangrango National Park Area]. Media Konservasi [Internet]. [cited 2023 Apr 9]; 11(1):26-8. DOI: 10.29244/medkon.11.1.%25p

Rutishauser E, Noor'an F, Laumonier Y, Halperin J, Rufi'ie, Hergoualc'h K, Verchot L. 2013. Generic allometric models including height best estimate forest biomass and carbon stocks in Indonesia. For Ecol Manag [Internet]. [Cited 2023 May 4]; 307 (2013):219-25. DOI: 10.1016/j.foreco.2013.07.013

Sadili A. 2013. Dinamika vegetasi pada petak permanen rasamala (Altingia excelsa Noronha) di Bodogol, Taman Nasional Gunung Gede Pangrango, Jawa Barat. [Vegetation dynamics at the rasamala (Altingia excelsa Noronha) Permanent plot in Bodogol area, GPNP, West Java]. Jurnal Biologi Indonesia [internet]. [Cited 2023 Oct 12]; 10(1):1-9. Available from: https://e-journal.biologi.lipi.go.id/index.php/jurnal_biologi_indonesia/article/view/323

Sadili A, Salamah A, Mirmanto E, Kartawinata K. 2023. Variation in the composition and structure of natural lowland forests at Bodogol, Gunung Gede Pangrango National Park, West Java, Indonesia. REINWARDTIA [Internet]. [Cited 2023 Oct 12]; 22(1):1-25. DOI: 10.55981/reinwardtia.2023.4399

Saefrudin E. 2013. Gunung Gede Pangrango National Park valuation method. Adelaide (AU): The University of Adelaide.

Salvaña FRP, Lopez CKC, Mangaoang CC, Bretaña BLP. 2019. Diversity and community structure of trees in two forest types in Mt. Apo Natural Park (MANP), Philippines. Biodiversitas [Internet]. [Cited 2023 Apr 30]; 20(7):1794-801. DOI: 10.13057/biodiv/d200702

Sarkar M, Devi A. 2014. Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. Trop Plant Res [Internet]. [Cited 2022 Des 19]; 1(2):26-36. Available from: https://www.tropicalplantresearch.com/archives/2014/vol1issue2/5.pdf

Schabel HG, Latiff A. 1997. Maesopsis eminii Engler. In: Hanum IF, van der Maesen LGJ (Editors.). Plant Resources of Southeast Asia. No. 11. Auxiliary Plants. Leiden (NL): Backhuys Publishers. p. 184-7.

Sheil D, Kartawinata K, Samsoedin I, Priyadi H, Afriastini JJ. 2010. The lowland forest tree community in Malinau, Kalimantan (Indonesian Borneo): Results from a one-hectare plot. Plant Ecol Diver 3(1):59-66. DOI: 10.1080/17550874.2010.484840

Siswantoro RD, Kartodihardjo H, Hendrayanto, Darusman D. 2021. The IAD method in analyzing the transfer of right of water utilization at Gunung Gede Pangrango National Park, Indonesia. AES Bioflux [Internet].[Cited 2023 Mar 15]; 13(1):26-36. Available from: http://www.aes.bioflux.com.ro/docs/2021.26-36.pdf

Soepraptohardjo M. 1975. Generalized soil map, Indonesia scale 1:2,500,000 3rd Edition. Bogor (ID): Soil Research Institute.

Speak A, Escobedo FJ, Russo A, Zerbe S. 2018. Comparing convenience and probability sampling for urban ecology applications. J Appl Ecol [Internet]. [Cited 2024 May 23]; 55(5): 2332-42. DOI: 10.1111/1365-2664.13167

Sudomo A, Siarudin A. 2008. Intensitas dan motivasi masyarakat dalam pengambilan tumbuhan hutan secara ilegal di seksi konservasi wilayah II Taman Nasional Gunung Gede Pangrango. [Intensity and Motivation of Forest Plant Illegal Taking in Conservation Section II, Gede Pangrango National Park]. Jurnal Penelitian Hutan dan Konservasi Alam [Internet]. [Cited 2023 Oct 14]; 5(5):435-49. DOI: 10.20886/jphka.2008.5.5.435-449

Suryanti T. 2006. Ekologi lanskap dalam manajemen dan konservasi habitat owa jawa (Hylobates moloch Audebert 1797) di Taman Nasional Gunung Halimun [Landscape Ecology in Management and Habitat Conservation of Javan Gibbon (Hylobates moloch Audebert 1797) in Gunung Halimun National Park]. [Dissertation]. Depok (ID): Universitas Indonesia.

Suyanto, Nugroho Y, Harahap MM, Kusumaningrum L, Wirabuana PYAP. 2022. Spatial distribution of vegetation diversity, timber production, and carbon storage in secondary tropical rainforest at South Kalimantan, Indonesia. Biodiversitas [Internet]. [Cited 2023 May 24]; 23(12):6147-54. DOI: 10.13057/biodiv/d231208

Yamada I. 1975. Forest ecological studies of the montane forest of Mt. Pangrango, West Java. South East Asian Studies [Internet]. [Cited 2023 Mar 10]; 13(3):402-26. Available from: https://kyoto-seas.org/pdf/13/3/130304.pdf

Yusuf R. 2004. Keanekaragaman jenis pohon pada hutan terganggu di daerah koridor Taman Nasional Gunung Halimun [Diversity of Tree Species in Degraded Forest of Corridor Area in Gunung Halimun National Park]. Berita Biologi [Internet]. [Cited 2024 May 25]; 7(1):41-50. Available from: https://biologyjournal.brin.go.id/index.php/berita_biologi/article/view/1234/1107