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CARBON STOCK AND CARBON ECONOMIC VALUE OF FOREST ECOSYSTEM IN THE SUWANGI ISLAND NATURE PARK, TANAH BUMBU REGENCY, SOUTH KALIMANTAN, INDONESIA

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ABSTRACT

REZEKIAH, A. A., FITHRIA, A., YAMANI, A., ROSIDAH, RUDY, G. S., ALI, S. D. & SHIBA, Y. N. 2026. Carbon stock and carbon economic value of forest ecosystem in the Suwangi Island Nature Park, Tanah Bumbu Regency, South Kalimantan, Indonesia. *Reinwardtia* 25(1): 1–11. — The forests on Suwangi Island are currently facing significant challenges arising from human activities, land degradation, and potential land-use conflicts, all of which critically undermine their capacity to absorb and store carbon. The purpose of this study was to analyze the carbon stock value and economic value of carbon stored in Suwangi Island Nature Park. The allometric method was employed to calculate carbon stocks, with sampling locations determined using purposive sampling. The carbon stock results were subsequently converted to estimate the economic value of carbon. The land cover types identified in Suwangi Island Nature Park include primary forest, secondary forest, plantation, medium-density mangrove forest, and high-density mangrove forest. The analysis revealed that the highest biomass was stored in the primary forest and the lowest in the medium-density mangrove forest. The total carbon that can be stored at the research site is 80.45554667 tons/ha, and the resulting carbon economic value is IDR 2,851,347,872.68. These findings highlight the significant variation in carbon storage across different land cover types and underscore the critical role of primary forests as major carbon sinks. The novelty of this study lies in the integration of spatial (ArcGIS), ecological (allometric), and economic approaches within a single analytical framework, which remains rarely applied. The practical implications of this research emphasize the importance of management strategies based on carbon economic valuation and the potential utilization of carbon trading schemes, such as REDD+, to enhance conservation incentives and ensure the sustainability of Suwangi Island Nature Park management.

Key words: Carbon, economic value, forest, nature park, Suwangi Island.

ABSTRAK

REZEKIAH, A. A., FITHRIA, A., YAMANI, A., ROSIDAH, RUDY, G. S., ALI, S. D. & SHIBA, Y. N. 2026. Cadangan dan nilai ekonomi karbon ekosistem hutan di Taman Wisata Alam Pulau Suwangi, Kabupaten Tanah Bumbu, Kalimantan Selatan, Indonesia. *Reinwardtia* 25(1): 1–11. — Hutan di Pulau Suwangi saat ini menghadapi tantangan yang signifikan yang berasal dari aktivitas manusia, degradasi lahan, dan potensi konflik penggunaan lahan, yang semuanya secara kritis melemahkan kapasitas hutan untuk menyerap dan menyimpan karbon. Tujuan penelitian ini adalah untuk menganalisis nilai cadangan karbon dan nilai ekonomi karbon yang tersimpan di Taman Wisata Alam Hutan di Pulau Suwangi saat ini menghadapi tantangan yang signifikan yang berasal dari aktivitas manusia, degradasi lahan, dan potensi konflik penggunaan lahan, yang semuanya secara kritis melemahkan kapasitas hutan untuk menyerap dan menyimpan karbon. Tujuan penelitian ini adalah untuk menganalisis nilai cadangan karbon dan nilai ekonomi karbon yang tersimpan di Taman Wisata Alam Pulau Suwangi. Metode yang digunakan untuk menghitung karbon stok yaitu metode allometrik dengan penentuan lokasi pengambilan sampel secara *purposive sampling*. Hasil karbon stok dikonversi untuk mendapatkan nilai ekonomi karbon. Jenis tutupan lahan yang terdapat di Taman Wisata Alam Pulau Suwangi adalah hutan primer, hutan sekunder, perkebunan, hutan mangrove kerapatan sedang, dan hutan mangrove kerapatan tinggi. Hasil analisis cadangan karbon menunjukkan bahwa biomassa tertinggi yang dapat disimpan di lokasi penelitian terdapat pada hutan primer dan terendah pada hutan mangrove kerapatan sedang. Total karbon yang dapat disimpan di lokasi penelitian adalah 80.45554667 ton/ha dan nilai ekonomi karbon yang dihasilkan sebesar Rp 2.851.347.872,68. Temuan ini menegaskan perbedaan signifikan antar tipe tutupan lahan dalam menyimpan karbon dan menunjukkan kontribusi penting hutan primer sebagai penyerap karbon utama. Keunikan penelitian ini terletak pada integrasi aspek spasial (ArcGIS), ekologi (alometrik), dan ekonomi dalam satu kerangka analisis, yang masih jarang diaplikasikan. Implikasi praktis hasil penelitian ini mendukung pentingnya strategi pengelolaan berbasis nilai ekonomi karbon serta peluang pemanfaatan skema perdagangan karbon, seperti REDD+, untuk meningkatkan insentif konservasi dan keberlanjutan pengelolaan Taman Wisata Alam Pulau Suwangi.

Kata kunci: Hutan, karbon, nilai ekonomi, Pulau Suwangi, taman wisata alam.

INTRODUCTION

Trees take in and store an enormous quantity of carbon dioxide in the air. That is why forests are so important to keep the earth's ecosystem balanced. Forest ecosystems, mangroves, and tropical rainforests among them being significant, through their carbon storage, play vital roles in the process to reduce atmospheric levels of greenhouse gases and meet global climate objectives (Raihan *et al.*, 2021). In addition to this, these ecosystems have the ability to increase their capacities for carbon storage through proper reforestation and environmentally friendly management strategies. The enormous carbon stock of forests is of immense economic significance. The potential of these ecosystem services to sequester carbon is one of the factors in programs highlighting the economic value of forest conservation and trigger investments with a balance of profitability-ecological sustainability (Raihan *et al.*, 2021). Among its many benefits that forests can offer are biodiversity, reduced impacts of climate change, and economic importance due to improved conservation techniques and ecological dividends (Liu *et al.*, 2022; Openko *et al.*, 2023).

Suwangi Island, which is presently a nature park, provides a large range of ecosystems from primary and secondary forests to plantation and mangrove forests varying in densities from moderately dense to very dense. As forests all over the world contribute significantly towards carbon sequestration, this diversity of ecosystems is also vital in order to sequester carbon. However, human activity, land degradation, and potential land-use conflicts endanger Suwangi Island to be capable of sequestering carbon (Li, 2023). According to studies, the ecological integrity of such forest ecosystems as on Suwangi Island can depend on efficient forest management regimes that maximize carbon sequestration while ensuring ecological integrity and economic return (Li *et al.*, 2021; Gren & Amuakwa-Mensah, 2018; Ameray *et al.*, 2021). Furthermore, the urgent need to measure the carbon storage potential on Suwangi Island is underscored by evidence that effective management practices can enhance carbon stocks and are vital for supporting climatic stability (Qi *et al.*, 2023; Theuerkauf & Rodriguez, 2017; Li *et al.*, 2023). In light of growing external pressures, estimating the economic value of carbon storage in this region not only helps to understand its ecological significance but also offers a framework for management strategies to preserve and maximize carbon storage capabilities (Raihan *et al.*, 2021; Gren & Amuakwa-Mensah, 2018; Theuerkauf & Rodriguez, 2017).

To date, the majority of Indonesian research has concentrated on quantifying carbon stocks in specific ecosystems, such as mangroves and production forests, often neglecting an integrated assessment of different types of land cover in smaller island contexts. Additionally, the majority of research focuses on estimating carbon stock and biomass independently; few attempts integrate ecological methods such as allometric equations, economic carbon resource valuation, and spatial analytical tools like ArcGIS. This lack of multidisciplinary studies is particularly so with Suwangi Island, where no multidisciplinary survey has been undertaken with a view to assessing possible carbon reserves and economic valuation. The lack of such integrative studies underlines the sheer research gap and the need for a more integrated approach to determine carbon dynamics in small island ecosystems. Closing this gap can help Indonesia make better policies and protect sustainable land use and fight climate change. Future studies must try to connect these components in order to have a better view of carbon stocks and their economic valuation.

Based on description of this study, the research questions posed in this study are: (1) How much carbon is stored in various types of land cover in Suwangi Island Nature Park? (2) What is the economic value of the carbon produced from these

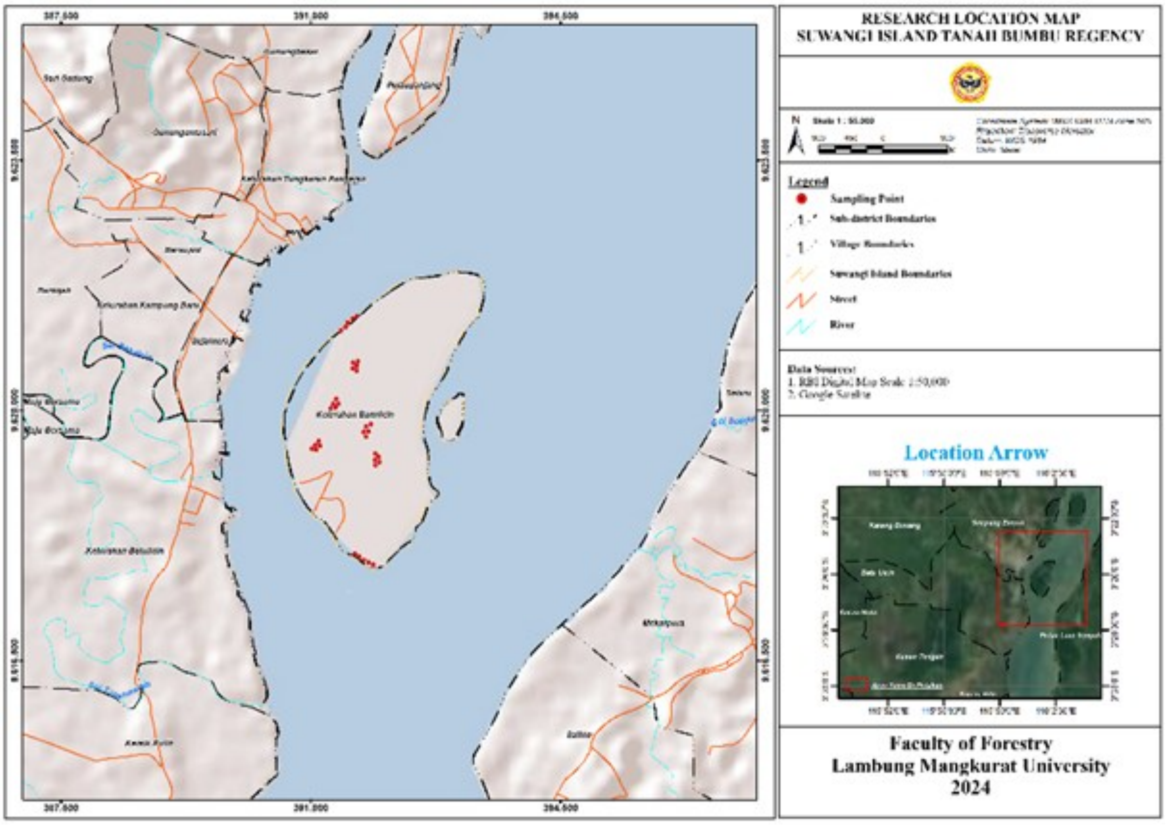

Fig. 1. Research location at Suwangi Island Nature Park.

carbon stocks? and (3) How can the results of this study contribute scientifically to the management of conservation areas while supporting carbon trading mechanisms as a climate change mitigation strategy?

MATERIALS AND METHODS

Study Area

This research was conducted in the Suwangi Island Nature Park (TWA Pulau Suwangi), Batulicin District, Tanah Bumbu Regency, South Kalimantan Province (Fig. 1). Based on the Decree of the Minister of Environment and Forestry No. SK.652/ MENLHK/SETJEN/PLA.2/8/2019, this area represents a functional change from the Teluk Kelumpang Nature Reserve in the Selat Laut and Sebuku Strait to the Suwangi Island and Burung Island Nature Park, covering an area of approximately 1,239 ha.

The observed land cover consists of five types: primary forest, secondary forest, plantation, high-density mangrove forest, and medium-density mangrove forest. Geographically, Suwangi Island is located at coordinates 03°25'10.7”S–116°02'25.8”E to 03°27'26.6”S–116°00'55.4”E. According to the Schmidt and Ferguson climate classification, the site falls into climate type A, characterized by an average monthly rainfall of ≥ 200 mm for nine months of the year. Data from the Gusti Syamsir Alam Meteorological Station in Kotabaru indicate relative humidity ranging from 77% to 85% (Ridwan *et al.,* 2024). The island’s topography is relatively flat, with slopes varying from 0–40% (Pusfatekgan, 2009).

Data Collection

The method employed was a non-destructive approach following the protocol of Kauffman & Donato (2012). This study specifically assessed aboveground carbon (AGC), which included the biomass of saplings, poles, trees, and mangrove vegetation. Belowground carbon (BGC) and soil carbon were not included in this study. Biomass measurements in this study were carried out using the path method with plot lines (Sutaryo, 2009) and can be seen in Fig. 2.

The plot design followed a nested plot method with the following dimensions:

- Saplings (dbh 2–9.9 cm): subplots of 5 m × 5 m.
- Poles (dbh 10–19.9 cm): subplots of 10 m × 10 m.
- Trees (dbh ≥ 20 cm): main plots of 20 m × 20 m

The number and location of plots were

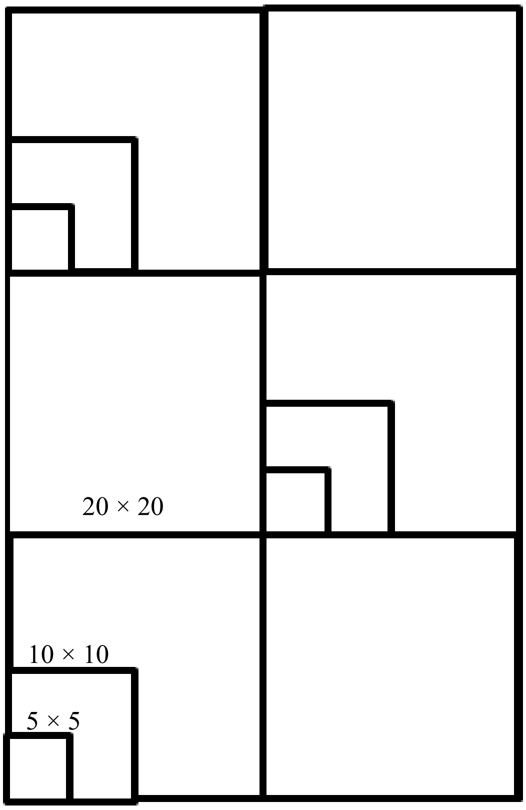

Fig. 2. Plot sketch.

determined using purposive sampling across different land cover types to represent ecosystem conditions and each levels was taken 3–5 plots as samples. For each individual tree or mangrove, data recorded included species, diameter at breast height (dbh, measured at 1.3 m above ground or above the highest prop root/pneumatophore), and total height. For certain mangrove species, specific measurement techniques were applied in accordance with the recommendations of Kauffman & Donato (2012).

Additional data on wood density (ρ) were obtained from various relevant scientific journals and literature, while carbon price information was derived from the official selling exchange rate published by Bank Indonesia in the year of the study.

Data Analysis

Data analysis in this study using biomass analysis to calculate the amount of carbon stored in Suwangi Island Nature Park. Moreover, the economic valuation of carbon was calculated using the market price of carbon at the time of study.

Biomass Measurement

The data analysis used to determine the amount of carbon stock in Suwangi Island Nature Park is the value of plant biomass. Data obtained from direct measurements in the field can be used to measure the level of above ground biomass contained in each plant species or level. Data obtained from the field include circumference and height data. The circumference data measured from the field was then converted into diameter values by dividing the circumference value by phi ($D = \text{Circumference}/\pi$), so that the diameter value could be entered into the allometric equation. Biomass was calculated using species-specific allometric equations. The equations applied in this study were as follows Table 1.

Carbon Measurement

Carbon was calculated based on biomass data obtained at the seedling, sapling, and tree levels. Carbon stock uses the formula according to Zhao *et al.* (2018), namely:

$$C = \text{Biomass} \times \%\ \text{C-organic}$$

Description:
C : Carbon stock (ton)

Calculation of the Economic Value of Carbon

The economic value of carbon is calculated using the price set by Pratamasari *et al.* (2018) which states that the price of carbon in standard carbon price from World Bank is US$ 10 per ton of sequestered carbon stocks

$$\text{Economic Value of Carbon} = \text{Carbon Stock} \times \text{Total Area (ha)} \times \text{Carbon Price}$$

Table 1. Formula for calculating biomass in Suwangi Island Nature Park.

Species Name	Allometric Model	Sources
Rhizophora sp.	$AGB = 0.1466 \times \rho^{2,3136}$	Dharmawan (2010)
Types of mangroves in general	$AGB = 0.251 \times \rho \times D^{2,46}$	Komiyama *et al.* (2005)
Other types	$AGB = \rho \times Vk \times BEF$	Wibowo *et al*. (2013)
All types of stake levels	$AGB = \exp(-3.23 + 2.17 \ln(D))$	Marianingsih *et al*. (2023)

Description:
AGB: Biomass (kg)
ρ : Specific gravity (g/cm^3)
D : Diameter (m)
BEF : Biomass Expansion Factor (1.67)

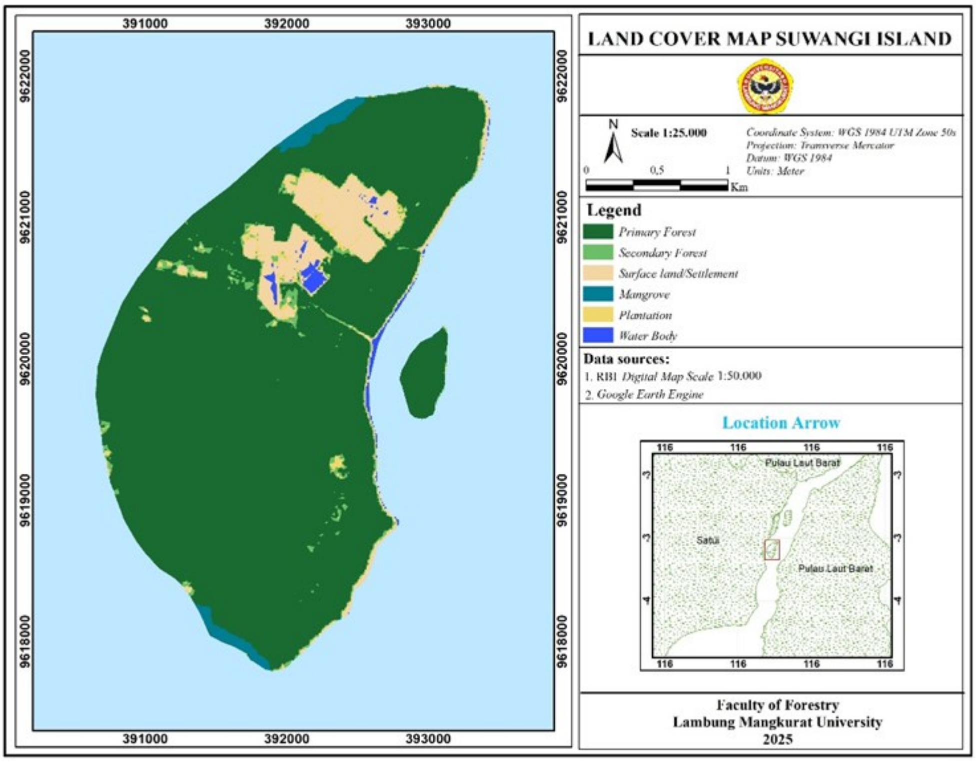

Fig. 3. Land cover map of Suwangi Island.

The exchange rate was calculated for 1 year since this study was analyzed so that US$1 is worth IDR 15,879.93.

RESULTS

Land Cover Type of Suwangi Island Nature Park

Suwangi Island Nature Park is divided into several types of land cover. Land cover type data in Suwangi Island Nature Park obtained from South Kalimantan Environment Department data. The land cover is divided due to differences in the vegetation that grows in it and the intended use of the area. Vegetation growing in the primary forest includes the Anacardiaceae, Araucariaceae, Dipterocarpaceae, Moraceae, Phyllanthaceae, Sapotaceae, Myristicaceae, and Myrtaceae, families. Vegetation growing in the secondary forest is quite diverse includes the Anacardiaceae, Araucariaceae, Arecaceae, Dipterocarpaceae, Fabaceae, Flacourtiaceae, Malvaceae, Moraceae, Myristicaceae, Myrtaceae, Phyllanthaceae, and Rubiaceae families. Vegetation growing in plantations is mostly fruit and rubber vegetation types. Meanwhile vegetation growing in mangrove forests are mangrove vegetation types such as *Sonneratia, Rhizophora*, and *Avicennia.* In general, the types and extent of land cover in Su-

Table 2. Land cover type of Suwangi Island Nature Park.

No.	Land Cover Types	Area (Ha)
1	Primary forest	345.95
2	Secondary forest	28.81
3	Surface land/settlement	65.69
4	Mangrove forest	227.27
5	Plantation	29.57
6	Water body	1.95

Data Source: South Kalimantan Environment Department Data (2024).

wangi Island Nature Park can be seen in Fig. 3 and the explanation of area can be seen in Table 2.

Biomass and Carbon Calculation in Suwangi Island Nature Park

Land cover types in this study include primary forest, secondary forest, plantation, medium density mangrove forest, and high density mangrove forest. For each type of land cover, measurements of tree circumference and height were taken to calculate the volume of wood used in plant biomass analysis. The vegetation levels measured for biomass and carbon in this study were divided into three levels: seedling (D < 10 cm), sapling (10 cm < D < 20 cm), and tree (D > 20 cm). Overall, the diameter of stems growing in the primary forest, secondary forest, plantation, medium density mangrove forest, and high density mangrove forest were ranged from 6 cm to 79 cm. Moreover, field measurements were made to determine the types of plants that live in each type of land cover so that the specific gravity of each plant could be found. The types of plants that live in each type of land have been explained in the previous paragraph.

Diameter, height, and specific gravity data obtained from field observations were then analyzed using allometric equations to measure aboveground biomass. The allometric equation used for analysis is adjusted to the type of plant present. For common plant species such as fruits and mixed hardwoods, the general allometric equation uses the biomass expansion factor (BEF). Based on the data collected, the following research results were obtained as in Table 3.

The largest biomass stored in Suwangi Island Nature Park was in the primary forest land cover type at 104.598188 tons/ha and the smallest stored was in the medium density mangrove forest with a value of 0.301784084 tons/ha. This is because in the primary forest area, the diameter of the trees that grow in it is large and dense and in accordance with the definition of primary forest, this forest is untouched by humans so that it is still maintained its authenticity. Based on the result of previous biomass calculation, the carbon stock contained in Suwangi Island Nature Park can be seen in Table 4.

Data from Table 4 explained that the largest carbon value at the seedling, sapling and tree levels is stored in primary forests with values of 0.000404328 tons/ha, 7.004733179 tons/ha, and 42.15348734 tons/ha, respectively. Followed by carbon values in plantations with 0.000191535 tons/ha, 2.257592581 tons/ha, and 22.50847652 tons/ha, respectively. The lowest total carbon value that can be stored in Suwangi Island Nature Park is found in the mangrove forest land cover type. At the sapling level, the smallest carbon value was found in the high-density mangrove forest at

Table 3. Result of biomass calculation at each vegetation level in Suwangi Island Nature Park.

No	Land Cover Type	Biomass (Ton/Ha)			Biomass Total
		Seedling	Sapling	Tree	
1	Primary forest	0.000860273	14.90368762	89.68827093	104.5928188
2	Secondary forest	0.000132321	2.240742085	10.9328178	13.1736922
3	Plantation	0.00040752	4.803388471	47.89037558	52.69417157
4	Medium density mangrove forest	0.000726817	0.073705048	0.22735222	0.301784084
5	High density mangrove forest	0.002498749	0.030046329	0.389129364	0.419554751
	Total	**0.002498749**	**22.05156955**	**149.1279459**	**171.1820142**

0.014121774 tons/ha and at the tree level, the smallest carbon value was found in the medium-density mangrove forest at 0.14183852 tons/ha. While at the seedling level, the smallest carbon value is in the secondary forest land cover type with a value of 0.00006219 tons/ha. However, overall the smallest carbon value is in the medium density mangrove forest with a value of 0.14183852 tons/ha and the highest in the primary forest type with a total carbon of 49.15862484 tons/ha. This is because in these forest areas the level of vegetation density is not too high compared to other land cover types, and the size of the stem diameter growing in he forest has a smaller range than other land cover types. So based on field data, the total value of carbon stored in Suwangi Island Nature Park is 80.45554667 tons/ha with the highest carbon stock in primary forest and the lowest in moderate mangrove forest.

Carbon Economic Value of Suwangi Island Nature Park

The problem of climate change and greenhouse gas emissions that are increasing every year makes people and environmentalists strive to mitigate the reduction of greenhouse gas emissions. Knowledge of the economic value of carbon is expected to be a stimulus for the wider community to participate in climate change mitigation. This study will analyze the economic value of carbon stocks stored in the Suwangi Island Nature Park forest area. The results of the calculation of the economic value of carbon in Suwangi Island Nature Park can be seen in Table 5.

Table 4 shows the calculation of the economic value of carbon stored in Suwangi Island Nature Park. The carbon price used in trade in this study is US$10 per ton. The exchange rate was calculated for 1 year since this study was analyzed so that US$1 is worth IDR 15,879.93. The economic value of carbon is aligned with the total carbon that can be stored in the forest area. The greater the total carbon, the higher the economic value of carbon. Primary forest has the largest carbon storage per ton, which is 17.006.426264 tons, so it has the highest carbon economic value, which is IDR 2,700,608, 508.02. While the dense mangrove forest has the least carbon storage of 16.117820 tons so that the economic value of carbon produced by the dense mangrove forest is IDR 2,559,498.49. The total economic value of carbon stored in Suwangi Island Nature Park is IDR 2,851,347,872.68.

DISCUSSION

Estimation of Biomass in Suwangi Island Nature Park

Since the diameter of the wood can be determined, the vegetation level examined for carbon value in this study was from seedling to tree level. Table 3 shows the results of biomass calculations conducted at Suwangi Island Nature Park. Biomass is the result of the photosynthesis process carried out by plants or living things that have chlorophyll. In this photosynthesis process, carbon in the air is absorbed by plants and then processed into oxygen and energy. Energy in plants is stored in the form of carbohydrates which are distributed throughout the plant's body (Hairiah & Rahayu, 2007). Based on the results, the tree vegetation level has the highest biomass value of 149.1279459 tons/ha because the diameter and height of the vegetation are large, which means that there is more biomass contained in trees than at the seedling level. The results of this study are in accordance with the statement of Uthbah *et al.* (2017) that the more CO_2 absorbed and stored in the tree trunk causes the diameter of the tree to get bigger. Carbon absorbed and stored in the trunk will be of greater value if the diameter of the trunk is also large. The results of this biomass calculation can be used to calculate the carbon stored in the vegetation growing in Suwangi Island Nature Park and will be explained in the next section.

The results of this research in Suwangi Island Nature Park are greater when compared to research conducted at Sederhana Beach, Bekasi District,

Table 4. Carbon calculation results for each land cover type in Suwangi Island Nature Park.

No	Land Cover Type	Carbon (Ton/Ha)			Carbon Total
		Seedling	Sapling	Tree	
1	Primary forest	0.000404328	7.004733179	42.15348734	49.15862484
2	Secondary forest	0.00006219	1.05314878	5.138424364	6.191635335
3	Plantation	0.000191535	2.257592581	22.50847652	24.76626064
4	Medium density mangrove forest	0.000341604	0.034641372	0.106855543	0.14183852
5	High density mangrove forest	0.000174754	0.014121774	0.182890801	0.19718733
	Total	**0.001174412**	**10.36423769**	**70.09013457**	**80.45554667**

Table 5. Carbon economic value of Suwangi Island Nature Park.

No	Land Cover Types	Carbon (Ton)	Carbon Price per Ton (IDR)	Carbon Economic Value (IDR)
1	Primary forest	17.006.426264	IDR 158,799	IDR 2,700,608,508.02
2	Secondary forest	178.381014	IDR 158,799	IDR 28,326,779.34
3	Plantation	732.338327	IDR 158,799	IDR 116,294,810.33
4	Medium density mangrove forest	16.117820	IDR 158,799	IDR 2,559,498.49
5	High density mangrove forest	22.407382	IDR 158,799	IDR 3,558,276.51
	Total	**17.955.670808**		**IDR 2,851,347,872.68**

West Java (Erniasari *et al.*, 2024) whose highest biomass yield was only 79.18 mg/ha and also in the rehabilitated area of Sinjai, South Sulawesi (Malik *et al.*, 2020), with a biomass value of 125.48 tons/ha. Meanwhile, another study conducted in Benoa Bay, Bali (Mahasani *et al.*, 2021) had a higher biomass value than this study with an analyzed biomass value of 364.241 tons/ha. Similarly, research by Marianingsih *et al.,* (2023) conducted in Kehati Asri Park had a higher biomass value than the research in Suwangi Island Nature Park with a biomass value of 2.745 tons/ha. The difference in biomass yields in each study was caused by differences in the level of plants used, namely in Kehati Asri Park using growth rates from seedlings to trees. In addition, the difference is due to the difference in the size of the research area and also the type of vegetation that grows in the research location.

Calculation of Carbon in Suwangi Island Nature Park

Indonesia's commitment to reduce greenhouse gas emissions was made by issuing Presidential Decree No. 61/2011 on the National Action Plan for Greenhouse Gas Reduction. The way to reduce greenhouse gas emissions is by preserving forests, especially tropical forests in Indonesia. One way to preserve Indonesia's tropical forests is to know the carbon reserves that can be stored in each type of plant. Each plant has carbon stored mostly in the tree trunk. The amount of carbon stock absorbed and stored in the trunk can be calculated based on the amount of tree biomass (Uthbah *et al.*, 2017).

The biomass data obtained in Table 3 was used to calculate the carbon stock presented in Table 4. The carbon results in this study were much greater than the carbon results studied in the Proboscis Monkey Ecotourism Ecosystem of PT. Antang Gunung Meratus Conservation Area and carbon stored in Mangrove stands in Pagatan Besar. In research in the Proboscis Monkey Ecotourism Ecosystem, carbon was analyzed based on the type of forest density with a total carbon stored of 12.35 tons/ha (Rezekiah *et al.*, 2024a) while research on carbon stored in mangrove stands in Pagatan Besar produced a total carbon of 18.85 tons/ha (Rezekiah *et al.*, 2021). In other studies conducted in Kehati Asri Park, Benoa Bay-Bali, Guangdong Province-China (Liu *et al.*, 2014), and Sirik Azini Creek-Ormozgan-Iran (Askari *et al.*, 2022), the value of stored carbon in these studies was greater than the research in Suwangi Island Nature Park with stored carbon values of 1290.15 tons/ha, 171.193 tons/ha, 84.61 tons/ha, and 96 tons/ha, respectively. The value of stored carbon is strongly influenced by the value of biomass. The higher the biomass value, the higher the carbon value. Variations in carbon values can also be caused by the type, age, and environmental conditions of the ecosystem (Sugiana *et al.*, 2024), which mostly come from external factors such as climate and weather.

Carbon Economy Value of Suwangi Island Nature Park

The results of economic value research in other studies such as research by Rezekiah *et al.* (2024b) conducted at Indonesia’s Tropical Rainforest Park resulted in a carbon economic value of IDR 26,536,273.31 which is smaller than the results in this study. Research by Farista & Virgota (2021) in Bagek Kembar Mangrove Ecotourism Area had a smaller carbon economy value than the research in Suwangi Island Nature Park, which amounted to IDR 482,384,700 per year. However, in other studies the value of carbon economy in Wakatobi (Manan *et al.*, 2025) reached IDR 18,763,377,420 or USD 1,159,307 and carbon economy research in the U.S. National Wildlife Wetland Ecosystem (Patton *et al.*, 2015) the value based on US Value reached US $ 441,000 or at the current rupiah exchange rate (average US$ 1 in 2015 is IDR 13,397) amounting to IDR 5,908,150,500 while based on global value reached US $ 5,200,000 or IDR 69,665,266,667. The results of the study by Manan and Patton have a higher carbon economic value than the carbon economic value of the results of this study. Some of the reasons that cause variations in carbon prices are the different carbon prices used, such as in Rezekiah and Farista's research which uses carbon prices based on Indonesia's ecological value issued by the Minister of Environment of the Republic of Indonesia, and in research at the U.S. National Wildlife using US value and global value, each of which has a different price.

The results of this study show that the carbon economic value of Suwangi Island Nature Park is relatively significant, although still lower than several international studies. The variation is largely determined by the reference price of carbon—whether national ecological value, domestic market value, or global market value. Furthermore, vegetation with dense and hardwood species tends to store greater amounts of carbon, which leads ecosystems dominated by such species to have higher carbon economic values.

This research provides an important contribution as it integrates aboveground biomass measurement, carbon stock estimation, and conversion into carbon economic value in a comprehensive manner. Such an integrated approach is rarely applied, thereby offering a novel contribution to forest resource conservation based on ecosystem services. The measured carbon economic value is also expected to raise awareness, particularly among local communities, about the importance of forest conservation and the economic opportunities it provides.

Moreover, the findings of this study are highly relevant within three major global contexts. First, they contribute to Indonesia's Nationally Determined Contributions (NDCs), as the carbon stocks in Suwangi Island's mangrove ecosystems can strengthen national emission reduction targets under the Paris Agreement. Second, the results have direct implications for carbon trading mechanisms, both within the domestic registry system (Sistem Registri Nasional Pengendalian Perubahan Iklim/ SRN PPI) and in international carbon markets, thereby potentially supporting economic incentive schemes for sustainable forest management. Third, this study aligns with the framework of Nature-Based Solutions (NbS), as mangrove conservation not only functions as a carbon sink and storage system, but also delivers co-benefits such as coastal protection, biodiversity conservation, and enhanced resilience of coastal communities.

Thus, the findings of this study provide not only academic and scientific value but also serve as a basis for supporting national climate policy, fostering economic opportunities through carbon trade, and advancing the implementation of nature-based solutions that are now central to sustainable development agendas.

CONCLUSION

Suwangi Island Nature Park has five types of land cover: primary forest, secondary forest, plantation, medium mangrove forest and dense mangrove forest. Each of these land cover types can store different amounts of carbon. The biomass per hectare produced by Suwangi Island Nature Park is 171.1820142 tons. So that the carbon produced in this study is 80.45554667 tons/ha. The economic value of carbon stored in Suwangi Island Nature Park amounted to IDR 2,851,347,872.68.

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EXOTIC WILD PLANTS, CULTURAL ADAPTATION, AND LOCAL FOOD DIVERSITY IN MEKARSARI, A TEA ESTATE’S BUFFER-VILLAGE IN WEST JAVA, INDONESIA

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ABSTRACT

AULIA, S. A. Z., MULYANTO, D., ISKANDAR, B. S. & ISKANDAR, J. 2026. Exotic wild plants, cultural adaptation, and local food diversity in Mekarsari, a tea estate’s buffer-village in West Java, Indonesia. *Reinwardtia* 25(1): 13–29. — This research examines the ethnobotanical knowledge of exotic wild plants utilized as complementary food in Tegallega hamlet, a part of the buffer village adjacent to a historic tea estate in West Java, Indonesia. Through semi-structured interviews and field surveys with 22 local informants, 42 exotic wild plants from 22 families were recorded, primarily from Asteraceae and Solanaceae. Predominant species were herbaceous neophytes introduced during or after European colonization, illustrating the historical impact of the Columbian Exchange and plantation practices. Leaves were the most commonly used plant part, frequently consumed as *lalapan*, an essential ingredient of Sunda cuisine. The community emphasizes readily accessible resources that require the least effort, consistent with optimal foraging theory, whereas gender roles markedly affect foraging practices—women generally collect plants near villages, whereas men tend to explore farther into the forest. The incorporation of these exotic wild plants into local diets underscores cultural adaptation and the enhancement of local knowledge. Using exotic wild plants sparingly can enhance conservation of native and endemic species, lessen the negative effects of invasive species, and create opportunities for ecotourism growth. This study highlights the interaction of historical, ecological, and cultural factors that influence local plant utilization practices.

Key words: Complementary food, ethnobotany, exotic plants, Sundanese cuisine, tea plantation.

ABSTRAK

AULIA, S. A. Z., MULYANTO, D., ISKANDAR, B. S. & ISKANDAR, J. 2026. Tumbuhan liar eksotis, adaptasi budaya, dan keragaman pangan lokal di Mekarsari, desa penyangga perkebunan teh di Jawa Barat, Indonesia. *Reinwardtia* 25(1): 13–29. — Penelitian ini mengkaji pengetahuan etnobotani tumbuhan liar eksotik yang digunakan sebagai makanan pelengkap di Kampung Tegallega, bagian dari sebuah desa penyangga di sekitar perkebunan teh bersejarah di Jawa Barat, Indonesia. Melalui wawancara semi-terstruktur dan survei lapangan dengan 22 informan, tercatat 42 jenis tumbuhan liar eksotik dari 22 suku, mayoritas berasal dari suku Asteraceae dan Solanaceae. Sebagian besar jenis merupakan herba neofit yang diintroduksi selama atau setelah masa kolonial Eropa yang mencerminkan pengaruh sejarah dari Pertukaran Columbus serta praktik perkebunan. Daun merupakan bagian tumbuhan yang paling banyak dimanfaatkan, sering dikonsumsi sebagai lalapan, makanan penting dalam kuliner Sunda. Penduduk cenderung memanfaatkan sumber daya yang paling mudah diakses dengan upaya yang minimal, sejalan dengan teori *optimal foraging*. Selain itu, peran gender memengaruhi praktik ini, perempuan lebih sering mengumpulkan tumbuhan di sekitar permukiman, sedangkan laki-laki menjelajah ke area hutan. Penggunaan tumbuhan liar eksotik dalam pola konsumsi lokal menunjukkan adanya adaptasi budaya dan pengayaan pengetahuan lokal. Pemanfaatan tumbuhan liar eksotik dapat membantu mengurangi efek negatif jenis invasif, mendukung pelestarian jenis asli dan endemik, serta membuka peluang untuk pengembangan ekowisata. Studi ini menekankan pentingnya interaksi antara faktor sejarah, ekologi, dan budaya dalam membentuk praktik pemanfaatan tumbuhan oleh masyarakat lokal.

Kata kunci: Etnobotani, makanan pelengkap, masakan Sunda, perkebunan teh, tumbuhan eksotik.

INTRODUCTION

Some species of wild plants commonly harvested by local communities are actually non native to the area (Gras *et al.,* 2019; Łuczaj *et al.,* 2024; Lautenschläger *et al.,* 2018; Motti & Motti, 2017; Motti, 2022). This phenomenon can also be found in West Java, an area widely known as a rich source of exotic plant species in Indonesia. West Java is one of the most fertile regions in Indonesia due to its volcanic environment and abundant rainfall. It is also an essential area in Indonesia for studying the dynamic relationship between humans and plants within a biocultural context. Ethnobotany provides a useful framework for examining local knowledge, beliefs, and resource-management practices related to plants (Albuquerque *et al.,* 2017; Hurrell, 2016; Toledo, 2002). Numerous ethnobotanical studies have been conducted in the province, but most of them have focused on how wild plants contribute to income generation, nutrition, and food security for residents (Kulsum & Susandarini, 2023; Rahayu *et al.,* 2024; Sriwahjuningsih & Putri, 2022; Yanty *et al.,* 2024). Much of this work has focused on wild medicinal plants, with little focus on other categories, such as exotic wild plants (Aulia & Mulyanto, 2024; Rahayu *et al.,* 2024; Fatimah & Mulyanto, 2025). Furthermore, surveys conducted in West Java have also shown a gradual decline in the use of wild plants due to rarity and declining local knowledge, highlighting the need for further research (Pratama *et al.,* 2019; Rahayu *et al.,* 2024; Aulia & Mulyanto, 2024; Aulia *et al.,* 2025).

In 1909, the Dutch botanist Cornelis Andries Backer documented 153 plant species naturalized in Java, a number that had increased to around 300 by 1928. Backer also concluded that one of the naturalization centers for exotic plants on the island of Java is the plantations surrounding (see also Backer, 1928). This pattern shows the global tendency of plant homogenization since the Columbian Exchange, when plant species from other continents were extensively introduced and grown throughout the tropics, including Southeast Asia (Voeks, 2013). During this colonial period of Java’s history, concurrent with the introduction of new crops and plantation plants from the American continent, colonists also brought in other exotic plants with little or no food use, accidentally or deliberately (Kudo *et al.*, 2014; Padmanaba *et al.,* 2017; Pols, 2009; Rahmawati & Rosleine, 2023). At present, in areas near plantations, some of these plants have not only become naturalized but are also used by local people as complementary food. However, no single study presents a detailed list of these species, including their cultural contexts. The diversity and abundance of exotic wild plants have also not been systematically studied ethnobotanically for the plantation ecosystems of Java’s mountainous regions (Handayani & Hidayati, 2020; Handayani *et al.,* 2021), and exotic wild plants have not received enough scientific attention, although it has been documented that some of them are components of local subsistence (Junaedi *et al.,* 2021; Handayani *et al.,* 2021; Farikha *et al.,* 2024; Triyanto *et al.,* 2024).

From an evolutionary ethnobotany perspective, integration of exotic plants into local knowledge and practices helps fill the gaps left by native species, diversifies the botanical repertoire, and expands treatment options for diseases within local health systems (Gama *et al.,* 2018; Silva *et al.,* 2024). On the other hand, the use of exotic wild plants may divert harvesting pressure from native species, especially endemic ones, thereby contributing, albeit unintentionally, to their conservation and ecological sustainability. Therefore, the aim of this ethnobotanical study is to document local knowledge of exotic wild plants and their use as complementary food by residents of one of the oldest tea plantations in West Java (Gambung). This study also investigates how the integration of exotic wild plants impacts food security, consumption patterns, and ecological sustainability.

MATERIALS AND METHODS

Study Site

This field study was conducted in Tegallega hamlet, Mekarsari Village, Pasirjambu District, Bandung Regency, West Java, Indonesia (7° 13'36.9"S; 107°51'84.1"E) (Fig. 1). The village and its farmland are located between two historical landscapes: Gambung Tea Estate and Mount Tilu Nature Reserve. The 600-hectare tea plantation in the north is one of the oldest in West Java. It was established in 1874 by a Dutch planter, Rudolph Eduard Kerkhoven, and is still run by a state-

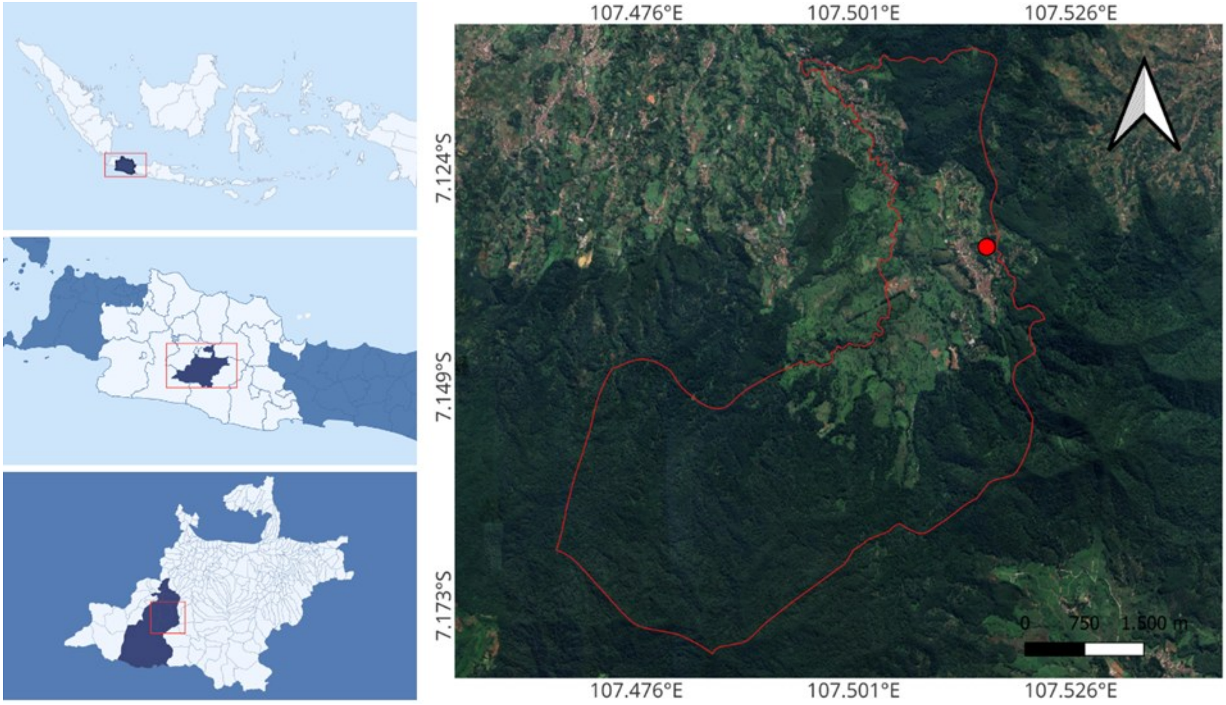

Fig. 1. Study site in Mekarsari Village, Pasirjambu District, Bandung Regency, West Java, Indonesia.

owned enterprise. Due to similar geographical and climatic conditions, this is one of the places in Java where tea and cinchona plants were commonly found. The Mount Tilu Nature Reserve currently covers an area of 8,000 hectares and is the largest nature reserve that located in Bandung Regency.

The village has a cool climate, with annual temperatures ranging from 16°C to 25°C, rarely dropping 14°C below or exceeding 27°C. It is located at an altitude of 1,000-1,800 meters. The average annual rainfall is about 2,068 mm, and the region has a distinct rainy season lasting for seven months from October to May. These factors create favorable conditions for a variety of environmental and agricultural ventures. The growth of tea plantations during the colonial period established the village's historical status as a buffer village, and its cool climate encouraged locals to produce temperate vegetables such as lettuce, leeks, cauliflower, carrots, cabbage, potatoes, and tomatoes for the European and Chinese settlers. These products are still grown today and supply the urban markets in Bandung, the capital of West Java province, 40-50 km to the north. Since 2015, some farmers have also been cultivating coffee on the northern foothills of Mount Tilu.

With a population density of 310 people/km^2, most inhabitants are small farmers who own less than 1 hectare of land. Fewer than 5% of those farmers own land; the rest belong to the rural working class and make a living from farming, tea growing, or both. Thanks to its colonial history and beautiful location on the tea plantations, the village has, in recent years, been working to diversify its economy through tourism.

Data Collection

In the study area, knowledge of wild plants as dietary supplements is considered to be a specific cultural domain. In the pilot study, respondents frequently pointed out others they considered more suitable and deserving to be interviewed because they recognized as having this knowledge. Using the snowball technique, 22 study participants (13 men and 9 women) were interviewed. The informants were aged between 39 and 79 years and worked as tea plantation workers, smallholder farmers, and agricultural labourers. The interviews were conducted in various locations, including households, tea plantations, coffee agroforests, and farms, with participants' consent. To facilitate communication and ensure accuracy of information, all interviews were conducted and recorded in Sundanese, the native language spoken in Western Java.

Data on exotic wild plants used as supplementary foods were collected through open descriptions (free-listing and free-walking) and semi-structured interviews and included informants' knowledge of plant vernacular names, plant's morphological characteristics, habitat distribution, harvesting time, methods and tools, as well as use categories.

Plant samples were collected and recorded with local names provided by informants to confirm scientific nomenclature. Specimens were verified in the field using the *Flora of Java* (Backer & Bakhuizen den Brink Jr, 1968) and the *Mountain Flora of Java* (van Steenis, 1972). Some were identified by plant taxonomists and stored in the Herbarium Jatinangoriense (UNPAD), administered by the Department of Biology, Padjadjaran University, located in Sumedang, West Java. This procedure ensured the validity of the plant identification data. Scientific names were additionally cross-checked using Plants of the World Online (POWO, 2024).

Data Analysis

After the interviews, all collected information, including plant name, plant classification, life form, biogeographical distribution, habitat type, harvest time, collection method and tools, parts used, use categories, and number of citations, was tabulated and organized using Microsoft Excel 2016. The organized data were presented in grid charts, tables, and Venn diagrams. The following formula was also used to calculate the data based on the relative frequency of citation (RFC) index (Tardío & Pardo-de-Santayana, 2008):

$$RFC = \frac{FC}{N}$$

Where FC is the number of informants mentioning a species, and N is the total number of informants. The RFC value ranges from 0 to 1, with 1 indicating that the species was mentioned by all informants.

To determine the species similarity among various site categories (in the village, around the village, and forest), Sørensen's similarity coefficient was used. The evaluation results ranged between 0 and 1, and the formula was expressed as follows (Araújo & Ferraz, 2014):

$$SSC = \frac{2a}{a+b+c}$$

Where:
SSC = Sørensen's Similarity Coefficient
a = Number of species with simultaneous occurrence in site 1 and site 2
b = Number of species that occur only in site 1
c = Number of species that occur only in site 2

Qualitative data, including the methods used, the uses of exotic wild plants, the sources of knowledge about exotic wild plants, and the stories informants told, were qualitatively analyzed to construct a narrative. This process involved cross-checking, summarizing, and synthesizing.

RESULTS

Botanical Characteristics

The result of this study indicates that 42 exotic species were collected, harvested, and consumed by local people. These plants belong to 34 genera from 22 families (Table 1). The Asteraceae has the highest number of species represented with seven species (16%) of the total (Fig. 2) followed by Solanaceae with five species (12%), Euphorbiaceae, Fabaceae, and Oxalidaceae, each with three species.

As shown in Fig. 3, 34 species (81%) of the exotic wild plant species are herbaceous, with perennial herbs forming the largest group (22 species; 52%), followed by annual herbs (12 species; 29%).

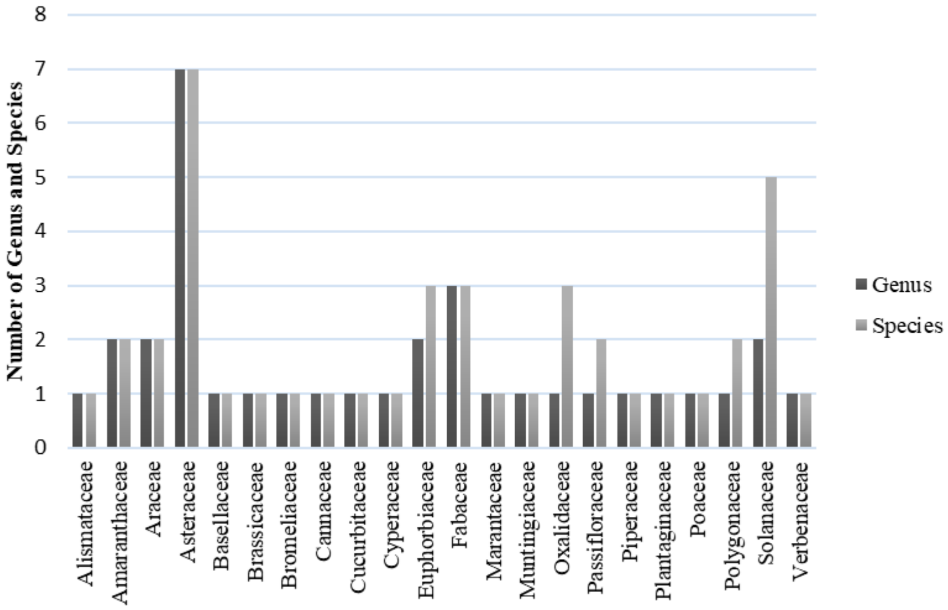

Fig. 2. Distribution of genera and species in plant families.

Table 1. List of exotic wild plants used as complementary food in the study site.

Scientific name	Life form	Part used	Native range (simplified)	RFC
Acmella oleracea (L.) R.K.Jansen, Asteraceae	Perennial herb	Leaves	Nt	0.68
Alternanthera philoxeroides (Mart.) Griseb., Amaranthaceae	Perennial herb	Leaves	Nt	0.18
Amaranthus blitum L., Amaranthaceae	Annual herb	Leaves	Nt, Cp	0.95
Ananas comosus (L.) Merr., Bromeliaceae	Perennial herb	Fruits	Nt	0.72
Anredera cordifolia (Ten.) Steenis, Basellaceae	Perennial herb	Leaves	Nt	0.54
Bambusa vulgaris Schrad. ex J.C.Wendl., Poaceae	Bamboo	Shoots	Im	0.86
Bidens pilosa L., Asteraceae	Annual herb	Leaves	Nt, Cp	0.82
Canna indica L., Cannaceae	Perennial herb	Tubers	Nt, Ha	0.77
Crassocephalum crepidioides (Benth.) S.Moore, Asteraceae	Annual herb	Leaves	Af	1
Cyclanthera brachystachya (DC.) Cogn., Cucurbitaceae	Annual herb	Fruits	Nt	1
Erigeron sumatrensis Retz., Asteraceae	Annual herb	Leaves	Nt	0.68
Euphorbia heterophylla L., Euphorbiaceae	Annual herb	Leaves	Nt	0.36
Euphorbia thymifolia L., Euphorbiaceae	Annual herb	Leaves, stems	Nt, Ha	0.68
Galinsoga parviflora Cav., Asteraceae	Annual herb	Leaves	Nt, Cp, Ha	0.27
Lantana camara L., Verbenaceae	Shrub	Fruits	Nt	0.22
Leucaena leucocephala (Lam.) de Wit, Fabaceae	Tree	Seeds	Nt	1
Limnocharis flava (L.) Buchenau, Alismataceae	Perennial herb	Aerial parts	Nt	1
Maranta arundinacea L., Marantaceae	Perennial herb	Tubers	Nt	0.73
Mimosa pigra L., Fabaceae	Shrub	Roots	Nt, Ha	0.13
Muntingia calabura L., Muntingiaceae	Tree	Fruits	Nt	0.86
Nasturtium officinale W.T.Aiton, Brassicaceae	Perennial herb	Aerial parts	Ha, Sa, Af, Im	1
Oxalis barrelieri L., Oxalidaceae	Perennial herb	Aerial parts	Nt	0.13
Oxalis corniculata L., Oxalidaceae	Perennial herb	Fruits	Ha, Im	0.13
Oxalis triangularis A.St.-Hil., Oxalidaceae	Perennial herb	Tubers, stems	Nt	0.68
Passiflora edulis Sims, Passifloraceae	Perennial herb	Fruits	Nt	1
Passiflora ligularis Juss., Passifloraceae	Shrub	Fruits	Nt	1
Peperomia pellucida (L.) Kunth, Piperaceae	Annual herb	Leaves	Nt, Ha, Af	0.18
Physalis angulata L., Solanaceae	Annual herb	All parts	Nt, Ha	1
Physalis peruviana L., Solanaceae	Perennial herb	All parts	Nt	1
Plantago major L., Plantaginaceae	Perennial herb	All parts	Ha, Sa	0.86
Ricinus communis L., Euphorbiaceae	Shrub	Fruits	Af	0.23
Rhynchospora colorata (L.) H.Pfeiff., Cyperaceae	Perennial herb	Rhizomes	Nt, Ha	0.09
Rumex rugosus Campd., Polygonaceae	Perennial herb	Leaves	Ha	0.77
Rumex patientia L., Polygonaceae	Perennial herb	Leaves	Ha, Sa, Im	0.5
Schismatoglottis calyptrata (Roxb.) Zoll. & Moritzi, Araceae	Perennial herb	Aerial parts	Im	0.68
Senna occidentalis (L.) Link, Fabaceae	Perennial herb	Seeds	Nt	0.5
Solanum americanum Mill., Solanaceae	Annual herb	Fruits, leaves	Nt, Ha	0.86
Solanum nigrum L., Solanaceae	Perennial herb	Fruits, leaves	Ha, Sa, Af, Im	0.91
Solanum torvum Sw., Solanaceae	Perennial herb	Fruits	Nt	1
Taraxacum officinale F.H.Wigg., Asteraceae	Perennial herb	Leaves	Ha, Sa	0.91
Tithonia diversifolia (Hemsl.) A.Gray, Asteraceae	Shrub	Leaves	Nt	0.09
Xanthosoma sagittifolium (L.) Schott, Araceae	Annual herb	Tubers	Nt	0.54

Note: Af=African realm, Im=Indo-Malesian realm (exclude Java), Cp=Chile-Patagonian realm, Nt=Neotropical realm, Ha=Holarctic realm, Sa=Saharo-Arabian realm.

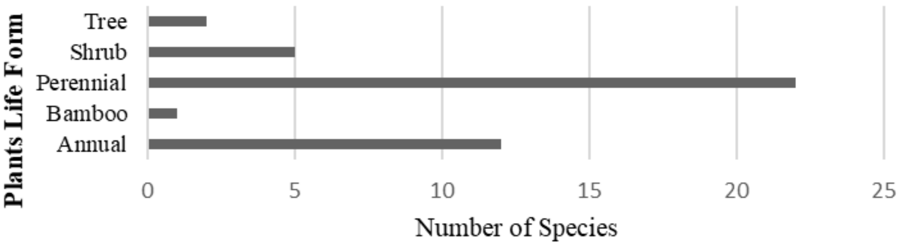

Fig. 3. The distribution of plant life forms.

A smaller number of shrubs (five species), trees (two species), and bamboo (one species) are also included.

Floral Biogeographic Distribution

This study found that more than half of the total, 22 wild plant species (52.38%) are exclusively native to the Neotropical realm, alongside 6 species that are also native to the Holarctic realm, and some species that are shared with the Chile-Patagonian realm (Fig. 4). Only one species was exclusively native to the Holarctic realm, whilst others were also native to the Indo-Malesian, African, and Saharo-Arabian realms. One species was native to the Holarctic and Saharo-Arabian regions, as well as to the Holarctic and Indo-Malesian regions.

Distribution of Habitat

Our findings show that exotic wild plants used as complementary food have been collected from several collection sites. These locations are divided into three main categories by their distance from the village: in the village, around the village, and in the forest. The first category consists of home gardens, roadsides, and artificial pools; the second category mainly consists of farmlands, uncultivated lands, tea plantation gardens, natural pools, and waterways; and the third category includes forest and coffee agroforests. Some plants may inhabit more than one site category (Fig. 5).

One exotic species, garden sorrel (*Rumex rugosus*), was found exclusively in the village, specifically in the home garden, whereas five species (12%), including cuchinito (*Cyclanthera brachystachya*) were found at tea plantation gardens around the village. Passion fruit (*Passiflora edulis*) was one of two species identified solely in the forest. Sixteen species (38%), including Mexican sunflower (*Tithonia diversifolia*), were found in both the village and around the village, while three species, such as Madeira-vine (*Anredera cordifolia*), were identified in both the village and the forest. In this study, tall fleabane (*Erigeron sumatrensis*) and giant sensitive tree (*Mimosa pigra*), which are usually considered weeds in home gardens, farmland, and coffee agroforests, are among the ten exotic species (24%) that were found across the three categories.

Based on Sørensen's similarity coefficient, inner villages and the surrounding area have the highest similarity (0.79). In contrast, the lesser similarities occur between the area around the village and the forest (0.54), and further between the village and

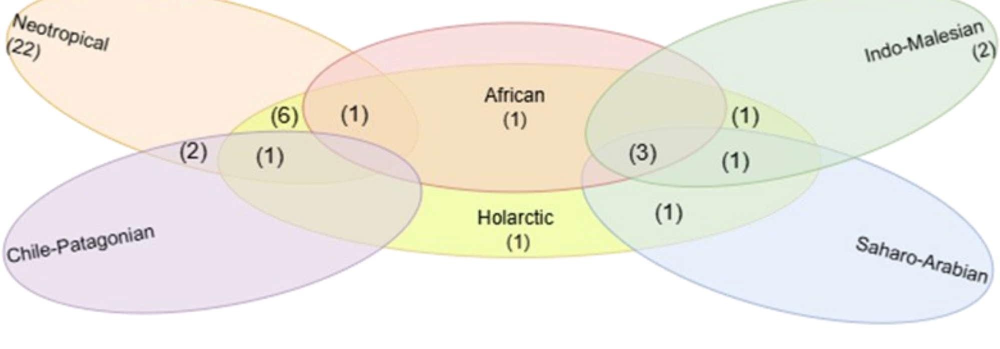

Fig. 4. Native realms of wild exotic plants.

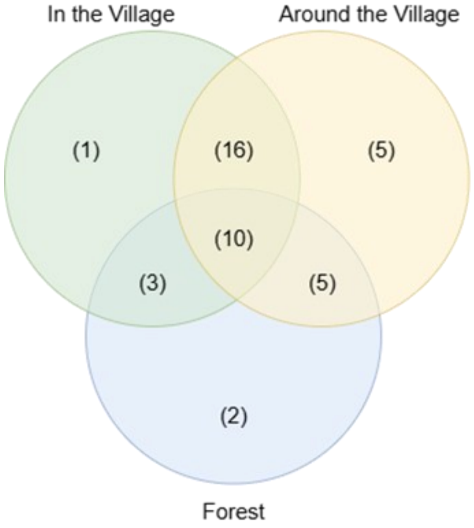

Fig. 5. Distribution of foraging sites.

the forest (0.52). This indicates that although certain exotic species may spread, their growth is constrained by ecological differences and a lack of human influence. The forest's conditions and the greater effort required for foraging make it a less favorable area for plant collecting, further decreasing similarity in plant composition.

Foraging Seasons and Methods

All-season plants, which can be foraged year-round, dominate the resource with 25 species (64%). The all-season category is largely filled by plants that produce leaves and aerial parts to consume, reflecting their steady availability, such as creeping wood sorrel (*Oxalis corniculata*). During the dry season, the number of harvested species decreases to 12 species (29%). Because above-ground sections are less accessible or nutrient-dense during this period, the emphasis switches to underground components, such as tubers of tania (*Xanthosoma sagittifolium*). Seeds and mature fruits are also collected as they are often ready during the dry season after the wet-season growth. During the dry season, locals typically gather wild fruit plants while searching for firewood.

The variety further reduces to only five species (12%) in the wet season. Tender parts like leaves, shoots, and some fruits grow faster during the wet season and are primarily collected at this time. For example, beggarsticks (*Bidens pilosa*) leaves are more frequently collected during the wet season since the plant grows abundantly, the leaves are softer, bigger, greener, and it is easier to pick them without the disturbance of sharp and dry seeds as in the dry season.

Depending on the plant's condition, locals either used a single method or combined several methods to collect exotic wild plants. Overall, 36 species (86%) included in this study are commonly collected by handpicking (Fig. 6). The handpicked method is mostly used for herbaceous plants, such as toothache plant (*Acmella oleracea*). Handpicked methods are sometimes combined with other tools, such as a machete, to collect lead tree (*Leucaena leucocephala*), making it easier to collect its fruit by hacking down its branches. Hand-picking, along with the use of poles, is used to collect the sweet fruits of the Jamaica cherry (*Muntingia calabura*), which usually grows along roadsides. The fruit frequently develops on tall branches. To simplify picking the fruits from the ground, a pole is used to shake or knock them down. Combining handpicking with tools is a useful strategy to get around challenges like plant height and improve efficiency.

The remaining six species can be collected in various ways. Four plants were gathered by digging and using machetes. These are usually plants with underground or near-ground parts and hard parts, such as the tubers of Indian shot (*Canna indica*). Two plants are collected solely with a machete. A machete is usually used to collect plants with hard, spiny parts, such as *Ananas comosus*.

Utilizations

Of these, leaves were the most used part (Fig. 7), with 14 species (33%), including *Rumex patientia* that usually eaten raw. With nine species (21%), including tickberry (*Lantana camara*), fruits were the second most widely eaten part. Furthermore, 8% of species used both aerial parts and all parts; Turkey berry (*Solanum torvum*) is an exam-

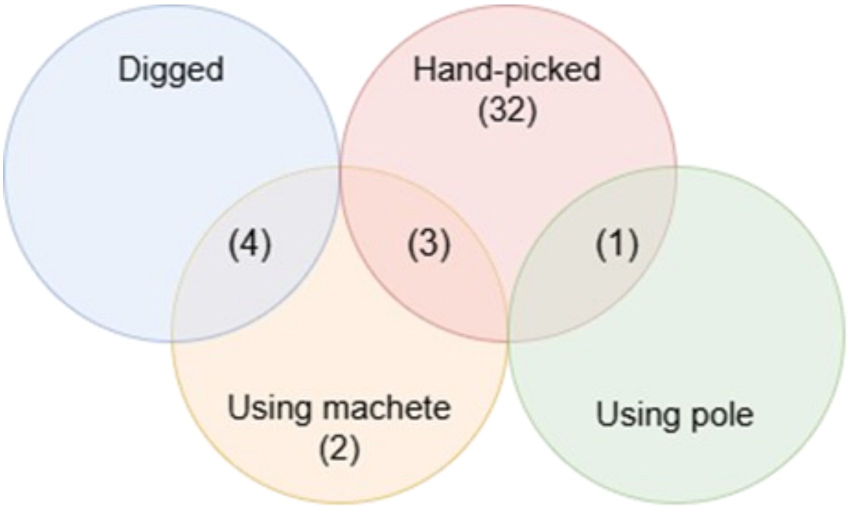

Fig. 6. Distribution of plants collecting methods.

ple of the latter, with fruits consumed as vegetables, or the root and stem decocted into a beverage. Some plants, like false shamrock (*Oxalis triangularis*), which combines tubers and stems usage, and *Solanum nigrum,* which is used for both its fruits and leaves, showed multi-part usage. Other plant parts are less commonly used, such as coffee senna (*Senna occidentalis*) seeds for making beverages.

Among the various food categories considered, 81% of the total species were restricted to a single category (Fig. 8). Vegetables were the largest group (20 species), followed by beverages (six species), desserts (five species), and snacks (three species). Additionally, there were two combination categories: vegetable and beverages (six species) and dessert and beverage (two species). Vegetables can be eaten raw, cooked, or both. For example, Guernsey pigweed (*Amaranthus blitum*) leaves are usually cooked, either boiled or stir-fried.

Sweet granadilla (*Passiflora ligularis*) fruits are eaten raw and are categorized as a dessert. In the beverage category, decoction is a primary method, such as a decoction of the root of whitetop sedge (*Rhynchospora colorata*), which was used for medicine. In Tegallega, snacks are eaten at night or early afternoon. Snacks are usually made from boiled tubers, for example, arrowroot (*Maranta arundinacea*). The leaves and stems of Gulf sandmat (*Euphorbia thymifolia*) were utilized in both the vegetable and beverage categories. Cooked *Euphorbia thymifolia* is utilized as food, and its decoction is used as medicine. Meanwhile, cutleaf groundcherry (*Physalis angulata*) can be used for dessert and beverages. Its root, stem, and leaves are occasionally used to make a beverage that has been used as medicine, and its fruit can be eaten raw.

Eleven different categories were created from the study's classification of the taste of wild exotic plants (Fig. 9). With eight species each, the most prevalent tastes among these were mild and bland (19%), slightly bitter (19%), and slightly sweet (19%). For example, *Anredera cordifolia* leaves are

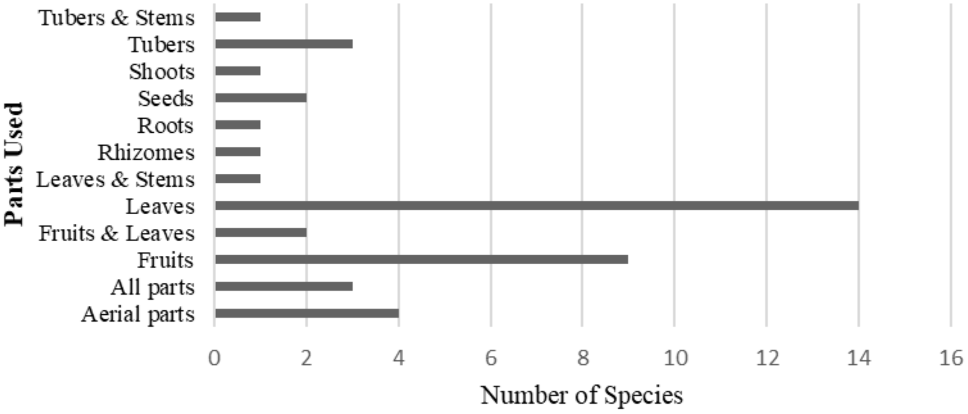

Fig. 7. Plant parts used across species.

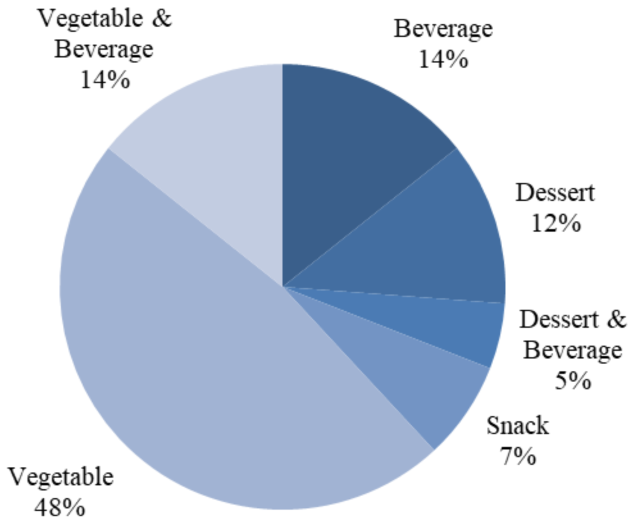

Fig. 8. Percentage of food types distribution.

classified as mild and bland, fireweed (*Crassocephalum crepidioides*) leaves are slightly bitter, and the fruits of American black nightshade (*Solanum americanum*) are slightly sweet (Figure 10).

Other important taste categories are slightly sour (17%), including woodsorrel (*Oxalis barrelieri*), whose aerial parts are eaten. Meanwhile, sweet and slightly sour categories include only three species (7%), including goldenberry (*Physalis peruviana*). Less common tastes were represented by individual species, such as slightly sweet and spicy, found in the young leaves of wild poinsettia (*Euphorbia heterophylla*). Bitter tastes are defined, for example, by the taste of broadleaf plantain (*Plantago major*), which can be both a vegetable and a beverage.

DISCUSSION

Species Composition and Life Forms

Asteraceae was the richest family recorded in this study. This family is known for its adaptability to a wide range of ecological conditions, including disturbed ecosystems (Roeble *et al.,* 2024). Many Asteraceae species are also widely used as food and medicine in many places (Petropoulos *et al.*, 2019; Rolnik & Olas, 2021). Solanaceae was the second most represented family, showing its culinary value due to its edible fruit (Samuels, 2015). In addition, the Solanaceae plants are rich in alkaloids, which have been traditionally used in various systems of medicine, especially as anti-inflammatory, antifungal, and antibacterial agents (Afroz *et al.,* 2020; Naseem *et al.*, 2023).

Beyond their nutritional and medicinal value, the prominence of Solanaceae in this study shows a broader pattern that is seen throughout Java, where this family consistently ranks among the most dominant in edible plant diversity and market systems (Iskandar *et al.*, 2021; 2023a; 2024; Nurshillah *et al.*, 2022; Fitriah & Mulyanto, 2025). This trend indicates that numerous Solanaceae species, including extensively cultivated exotic taxa, such as various chilies and potatoes, have been incorporated into local food systems. Their dominance may also be linked to practical factors, including ease of cultivation, short growth cycles, and high adaptability to anthropogenic landscapes.

Perennial herbs predominate among the documented species. Their persistence allows repeated harvesting possible and their well-developed root systems enable them to thrive in a wide range of environmental conditions. This year-round availability of resource may represent an adaptive strategy to ensure the stability of local food supplies (Medeiros *et al.*, 2021; Albuquerque *et al.*, 2015)**.** The predominance of perennials also reflects their function as complementary food resources, especially in disturbed and anthropogenic ecosystems where many exotic species are established. While some of these plants may have been introduced for various purposes, their persistence in the landscape has enabled them to be included in local food practices as complementary foods. Annual herbs were also commonly observed. These types of herbs tend to be invasive plants with larger seeds and fine roots to optimize resource acquisition (Funk *et al.*, 2016; Poppenwimer *et al.*, 2023). Most herbs also have a short life span and a short life cycle, which allows them to accumulate highly bioactive chemicals and be highly useful for human needs (Albuquerque *et al.*, 2015).

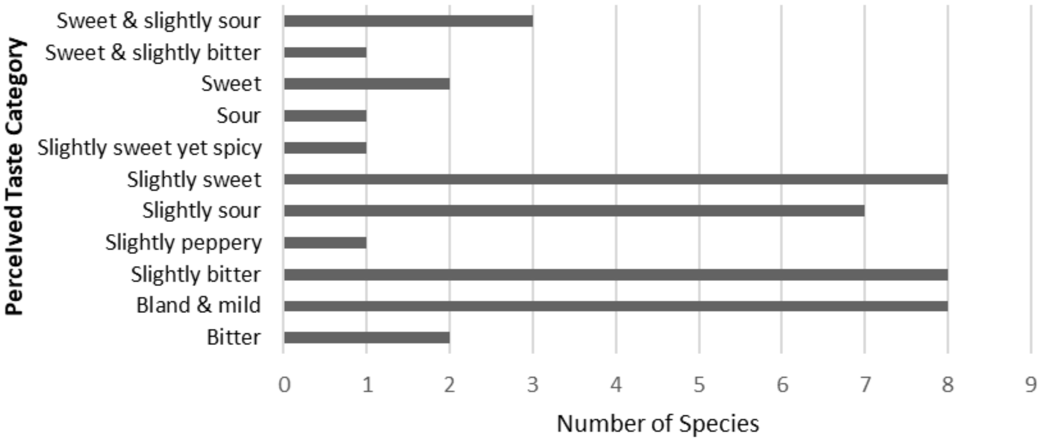

Fig. 9. Distribution of plant species by taste characteristics

Biogeographic Distribution and the Introduction of Exotic Plants

A large proportion of the documented species in this study originated from the Neotropical realm, indicating the strong historical impact of plant introductions from the American continent, ranging from southern Mexico and the Caribbean islands in the north to southeastern Brazil and the Andes in the south. These American species are likely neophytes, introduced after the Columbian Exchange as part of the global dissemination of crops and beneficial species during and following European colonial expansion (Preston *et al.*, 2004).

Other species may be archaeophytes introduced prior to European contact, potentially brought to Java during earlier cultural exchanges, such as Indianization and Austronesian migration, or through ancient trade networks, such as the Maritime Silk Road. For example, dandelion (*Taraxacum officinale*), a Eurasian species, is recognized for its pre-colonial presence in Java (Mulyanto *et al.*, 2024). Similarly, it is said that the Portuguese brought watercress (*Nasturtium officinale*) in the 16th century, a significant species native to several realms (Holarctic, Saharo-Arabian, African, Indo-Malesia) (van Steenis, 1972). This plant is known as *saladah* in Sundanese, perhaps from the Portuguese word *salada*. Another example is the castor bean (*Ricinus communis*), a species native to Africa and considered a notable archaeophyte, and most likely arrived in Java through ancient maritime trade routes (Xu *et al.*, 2021).

Of these finds, over 76% of the species in this study can be categorized as neophytes introduced after 1492, either intentionally (*e.g.,* useful, medicinal, forestry, or ornamental plants) or unintentionally as a result of human activity (*e.g.,* seeds in bird food). Most of these were Neotropic, Madrean, or Mediterranean plant species (Pols, 2009; Preston *et al.,* 2004). The high frequency of neophytes in the study area is probably related to the Columbian Exchange, as it is a buffer village of the oldest tea plantation in Java (Nunn & Qian, 2010). During the colonial period, the Dutch East Indies government established botanical gardens and introduced important crops, and colonists brought exotic plants to Java (Kudo *et al.*, 2014; Rahmawati & Rosleine, 2023).

A smaller proportion consists of archaeophytes or exotic plants with a longer history. Native to Holarctic, Indian, Indochinese, or African regions that were probably introduced before European colonization, during the Indianization and ancient Maritime Silk Road period, or even further back during the Austronesian migration (Aritonang *et al.,* 2024; Mulyanto *et al.,* 2023; Mulyanto *et al.,* 2024; Sujarwo *et al.,* 2016). Some archaeophytes are likely part of the local botanical knowledge in pre-colonial times, as evidenced by references to them in ancient literature (Mulyanto *et al.,* 2024).

Landscape Distribution and Foraging Behavior

Human activities, such as agriculture, tea plantations, and roadsides, affect the distribution of wild plants in anthropogenic landscapes. These environments often facilitate the spread of exotic species, many of which behave as invasive plant species that can disrupt native species and ecosystem functioning (González *et al.,* 2024). The availability of such environments also affects foraging behavior. Optimal foraging theory posits that foragers tend to prioritize resources that offer the greatest benefit relative to the effort required to collect them (Albuquerque *et al.,* 2015; Júnior *et al.,* 2015; Soldati *et al.,* 2017; Medeiros *et al.,* 2021). As a result, wild plants grow near settlements, farms, and plantation edges, and are harvested more often due to the reduced time and

Fig. 10. Bland to slightly flavoured plants (example only) A. *Maranta arundinacea*, B. *Crassocephalum crepidioides,* C. *Solanum americanum*, D. *Oxalis barrelieri*, E. *Physalis angulata*, F. *Euphorbia heterophylla.*

effort required for collection. Therefore, this pattern also corresponds with the concept of convenience, a pragmatic factor that includes not only proximity but also the simplicity of collecting, processing, and integrating plants into everyday meals (Nobayashi, 2022). Despite environmental changes, such as the conversion of forests to coffee agroforestry, women continue to forage near their settlements. This preference indicates that practical factors include protection from wild animals, time constraints owing to domestic obligations, and the accessibility of plant resources in convenient areas.

Social Background and Gender Roles in Wild Plants Knowledge

Informants' interaction with wild plants is shaped by their social background. The majority of this study's informants were tea plantation workers, while many elderly informants were retired plantation workers who now work on coffee plantations and farms and raise livestock. These livelihood activities maintain continuous interaction with surrounding environments such as plantations, agricultural land, and forest margins, creating opportunities to encounter and learn about wild plants.

Knowledge of wild plants is primarily transmitted within families, particularly from mothers. Many informants reported that they had accompanied their mothers to work on a plantation or farm, where they saw wild plants gathered for the midday meal. Informants sometimes see their colleagues gather edible wild plants they encounter on their way home and bring them home to prepare and feed to their family. These patterns show both vertical knowledge transmission within families and horizontal learning through interaction with neighbors and coworkers (Alqethami *et al.,* 2017; Mantuan & Sannomiya, 2024).

Livelihood practice also influences the distribution of botanical knowledge. Coffee plantations in the region are typically managed using agroforestry systems, allowing workers to interact with a semi-forested ecosystem rich in wild species. While both genders engage in these activities, their roles are distinct. Men are more inclined to venture into deeper forest regions for activities such as gathering firewood and maintaining water pipes, which may increase their knowledge of forest species. Women frequently gather wild plants near tea plantations, farms, or residences and typically have extensive knowledge of edible species and their preparation techniques. This dynamic illustrates a broader trend, women generally exhibit wider knowledge of species used especially for home care (*e.g.*, edible, medicinal, ornamental), whilst men are more knowledgeable about plants utilized for timber and fiber (Rangel-Landa *et al.,* 2017; Acosta-Naranjo *et al.,* 2021; Costa *et al.,* 2021; Novriyanti *et al.,* 2021; Tng *et al.,* 2021; Shrestha *et al.,* 2024).

Gender roles also affect how tools are used. In Sundanese agricultural society, the traditional machete (*bedog*) is typically linked to men and symbolizes masculinity (Primaditya, 2008). Men often use such tools for labor-intensive tasks, such as weeding. Conversely, in occupations requiring accuracy and manual dexterity, women are often seen as having an advantage, such as on tea plantations, where they are often assigned as pickers. Meanwhile, in collecting wild plants, women use their ability to collect leaves and soft fruits, which require careful picking to avoid damaging the harvest. Women are less likely to utilize tools when collecting wild plants because these activities are usually carried out in easily accessible locations close to their houses (da Costa *et al.,* 2021; Acosta-Naranjo *et al.,* 2021; Mulyoutami *et al.,* 2015). Women are often responsible for more household duties, such as managing home gardens and nearby land. These locations are typically rich in exotic plants (Tng *et al.,* 2021), most of which are herbs and are usually collected by women without specialized tools (Fatimah & Mulyanto, 2025).

Alongside familial transmission, self-experience is also a source of knowledge. Foragers who raise cattle travel daily to farmlands, forest edges, and the uncultivated areas to search for fodder. They usually know a species is edible when their cattle would eat it.

Lalapan and Sundanese Culinary Identity

Sundanese cuisine emphasizes vegetables, with *lalapan* serving as an important component. *Lalapan* refers to fresh or blanched leafy greens, sourced from both cultivated and wild plants (Hernawati *et al.,* 2022; Septiani *et al.,* 2020; Suwartapradja *et al.,* 2023; Iskandar *et al.,* 2018; Iskandar, 2018). It is commonly paired with *sambal* (Soemarwoto & Iskandar, 2021), a chili-based sauce made with a mixture of chilies, garlic, shallots, sugar, and salt. With its many variations, including *sambal terasi* and *sambal héjo*, *sambal* not only enhances *lalapan* but also strengthens the Sundanese culinary identity. The high demand for *lalapan* highlights its significance in Sundanese households (Iskandar *et al.,* 2023b; Iskandar *et al.,* 2024; Iskandar *et al.,* 2018), as it is typically consumed with rice and side dishes at every mealtime (Amrinanto *et al.,* 2019; Septiani *et al.,* 2020). Readily available in both semi-modern and traditional markets, *lalapan* is also a staple offering in food stalls and Sundanese restaurants, further cementing its role in daily cuisine (Amalia & Marta, 2018; Kodir & Moektiwardoyo, 2022; Mulyanto *et al.,* 2018; Fitriah & Mulyanto, 2025).

As seen in Fig. 9, there is no clear preference for a dominant taste. However, in Sundanese culture, bitterness appears to be particularly significant. Many vegetables, both wild and cultivated, are known for their bitter taste, including bitter gourd, stinky bean, dogfruit, and papaya leaves. These bitter cuisines are often considered “adult foods” and are typically eaten by adults and the elderly (Hernawati *et al.,* 2022). This taste preference for bitter food is influenced by societal and cultural variables in addition to personal preference. For instance, Eurasian black nightshade (*Solanum nigrum*), which has a slightly bitter taste, is often introduced to children during family meals, where they observe and gradually come to enjoy it by imitating older family members (Mulyanto *et al.,* 2018). However, in many studies, children are more sensitive to bitterness than adults, which contributes to their early reluctance to consume bitter vegetables. The underlying genetic and environmental factors, such as an innate evolutionary preference for sweet foods, heritable genotype markers, bitter-taste endophenotypes, and parental feeding practices, food availability, accessibility, and exposure, may be the cause of their preference for discretionary foods (Mennella & Bobowski, 2015; Yang *et al.,* 2024).

CONCLUSION

The introduction of exotic plant species has become an inevitable phenomenon in the context of globalization. This study describes local knowledge of exotic wild plants used as complementary food in a buffer area of a historic West Java tea estate. Forty-two edible exotic species were found, mainly herbaceous species. Most of these species are neophytes, introduced during or after European colonization. The occurrence of many naturalized plant species in the study area is likely attributable to historical plantation activities, part of the Columbian Exchange, which introduced these species to Java, either deliberately or accidentally. These plants are primarily located around the hamlet, with leaves being the most frequently utilized part, particularly for *lalapan*, an essential element of Sundanese culinary culture. The community prioritizes readily available resources that require the least effort, consistent with optimal foraging theory. Gender roles also have a significant effect, where women typically gather plants in villages, whilst men tend to go farther into the forest. The selective use of edible yet invasive exotic species can reduce their adverse effects and support the conservation of native and endemic plant species. Moreover, these practices may be incorporated into ecotourism initiatives such as wild edible plant walking tours and culinary experiences. The integration of exotic wild plants into local practices indicates processes of cultural continuity, ecological resilience, and socioeconomic opportunities.

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TREE SPECIES COMPOSITION OF THE LOWLAND FOREST IN BUKIT BAKA BUKIT RAYA NATIONAL PARK, EAST KALIMANTAN, INDONESIA

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ABSTRACT

SUSANTI, R., GIRMANSYAH, D., PRATAMA, B. A. & JAKALELANA, S. 2026. Tree species composition of the lowland forest in Bukit Baka Bukit Raya National Park, East Kalimantan, Indonesia. *Reinwardtia* 25(1): 31–40. — Tree species diversity and structural characteristics in the lowland forest of Bukit Baka Bukit Raya National Park (TNBBBR) were examined to assess the overall floristic diversity of this conservation area. A survey was conducted at the national park boundary with PT. Sari Bumi Kusuma, a forest company concession in East Kalimantan. Data were collected using transect plots of 50 × 10 m at 100 m elevation intervals across three locations (Km. 37, Km. 39a, and Km. 39b), for a total of eight plots. All trees with a diameter at breast height (DBH) ≥ 10 cm were measured and identified. We recorded 352 trees inside the plots, representing 138 species and 35 families, with a total basal area of 24.7 m^2/0.4ha. The dominant families in terms of basal area are Dipterocarpaceae and Myrtaceae. We found 79 Dipterocarpaceae trees, representing 22.4% of individuals, in the surveyed area. In terms of species richness, Dipterocarpaceae composed 21% of the species. There were seven genera (*Dipterocarpus, Dryobalanops, Hopea, Shorea, Rubroshorea, Richetia,* and *Anthoshorea*) and 29 species. *Shorea* was the richest genus among them. *Shorea laevis, Rubroshorea leprosula,* and *R. dasyphylla* were the most common species found in Dipterocarpaceae.

Key words: Bukit Baka Bukit Raya National Park, Dipterocarpaceae, lowland forest, tree diversity.

ABSTRAK

SUSANTI, R., GIRMANSYAH, D., PRATAMA, B. A. & JAKALELANA, S. 2026. Komposisi pohon hutan dataran rendah di Taman Nasional Bukit Baka Bukit Raya, Kalimantan Timur, Indonesia. *Reinwardtia* 25(1): 31–40. — Penelitian keanekaragaman jenis pohon dan karakteristik struktur hutan dataran rendah di Taman Nasional Bukit Baka Bukit Raya (TNBBBR) dilakukan untuk mengetahui keanekaragaman floristik umum di kawasan konservasi ini. Survei dilakukan di perbatasan taman nasional dengan PT. Sari Bumi Kusuma, sebuah perusahaan konsesi hutan di Kalimantan Timur. Pengumpulan data dilakukan dengan menggunakan transek berukuran 50 × 10 m pada setiap gradien elevasi 100 m di tiga lokasi (Km. 37, Km. 39a, dan Km. 39b), dengan total delapan transek. Semua pohon dengan diameter setinggi dada (DBH) ≥10 cm diukur dan diidentifikasi. Sebanyak 352 pohon tercatat dalam plot penelitian, mewakili 138 jenis dari 35 suku, dengan total luas bidang dasar sebesar 24,7 m^2. Suku dengan bidang dasar dominan adalah Dipterocarpaceae dan Myrtaceae. Sebanyak 79 pohon Dipterocarpaceae ditemukan, yang mencakup 22,4% dari total kepadatan pohon di area survei. Dari segi kekayaan jenis, Dipterocarpaceae menyusun 21% dari total jenis yang ditemukan. Terdapat 7 marga (*Dipterocarpus, Dryobalanops, Hopea, Shorea, Rubroshorea, Richetia,* dan *Anthoshorea*) dan 29 jenis, *Shorea* merupakan marga yang paling beragam dibandingkan dengan marga lainnya. *Shorea laevis, Rubroshorea leprosula*, dan *R. dasyphylla* adalah beberapa jenis Dipterocarpaceae yang paling umum ditemukan.

Kata kunci: Dipterocarpaceae, hutan dataran rendah, keanekaragaman pohon, Taman Nasional Bukit Baka Bukit Raya.

INTRODUCTION

Bukit Baka and Bukit Raya National Park (TNBBBR) is one crucial conservation area within the Heart of Borneo Conservation Initiative (Persoon & Ossenweijer, 2008; Sloan *et al.*, 2019). Like other conservation areas across the globe, this national park also faces various threats, including habitat destruction and deforestation (Austin *et al.*, 2019), illegal activities, including logging, poaching, and mining (Alfon, 2014; Manik, 2007). In 2020, an estimated 461,588 ha of forest in Kalimantan were degraded. Between 2001 and 2016, oil palm plantations, timber expansion, and large-scale plantations (Austin *et al.*, 2019) were the major drivers of deforestation in Kalimantan. Despite the pressure it faces, this national park continues to play an important role, not only in conserving flora and fauna but also in providing ecosystem services.

The floristic information concerning this national park is quite limited, in contrast with the ample information available on animal diversity. There are only a few publications on the plant diversity of this park, most of which are reports. The most comprehensive botanical survey was conducted in 1992–1995 and successfully identified 1,054 plant taxa from 357 genera and 132 families in TNBBBR (Jarvie *et al.*, 1998). The other research was conducted for specific taxa, such as palms (Rustiami, 2013), Pandanaceae (Keim *et al.*, 2011), *Rubroshorea leprosula* (old name: *Shorea leprosula*) (Habeahan *et al.*, 2017), and the most recent publication is regarding invasive species (Abduh *et al.*, 2021), medicinal plants (Mariani *et al.*, 2023), and heath forest diversity (Rifanjani *et al.*, 2023).

The forest in TNBBBR can be classified as a lowland forest, with specific areas dominated by Dipterocarpaceae, forming a Mixed Dipterocarp Forest. Within the lowland Dipterocarpaceae forest in Borneo, Slik *et al.* (2003) identified five central floristic regions characterized by distinct genera. However, the absence of comprehensive published floristic studies in the TNBBBR area has resulted in its exclusion from previous publications. The most recent tree monitoring survey in the national park was conducted in 2010 and 2012 at seven locations (Abduh *et al.*, 2018). This study aims to expand upon previous monitoring efforts by adding additional sites and providing a comprehensive overview of the floristic information in TNBBBR.

The objective of this study was to assess the tree structure, composition, and diversity in the lowland forest of TNBBBR. Additionally, the study provides information on the floristic composition, with particular emphasis on endangered, endemic, and protected tree species. Understanding the structure, composition, and diversity of trees, as well as the floristic information on key species, is essential for sound, sustainable management of the conservation area.

MATERIALS AND METHODS

Study Area

Bukit Baka Bukit Raya National Park (TNBBBR) is a conservation area located in the heart of Kalimantan, Indonesia. Administratively, this national park is located in Central and West Kalimantan Province, covering 181,090 ha. The national park is located between 112°12’12.345”E –112°56’31. 295”E longitude and 0°28’41.32”S–0°56’22.252”S latitude. Several major rivers that flow into the West and East Kalimantan regions flow through this national park. The area's topography is predominantly steep, particularly within the Schwaner mountain range.

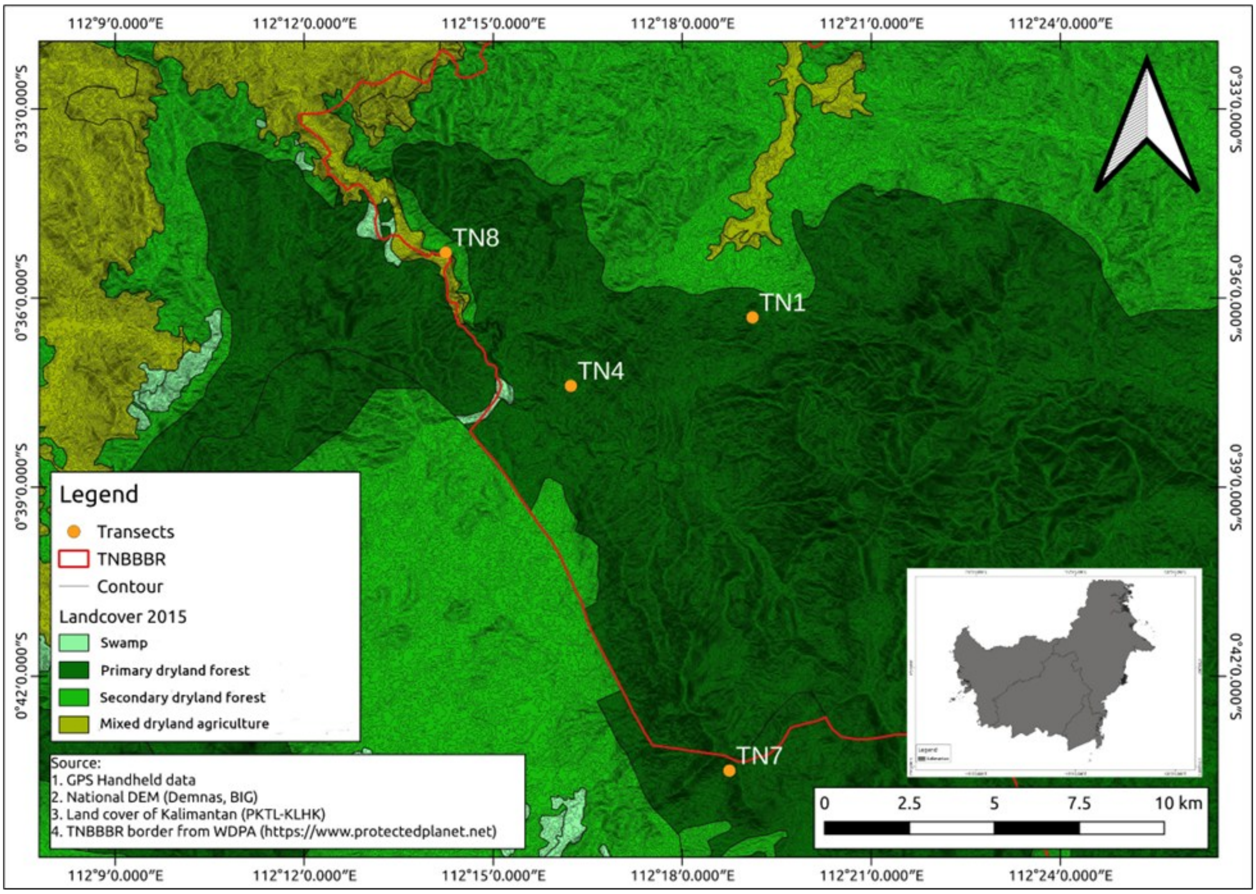
The data collected for this study were obtained in 2014 at the northwest border of the national park, within a private concession, at elevations of 300–500 m above sea level (m asl). The company, PT. Sari Bumi Kusuma (SBK) began operations in 1978, when the national park was designated a nature conservation area covering approximately 50,000 ha. The lowland forest in which the study was conducted is in relatively good condition and is abundant in various Dipterocarpaceae species.

Data were collected at four locations (see Fig. 1), selected based on accessibility. At two locations (Km. 37, and Km. 39a), three 50 × 10 m plots were established, each separated by a 100 m elevation gain. At locations Km. 39b and Km. 39c, only one plot was established, for a total of eight plots and an area of 0.4 ha. Plot elevations varied from 300 m asl to 500 m asl (see Table 1). Within these plots, every tree with a diameter greater than 10 cm (DBH ≥ 10 cm) was measured. A rapid field identification was conducted, and representative samples of all recorded taxa were collected. Specimens that could be identified in the field, as well as representative trees of the same taxa, were collected and preserved as a herbarium specimens.

Species Determination

Initial species identification was conducted in the field by local people using local names. Formal identification was conducted in the Herbarium Bogoriense, National Research and Innovation Agency (formerly the Indonesian Institute of Sciences). Fertile specimens were preserved as herbarium collections, while sterile specimens were kept as voucher specimens at Herbarium Bogoriense. We identified 75% of individuals at the species level, 13 at the family level, and 26 could not be identified. Unidentified specimens were assigned separate numbers and treated as distinct individuals.

The most recent taxonomical name is used following Plants of the World Online (https://



Source:
1. GPS Handheld data
2. National DEM (Demnas, BIG)
3. Land cover of Kalimantan (PKTL-KLHK)
4. TNBBBR border from WDPA (https://www.protectedplanet.net)

Fig. 1. Study location on the border of TNBBBR with PT. SBK Membalong, 19. Perawas, 20. Kembiri villages.

powo.science.kew.org/) and Ashton & Heckenhauer (2022). In total, 104 individual trees were identified to the genus level, while 36 individual trees (representing 10% of all sampled individuals) belonging to 23 taxa could not be identified at any taxonomic level.

The conservation status of trees, particularly dominant species and Dipterocarpaceae species, is determined based on the criteria set by the International Union for the Conservation of Nature and Natural Ecosystem (IUCN) (International Union for Conservation of Nature, 2025), and according to Government Regulation (PP no. 7/1999) concerning the Preservation of Plant and Animal, as well as Ministerial Regulation No. P. 106/MENLHK/SETJEN/KUM.1/12/2018, which pertains to the Second Amendment to the Regulation of the Minister of Environment and Forestry No. P.20/MENLHK /SETJEN/KUM.1/6/2018 regarding Types of Protected Plants and Animals. Species endemicity is determined based on the results of Sidiyasa's study (Sidiyasa, 2015) and information from the Global Biodiversity Information Facility (GBIF) (GBIF Secretariat, 2023).

Data Analysis

Tree diversity, structure, and composition were measured for each plot. The collected data were used to determine species dominance through the calculation of Basal Area (BA, as referenced in equation 1) and the density of each species.

$$BA = \frac{1}{4}\pi D^2 \qquad (1)$$

Tree diversity was calculated using Shannon-Weaver and Simpson's diversity index, as defined in equations (2) and (3), respectively. The higher index value (H' and/or D) indicates higher diversity within the vegetation.

Shannon Weaver (H)

$$H' = -\sum_{i=1}^{N} \frac{n_i}{N} \ln \frac{n_i}{N} \qquad (2)$$

Simpson (D)

$$D = 1 - \frac{\sum n_i(n_i - 1)}{N(N - 1)} \tag{3}$$

Where H’ is Shannon Weaver's diversity index. D is Simpson's diversity index. n_i is the number of individuals of the i species and N: total number of individuals of all species.

The evenness index (e) is calculated to measure the relative size of the population, as described by equation (4) (Oksanen *et al.*, 2022). This index ranges from 0 to 1, with a value close to 1 indicating that all species are equally represented and the community is in a stable condition. Further, a J value close to or equal to zero suggests that the community is depressed and that a species may potentially become dominant (Ulfah *et al.*, 2019).

Evennes index

$$J = \frac{H'}{\log(s)} \tag{4}$$

Where H’ is the diversity index and s is the number of species.

A Pearson correlation test was conducted to investigate the relationships among elevation, species diversity, basal area, dominance, and number of individuals across plots. The Sorenson-Dice similarity coefficient was also used to determine species similarity in each plot. All data analyses were conducted in R, using the ‘vegan’ package for vegetation analysis, the ‘corrplot’ package for correlation testing, and the ‘ggplot2’ and ‘ggpattern’ packages for visualization.

Table 1. The characteristics of the forest in each sampling plot.

Location	Code	Alt (m asl)	Density*	Num. of Fam.	Num. of Species	Num. of Dipt.	BA**	Dominant species***
1 (Km. 37)	TN1	313	52	21	52	11	1.77	*Tristania* sp. *Shorea smithiana*
	TN2	400	54	16	54	10	3.03	*Syzygium* sp. *Cleistanthus* sp.
	TN3	500	53	19	53	15	6.24	*Shorea laevis* *Baccaurea costulata*
2 (Km. 39a)	TN4	315	37	15	37	5	2.88	*Richetia multiflora* *Calophyllum teysmannii*
	TN5	401	57	18	57	7	3.31	*Koompassia malaccensis* *Garcinia celebica*
	TN6	500	36	8	36	12	2.45	*Anthoshorea virescens* *Anthoshorea symingtonii*
3 (Km. 39b)	TN7	401	31	10	31	8	2.97	*Rubroshorea dasyphylla* *Xanthophyllum* sp.
4 (Km. 39c)	TN8	401	32	12	32	11	2.01	*Driobalanops* sp. *Koompassia malaccensis*
	Total in 0.4 ha		352		352	79	24.67	

* density: number of trees per 0.4 ha
** BA: total Basal Area of each plot
*** Dominant species: Two dominant taxa for each plot are listed in descending order of BA

Table 2. Dipterocarpaceae species composition found inside the plots.

Forest characteristic	Dipterocarpaceae	%	Non Dipterocarpaceae	%	Total
Number of species	30	21.0	109	79.0	139
Density	79	22.4	273	77.6	352
Total BA	11.08	44.9	13.59	55.1	24.67

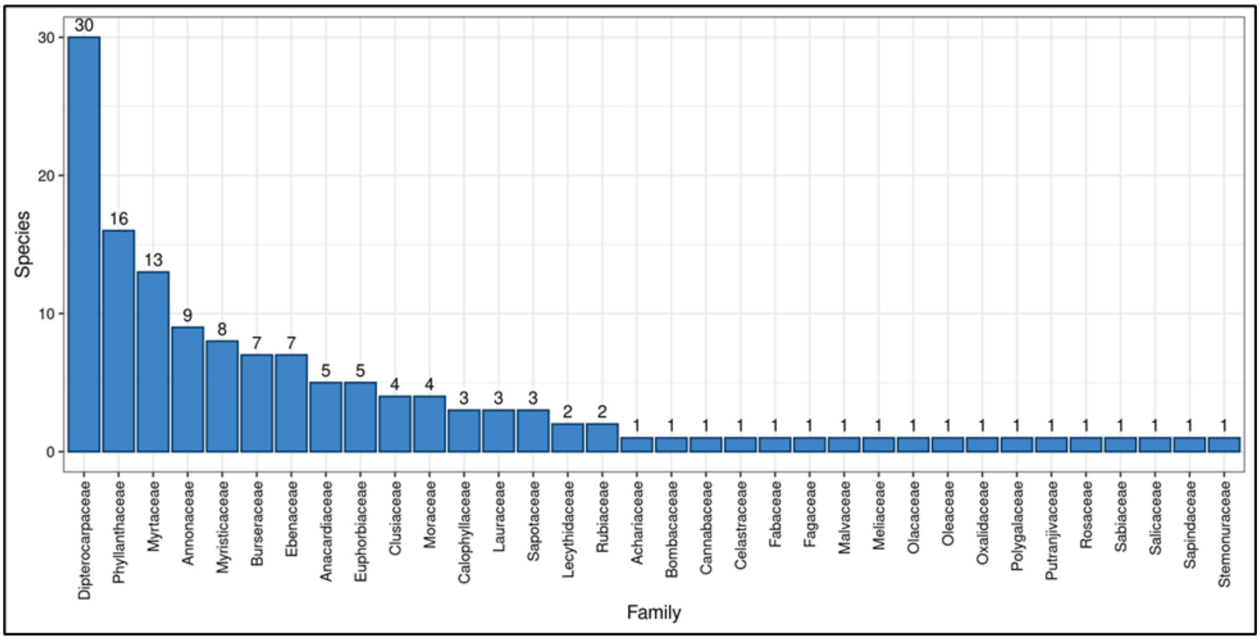


Fig. 2. Species richness at the family level.

RESULTS AND DISCUSSION

Forest Structure and Composition Characteristics

The study recorded 352 tree samples (Table 1), representing 35 families, 58 genera, and 139 species. The number of species identified in this study is relatively high compared to previous studies in Kalimantan (Pratama *et al.*, 2021; Purwaningsih, 2009). However, other studies conducted with larger plots in Kalimantan (Abduh *et al.*, 2018; Kartawinata *et al.*, 2008; Sheil *et al.*, 2010) have recorded higher tree species diversity compared to the study area. The general assessment of the TNBBBR whole area revealed a total of 1,227 plant species from various types of habitus (herbs, shrubs, and trees) (Abduh *et al.*, 2018).

Dominant species, based on Basal Area, varied across all eight plots with no distinct differences among altitudes (300–500 m asl). Some dominant species could not be identified at the species level due to incomplete samples, but were confidently identified at the genus level. Dipterocarpaceae species predominated the area, including *Shorea laevis, Rishetia multiflora* (syn. *S. multiflora*), *Anthoshorea virescens* (syn. *S. virescens*), *Anthoshorea symingtonii* (syn. *S. symingtonii*), *Rubroshorea dasyphylla* (syn. *S. dasyphylla*), and *Dryobalanops* sp. Other dominant species included *Tristania* sp. and *Syzygium* sp. (Myristicaceae), *Cleistanthus* sp. (Phyllanthaceae), *Koompassia malaccensis* (Fabaceae), *Garcinia* sp. (Clusia-ceae), *Calophyllum teysmannii* (Calophyllaceae), and *Xanthophyllum* sp. (Polygalaceae). A total of 30 Dipterocarpaceae species from seven genera (*Dipterocarpus, Dryobalanops, Hopea, Shorea, Rubroshorea*, *Richetia*, and *Anthoshorea*) were identified in the study area, comprising 21% of the total tree species identified (Table 2).

Dipterocarpaceae diversity in this area is relatively high compared with the total number of tree species identified within the plot. A total of 84 Dipterocarpaceae species (seven genera) of the total 200 species known in Kalimantan (Purwaningsih, 2004; Indrioko *et al.*, 2006) were found throughout TNBBBR areas (Abduh *et al.*, 2018). Previous studies predicted that Dipterocarpaceae compose approximately one quarter of all trees in most lowland forests in Borneo, with *Rubroshorea* and *Shorea* as the most abundant genus (Ashton 1982; Slik *et al.,* 2003). In this study, *Rubroshorea* accounted for 47% (14 of 32) of the total Dipterocarpaceae species. There was only one species in each of the other genera (*Anthoshorea*, *Dryobalanops,* and *Vatica*), and two species in *Dipterocarpus* and *Hopea.*

Table 3. Diversity index in four sampling locations.

Index	Km. 37	Km. 39a	Km. 39b	Km. 39c
Shannon-Weaver (H’)	4.35	4.45	3.34	3.21
Simpson (D)	0.98	0.99	0.96	0.95
Evenness (E)	0.94	0.97	0.99	0.97

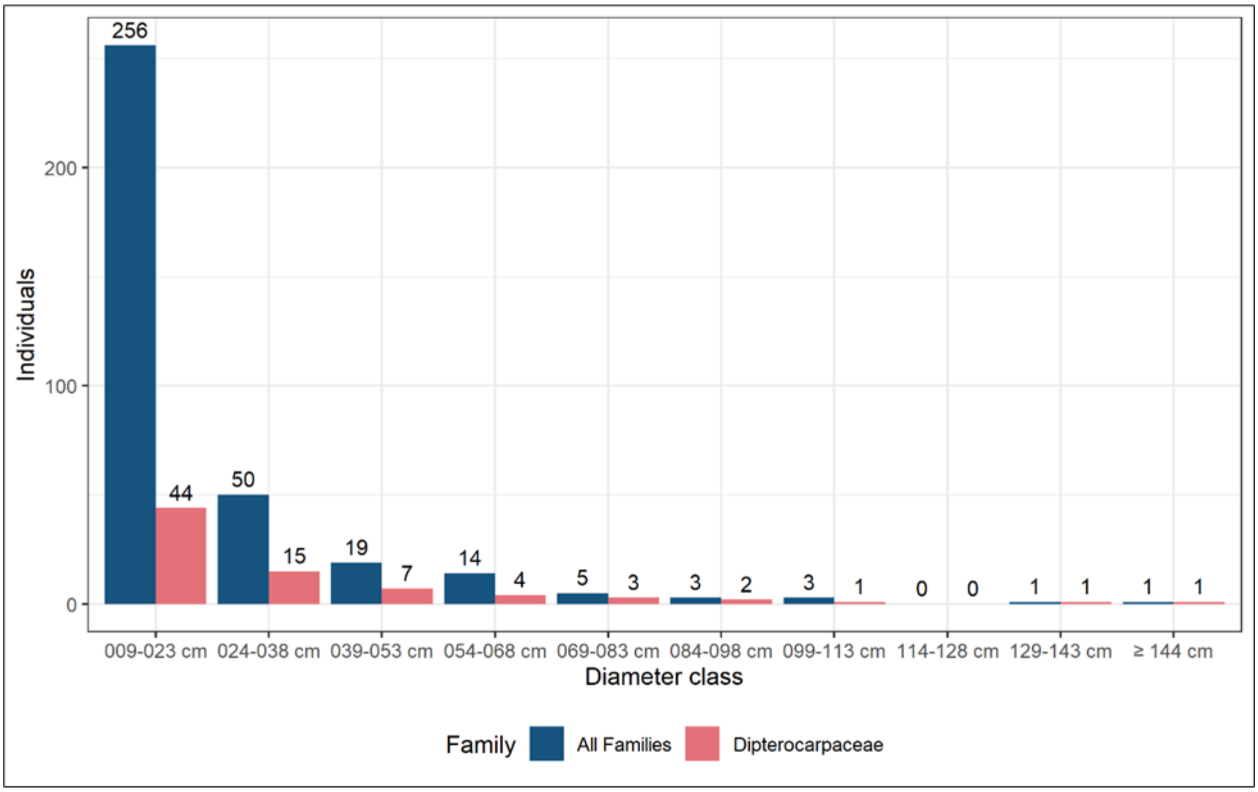


Fig. 3. Number of individuals by diameter class.

Dipterocarpaceae species also had the highest relative abundance (22.4%) among species from other families. The number of individuals per plot ranged from 31 to 57 (Table 1), with an average of 44 individuals per 500 m^2 plot (880 individuals per hectare). The density distribution of all species from each tree family is shown in Fig. 2. Apart from Dipterocarpaceae, other families with high abundance are Phyllanthaceae (*Aporosa* and *Baccaurea*), Myrtaceae (*Syzygium*), Annonaceae (*Polyalthia* and *Goniothalamus*), and Myristicaceae (*Myristica*) (Fig. 2).

The tree density of the studied site (880 trees ≥ 10 cm DBH ha^{-1}) exceeds the mean stem density reported for lowland dipterocarp forests in Kalimantan, which is approximately 500–550 stems ha^{-1} for trees ≥ 10 cm DBH (Paoli *et al.*, 2008). Such elevated stem density is therefore more plausibly associated with a history of local disturbance.

Dipterocarpaceae composed 22.4 % of the total tree density in this area, and its DBH ranged from 10 to 160 cm. At the genus level, the most common tree genera were *Robroshorea* (Dipterocarpaceae), *Syzygium* (Myrtaceae), *Shorea* (Dipterocarpaceae), *Baccaurea* (Phyllanthaceae), and *Diospyros* (Ebenaceae). This result is consistent with the description by Slik *et al.* (2003) that the most common tree genera in the lowland forests of Borneo are *Syzygium* (Myrtaceae), *Diospyros* (Ebenaceae), *Madhuca* (Sapotaceae), and *Dipterocarpus* (Dipterocarpaceae). Although *Madhuca* and *Dipterocarpus* are present in this area, their abundance is low. At the family level, Euphorbiaceae is usually found as the most abundant tree family (Cannon *et al.,* 1994; Sheil *et al.*, 2010; Sidiyasa 2001); however, changes in taxonomical nomenclature (Board of Trustees of the Royal Botanic Gardens Kew, 2019). This leads to changes in family names. *Aporosa* and *Baccaurea,* which are commonly found in the lowland forest of Kalimantan, are now included in the *Phyllantaceae* family, not Euphorbiaceae. With this change, comparisons of floristic composition are better conducted at least at the genus level.

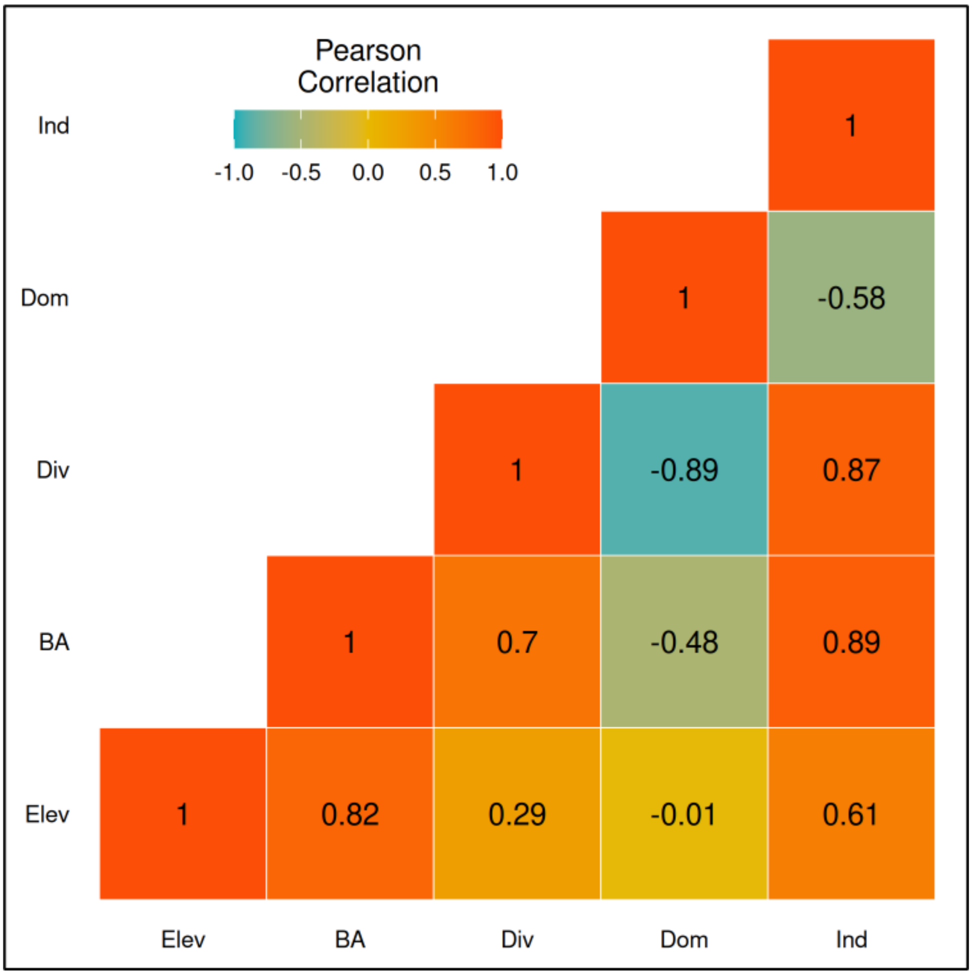


Fig. 4. A Pearson's correlation between elevation (Elev), basal area (BA), Shannon-Weaver's diversity index (Div), Dominance index (Dom), and number of individuals (Ind).

The diversity index indicates that, across the four sampling locations, tree diversity is relatively even (Table 3). The calculation indicates that Km. 39a has the highest tree diversity, whereas Km. 39c has the lowest. All locations were in stable condition based on the evenness index. Previous studies (Cannon *et al.*, 1994; Kartawinata *et al.*, 2008; Sheil *et al.*, 2010) explained that lowland forests in Kalimantan were initially dominated by Dipterocarpaceae species and were known as Mixed Dipterocarp Forest. However, continued pressure on lowland forests in Kalimantan is altering forest diversity (Lawrence, 2004; Qirom *et al.*, 2022). Our study showed that Dipterocarp species continue to dominate the national park boundary in terms of basal area and abundance (Table 2), due to pressure from land-cover and land-use change. *Shorea laevis* is the most abundant species in the dipterocarp family, followed by *Rubroshorea leprosula* and *S. superba.* Most of the trees found inside the plot have a diameter less than 60 cm (Fig. 3); only three individuals have a diameter over 100 cm: *Shorea laevis* (160 cm), *Richetia multiflora* (140 cm), and *Rubroshorea dasyphylla* (110 cm). The diameter distribution of Dipterocarpaceae has an inverse J-curve pattern (Fig. 3), which suggests possible regeneration of Dipterocarp species in this area.

Conservation Status of Tree Species

Using the IUCN classification, the study conducted was able to distinguish Dipterocarpaceae species as Critically Endangered, *Shorea cf. rotundifolia*, and four species Endangered: *Rubroshorea splendida, R. uliginosa, Shorea sumatrana*, and *Anthoshorea virescens*. None of the sampled individuals are endemic to Indonesia nor protected under Indonesian Government regulation (P.106). Although the diameter distribution of Dipterocarpaceae still shows an inverse J-curve (Fig. 3), a more detailed investigation of density at each growth stage is needed to predict species sustainability.

Indonesia has already released a list of 50 rare plant species (Rugayah et al., 2017) based on a national assessment and the adoption of the International Union for Conservation of Nature (IUCN) Red List criteria. Six Dipterocarpaceae species are included in the list, but none found in this area meet the criteria. IUCN already included 307 plant species in their global conservation assessment, including 16 species Critically Enda-

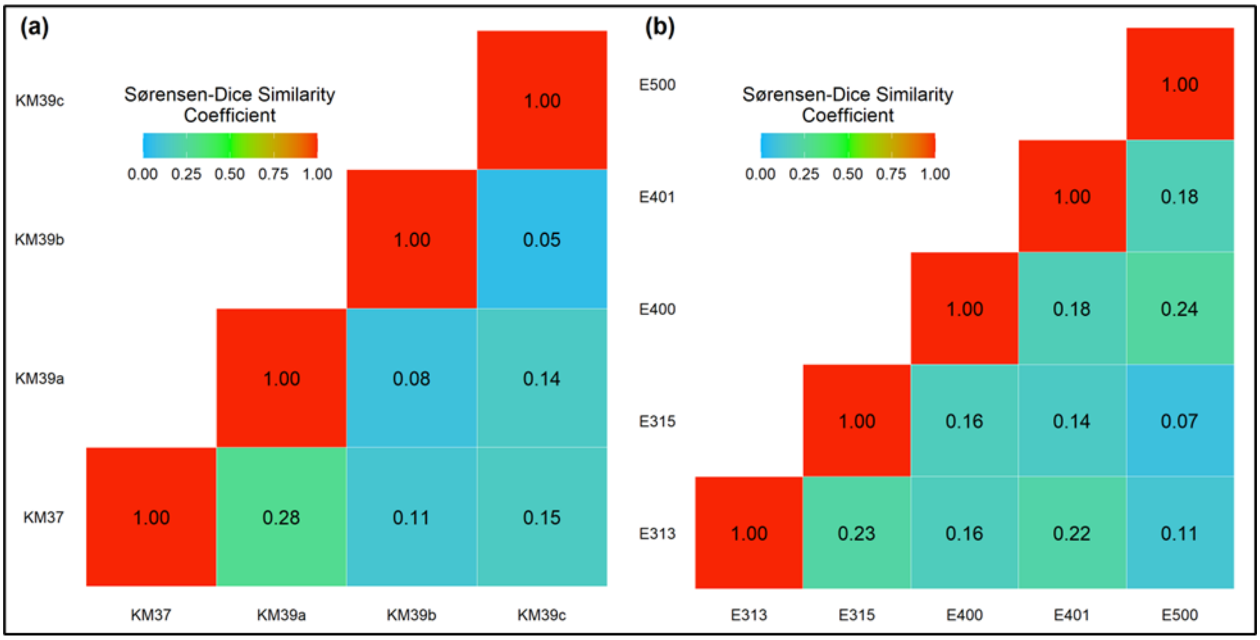


Fig. 5. Sørensen-Dice similarity coefficient. Based on location (a); and elevation (b).

ngered (CR), 43 species Endangered (EN), 58 species Vulnerable (VU), 47 species Not Threatened, 111 species Least Concern (LC), and 32 species Data Deficient (DD) (International Union for Conserva-tion of Nature, 2025).

Various conservation efforts are needed to reduce pressure on threatened species. Changing shifting cultivation patterns and intensive farming to agroforestry patterns can be an effort to maintain threatened species amidst changes in land use (Siregar, 2006). Apart from agroforestry activities, efforts to maintain the existence of sacred forests can also be an effort to conserve biodiversity through a social approach (Wadley & Colfer, 2004).

Ex-situ conservation activities, such as botanical gardens or the construction of arboretums or village gardens, are feasible (Marjokorpi & Ruokolainen, 2003). This is especially true for threatened species whose natural habitats are disturbed or severely damaged by natural or human-made disasters.

Relationship Between Elevation and Abundance of Tree Species

Correspondence Analysis (CA) of floristic composition across plot locations revealed three ecologically distinct clusters (Fig. 4). Cluster 1 was represented exclusively by plot Km. 39b, whereas Cluster 2 comprised Km. 37 and Km. 39a, indicating congruent species assemblages (Jost *et al.*, 2010). Cluster 3 emerged as an outlier, containing only Km. 39c. Dimension 1 (Dim1) of the ordination showed exceptionally high species representation values ($\cos^2$) for *Litsea* sp. ($\cos^2 = 0.9979$), *Hopea* sp. ($\cos^2 = 0.971$), and *Popowia corymbosa* ($\cos^2 = 0.971$). Furthermore, *Richetia cuspidata*, *Rubroshorea pilosa*, and *Rubroshorea sagittata* (all $\cos^2 \geq 0.97$), all Dipterocarpaceae species, exhibited robust associations with their respective clusters, confirming their diagnostic value as habitat indicators.

A correlation plot indicated that only the basal area showed a strong positive correlation with elevation. Furthermore, basal area was positively correlated with species diversity and individual abundance, but negatively correlated with the dominance index. A similar correlation was observed between the diversity and dominance indices. This is understandable, considering that high species diversity naturally reduces dominance between species (Kunte, 2008; Mortensen *et al.*, 2018).

Furthermore, the Sørensen-Dice similarity coefficient (< 0.5; Fig. 5) demonstrated high β-diversity across transects, which means that no transect in this study has a similar floristic composition. In contrast with Brearley *et al.* (2016), the finding of a relatively homogeneous community across a similar gradient in Central Kalimantan. Previous studies (Cirimwami *et al.*, 2019; Negi *et al.*, 2024) prove that differences in altitude tend to change the composition of vegetation and its species richness (Cirimwami *et al.*, 2019; Negi *et al.*, 2024).

CONCLUSION

Our study recorded 352 trees with DBH ≥10 cm within 0.4 ha plots, representing 138 species and 35 families, with a total basal area of 24.7 m^2. The dominant family by basal area and density is Dipterocarpaceae. The study area exhibits high diversity and stable community conditions. This study also found two species in CR status, four species in EN status, and ten species in VU status. There is no similarity between the plots.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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BULBOPHYLLUM ALSIOSUM (ORCHIDACEAE): A NEW RECORD FROM SULAWESI, INDONESIA

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ABSTRACT

MUSTAQIM, W. A., HUTABARAT, P. W. K., PUTERA, A. K. S., BANDJOLU, K. P., AHMAD, R. P. P. & YUDISTIRA, Y. R. 2026. *Bulbophyllum alsiosum* (Orchidaceae): a new record from Sulawesi, Indonesia. *Reinwardtia* 25(1): 41–47. — *Bulbophyllum alsiosum* Ames, a previously Philippines endemic, is reported for the first time in Sulawesi and also represents the first country record for Indonesia. The species was collected from three localities in the montane forest of central and the upper montane forest of the southwestern part of the island. The finding increases the number of *Bulbophyllum* sect. *Beccariana* in Sulawesi to nine species. Description, note, preliminary conservation status, and photographs are given.

Key words: Epiphyte, monocots, montane, taxonomy, Wallacea.

ABSTRAK

MUSTAQIM, W. A., HUTABARAT, P. W. K., PUTERA, A. K. S., BANDJOLU, K. P., AHMAD, R. P. P. & YUDISTIRA, Y. R. 2026. *Bulbophyllum alsiosum* (Orchidaceae): sebuah rekaman baru dari Sulawesi, Indonesia. *Reinwardtia* 25(1): 41–47. — *Bulbophyllum alsiosum* Ames, jenis yang sebelumnya dianggap endemik Filipina, dilaporkan untuk pertama kalinya dari Sulawesi dan juga merupakan rekaman pertama untuk Indonesia. Jenis ini dikoleksi dari tiga lokasi di hutan pegunungan bagian tengah dan hutan pegunungan atas barat daya pulau. Penemuan ini menambah jumlah jumlah *Bulbophyllum* seksi *Beccariana* di Sulawesi menjadi sembilan jenis. Pertelaan, catatan, status konservasi awal, dan foto-foto disajikan.

Kata kunci: Epifit, monokotiledon, pegunungan, taksonomi, Wallacea.

INTRODUCTION

Sulawesi is the largest island in the Wallacea bioregion. The island has a complex geological history, formed by Laurasian, Australasian, and oceanic elements (Hall, 2002). There are an estimated 5,972 species of plants that occur in the island, with around 2,225 species of them endemic (Middleton *et al.*, 2019). This island has a strong similarity in floristic composition with the Philippines, Java, the Lesser Sunda Islands, and the Maluku Archipelago, but not with neighbouring Borneo (van Welzen & Raes, 2011).

Bulbophyllum Thouars is among the most species-rich genera in Sulawesi. The latest monographic work on Sulawesi species was published by Vermeulen & O'Byrne (2011), where 123 species were recorded for the island. Despite being already revised, the genus in Sulawesi is considered poorly known. Several new species were described or records published after the revision, bringing the total number of known species to 132 (POWO, 2024). The latest new species include *Bulbophyllum mamasaense* Wibowo, Juswara & J.Champ. (Wibowo *et al.*, 2022).

Continuous exploration of the orchids of Sulawesi yielded further noteworthy findings. In mid-2023, an exploration in the mountainous regions of Mamasa, Sulawesi Barat Province, yielded the discovery of plants that do not match species previously recorded in Sulawesi (Thomas & Schuiteman, 2002; Vermeulen & O'Byrne, 2011). One year later, a similar plant was found in the montane forest of Tentena, Poso Regency, Central Sulawesi Province. Further identification showed that this species belongs to *B. alsiosum* Ames, a species previously known only from the Philippines. Therefore, the findings represent the first record for Sulawesi and the first country record for Indonesia.

MATERIALS AND METHODS

The materials used in this study were collected during a sequential exploration in two areas in Sulawesi by the authors. The first exploration was conducted in Mamasa, Sulawesi Barat in 2023, and in Poso, Sulawesi Tengah in 2024. Plants were collected and preserved in dried herbarium supplemented with flowers in 70% ethanol following guidelines from Davies *et al.* (2023). Identification was done using type examinations in JSTOR Global Plants (https://plants.jstor.org), specimen and photographs comparison, and relevant literature (Ames, 1912; Comber, 1990, 2001; Seidenfaden & Wood, 1992; Thomas & Schuiteman, 2002; Vermeulen & O'Byrne, 2008, 2011; Pelser *et al.*, 2011; de Vogel *et al.*, 2014-onwards; Vermeulen *et al.*, 2015). Morphological descriptions were prepared primarily from fresh specimens combined with protologue in Ames (1912). The IUCN Red List conservation status assessment was carried out following guidelines (IUCN Standards and Petitions Committee 2024). Area of Occupancy (AOO) and Extent of Occurrence (EOO) were calculated using GeoCAT (Bachman *et al.*, 2011). The results, combined with threat data either directly observed and inferred from Google Satellite Images were checked against the criteria in IUCN (2012).

TAXONOMIC TREATMENT

Bulbophyllum alsiosum Ames, Leafl. Philipp. Bot. v. 1583 (1912). — Type: PHILIPPINES, Negros: Negros Oriental, Cuernos Mtns, Apr 1908, Elmer 9817 (holotype: AMES; isotypes: AMES-image! [00000382], BM-image! [000516997], F-image! [V0046257F], GH-image! [02385724], L, MO-image! [100257642], NY, US, Z-image! [Z-000062297]). Figs. 1–2.

Long creeping or ascending *epiphyte*, often on the base of tree trunk, rhizome to *ca.* 3 m. Rhizome slightly flexuous, covered by marcescent, light brown sheaths, sparsely rooted along. *Pseudobulb* cylindric, 2.0–3.5 cm long, covered by marcescent sheaths; section between pseudobulb up to 13.5 cm. *Leaf* lamina green, paler beneath, elliptic, 11.0–13.2 × 4.0–7.5 cm, base cuneate, apex acute, midrib sunken above, raised beneath; petiole 2.0–3.0 cm long. *Inflorescence* 1(–2)-flowered, from the rhizome, peduncular bracts 6, greenish yellow, marcescent, sheathing, up to 1.1 cm long, apex apiculate, longitudinally ribbed, uppermost bracts *ca.* 1.0 cm long, connate at ¼ basal, longitudinally ribbed outside, all glabrous. *Flowers ca.* 2.7 cm long, not opening widely. *Pedicels* and ovary 1.3 cm long, ovary greenish-yellow, purple mottled, sulcate, with rounded ribs. *Dorsal sepals* greenish cream outside, inside red, with creamy margin, ovate, 2.8 × 1.3 cm, apex acute to subobtuse, glabrous. *Lateral sepals* with the same color as dorsal sepals, asymmetric, narrowly ovate-triangulate, 2.6 × 1.1 cm, lower margin recurved, forming an acute angle in the lower third, indistinctly 7-veined, apex acute. *Petals* outside white with upper half pale red, inside red, margin white, oval, 1.1 × 0.6 cm, 5-veined, apex rounded or obtuse, glabrous. *Labellum* thick, upper surface red or bright yellow, lower surface white, pinkish or yellowish at the margin, lanceolate in outline, 1.7 × 0.6 cm, margin upcurved, apex acute, upper surface with 3 longitudinal calli from near the base and running close to the apex, callus sometimes not prominent, slightly wavy, especially toward the apex, glabrous. *Column* including stelidia 4.5 mm long, cream above, lower margin red, stelidia triangular, *ca.* 1.2 mm long, lower margin with a broadly deltoid 0.5 mm long wing; stigma obdeltoid in outline. *Anther* cucullate, yellow-orange, front part tinged with red, obovate, *ca.* 3 × 2.5 mm, drawn out, containing 4 pollinia, pollinia yellow.

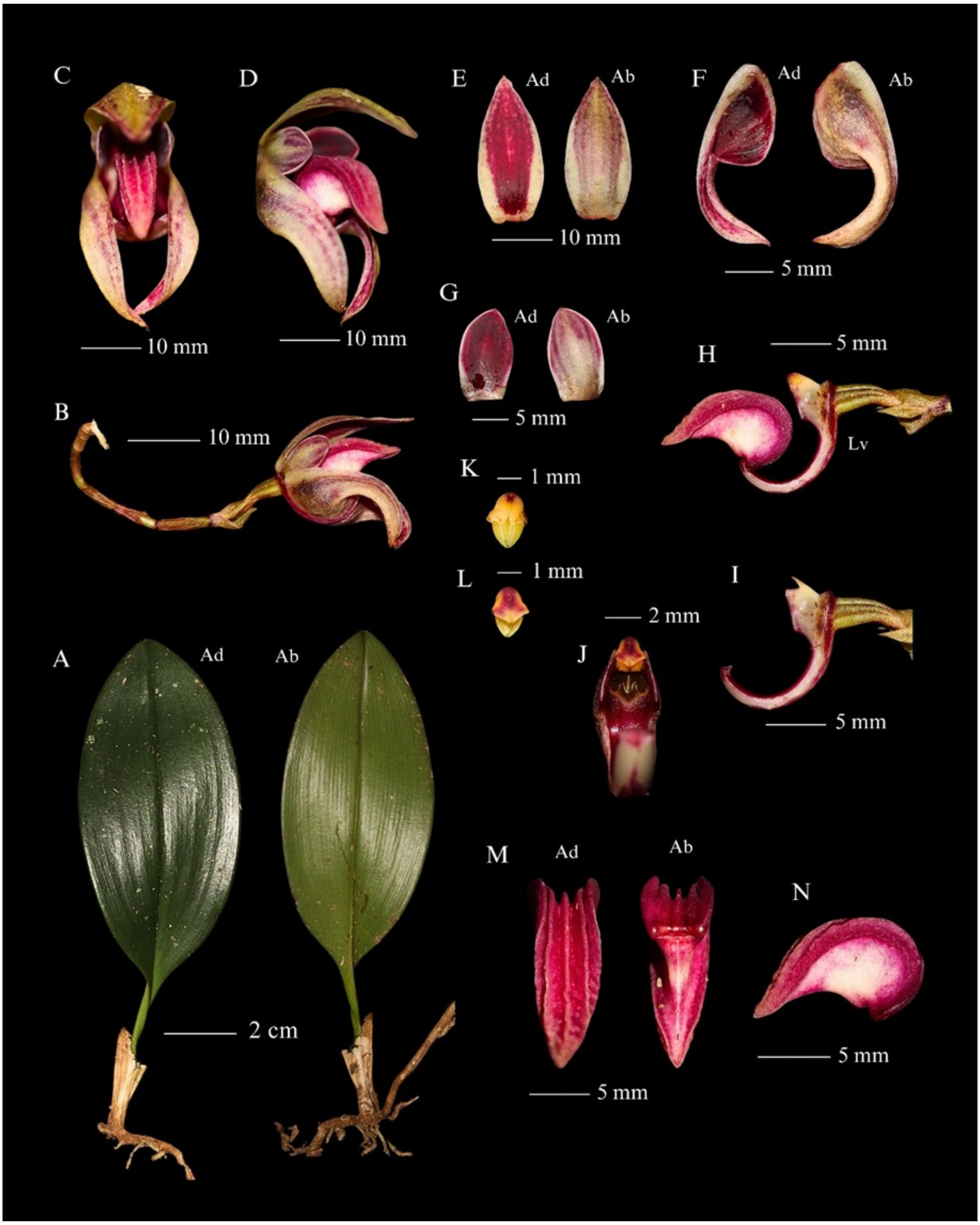

Fig. 1. Detailed morphology of *Bulbophyllum alsiosum* Ames. A. Rhizome and leaves. B. Inflorescence. C. Front-view of flower. D. Lateral view of flower. E. Dorsal sepal. F. Lateral sepals. G. Petals. H. Flowers with perianth removed. I. Ovary, column, and column foot. J. Ventral view of column and stigma. K–L. Anther. M. Labellum. N. Labellum, lateral view. Ad = adaxial, Ab = abaxial. Photos by Wendy A. Mustaqim & Yuda R. Yudistira.

Fig. 2. In-situ photographs of *Bulbophyllum alsiosum*. A. Living plant. B. The 2-flowered inflorescence in Mamasa. C. Lateral view of flower. D. Front-view of flower. Photos A–B by Wendy A. Mustaqim, C–D by Prima W.K. Hutabarat.

Specimens examined. INDONESIA. Sulawesi Barat. Mamasa regency, Nosu subdistrict, Batu Papan (3°09'05.8"S 119°27'21.2"E), 1,980 m asl, 2 Aug. 2023, *Mustaqim et al. 2768* (CEB); Mamasa regency, Lambanan, near Pasapa' Lombonan (2° 55'05.2"S 119°28'56.1"E), 1,930 m asl, 4 Aug. 2023, *Mustaqim et al. 1784* (CEB). Sulawesi Tengah. Poso regency, Bomba subdistrict, before Petirorano (1°47'35.8"S 120°28'39.7"E), 1,523 m asl, 24 Nov. 2024, *Hutabarat et al. 1645* (UIDEP).

Distribution. Philippines (Luzon, Leyte, Negros, and Mindanao) (Ames, 1912; Pelser *et al.*, 2011) and Sulawesi (Sulawesi Barat and Sulawesi Tengah Province) (Fig. 3).

Habitat and Ecology. In the Philippines, this species was found on moss-covered trees at elevations from 600 to 1,300 m asl (Ames, 1912; Pelser *et al.*, 2011). In Sulawesi, this species was recorded from undisturbed montane to upper montane forests at 1,523 m and 1,980 m asl, all in shaded habitats.

Phenology. Flowering in June (Ames, 1912), August, and November.

Preliminary IUCN Red List conservation status. The species was recorded from at least seven locations, four in the Philippines and three in Indonesia, with an EOO of 575,927 km^2 (Least Concern) and an AOO of 36 km^2 (Endangered). The population

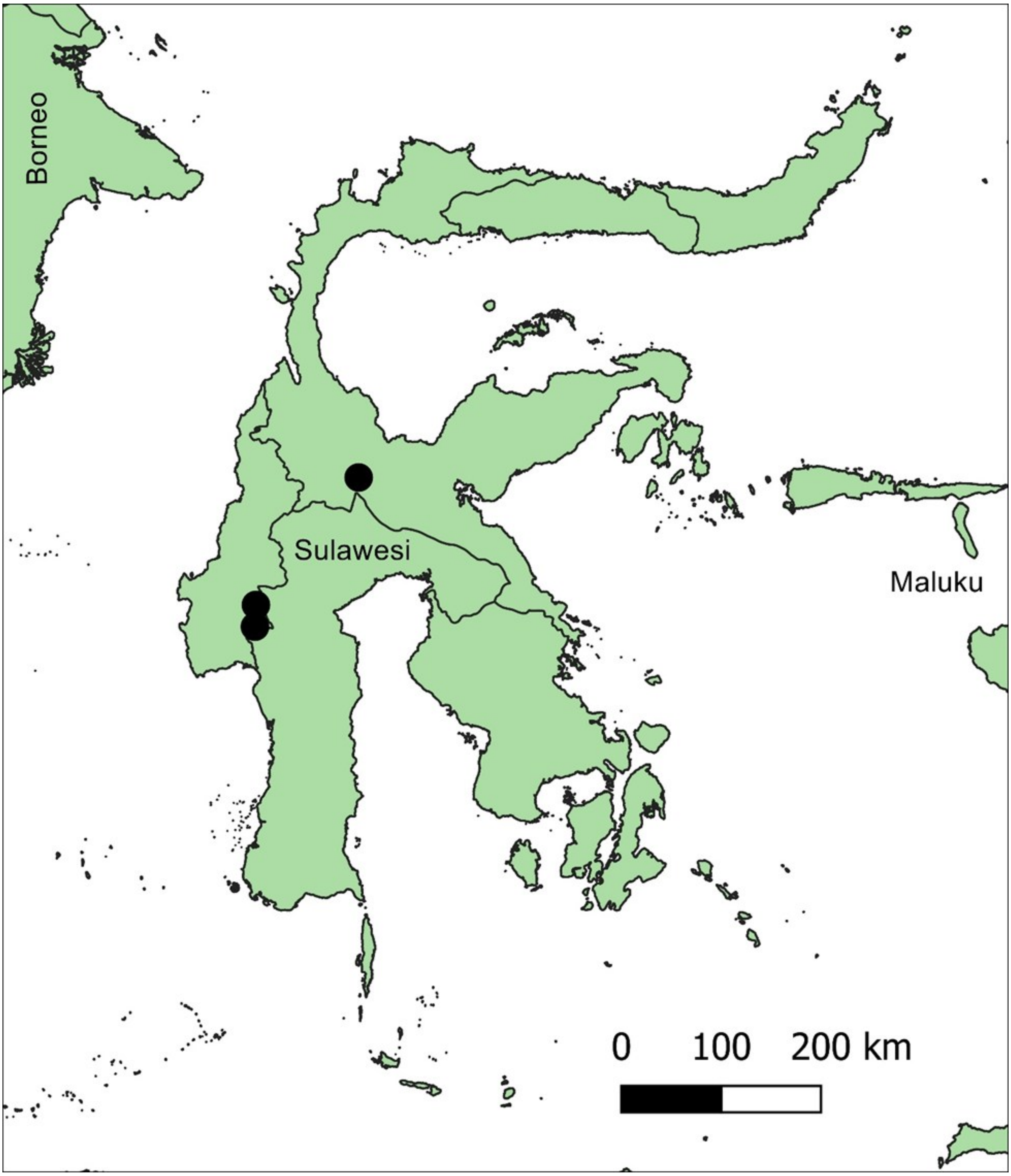

Fig. 3. Geographical distribution of *Bulbophyllum alsiosum* in Sulawesi (●).

on Luzon Island is located near rapidly developing city of Antipolo, and the potential habitat is likely threatened by rapid conversion, especially in lower elevations. Meanwhile, the other populations are relatively safe. Despite the AOO reaching the EN threshold, the level of threats is considered insufficient to warrant a threatened status. Besides that, despite its large flowers, this species is not a priority for poachers in orchid collecting, as we have seen in Sulawesi. Therefore, the species is best assigned as Near Threatened (NT).

Note. This species belongs to section *Beccariana,* which is characterized by leaves that have visible reticulate venations and flowers with free lateral sepals with the upper margin twisted proximally, 5–7-veined petals, and the base of pedicels level with the bract attachment (Vermeulen *et al.*, 2014). The most similar species in Sulawesi is *B. uniflorum* due to their 1(–2)-flowered inflorescence and ovary with rounded ridges. While *B. alsiosum* is strictly Wallacean species, *B. uniflorum* has a wider geographic range, from Sumatra, Peninsular Malaysia, Java, Borneo, and Sulawesi (Vermeulen *et al.*, 2011; 2015), but this species differs in having much shorter inflorescence (8 cm *vs* 10 to 30 cm long), flowers with rounded (*vs* acuminate) tepals, and labellum lanceolate (*vs* subtriangular ovate). This finding added the number of *Bulbophyllum* section *Beccariana* in Sulawesi to nine species.

The discovery of Sulawesi's material improves the current morphological scope of *B. alsiosum*. Previously, this species was reported to have only 1-flowered inflorescences (Ames, 1912), whereas the plant from Mamasa has 2-flowered inflorescences. Such variation, *i.e.* the occurrence of both one to two flowers in a single species, has also been found in other species within section *Beccariana*, like *B. uniflorum*, the Bornean endemics like *B. sububellatum* Ridl. and *B. nabawanense* J.J.Wood & A.Lamb, and several more (Comber, 2001; Vermeulen *et al.*, 2015).

Besides that, most known *B. alsiosum* have red labellum, but plants from Tentena, Poso, Sulawesi Tengah have yellow labellum. The current findings also add ecological information. This species was previously recorded from elevations of 600–1,300 m asl in the Philippines (Pelser *et al.*, 2011). Meanwhile, the records in Sulawesi span a higher elevation range, from 1,523 to 1,980 m asl. This means that this species can be found in lowland to upper montane ecosystems according to elevational zonation in Southeast Asia (van Steenis, 1972; Kartawinata, 2016). This new elevation range (from 600 to 1,980 m) is considered for the section Beccariana, but it is rather considered normal situation. Some species within this section also have a broad range of elevational distribution, like *B. membranifolium* Hook.f. subsp. *inunctum* (J.J.Sm.) J.J.Verm., P.O'Byrne & Lamb (100 to 1,800 m), *B. sanguineomaculatum* Ridl. (100 to 1,300 m), and *B. uniflorum* (600 to 2,000 m) (Vermeulen *et al.*, 2015).

The discovery of *B. alsiosum* in Sulawesi adds to the records of phytogeographical continuity between the Philippines and Sulawesi. Both areas belong to a biogeographical unit called Wallacea, and their floristic similarity is high (van Welzen & Raes, 2011). Some of the latest records of the Philippines flora newly recorded for Sulawesi, or geographically extending to the southern part of Sulawesi, have been published (*e.g. Calanthe stenocentron* (Schltr.) M.W.Chase, Christenh. & Schuit. (Mustaqim *et al.*, 2022)). New records of flora for Sulawesi previously known from surrounding areas are likely a result of the low scientific plant collecting in this area, as indicated by the low density of scientific plant collections (Middleton *et al.*, 2019). Another possible reason could be the regional collecting gaps since the finding localities, especially in Sulawesi, are all botanically under-explored as evidenced by the finding of many new endemic plant species, *i.e.*, Poso (*e.g.* Ardiyani *et al.*, 2021; Hutabarat *et al.*, 2022; Saleh *et al.*, 2023) and Mamasa (*e.g.* Ardiyani & Poulsen, 2019; Ardi & Thomas, 2020; Wibowo *et al.,* 2022; Hutabarat *et al.,* 2022).

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CLIMATE-DRIVEN RANGE SHIFTS THREATEN KEYSTONE ENDEMIC FIGS OF JAVA: COMPLEMENTING IUCN RED LIST ASSESSMENT WITH SPECIES DISTRIBUTION MODELLING TO GUIDE CONSERVATION PRIORITIES

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ABSTRACT

RISNA, R. A., LUGHADHA, E. N., PRASETYO, L. B., SUTOMO, AIDI, M. N., BUCHORI, D., PLUMMER, J., LATIFAH, D., YUSWANDI, A. Y. & YUDISTIRA, A. I. 2026. Climate-driven range shifts threaten keystone endemic figs of Java: complementing IUCN Red List assessment with species distribution modelling to guide conservation priorities. *Reinwardtia* 25(1): 49–63. — This study evaluates the extinction risk and climate-driven habitat dynamics of two endemic figs of Java, *Ficus trachycoma* Miq. and *F. miqueliana* C.C.Berg. Both species are poorly known, with no confirmed field records for more than six decades. Conservation status was assessed under IUCN Red List criteria, with extent of occurrence (EOO) and area of occupancy (AOO) calculated using validated herbarium records. *Ficus trachycoma* is restricted to a single 19th-century locality, with an EOO and AOO of 4 km², a single known location, and continuing decline in habitat, qualifying it as Critically Endangered. *Ficus miqueliana* has been more widely recorded, with an AOO of 20 km² and an EOO of about 600 km², ≤5 locations, and continuing decline in habitat, meeting the thresholds for Endangered. Species distribution modelling using MaxEnt and CMIP6 climate projections (SSP2-4.5 and SSP5-8.5) was applied to predict current and future habitat suitability. The models performed with high accuracy (AUC = 0.912–0.935, TSS = 1.0) and identified slope (52–73% contribution), temperature seasonality, and precipitation in the wettest, warmest, and coldest quarters as key predictors of occurrence. *Ficus miqueliana*'s current suitable habitat is 16,233 km² (12.4% of Java) in fragmented lowland, and foothill forests. CMIP6 projections (MIROC6, SSP2-4.5/SSP5-8.5 for 2050s and 2090s) forecast net contractions with upslope shifts: mid-century losses of 9–11% in Java, late-century persistence in montane refugia under moderate emissions but severe fragmentation under high emissions. These findings demonstrate that both endemic figs are highly vulnerable to environmental change. Applying IUCN Red List assessments alongside species distribution modelling provides a replicable framework for evaluating extinction risk in data-limited species and identifies priority areas for climate-adaptive conservation planning on Java.

Key words: Climate change, connectivity, extinction risk, habitat suitability, MaxEnt.

ABSTRAK

RISNA, R. A., LUGHADHA, E. N., PRASETYO, L. B., SUTOMO, AIDI, M. N., BUCHORI, D., PLUMMER, J., LATIFAH, D. & YUSWANDI, A. Y. 2026. Pergeseran jangkauan akibat perubahan iklim mengancam jenis penting tumbuhan ara endemik Jawa: melengkapi penilaian IUCN Red List dengan pemodelan sidtribusi jenis sebagai petunjuk prioritas konservasi. *Reinwardtia* 25(1): 49–63. — Penelitian ini mengevaluasi risiko kepunahan dan dinamika habitat akibat perubahan iklim pada dua jenis ara endemik Jawa, *Ficus trachycoma* Miq. dan *F. miqueliana* C.C.Berg. Kedua jenis ini kurang dikenal, tanpa catatan lapangan terkonfirmasi selama lebih dari enam dekade. Status konservasi dinilai menggunakan kriteria *IUCN Red List*, dengan perhitungan *extent of occurrence* (EOO) dan *area of occupancy* (AOO) berdasarkan data herbarium yang tervalidasi. *Ficus trachycoma* dijumpai terbatas pada satu lokasi dengan AOO dan EOO 4 km², dan menerusnya penurunan kualitas habitat, sehingga memenuhi kriteria Kritis (Critically Endangered). *Ficus miqueliana* menempati AOO 20 km² dan EOO sekitar 600 km² pada ≤5 lokasi dan terjadinya degradasi habitat sehingga memenuhi kriteria Terancam (*Endangered*). Pemodelan distribusi *F. miqueliana* menggunakan MaxEnt dan proyeksi iklim CMIP6 (SSP2-4.5 dan SSP5-8.5) diterapkan untuk memprediksi kesesuaian habitat saat ini dan masa depan. Model menunjukkan akurasi tinggi (AUC = 0,912–0.935; TSS = 1.0) dan mengidentifikasi kemiringan lereng (kontribusi 52–73%), musim, suhu, serta curah hujan pada kuartal terbasah, terpanas, dan terdingin sebagai prediktor utama keberadaan. Habitat yang sesuai bagi *Ficus miqueliana* saat ini mencakup 16.233 km² (12,4% dari Jawa), terutama pada hutan dataran rendah dan kaki bukit yang terfragmentasi. Proyeksi CMIP6 (MIROC6, SSP2-4.5/SSP5-8.5 untuk pertengahan dan akhir abad ke-21) memperkirakan kontraksi dengan pergeseran ke arah pegunungan: kehilangan habitat pada pertengahan abad hingga 9–11% dari Jawa, serta keberlanjutan di refugia montana pada emisi moderat namun fragmentasi parah pada emisi tinggi. Temuan ini menegaskan kerentanan tinggi jenis terhadap perubahan lingkungan. Penggunaan asesmen IUCN Red List dengan pemodelan distribusi jenis memberikan kerangka kerja yang dapat direplikasi untuk mengevaluasi risiko kepunahan pada jenis dengan data terbatas, serta mengidentifikasi area prioritas bagi perencanaan konservasi adaptif iklim di Jawa.

Kata kunci: Konektivitas, MaxEnt, pemodelan kesesuaian habitat, perubahan iklim, risiko kepunahan.

INTRODUCTION

The genus *Ficus* L. (Moraceae) is one of the most ecologically significant and taxonomically diverse plant groups in tropical ecosystems, comprising *ca.* 900 species worldwide (POWO, 2024), of which at least 367 species are distributed across the Malesia region (Berg *et al.*, 2006). Indonesia, particularly the island of Java, is a biogeographic hotspot for *Ficus* diversity, hosting 75 species (Berg *et al.*, 2006; Yusuf, 2011) with two confirmed Java endemics: *Ficus miqueliana* C.C.Berg and *F. trachycoma* Miq. These species are known only from historical herbarium records, with no confirmed wild observations for over six decades (GBIF, 2022a; 2022b). Their restricted distribution and long absence from field surveys raise urgent questions about their current status and vulnerability to environmental change.

Ficus, or figs, is widely recognized as a keystone resource in tropical forests due to its asynchronous fruiting phenology, which supports a diverse assemblage of frugivores and pollinators throughout the year (van Vankelburg & Bunyapraphatsara, 2002; Chantarasuwan, 2014; Mackay *et al.*, 2018). Recent studies reaffirm their ecological centrality in both natural and urban landscapes. *Ficus* species provide essential food resources for 54 frugivore species in the Pakke Wildlife Sanctuary, India, highlighting their critical role in sustaining frugivore populations (Gogoi *et al.,* 2023). *Ficus* also plays a crucial role in maintaining biodiversity and microclimatic stability in urban green spaces in Bogor, West Java (Peniwidiyanti *et al.*, 2022). The loss of such species can disrupt ecological networks and impair forest regeneration, particularly in ecosystems where anchor trophic networks are present. Fragmentation in tropical forests can lead to the breakdown of plant-animal mutualism, reducing ecosystem resilience and regeneration capacity (Marjakangas *et al.,* 2020). These disruptions are espe-

Table 1. Occurrence data of *F. miqueliana* and *F. trachycoma* from the Global Biodiversity Information Facility (GBIF) database.

No.	Collector names	Codes	Locations	Years	Coordinates	Remarks
Ficus miqueliana C.C.Berg						
1	Koorders SH	24612*	Banyumas, Central Java	No data	-7.52 S 109.28 E	*ca*. 1898–1900
2	Koorders SH	9380	Ngebel, Madiun, East Java	1896	-7.63 S 111.52 E	Wood sample
3	Koorders SH	9380*	Ngebel, Madiun, East Java	1896	-7.63 S 111.52 E	Herbarium sheets
4	Koorders SH	38811B	Ngebel, Madiun, East Java	1896	-7.79 S 111.62 E	Wood sample
5	Koorders SH	38811B	Ngebel, Madiun, East Java	1896	-7.79 S 111.62 E	Herbarium sheets
6	Koorders SH	20669B	Besuki, East Java	1889	-7.75 S 113.68 E	Herbarium sheets
7	Koorders SH	38773B	Ngebel, Madiun, East Java	1900	-7.79 S 111.62 E	Herbarium sheets
8	Jacob, M.	4818*	Mt. Raung, Besuki, East Java	1957	-8.25 S 114.08 E	Herbarium sheets
9	Jacob, M.	4841	Mt. Raung, Besuki, East Java	1957	-8.25 S 114.08 E	Herbarium sheets
10	Jacob, M.	4834	Mt. Raung, Besuki, East Java	1957	-8.25 S 114.08 E	Herbarium sheets
11	Jacob, M.	4834	Mt. Raung, Besuki, East Java	1957	-8.25 S 114.08 E	Herbarium sheets
12	Jacob, M.	4834	Mt. Raung, Besuki, East Java	1957	-8.25 S 114.08 E	Extra herbarium sheets
Ficus trachycoma Miq.						
1	Teysmann	-	Bogor	1860	No data	Collected from Hortus Botanicus Bogoriense
2	Zollinger	456	Mt. Gede	No data	No data	Holotype at National Herbarium Nederland

cially pronounced for endemic taxa with narrow ecological niches, which face heightened extinction risks under combined pressures of habitat loss and climate change (Tejedor-Garavito *et al.*, 2015; Urban, 2015).

Assessing the conservation status of species is essential for safeguarding biodiversity and guiding conservation priorities, particularly under the Convention on Biological Diversity's Global Strategy for Plant Conservation (Sharrock *et al.*, 2018; IUCN Standards and Petitions Committee, 2024). Extinction risk, quantified through standar-dized criteria, has revealed that nearly half of all tree species may be threatened globally due to their relatively limited ecological range and exposure to human pressure (Silva *et al.,* 2022; Bachman *et al.,* 2024). Additionally, endemic plant species and those known from few occurrence records are typically more threatened than widespread species (Jose, 2025), highlighting the urgency of integrating spatial modelling into conservation planning for these vulnerable taxa. Within the genus *Ficus*, where approximately 66.26% (487 species) of species have assessment on the IUCN Red List of Threatened Species, with 82 currently listed as threatened (IUCN, 2024). However, no formal assessment exists for the Javan endemics *F. miqueliana* C.C.Berg and *F. trachycoma* Miq., despite their ecological importance and paucity of occurrence records.

To strengthen conservation evaluations, species distribution modelling (SDMs) can provide spatially explicit insights into habitat suitability and potential range shifts under climate change scenarios. While more widely applied to data-rich species, SDMs can also prove valuable when applied to rare, data-sparse species, enabling researchers to integrate occurrence records with environmental predictors to identify priority areas for conservation and anticipate future risks (Qazi *et al.*, 2022; Rathore & Sharma, 2023).

Therefore, this study aims to 1) assess the conservation status of *F. miqueliana* and *F. trachycoma* under the IUCN categories and criteria, 2) model the current and future habitat suitability of *F. miqueliana* under climate change scenarios, 3) identify potential shifts and refugia, and 4) provide evidence-based recommendations for these Javan endemic figs.

MATERIALS AND METHODS

Study Site

This study covers Java Island, Indonesia, which is located between 5°50′- 8°30′S and 105°15′- 114°30′E (Fig.1) with a total area of approximately 132,523 km^2. The island has an altitudinal range from sea level to 3,676 m asl., with mountains stretching from west to east in the central part of the island. Many of these mountains are volcanoes. Lowland areas are primarily situated in the northern and southern parts of the island. The general land use is categorized as forests, settlements, agriculture, industrial and infrastructure areas, but Setiawan & Yoshino (2014) detailed it into 25 classes including forest. The remaining terrestrial forest area is estimated to be around 12,000 km^2 and mostly situated at high altitude in 2005 (Prasetyo *et al.,* 2009), but continuing to decline during the last two decades, especially in East Java Province (Global Forest Watch, 2023). The study was carried out from December 2023 to December 2024.

Species Data Collection

Occurrence records of *F. miqueliana* and *F. trachycoma* were obtained from the Global Biodiversity Information Facility global database (GBIF.org, 2022a). Records were filtered to remove duplicates and occurrences of cultivated specimens. Each occurrence point was georeferenced using QGIS 3.28.4 (QGIS Development Team, 2023). Location names were validated using Geonames (GeoNames, 2022), whilst accepted species names were checked using the World Checklist of Vascular Plants (WCVP) database on Plants of the World Online (POWO, 2024). A herbarium study was also conducted at Herbarium Bogoriense (BO), National Research and Innovation Agency (BRIN).

Projecting Deforestation and its Impact on Habitat

To assess the potential impact of deforestation on the habitat of *F. miqueliana*, a species assumed to be forest-dependent, we conducted a spatial analysis of forest cover change. All geoprocessing and spatial modeling were performed using QGIS software v.3.38 (QGIS Development Team, 2023).

The primary analysis involved projecting future forest cover and evaluating its effect on species habitat. First, we utilized the MOLUSCE (Modeling Land Use and Surface Coupled Environment) plugin within QGIS to model forest cover change for the years 2050 and 2090 across Java. The model was calibrated using historical land cover data from MAPBIOMAS Collection 4.0 (Mapbiomas, 2025) and several predictor variables. These variables included human population density data on WorldPop hub (WorldPop, 2025) and Euclidean distances to rivers, roads, and built-up areas, the latter of which were derived from OpenStreetMap data (OSM, 2025). The resulting land cover projections were then reclassified into a binary schema of 'forest' and 'non-forest' to delineate potential areas of forest loss.

Subsequently, to quantify the impact on *F. miqueliana*, we intersected the projected forest loss maps with the species' potential habitat map. This intersection identified specific areas of "suitability contraction"—locations where suitable habitat is projected to be lost due to deforestation. Finally, to evaluate the vulnerability of these habitats within protected zones, the suitability contraction maps were clipped using the official conservation area boundary map from the Sistem Informasi Geospasial Kementerian Lingkungan Hidup dan Kehutanan (SIGAP) (Kementerian Kehutanan RI, 2024). This final step yielded a spatially explicit quantification of projected suitable habitat loss within the designated conservation areas of Java.

Complementarity with Red List Assessment

The species distribution modelling approach was selected to complement the IUCN Red List conservation status assessment. While bioclimatic modelling techniques are acceptable to inform Red List assessments, their direct use for creating the official distribution map or calculating the key metrics of Extent of Occurrence (EOO) and Area of Occupancy (AOO) is not permitted (IUCN Standards and Petitions Committee, 2024). Therefore, our modelling results are intended to provide complementary information on potential habitat shifts and threats, which can inform qualitative assessments of a species' long-term viability, rather than to replace the standard IUCN mapping and quantification protocols.

RESULTS

Conservation status assessment

Ficus miqueliana is known from historical collections dating from 1896 (S. H. Koorders) through 1957 (Banyumas, Central Java), with no confirmed recent field reports. From the ini-

Table 2. Summary of model evaluation under multiple climate scenarios.

Models	AUC	TSS
Current	0.912	1.0
SSP2-4.5 (2041 – 2060)	0.929	1.0
SSP5-8.5 (2041 – 2060)	0.924	1.0
SSP2-4.5 (2081 – 2100)	0.935	1.0
SSP5-8.5 (2081 – 2100)	0.921	1.0

tial retrieval of 12 records from the GBIF database (Table 1), subsequent filtering to remove duplicates and specimens cultivated in botanic gardens yielded three unique georeferenced points. These three records represent distinct threat-defined locations across East and Central Java. Based on Criterion B of the IUCN Red List, the species meets the following quantitative thresholds: the Area of Occupancy (AOO) was calculated as 20 km^2 and the Extent of Occurrence (EOO) was estimated at 600 km^2. Thus, *F. miqueliana* qualifies for the Endangered (EN) category under criteria B1 (EOO < 5,000 km^2) and B2 (10 km^2 < AOO <500 km^2), and sub-criterion (a) (≤ 5 locations), and sub-criteria (b)(iii) (continuing decline in habitat quality).

Ficus trachycoma is known from a single herbarium record collected in 1864 from Cibodas, Mount Gede, West Java. When restricted to a single historical collection, assigning a data-adequate extinction risk category is challenging. However, close scrutiny of the specimen label limits the collection locality to an area within +/- 275 m elevation of the Cibodas Botanic Garden. Taking a precautionary approach, as recommended by IUCN standards (IUCN Standards and Petitions Committee, 2022), the species is assumed to be severely restricted and may not occur naturally at less-disturbed, higher elevations on Mt. Gede volcano. Based on this extreme limitation and plausible threat, the species is proposed as Critically Endangered (CR) under criteria B1ab (iii)+2ab(iii). This assessment was supported by estimates for EOO and AOO of 4 km^2 which meet thresholds for CR under criterion B1 (EOO < 100 km^2), and B2 (AOO < 10 km^2), respectively, and sub-criteria a (one location) and b(iii) (continuing decline in habitat).

Habitat suitability modelling

Model evaluation and predictive performance

Species distribution models (SDMs), particularly those using presence-only algorithms such as MaxEnt, require a minimum number of occurrence records to produce statistically robust and ecologically meaningful predictions. In the case of *F. trachycoma,* which has only one known occurrence point, modelling its potential distribution is not feasible due to insufficient environmental representation. A single occurrence point cannot capture the environmental breadth or niche of the species, leading to unreliable or biased predictions. According to van Proosdij *et al.* (2016) SDMs should not be attempted for species with fewer than three records, especially for narrowly-distributed species, and even greater numbers of records are required for such species in certain biomes (Sampaio & Cavalcante, 2023). Therefore, *F. trachycoma* was excluded from modelling to maintain methodological integrity and avoid unsupported spatial extrapolation; only *F. miqueliana* can be modeled for current and future distribution.

MaxEnt evaluation models (Table 2) exhibited excellent discriminatory performance across climate scenarios, with AUC values ranging from 0.912 (current) to 0.935 (SSP2-4.5 2081–2100) and consistent TSS=1.0. Although these results indicate perfect threshold-independent discrimination, careful interpretation is required. Slope was identified as the dominant predictor contributing the distribution of *F. miqueliana*'s distribution across climate scenarios (Table 3). Slope consistently contributed to each scenario (25.8–72.8%), with permutation importance reinforcing its role (up to 52.4%). Temperature seasonality (BIO4) and precipitation variables in wettest, warmest, and coldest quarters (BIO16, BIO18, BIO19, respectively) emerged as secondary drivers, peaking at 30% contribution in SSP2-4.5 in 2041–2060 and notable permutation values, while isothermality (BIO03) and topographic aspect showed scenario-specific influence up to 28.5%. Model performance underscored these variables' independent explanatory power, with soil factors (BD, OCD, SOC) exhibiting negligible effects throughout. Precipitation in driest quarter (BIO17) consistently contribute negligibly.

Table 3. MaxEnt modelling results.

Environmental variables	Percent contribution					Permutation importance				
	Current	SSP2-4.5 (2041–2060)	SSP5-8.5 (2041 –2060)	SSP2-4.5 (2081–2100)	SSP5-8.5 (2081–2100)	current	SSP2-4.5 (2041 –2060)	SSP5-8.5 (2041 –2060)	SSP2-4.5 (2081–2100)	SSP5-8.5 (2081–2100)
BIO03 (isothermality)	0	0	0	9.1	0	0	0	0	0	0
BIO04 (temperature seasonality)	0.5	29.8	3.8	39.4	3.5	0	37.7	16.9	44.3	7.9
BIO16 (Precipitation of Wettest Quarter)	0.1	4.8	0	0	0	0	26.7	29.9	0	28.7
BIO17 (Precipitation of Driest Quarter)	0	0	0	0	0	0	0	0	0	0
BIO18 (Precipitation of Warmest Quarter)	0	0	0	24.0	0	0	0	0	43.7	0
BIO19 (Precipitation of Coldest Quarter)	13.2	0	8.4	0	20.9	19.1	0	9.3	0	28.1
Aspect	15.2	9.9	14.9	1.6	12.7	28.5	3.2	9.8	0	13.1
Slope	71.1	55,5	72.8	25.8	62.9	52.4	32.5	34.1	12	22.2
BD (Bulk density)	0	0	0	0	0	0	0	0	0	0
OCD (Organic Carbon Density)	0	0	0	0	0	0	0	0	0	0
SOC (Soil Organic Carbon)	0	0	0	0	0	0	0	0	0	0

Current and future habitat suitability projection

The MaxEnt model for current bioclimatic condition predicts a highly fragmented distribution of suitable habitat for *F. miqueliana* across Java (Fig. 1). Across the island, suitable habitat is concentrated in the following ecological zones: humid lowland forests of West Java, foothill zones of Central Java, and southern montane slope of East Java. These areas are characterized by a stable temperature regime and low temperature seasonality, aligning with the species' known ecological preferences.

Under current conditions, the suitable habitat of *F. miqueliana* comprised approximately 16,233 km^2 (12.4% of the total 131,302 km^2 of Java Island), predominantly absent from 115,069 km^2 (Table 4; Fig. 2). The suitable habitat was concentrated in lowland and foothill forests. This baseline supports the characterization of *F. miqueliana* as a low- to mid-elevation endemic fig. The modelling results indicated that the species is sensitive to future climate trajectories, with marked differences between moderate (SSP2-4.5) and high-emission (SSP5-8.5) scenarios across Java (Table 4; Fig. 3).

Future projections indicated net contractions. By mid-century (2041–2060 or 2050s), both scenarios project substantial reductions in suitable habitat. Under SSP2-4.5, the suitability habitat was reduced to 11,974 km^2 (9.0% of the total Java Island), with the range contracted to 4,439 km^2 and only 6,747 km^2 of expansion. This indicates a net decline and moderate contraction, with habitat shifting upslope. A similar contraction occurs under SSP5-8.5, where the suitable area decreases to 13,820 km^2 (10.5%), coupled with 4,104 km^2 expansion and minimal contraction among scenarios (2,413 km^2).

By the late century (2081–2100 or 2090s), trajectories diverge sharply. Under SSP2-4.5, *F. miqueliana*'s suitable habitat covered only 9,058 km^2 (6.9%), with severe but relatively balanced between contraction and expansion (7,175 and 7,612 km^2, respectively). In contrast, SSP5-8.5 projected minimum expansion (2,915 km^2), maintained 12,764 km^2 (9.7%) remaining suitable. The model predicts persistence only in isolated montane patches, severe-

Table 4. Size of predicted habitat transition summary (km^2).

Scenario	Present	Contraction	Expansion	Absent	Spatial trend
Current climate	16,233	-	-	115,069	Lowland and foothill habitats.
SSP2-4.5 (2041-2060)	11,794	4,439	6,747	108,322	Upslope shift to montane zones
SSP2-4.5 (2081-2100)	9,058	7,175	7,612	107,457	Continued upslope shift with increased fragmentation
SSP5-8.5 (2041-2060)	4,439	2,413	4,104	110,965	Initial upslope shift with fragmentation
SSP5-8.5 (2081-2100)	12,764	3,469	2,915	112,154	Severe contraction to isolated montane refugia

ly reducing connectivity and elevating extinction risk.

Figure 4 visualizes the spatial overlap between forest loss-driven habitat contraction for *Ficus miqueliana* and designated conservation areas across Java under different climate scenarios. The maps delineate areas of habitat contraction due to forest loss (brown), persistent suitable and unsuitable habitat (green), with conservation area boundaries (*e.g.* national parks) clearly demarcated. The visualization demonstrates that habitat contraction occurs within designated protected zones, indicating that forest loss compounds climate-induced habitat reduction. The spatial extent of contraction varies across scenarios, with notable fragmentation visible in both SSP2-4.5 and SSP5-8.5 projections, particularly in lowland and foothill regions.

In 2050s, low emission SSP2-4.5 (Fig. 4A) model shows habitat contraction due to forest loss is most severe in western and central Java conservation area. In contrast, SSP5-8.5 with high emission (Fig. 4B) shows more fragmented loss with smaller, scattered patches of contraction in the same regions, suggesting reduced pressure on protected habitats under extreme warming climate. By the 2090s, SSP2-4.5 indicates worse habitat contraction across central and eastern Java protected areas (Fig. 4C), while the high emission SSP5-8.5 (Fig. 4D) shows more moderate habitat contraction. In this period, habitat suitability contraction outside PA boundaries was also extensive that need strong conservation measures against deforestation. These findings imply that current protected areas (PA) are insufficient and require a dual, scenario-specific strategy. Under SSP2-4.5 pathway, the extensive and contiguous habitat suitability loss within PAs signals an immediate need for enhanced in-situ protection.

DISCUSSION

Conservation Status of Javan Endemic Figs

The proposed conservation statuses of *F. miqueliana* (Endangered) and *F. trachycoma* (Critically Endangered) highlight the high degrees of extinction risk faced by Javan endemic figs. *Ficus miqueliana* is threatened by ongoing habitat loss and the future impacts of climate change. The status of *F. trachycoma* is more challenging to ascertain on account of record scarcity, however, several lines of evidence may be used to infer habitat loss and a highly restricted distribution. The threat of agricultural and settlement expansion in the immediate vicinity of the Cibodas Botanic Garden is taken as evidence for its restriction to a single threatened location. Additionally, given the proximity of the type collection to a major botanic garden, the prolonged absence of collections over the intervening 150+ years suggests that this plant is likely very rare, if indeed it is still present in the vicinity of the type locality. Therefore, these conditions warrant immediate field verification to identify any remaining populations and to implement precautionary protection measures to prevent the potential loss of this species before it can be better understood and conserved.

The assessment of these two species underscores critical conservation concerns for Java's endemic flora. The diagnosis of restricted distribution, few known locations, and ongoing habitat degradation suggests a pervasive pattern of population decline, consistent with documented trends for other range-restricted tropical trees (Tejedor-Garavito *et al.,* 2015, Bachman *et al.,* 2024). As keystone species, the potential extinction of these figs could severely disrupt ecological networks, particularly fig-frugivore interactions that are vital for

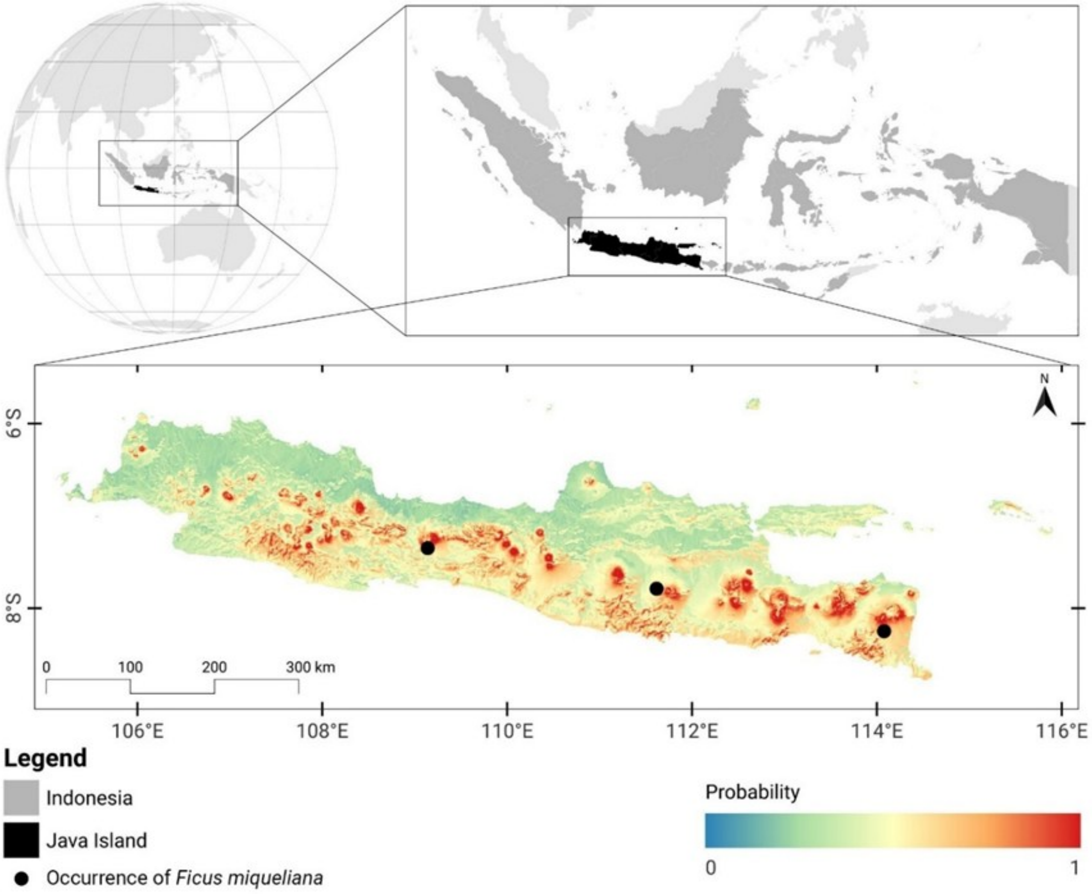

Fig. 1. Predicted habitat suitability of *Ficus miqueliana* in current bioclimatic condition.

sustaining forest regeneration (Marjakangas *et al.,* 2020). Therefore, the assessed status for both species warrants formal inclusion in national threatened species lists and demands the immediate implementation of precautionary protection measures.

Environmental Drivers

The dominance of slope as the primary predictor (52–73% contribution) in MaxEnt models aligns with its role in modulating microclimatic stability, soil drainage, and erosion resistance, thereby shaping habitat suitability for forest species across current and future SSP scenarios. Slope influences microclimatic conditions critical to plant growth by affecting sunlight exposure, water retention, and soil stability, in which topographic gradients explained substantial distributional variance in heterogeneous landscapes (Liao *et al.*, 2025). Our findings, which identify temperature seasonality (bio4) and precipitation metrics of the warmest and coldest quarter (bio18, bio19) as important drivers, are consistent with Prasetyo *et al.* (2022). They also found these same variables to be among the most important predictors for teak growth on Java, underscoring the overarching influence of seasonal climate dynamics on species distribution in the region. Temperature seasonality captures thermal variability constraining phenological cycles. At the same time, precipitation of the wettest, warmest, and coldest quarters defines hydrological niches, with permutation importance highlighting their scenario-specific gains in predictive power (Li *et al.*, 2024). The inclusion of all uncorrelated variables, despite negligible contributions from soil factors (BD, OCD, SOC), follows established MaxEnt protocols to capture comprehensive ecological niches, mitigate overfitting risks from post-hoc exclusion, and enable robust validation of independent predictor effects, as premature filtering may omit subtle interactions or future scenario relevance.

Future Range Shifts and Vulnerability Under Climate Change

Ficus miqueliana’s future suitable habitat declines 10–43% across SSP scenarios relative to current baselines, driven by topographic-climatic mismatches amplifying contraction over expansion. This result is consistent with MaxEnt’s slope and temperature seasonality dominance under warming trajectories. SSP2-4.5's steeper losses by

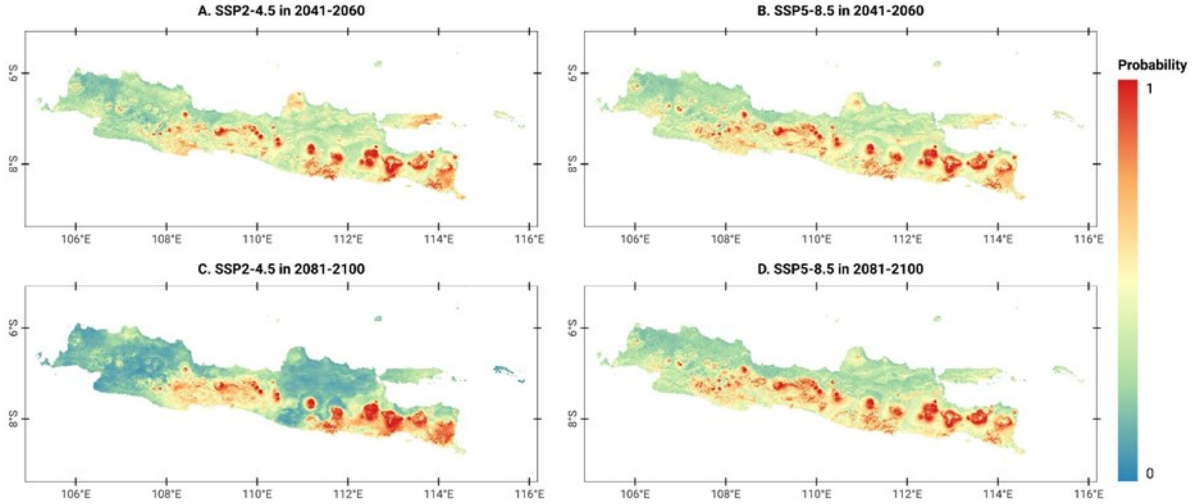

Fig. 2. Predicted future habitat probability of *F. miqueliana* in Java under different climate change scenarios: A) SSP2-4.5 in 2041–2060; B) SSP5-8.5 in 2041–2060; C) SSP2-4.5 in 2081–2100; D) SSP5-8.5 in 2081–2100.

2090s signaled moderate emissions' delayed impacts on niche stability, whereas SSP5-8.5's relative stability underscores high-emission resilience via expanded margins, though net contractions highlight vulnerability in rugged terrain (Liao *et al.*, 2025). The spatial trend toward montane zones also aligns with established elevational migration patterns observed in plant species (Chen *et al.*, 2012). These range shifts strongly suggest that refugia should be mapped with a view to assisted migration; however, any such conservation interventions must be implemented with caution, taking into account the risk of model overfitting due to limited sample size (Radosavljevic & Anderson, 2014).

These climatic sensitivities have significant implications for the species' future under changing climate scenarios. The contrasting outcomes highlight that *F. miqueliana*'s persistence is contingent on emission pathways and habitat continuity. Moderate warming may facilitate upslope migration into montane refugia, echoing patterns in other tropical montane taxa (Feeley *et al.*, 2023). However, under high-emission scenarios, the species faces a combination of range collapse, habitat fragmentation, conditions often associated with elevated extinction risk in narrow-range tropical trees (Tejedor-Garavito *et al.*, 2015; Bachman *et al.*, 2024).

We highlighted the net present change in *F. miqueliana*'s habitat consistently declines across all scenario (Table 4). The gross values of habitat expansion range (2,915–7,612 km²) compared to contraction (2,413–7,175 km²) may indicates potential dispersal constraints, consistent with theoretical limitations on tropical plant migration rates (Corlett & Westcott, 2013). The projected fragmentation into isolated montane refugia raises concerns about genetic diversity loss and local extinction risk, particularly given the species' already restricted distribution (12.4% of the study area).

Looking forward, model outputs suggest that under moderate climate trajectories (SSP2-4.5), suitable habitat may expand upslope into montane refugia by the late century (Fig. 3). In contrast, under high-emission pathways (SSP5-8.5), the species faces severe contraction and fragmentation, with only small isolated patches persisting. This apparent "expansion" in the modeled scenarios does not imply natural recovery, as colonization of new areas depends on the species' dispersal capacity and the maintenance of habitat connectivity along elevational gradients. Consequently, the smaller historical EOO relative to the present predicted distribution may reflect a history of range decline. At the same time, future projections highlight that persistence will depend on rediscovery, the protection of remaining foothill and montane forests, and the establishment of ecological corridors that enable upslope migration. These findings highlight the urgency of precautionary conservation. The historical contraction of *F. miqueliana*, together with projected climate-driven range shifts, increases its extinction risk. Immediate action is needed to secure refugia and maintain elevational connectivity.

A direct comparison of paired scenarios reveals a counterintuitive pattern between emission severity and forest loss-driven habitat contraction. For

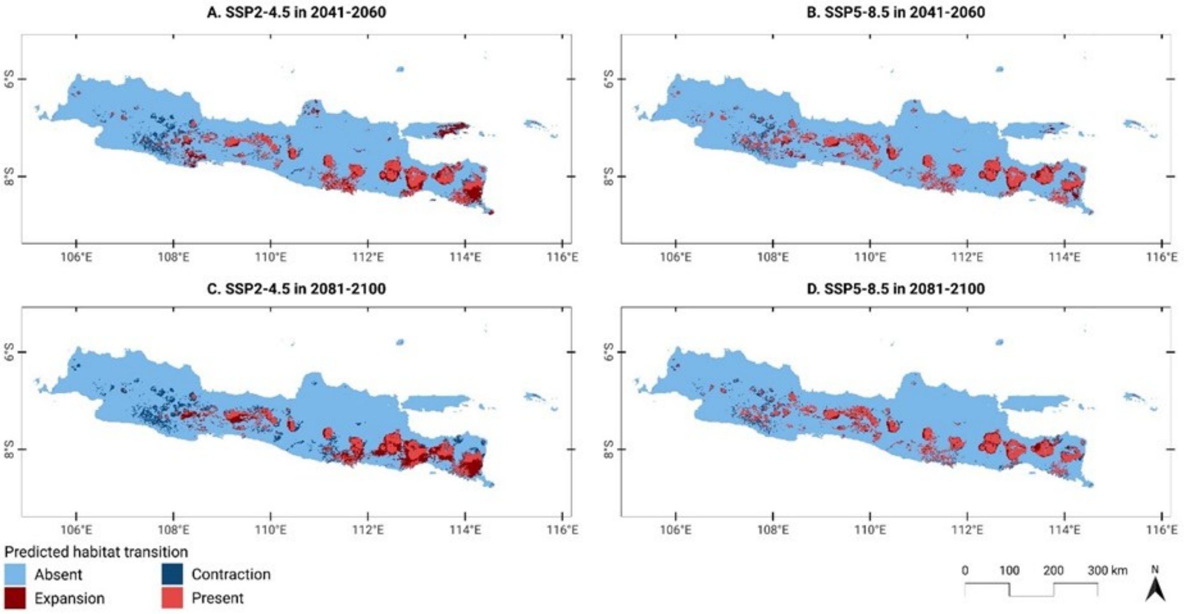

Fig. 3. Predicted habitat transition across climate scenarios in 2041–2060 and 2081–2100 compared to the current condition as baseline. Absent = no change in unsuitable habitat; contraction = suitable in the current became unsuitable in the future; expansion = unsuitable in current condition, became suitable in the future; present = no change in suitable habitat between current and future.

the 2041–2060 period (Fig. 4A *vs.* 4B), the high-emission SSP5-8.5 scenario projects less habitat contraction compared to the medium-emission SSP2-4.5 scenario. This trend persists into the 2081-2100 period (Fig. 4C *vs.* 4D), where SSP5-8.5 again shows lower contraction than SSP2-4.5. This discrepancy suggests that the relationship between climate warming and forest loss is not linear; the more extreme warming under SSP5-8.5 may lead to rapid vegetation shifts that initially reduce the rate of targeted forest loss within the species' specific niche, whereas the intermediate warming of SSP2-4.5 allows for prolonged human activities (*e.g.* selective logging, agriculture expansion) to degrade habitats gradually. The implication is that conservation efforts must consider that intermediate climate pathways may pose a more insidious threat through sustained, incremental habitat loss, rather than the abrupt changes associated with high-emission scenarios. This aligns with observations that gradual environmental change can facilitate more persistent and pervasive anthropogenic pressures (Barlow *et al.*, 2018).

Implications for Conservation

The spatial patterns presented in Fig. 4 corroborate the range shift trends detailed in Table 4, highlighting the synergistic threats of climate change and deforestation. The occurrence of habitat contraction within conservation areas underscores the limitations of static protected area boundaries in mitigating biodiversity loss under dynamic environmental change. The pronounced contraction in lowland protected areas aligns with the species' projected upslope shift, suggesting that current reserves may not encompass future suitable habitats. This spatial evidence reinforces the conclusion that forest loss intensifies climate-driven habitat fragmentation, emphasizing the critical need for integrated conservation strategies that address both deforestation and climate adaptation to ensure the long-term persistence of *Ficus miqueliana.*

From a conservation perspective, our modelling results underscore three urgent priorities. First, targeted field surveys are essential to verify extant populations and assess their elevational range, especially in predicted refugia zones. Second, protection of montane forests should be prioritized to secure future habitat, complemented by ex-situ measures such as seed banking to mitigate catastrophic loss. Third, maintaining connectivity across elevational gradients will be critical to facilitate upslope migration and ensure gene flow. Without such integrated measures, the species may face irreversible decline, particularly under high-emission scenarios where suitable habitat becomes fragmented and isolated.

Given the high extinction risk for both Javan endemic figs, an integrated, climate-adaptive conservation strategy must be implemented, addressing the dual pressure of habitat loss and climate change. This strategy is recommended on three complementary pillars. Firstly, an immediate field

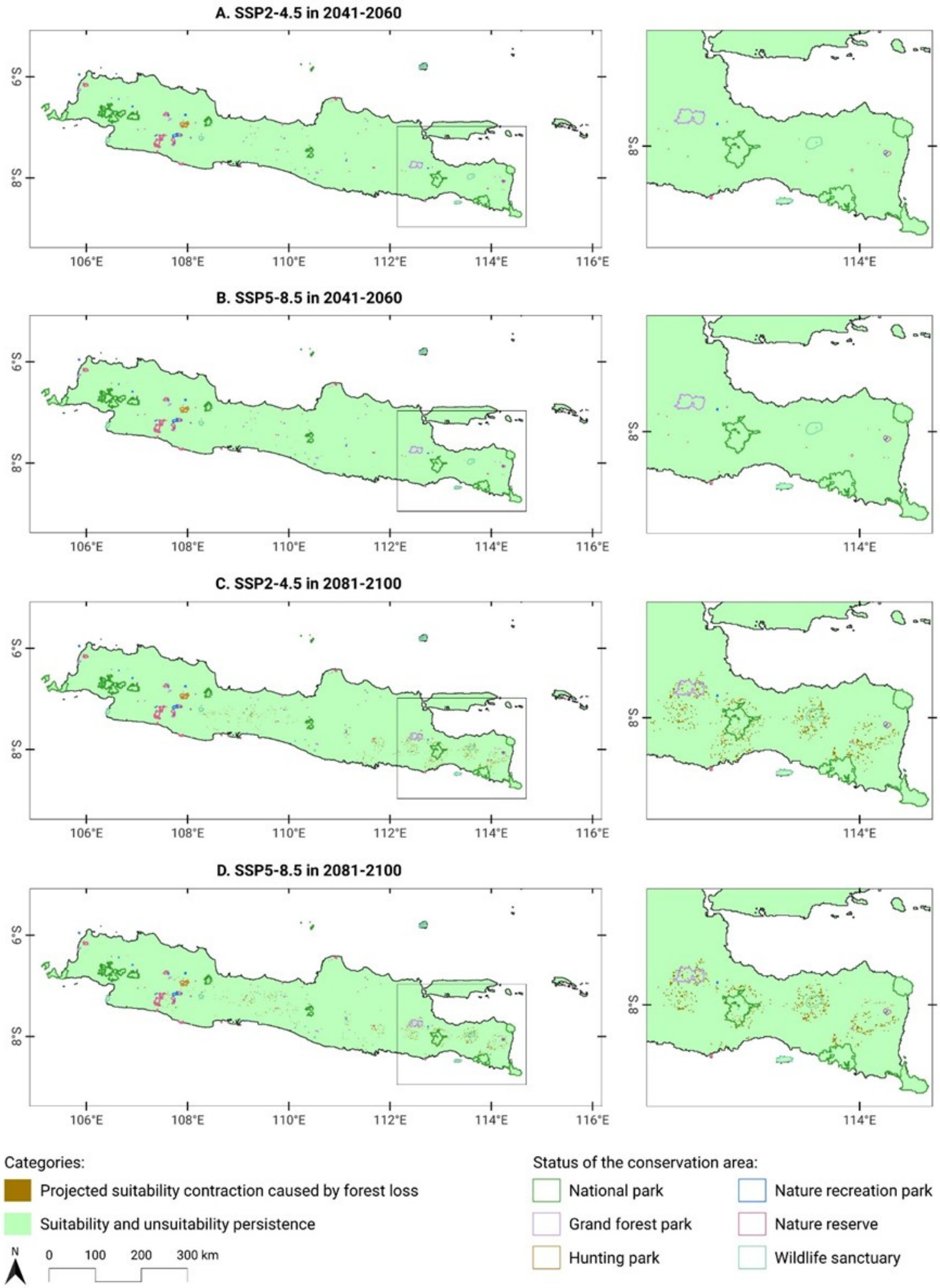

Fig. 4. *Ficus miqueliana*’s projected suitable habitat contraction caused by forest loss across conservation areas in Java.

verification and rediscovery programme is the highest priority. Targeted expeditions should prioritize climatically stable refugia predicted under the moderate emission scenario (SSP2-4.5, 2041–2060), where *F. trachycoma* may persist undetected and where *F. miqueliana* retains habitat continuity. These surveys will provide critical data on current population status, ecological requirements, and confirm the validity of model-identified refugia. Empirical work shows that SDM-guided surveys repeatedly improve detection efficiency and have led to rediscoveries or range extensions for rare taxa, making this the immediate operational priority (Sofaer *et al.,* 2019).

Secondly, an integrated ex-situ and in-situ protection must be established. For *F. miqueliana*, this involves formally designating current and projected refugia as key biodiversity areas for immediate in-situ protection. In parallel, ex-situ conservation measures – including seed banking, tissue culture, and other living collections – are essential to safeguard against catastrophic loss, especially under the high-emission pathway where the species is predicted to persist only in isolated montane fragments. The feasibility of this ex-situ approach is strongly supported by the biology of the *Ficus* genus; seeds of more than 50 fig species are known to be orthodox, making them highly suitable for long-term storage in seed banks (Anilkumar *et al.*, 2008; SER, INSR & RGBK, 2025). Seed banks and living collections are proven, cost-effective components of integrated conservation strategies and are essential when in-situ populations are fragmented or extremely small (Hoyle *et al.,* 2023).

Thirdly, a landscape-level management strategy is required. The predicted upslope migration underscores the need to maintain elevational connectivity across Java's fragmented forest landscapes. This involves management that extends beyond static protected areas, integrating buffer zones, ecological corridors, and restoration in production landscapes to facilitate dispersal and gene flow. Such an approach aligns with climate-adaptive conservation principles, which emphasize dynamic spatial planning in response to shifting species distributions. Evidence from Borneo demonstrates that proactively identifying and securing priority corridors can mitigate the combined pressures of warming and forest loss, underscoring the urgency of integrating connectivity into long-term conservation planning (Struebig *et al.,* 2024).

Model Limitations and Future Research

The primary limitation of this study stems from the scarcity of the species occurrence records, which restricts model reliability despite high AUC and TSS values. These metrics, derived from training data, may reflect overfitting rather than true predictive power, necessitating spatially independent validation such as block cross-validation. Reliance on a single GCM (MIROC6) – although having strong performance in Southeast Asia (Nguyen *et al.,* 2024) and discrepancies between contribution and permutation importance further constrain robustness. The mismatch between historical EOO and modeled distribution signals ongoing range contraction from habitat loss, as evidenced by forest cover decline in East Java (Global Forest Watch, 2023).

Future research should prioritize field surveys to expand occurrence data and validate projections, incorporating multi-model ensembles for greater reliability. To maximize conservation impact, we recommend for scaling this approach beyond single-species assessment. Extending analyses to co-occurring *Ficus* species or community-level of key plant functional groups – such as *Ficus* and other keystone taxa – across the entire Java or even multiple islands. Such landscape-scale analyses would be critical for identifying shared climate refugia and establishing interconnected conservation networks that enhance ecosystem resilience, moving from species-specific to biodiversity-centric conservation planning.

CONCLUSION

This study provides assessments of extinction risk for two endemic figs of Java: *Ficus trachycoma* Miq. and *Ficus miqueliana* C.C. Berg, under the IUCN Red List Criteria Version 3.1. *Ficus trachycoma* is confirmed to face the highest extinction risk, meeting the criteria for Critically Endangered CR B1ab(iii)+2ab (iii). *Ficus miqueliana* is assessed as Endangered EN B1ab(iii)+2ab(iii). These assessments emphasize the urgent need for conservation measures to prevent further decline.

Complementing the conservation assessments, the habitat suitability model for *F. miqueliana* demonstrated high predictive accuracy, identifying temperature seasonality and precipitation during the wettest, warmest, and coldest quarter as the primary niche drivers. Its current suitable habitat is highly fragmented, covering approximately 16,233 km^2 of lowland and foothill forests in Java. Future projections under CMIP6 scenarios reveal considerable range contraction, indicates a pronounced contraction, fragmentation, and upslope displacement of suitable habitat. Under moderate emissions scenarios (SSP2-4.5), the species may find refuge in montane areas, continued to upslope shift with increased fragmentation. High-emission scenarios (SSP5-8.5) predict severe contraction and isolation into small, fragmented patches, that increased extinction risk. Understanding this climatic sensitivity is critical for anticipating the species' response to future environmental changes.

Based on these findings, conservation efforts must prioritize the verification of extant populations, protection of climatically stable refugia, and maintenance of elevational connectivity to facilitate upslope migration. An integrated, evidence-based conservation strategy that includes in-situ protection, ex-situ measures such as ex-situ banking, and connectivity restoration is essential to safeguard these keystone endemics against compound climate and land-use threats.

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