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Biodiversity value of tree vegetation in Rainbow Forest Biosite, Ijen Geopark, East Java, Indonesia

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Abstract. *Sulistiyowati H, Hasanah EA, Siddiq AM, Ratnasari T, Dewi N, Kurnianto AS. 2024. Biodiversity value of tree vegetation in Rainbow Forest Biosite, Ijen Geopark, East Java, Indonesia. Biodiversitas 25: 2670-2678.* Biodiversity value representing the monetary estimation of the ecological value (ecoval) of species composing a forest is often applied for ecosystem change assessment. Tree community in Rainbow Forest Biosite (RFB) or *Biosite Hutan Pelangi*, Ijen Geopark, East Java, Indonesia was planted in 1937 and has experienced significant regrowth and changes over time by replacing one another until a mature forest becomes established. Yet, no empirical work has been done to assess the biodiversity value in RFB. Therefore, this study aims to provide a comprehensive estimation of the ecological value of tree vegetation in the RFB at Ijen Geopark. As many as 100 plots with size of 10×10 m each were established to acquire structural data of tree vegetation. Semi-destructive method was used to collect functional data on tree carbon. The result shows that RFB comprises 21 families, 34 genera, and 43 species. This forest has high diversity with dominant tree species are *Trevesia sundaica* Miq. and *Dendrocnide stimulans* (L.fil.) Chew due to the large number of individual and area coverage. Tree vegetation in RFB has a total basal area of 330 m^2/ha and a total volume of 4,171.01 m^3/ha, equivalent to an ecoval 182,439,286,595 IDR/ha in monetary terms. Three species including *Agathis dammara* (Lamb.) Rich. & A.Rich. and *Cedrela odorata* L., have unique existence, while others are quite unique (88.37%). Tree growth in RFB sequesters approximately 9,773.30 Mg CO_2eq/ha while storing 873.17 Mg C/ha and producing 7,105.19 Mg O_2eq/ha, equivalent to an ecoval of 11,401,417,827 IDR/ha. In total, the combined structural and functional biodiversity value of the explored vegetation is estimated to be 193,840,704,423 IDR/ha. By assigning this biodiversity value to RFB, authorities should focus on designing and implementing policies to maintain the existing tree species composition naturally and prevent deforestation.

Keywords: Biodiversity value, biosite, Ijen Geopark, Rainbow Forest

INTRODUCTION

One primary reason for ecological valuation is the lack of apparent economic worth assigned to biodiversity. Boyd and Banzhaf (2007) note that biodiversity's value is not easily recognized through commercial exchanges, as these resources are often shared and not bought or sold. The goal of ecological valuation is to address these "missing prices" by equating the value of biodiversity with consumer commodities. Sulistiyowati and Buot (2013) introduce the concept of "ecological value" or "ecoval" as the missing price in ecosystem interactions, influenced by a range of unpredictable internal and external factors. Additionally, ecological valuation is a tool to examine, estimate, and evaluate both the structure and function of ecosystems, encapsulating their ecoval, which is often overlooked in traditional economic valuations (Christie et al. 2012). Implementing this valuation helps to highlight the non-monetary benefits provided by ecosystems, such as biodiversity and carbon sequestration.

The role of biodiversity, particularly in forest ecosystems, is crucial for carbon sequestration and various other ecological processes. By understanding and promoting the ecological value of biodiversity, we can manage and protect ecosystems more effectively, ensuring they continue to provide essential services like climate regulation for future generations. Tree vegetation is central to carbon sequestration through photosynthesis, where trees sequester CO_2 from the atmosphere (Nowak et al. 2007; Liang et al. 2019; Shin et al. 2022). This CO_2 is then converted into organic matter stored in the tree's biomass, including trunks, branches, leaves, and roots (Shin et al. 2022). This conversion is a primary mechanism for carbon storage in forest ecosystems. Over time, trees sequester substantial amounts of carbon, especially in mature forests and long-lived species, creating significant carbon reserves (Lohbeck et al. 2015; Mildrexler et al. 2020).

One such mature forest is Rainbow Forest Biosite (RFB) or *Biosite Hutan Pelangi,* situated in Sumberwringin, Bondowoso District, East Java, Indonesia. The RFB is managed by Yogyakarta's *Balai Besar Pengujian Standar Instrumen Kehutanan,* Indonesia. This forest is aimed at biodiversity preservation and genetic research for breeding programs (BBPPBPTH 2013). The name "Rainbow Forest" originates from the presence of *Eucalyptus deglupta* Blume, whose bark displays colors resembling a rainbow. Due to this uniqueness, RFB was designated as a Biological Site (Biosite) under the management of Ijen Geopark in 2022 (Geopark Ijen 2023). Various tree species from different parts of the world were planted at this RFB between 1937 and 2004, and over time, the tree community has evolved through natural succession to form a mature forest.

As the RFB progresses towards a climax community, several dynamic changes will occur, influencing both the structure and function of the tree vegetation. The composition, diversity, richness, distribution patterns, and roles of each species evolve over time (Naidu and Kumar 2016; Manral et al. 2018; Tuan et.al, 2022). This can be due to their adaptability to the highland conditions and high rainfall. As new species spread and become established, the amount of species variety in trees may vary, either increasing or decreasing the total amount of species diversity. The volume of biomass and the basal area, or the cross-sectional area of a tree trunk, both rise with tree growth and maturity and serve as a reliable indicator of how a forest is developing toward maturity (Matsuo et al. 2021; Hoover and Smith 2023).

Mature trees with a dense canopy will increase the forest's ability to absorb and store atmospheric carbon dioxide, lessening the effects of climate change (Nowak et al. 2007; Liang et al. 2019; Shin et al. 2022). The forest's increased oxygen output as a result of photosynthesis will raise atmospheric oxygen levels and maintain general air quality. Additionally, Sulistiyowati and Buot (2016) suggest that additional data on endemicity, frequency of occurrence, and conservation status of vegetation factors can be assessed to improve knowledge of RFB conservation.

The ecological value (ecoval) of tree vegetation in the RFB can be estimated using both structural and functional attributes of the tree vegetation. These attributes serve as indicators of forest succession and overall biodiversity value, which is essential for monitoring regional and temporal changes, as highlighted by Gao et al. (2014). These insights will inform conservation strategies and support the sustainable management of the forest ecosystem, contributing to biodiversity conservation and climate change mitigation.

MATERIALS AND METHODS

Study period and area

This study was conducted in May 2023 at Rainbow Forest Biosite (RFB) or *Biosite Hutan Pelangi* of Ijen Geopark, Bondowoso District, East Java Province, Indonesia. Field data were collected at Station A (7°59'55" S and 114°0'11" E) and Station B (8°0'0" S and 113°59'55" E) (Figure 1). RFB's topography is situated at an elevation of 800 meters above sea level. The area has an average annual rainfall of 2400 mm, with the highest in January and the lowest in June and has climate type B of Schmidt and Ferguson (BBPPBPTH 2013). The average air temperature is 25.93±1.73°C, with humidity of 78.13±5.12% and soil moisture of 50.80±18.48%.

Vegetation sampling

Tree vegetation sampling was carried out using 100 plots, each measuring 10×10 m^2, placed along a transect line with 20 meters between each plot. In each plot, all trees with a DBH of 5 cm or greater were measured and recorded for scientific name, DBH, and height. Plant materials were collected for further identification or confirmation at the laboratory of the Biology Department, Faculty of Mathematics and Natural Sciences, Universitas Jember, following the methods described by Backer and van den Brink (1968). The individual number of each tree species in the plots was calculated. In contrast, the conservation status and geographic distribution of all tree species were determined based on the Red List of Threatened Species provided by the International Union for Conservation of Nature (IUCN) (https://www.iucnredlist.org/).

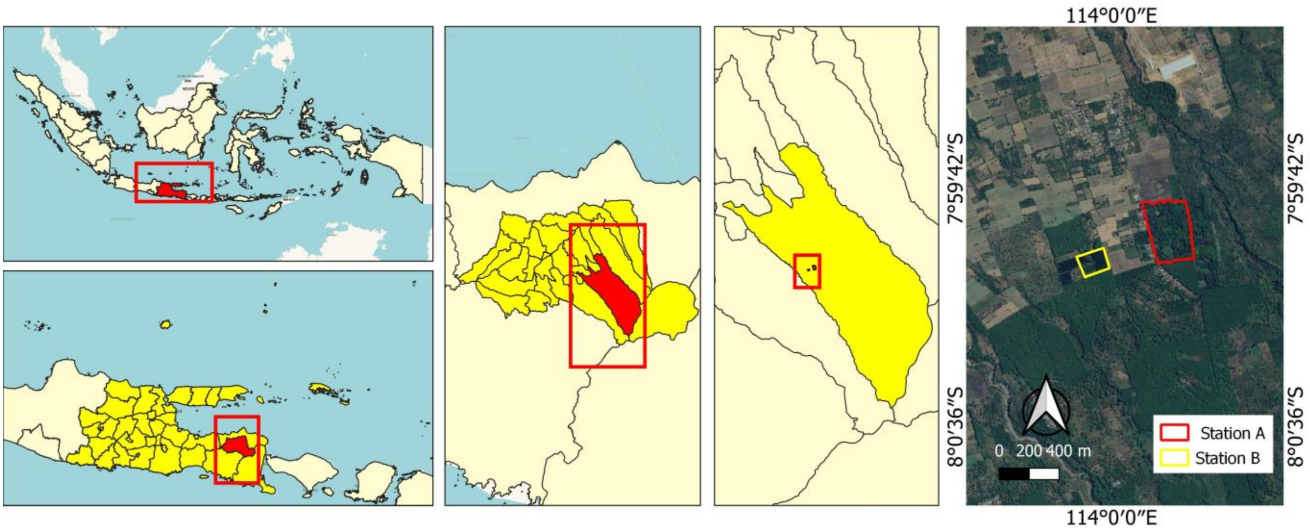

Figure 1. Map of study site in Rainbow Forest Biosite, Ijen Geopark, East Java, Indonesia

To assess tree function in the form of woody biomass, five wood samples of each species were collected by cutting into pieces reaching 10 cm in length, and the diameter of each wood was measured in the middle. These samples were cleaned and oven-dried at 105°C until the largest reached a constant weight (±3×24h) before calculating the dry mass. Additionally, abiotic factors, such as air temperature, air humidity, light intensity, pH, and soil humidity, were evaluated three times in each plot.

Structural value of tree vegetation

Structural value was assessed as the composition and diversity of tree species. The species composition in RFB was assessed by compiling all tree datasets into a list of family, genus, and species names. Subsequently, the dominance of tree species was calculated using the method described by Barbour et al. (1998). Importance Value Index (IVI), signifying the ecological importance and dominance of tree species, was calculated as the sum of relative density, dominance, and frequency. Furthermore, the Shannon-Wiener diversity index was calculated (Magurran 1988). The coverage or base area of each species was estimated using the basal area function described by Barbour et al. (1998) as follows:

$$BA = (¶D^2)/4(100)^2$$

Where:
BA: Basal Area (m^2)
¶: Constant (3.142)
D: DBH (cm)

The total basal area of each species was calculated by adding the basal area of the individuals comprising this population. Furthermore, the total tree volume was estimated through the summation of stem and canopy volume obtained using the Berkhout formula as well as the procedure described by Ponce-Hernandez et al. (2004), respectively. The existence of tree species in RFB was assessed by evaluating unique species that were rarely found, locally endemic, and characterized with high conservation status, using the Existence factor (Ef) equation proposed by Sulistiyowati and Buot (2016).

The functional value of tree vegetation

Carbon storage, carbon sequestration, and oxygen production were estimated to be the functional value of tree vegetation in RFB. The Pantropical allometric equation proposed by Chave et al. (2014) was used to estimate carbon storage as follows:

$$AGB_{est} = 0.0673\ (\rho D2H)\ 0.976$$

Where:
AGB: Above-Ground Biomass (kg)
ρ: Wood density (gr/m^3)
D: DBH (cm)
H: The height (m)

Specifically for one bamboo species, the biomass is calculated using a formula proposed by Hairiah et al. (2011):

$$W = 0{,}131D^{2{,}28}$$

Where:
W: Biomass
D: Diameter

The conversion of biomass to carbon storage used a factor of 0.50, and the conversion of carbon storage to carbon sequestration applied a factor of 3.667. At the same time, the photosynthesis equation shows that 1 g CO_2e emits 0.727 g O_2 into the atmosphere. In this study, the Rstudio 4.3.6 software was used to analyze the correlations between tree basal area, tree volume, tree number, and carbon storage through linear and power regressions. Differences were considered significant at $\alpha = 0.01$.

Biodiversity value of tree vegetation

The biodiversity value of tree vegetation in RFB was assessed using ecological valuation based on the following formula proposed by Sulistiyowati and Buot (2016):

$$Ɇ = S + F$$
$$= bS*D + bF*3.667*W*Ef$$

Where:
Ɇ: The ecoval of biodiversity value
bS: The cost base structure (wood price)
D: The dimension of tree volume
bF: Cost base Function (carbon trading and offset)
W: Carbon storage
Ef: The existence factor

RESULTS AND DISCUSSION

Structural value of tree vegetation in RFB, Ijen Geopark

The vegetation in RFB comprises 21 families, 34 genera and 43 species, as presented in Table 1, with different plant species resulting from the adaptation and tolerance abilities developed by a tree in forest succession. At the same time, the environmental circumstances initiate tree species to grow and regenerate. After years of growth, some trees have fallen, which generated openings in the canopy for incoming light to reach the forest floor, enabling seeds to germinate and grow in areas with adequate light and moisture. Kolaman and Yadid-Pecht (2011) stated that several environmental factors, such as humidity, temperature, and sunlight intensity, influenced vegetation growth and distribution.

According to Fischer et al. (2023), in forests with dense tree vegetation, canopy transpiration is significantly greater than soil evaporation. In RFB, the air humidity (78.12%; SD±5.12) is higher than the soil humidity (50.80%; SD±18.48), as relative air humidity is the amount of water vapor present in the air compared to the maximum amount that can be held at a particular temperature. This circumstance significantly influenced the measured value of low air temperature (25.93°C; SD±1.73) and neutral acidity (6.97; SD±0.22). According to Meili et al. (2021), evapotranspiration of well-watered plants can reduce local air temperature by approximately 5.8°C, and the moist conditions of forests are ideal for tree species growth.

The populations of *Trevesia sundaica* Miq. and *Dendrocnide stimulans* (L.fil.) Chew, which were not previously planted, are identified as the dominant and codominant species in RFB, with the highest Importance Value Index (IVI) percentages of 34.98 and 29.32, respectively. The moist environment of RFB, characterized by an average air humidity of 78.12%, facilitates the growth of post-planting tree vegetation, particularly these species. Both species favored by the environment stimulate natural regeneration, activating the germination of plants through adequate sunlight exposure to improve growth. The two tree species have glossy and broad leaf traits signifying plant adaptation to shade and moist environment. According to Wang et al. (2022), with increasing moisture, traits are shifted from glaucous and light green to mid-green and dark green leaves, smaller to larger leaves, as well as from semi-erect to patent orientation. Since the trees were established in 1937, when they were brought in from all over the world, the canopy closure has increased with age, expanding the plant species diversity. The Shannon Wiener Diversity Index (H') of tree vegetation in RFB is high (2.99), suggesting high species richness, with a reasonably even distribution and a large population. According to Pellat et al. (2023), plant succession promotes ecological stability because vegetation canopy cover has a positive impact on species diversity.

The average basal area covered by tree vegetation in RFB is 330 m^2/ha, signifying a robust stand structure composed of abundant trees. The total volume of the stand is 4,171.01 m^3/ha (Table 1), with *Pinus insularis* Endl. contributing the greatest volume of 1,759.35 m^3/ha, compared to other species. *P. insularis* is a fast-growing plant that is well adapted to moist conditions such as those found in RFB. Despite the relatively low population of only 17 individuals, this species contributes significantly to the total volume due to the enormous diameter and basal area. According to Hansen et al. (2003), *P. insularis* grows best in moist conditions with moderate to heavy rainfall and is suitable for reforestation and afforestation programs due to possessing a fast-growing nature as well as excellent tolerance to a wide range of climates and habitats (Thomte et al. 2023). In contrast, despite the high number of individuals, *Dendrocnide excelsa* (Wedd.) Chew, *Myroxylon balsamum* (L.) Harms, *Quercus alba* L., *Pterygota alata* (Roxb.) R.Br., *Ficus* sp., *T. sundaica*, *Dendrocalamus asper* (Schult.f.) Backer, *Voacanga foetida* (Blume) Rolfe, *Terminalia bellirica* (Gaertn.) Roxb., *Tabernaemontana globosa* Náves ex Fern.-Vill., 1880, *Piptadenia peregrina* (L.) Benth., *Eusideroxylon zwageri* Teijsm. & Binn., *Melia azedarach* L., *Cinnamomum burmanni* (Nees & T.Nees) Blume, and *Dissochaeta monticola* Blume only contribute volume less than 10 m^2/ha because of the small diameter size and basal area.

Based on frequency of occurrence, conservation status, and geographic distribution, the majority of tree species in RFB are considered unique (88.37%) (Figure 2 and Table 1). Only 6.98% of tree species are classified as unique, including *Ficus benghalensis* L., *Ficus* sp., and *Cedrela odorata* L., which have limited populations and geographic ranges in the Asian continent. The abundant *D. stimulans*, *M. balsamum*, and *T. sundaica* are categorized as less unique due to their wide distribution and low conservation status (LC). Conversely, *A. dammara* and *C. odorata*, with their limited population, Asian geographic distribution, and vulnerable conservation status, are the only species classified as unique in RFB. Managers of RFB should intensively monitor these unique species to prevent population decline or loss, thereby preserving biodiversity and maintaining a healthy ecosystem (Xu and Zang 2023).

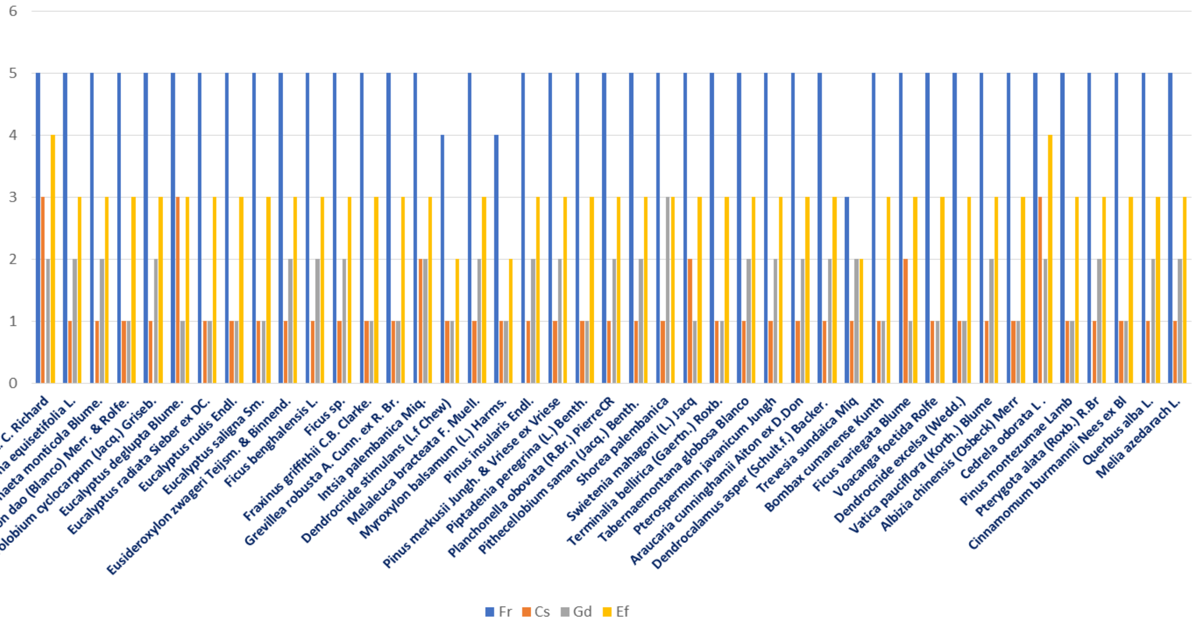

Figure 2. The level of uniqueness or existence factor (1: not unique, 2: less unique, 3: quite unique, 4: unique, and 5: very unique) of species in Rainbow Forest Biosite, Ijen Geopark, Indonesia calculated based on frequency, conservation status and geographic distribution

Table 1. List of tree species in Rainbow Forest Biosite, Ijen Geopark, Indonesia and its Conservation Status (CS), Relative Frequency (RF), Relative Density (RDe), Relative Dominance (RDo), and Important Value Index (IVI)

Family	Species	CS	RF	RDe	RDo	IVI
Anacardiaceae	*Dracontomelon dao* (Blanco) Merr. & Rolfe	LC	3.77	5.05	2.44	11.26
Apocynaceae	*Voacanga foetida* (Blume) Rolfe	LC	4.40	1.53	0.20	6.13
	Dendrocnide excelsa (Wedd.) Chew	LC	1.26	2.52	0.73	4.51
	Tabernaemontana globosa Náves ex Fern.-Vill., 1880	LC	0.63	0.18	0.02	0.83
Araliaceae	*Trevesia sundaica* Miq.	LC	15.72	18.92	0.34	34.98
Araucaricaceae	*Agathis dammara* (Lamb.) Rich. & A.Rich.	VU	2.52	6.40	3.11	12.02
	Araucaria cunninghamii Aiton ex A.Cunn.	LC	1.26	1.17	0.83	3.26
Bombaceae	*Bombax cumanense* Kunth	LC	1.26	0.99	1.88	4.12
Casuarinaceae	*Casuarina equisetifolia* L.	LC	1.26	3.69	2.33	7.28
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	LC	0.63	0.18	0.04	0.85
Dipterocarpaceae	*Shorea palembanica* Miq.	LC	4.40	2.52	4.52	11.44
	Vatica pauciflora (Korth.) Blume	LC	1.26	2.43	1.17	4.87
Fabaceae	*Enterolobium cyclocarpum* (Jacq.) Griseb.	LC	0.63	0.09	2.93	3.65
	Piptadenia peregrina (L.) Benth.	LC	0.63	0.09	0.02	0.74
	Myroxylon balsamum (L.) Harms.	LC	7.55	7.84	0.59	15.97
	Albizia chinensis (Osbeck) Merr.	LC	1.89	1.26	12.14	15.28
	Intsia palembanica Miq.	NT	3.77	8.83	1.02	13.62
	Quercus alba L.	LC	0.63	0.09	0.28	1.00
Lauraceae	*Eusideroxylon zwageri* Teijsm. & Binn.	LC	1.89	1.08	0.01	2.98
	Cinnamomum burmanni (Nees & T.Nees) Blume	LC	0.63	0.09	0.00	0.72
Leguminosae	*Pithecellobium saman* (Jacq.) Benth.	LC	1.26	1.71	3.86	6.83
Malvaceae	*Pterospermum javanicum* Jungh.	LC	1.89	0.81	7.55	10.25
	Pterygota alata (Roxb.) R.Br.	LC	1.26	0.54	0.52	2.32
Melastomataceae	*Dissochaeta monticola* Blume	LC	0.63	0.09	0.0005	0.72
Meliaceae	*Swietenia mahagoni* (L.) Jacq.	NT	3.77	2.52	4.71	11.01
	Cedrela odorata L.	VU	1.89	1.71	2.62	6.22
	Melia azedarach L.	LC	0.63	0.18	0.01	0.82
Moraceae	*Ficus variegata* Blume	NT	3.14	2.16	3.32	8.62
	Ficus benghalensis L.	LC	1.89	0.36	0.74	2.99
	Ficus sp.	LC	0.63	0.36	0.13	1.12
Myrtaceae	*Eucalyptus rudis* Endl.	LC	1.26	1.71	9.08	12.05
	Eucalyptus deglupta Blume	VU	1.26	1.35	5.69	8.30
	Eucalyptus saligna Sm.	LC	3.14	0.90	1.41	5.45
	Eucalyptus radiata A.Cunn. ex DC.	LC	0.63	0.36	1.61	2.60
	Melaleuca bracteata F.Muell.	LC	0.63	0.18	0.70	1.51
Oleaceae	*Fraxinus griffithii* C.B.Clarke.	LC	1.26	1.98	1.18	4.42
Pinaceae	*Pinus insularis* Endl.	LC	1.26	1.53	10.13	12.92
	Pinus merkusii Jungh. & de Vriese	LC	1.89	1.44	3.64	6.97
	Pinus montezumae Lamb.	LC	0.63	0.45	2.67	3.75
Poaceae	*Dendrocalamus asper* (Schult.f.) Backer	LC	1.26	0.45	0.07	1.78
Proteaceae	*Grevillea robusta* A.Cunn. ex R.Br.	LC	0.63	0.18	0.08	0.89
Sapotaceae	*Planchonella obovata* (R.Br.) Pierre	LC	0.63	0.45	2.56	3.64
Urticaceae	*Dendrocnide stimulans* (L.fil.) Chew	LC	12.58	13.60	3.13	29.32
Total			**100.00**	**100.00**	**100.00**	**300.00**

The functional value of tree vegetation in RFB, Ijen Geopark

The functional value of tree vegetation is estimated by the capability to sequester CO_2 for the photosynthetic process, which results in carbon storage and oxygen production. Trees store more carbon and hold it over an extended time than grasses, herbs, or shrubs due to being larger, denser, and able to live longer. Figure 3 shows that tree vegetation in RFB can absorb approximately 9,773.30 Mg CO_2eq/ha while producing 873.17 Mg C/ha. Based on the results, tree vegetation plays a key role in lowering atmospheric CO_2 levels due to sequestering more CO_2 than other vegetation types. The sequestration in the tropical forest of Brazil was 980.99 Mg CO_2/ha or 267.52 Mg/ha (Dantas et al. 2021), while 987.16 Mg CO_2/ha or 269.2 Mg C/ha was obtained in Bukit Tigapuluh National Park of Indonesia (Darmawan et al. 2022).

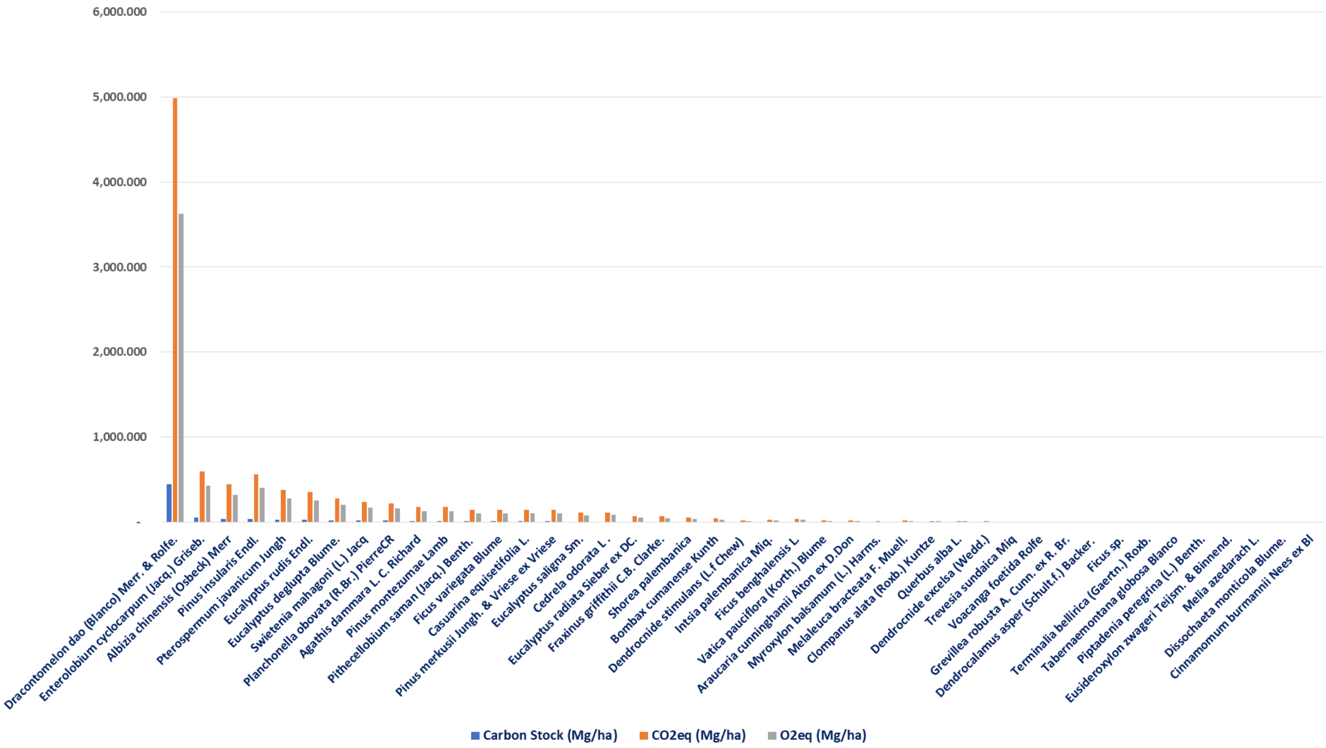

Figure 3. Carbon stock, CO_2eq and O_2eq of tree vegetation in Rainbow Forest Biosite, Ijen Geopark, Indonesia (Mg/ha)

Forests cover one-third of the Earth and support the existence of life, as tropical forests produce 40% of all available oxygen. Figure 3 shows that RFB contributes a high O_2 value of 7,105.19 Mg O_2eq/ha to support human and environmental well-being, making it an essential component of the Earth's life-sustaining ecosystem. This function is commonly recognized as an ecosystem service among the multiple benefits received by humans (Costanza et al. 2017; Chen et al. 2022; Zhang et al. 2022).

Large trees store a significant proportion of total carbon, making vegetation carbon storage in RFB crucial for mitigating climatic change. According to Figure 3, *Dracontomelon dao* (Blanco) Merr. & Rolfe and *Enterolobium cyclocarpum* (Jacq.) Griseb. contribute the highest carbon storage at 452.81 Mg/ha and 54.43 Mg/ha, respectively, resulting in a high value of CO_2 sequestration and O_2 generation. Both *D. dao*, which has a huge population (112), and E. cyclocarpum, with a large DBH of >200 cm, store high levels of carbon. Other tree species contributing low carbon (<1 Mg/ha) include *T. sundaica*, *V. foetida*, *G. robusta*, *D. asper*, *Ficus sp.*, *T. bellirica*, *T. globosa*, *P. peregrina*, *E. zwageri*, *M. azedarach*, *D. monticola*, and *C. burmanni.*

Carbon storage value is found to be highly sensitive to stand structure, including tree height, DBH, density, and basal area. According to Sahoo et al. (2021), there is a substantial association between tree basal area and biomass carbon storage for all land-use types. Similarly, this study found a substantial positive relationship between tree basal area and carbon storage (R^2 = .675**, p = 0.000) (Figure 4). Basal area is a good indicator and a continuous structural attribute influencing carbon storage that integrates the effect of tree number and size; hence, a larger basal area leads to a greater total carbon stored. Tree size, basal area, and growth pattern influence forest carbon storage (Raha et al. 2020; Baul et al. 2021; Chanlabut and Nahok 2022). Figure 5 shows a strong significant relationship between tree volume and carbon storage (R^2 = .281**, p = 0.000), which is estimated based on tree volume calculated from height and DBH. Since huge volume equates to high carbon storage, the tree is a long-lived plant with a large biomass that can capture and retain a significant amount of carbon over long periods.

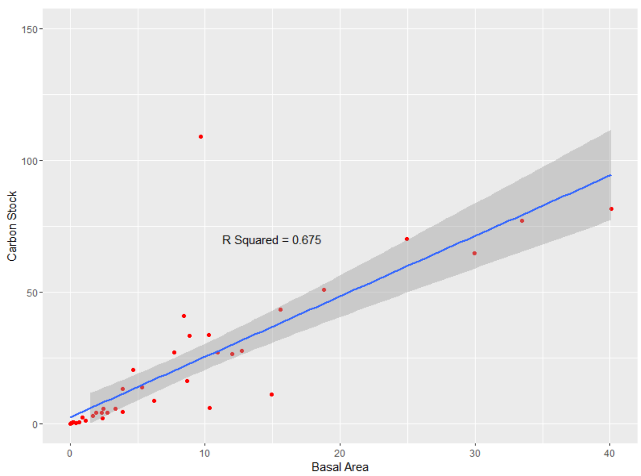

Figure 4. The correlation between tree basal area (m^2/ha) and carbon stock (Mg/ha) in Rainbow Forest Biosite, Ijen Geopark, Indonesia

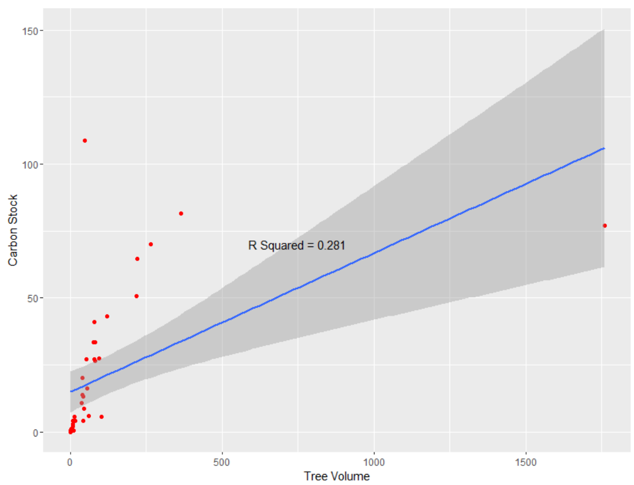

Figure 5. The correlation between tree volume (m^3/ha) and carbon stock (Mg/ha) in Rainbow Forest Biosite, Ijen Geopark, Indonesia

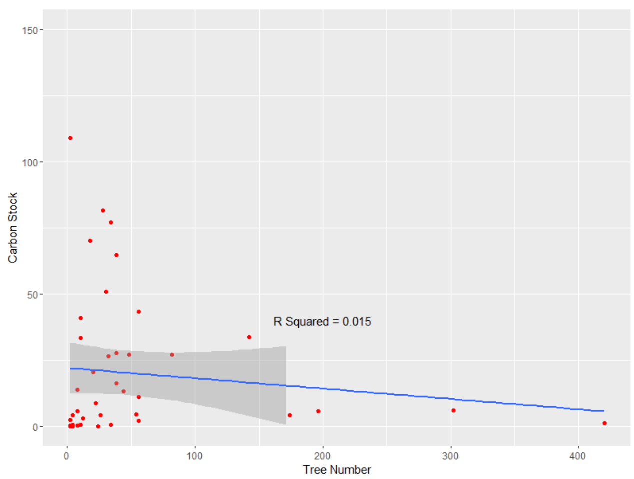

Figure 6. The correlation between total tree number (#/ha) and carbon stocks (Mg/ha) in Rainbow Forest Biosite, Ijen Geopark, Indonesia

The number of tree individuals in RFB significantly influences carbon storage as well as the ability to sequester CO_2 and produce O_2. Understanding the association between the number of tree species and carbon storage in the forest is crucial for the long-term operation of ecosystem services. The number of tree species can influence the pace of carbon sequestration and alleviate the consequences of climate change. Figure 6 shows that the total tree number has a significant negative relationship with the carbon storage level estimated (R^2 = 0.015**, p = 0.441) in RFB. This signifies that the total carbon storage of forests is often influenced by the sum of trees with bigger stem sizes rather than the total tree number.

Biodiversity value and the need to conserve tree vegetation in RFB, Ijen Geopark

Tropical forests are regarded as complex ecosystems due to their biological richness, interconnections, biogeochemical cycles, and supply of various ecosystem services. The biodiversity value of tree vegetation in RFB is difficult to estimate, yet the simplest way to determine it is through replacement cost. A method used for this purpose is ecological valuation, which assigns both structure and function values to tree vegetation. According to Sulistiyowati and Buot (2016), tree vegetation of a specific habitat is commonly assessed based on the structural dimension and carbon sequestration.

The total biodiversity value of tree vegetation in RFB is 193,840,704,423 IDR/ha, with 43 species contributing a structural value of 182,439,286,595 IDR/ha and a function value of 11,401,417,827 IDR/ha (Figure 7), among which the structure provides the highest contribution. These results are represented by the regression model with R^2 = 0.984*** and p = 0.000 for structure and biodiversity correlation versus R^2 = 0.049* and p = 0.155 for function and biodiversity value (Figure 8). Four species, including *P. insularis*, *Albizia chinensis* (Osbeck) Merr., *D. dao*, and *Pterospermum javanicum* Jungh., contribute more than 10 billion IDR/ha to RFB biodiversity value because of the large tree size. However, *Intsia palembanica* Miq., *Vatica pauciflora* (Korth.) Blume, *Q. alba*, *G. robusta*, and *D. excelsa* provide less than 1 billion IDR/ha.

In conclusion, the RFB has high species diversity, comprising 43 species dominated by the *T. sundaica* and *D. stimulans* populations. Most tree species are categorized as quite unique, with fewer species such as *Agathis dammara* (Lamb.) Rich. & A.Rich. and *C. odorata* being unique. The tree vegetation of the RFB is valued at approximately 193,840,704,423 IDR/ha, with 88.89% of this value mainly contributed by the tree vegetation structure. These 43 species can sequester about 9,773.30 Mg CO_2eq/ha, store 873.17 Mg C/ha, and produce 7,105.19 Mg O_2eq/ha. By recognizing the ecological value of diverse tree vegetation, we can better protect and manage forest ecosystems, ensuring their contributions to carbon sequestration and biodiversity conservation for future generations. To protect the species from any threats, monitoring efforts should prioritize rare and endemic species with high conservation status, as well as low ecoval, which represent limited numbers and small sizes. Considering the biodiversity value of RFB, the authorities need to design and implement policies to maintain the natural composition of valuable species and prevent illegal tree consumption.

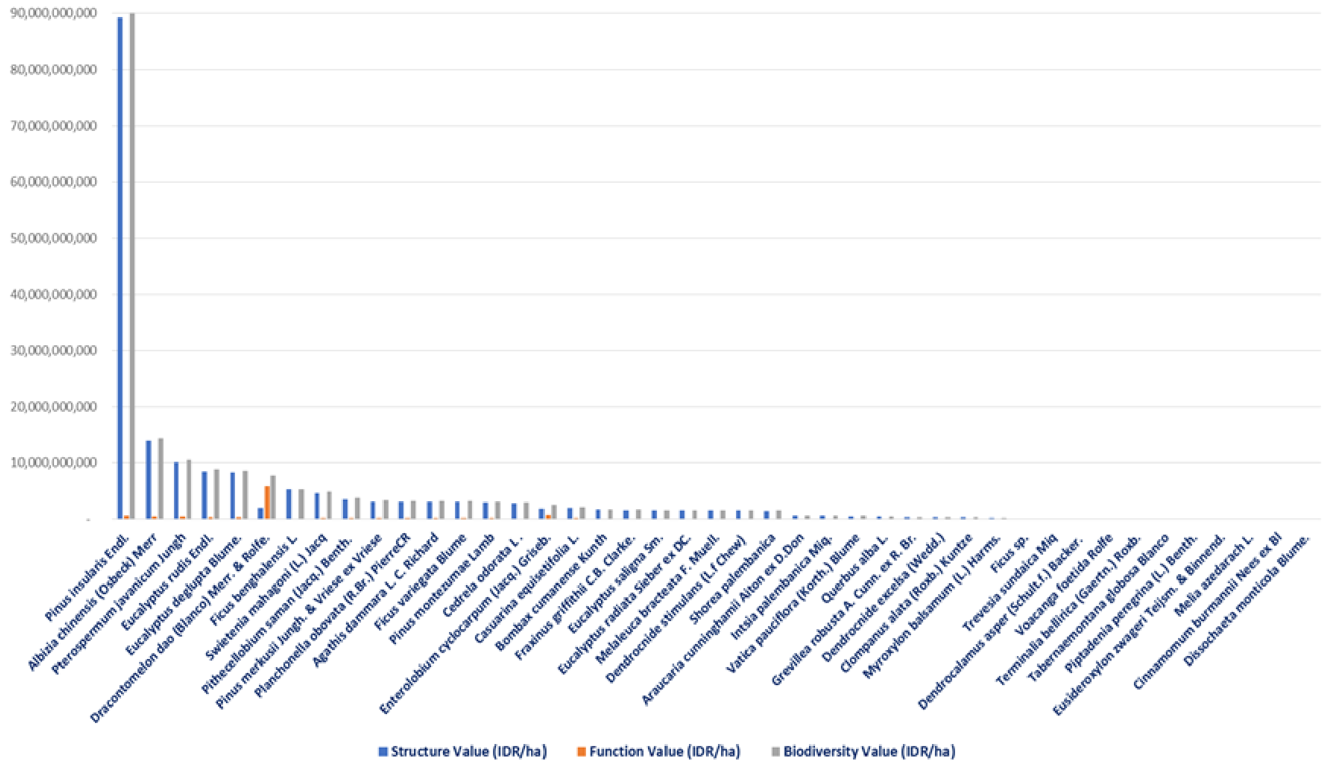

Figure 7. The structure, function and biodiversity values (IDR/ha) of tree vegetation in Rainbow Forest Biosite, Ijen Geopark, Indonesia

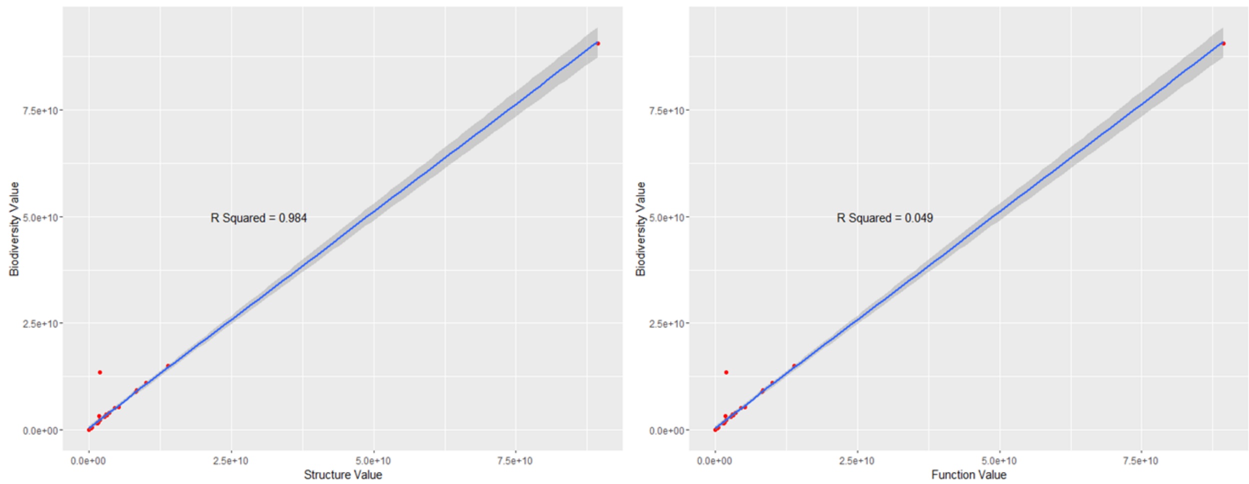

Figure 8. Regression analysis to assess the correlation between structure and function values (X axis) and biodiversity value (Y axis)

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