Nature Conservation

Nature Conservation 64: 27–40 (2026)
DOI: 10.3897/natureconservation.64.172897

Research Article

Population, expanded distribution, and conservation of the Sumatran endemic tree *Magnolia sumatrae* (Dandy) Figlar & Noot.

Zulfan Arico[1], Wendy A. Mustaqim[1,2,3], Aryo Adhi Condro[4], Angga Yudaputra[5], Dipta S. Rinandio[2,5], Jean Linsky[6], Enggal Primananda[2,5], Iyan Robiansyah[2,5]

1 *Program Studi Biologi, Fakultas Sains dan Teknologi, Universitas Samudra, Jl. Prof. Dr. Syarief Thayeb, Meurandeh, Langsa Lama, Langsa, Aceh 24416, Indonesia*
2 *Forum Pohon Langka Indonesia (FPLI), Jl. Ir. H. Juanda 13, Bogor 16122, Jawa Barat, Indonesia*
3 *Tumbuhan Asli Nusantara Foundation, BTN Korpri Blok C1 No 96, Kawatuna, Mantikulore, Palu, Sulawesi Tengah 94233, Indonesia*
4 *Tropical Biodiversity Conservation Program, Department of Forest Resources Conservation and Ecotourism, IPB University, Bogor 16680, Jawa Barat, Indonesia*
5 *Research Center for Biota Systems - BRIN, Jl. Raya Jakarta-Bogor Km. 46, Bogor 16911, Jawa Barat, Indonesia*
6 *Atlanta Botanical Garden, 1345 Piedmont Avenue, Atlanta, GA 30309, USA*

Corresponding author: Wendy A. Mustaqim (wendyachmmadm@gmail.com)

Abstract

Data deficiency remains a major constraint in understanding the extinction risk and conservation of *Magnolia* species globally. *Magnolia sumatrae* (Dandy) Figlar & Noot. is one of the Indonesian *Magnolia* species assessed as Data Deficient by the IUCN Red List. It is a tree endemic to Sumatra Island and is known only from Mount Singgalang, Mount Talamau, and Gunung Leuser National Park. In the present study, population surveys of *M. sumatrae* were conducted in the previously known locations. Additionally, new records of the species in Aceh Tengah Regency, Aceh Province, are reported, which represent its northernmost distribution on Sumatra Island. The implications of these new records for the conservation status of the species are discussed. To ensure the future survival of *M. sumatrae*, plant materials of the species have been collected to serve as *ex situ* collections for the first time and become the 11th *Magnolia* native to the country available in the Indonesian *ex situ* collections. Using species distribution modeling methods, the potential distribution of the species is also presented, which predicts the potential habitat in Sumatera Utara Province, where no records have been available so far.

Key words: Data Deficient, IUCN Red List, Magnoliaceae, species distribution modeling, threatened tree

OPEN ACCESS

Academic editor: Yuanjun Zhu
Received: 23 September 2025
Accepted: 28 April 2026
Published: 1 June 2026

ZooBank: https://zoobank.org/EA9C2B2E-F3A0-4B52-9BAD-24F46831AEFA

Citation: Arico Z, Mustaqim WA, Condro AA, Yudaputra A, Rinandio DS, Linsky J, Primananda E, Robiansyah I (2026) Population, expanded distribution, and conservation of the Sumatran endemic tree *Magnolia sumatrae* (Dandy) Figlar & Noot.. Nature Conservation 64: 27–40. https://doi.org/10.3897/natureconservation.64.172897

Introduction

Magnolia Plum ex. L. is a plant genus in the family Magnoliaceae with approximately 371 species (POWO 2025). The genus is widely distributed in tropical and temperate regions, with China having the highest richness of *Magnolia* species (114), followed by Vietnam (56), Colombia (37), and Mexico (35) (Linsky et al. 2022). It is one of the most threatened plant taxa in the world. Of 344 species that have been assessed for their extinction risk by the IUCN Red List (IUCN 2025), 190 species, or more than 55%, are threatened with extinction, with the categories of Critically Endangered (55 species), Endangered (103 species), and Vulnerable (32 species). The main threats to *Magnolia* are related to silviculture, agriculture, and ranching (Rivers et al. 2016; Linsky et al. 2022).

Despite most of the species within the genus having been assessed for their conservation status, data deficiency remains a major constraint in understanding the extinction risk and conservation of *Magnolia* species globally. There are a total of 98 species that are assessed as Data Deficient (IUCN 2025). These species are distributed in 31 countries, with the highest number found in China (50 species) and Indonesia (20 species). For Indonesia, the number is exceptionally high and equal to 70% of the total number of *Magnolia* species found in the country.

Magnolia sumatrae (Dandy) Figlar & Noot. is one of the Indonesian *Magnolia* species assessed as Data Deficient (Khela 2014). The species has two synonyms: *Michelia sumatrae* Dandy and *Michelia salicifolia* A.Agostini (Figlar and Nooteboom 2004). It is a tree endemic to Sumatra Island and was first described based on a type specimen collected from Mount Singgalang in Sumatra Barat Province in 1878 (Dandy 1928; Nooteboom 1988). The species was located in two other locations in Sumatra later on: Mount Talamau in Sumatra Barat in 1984 and Gunung Leuser National Park in Aceh Province in 1975 and 1979 (GBIF 2023). *Magnolia sumatrae* is currently not included on the list of protected plant species in Indonesia and has not been conserved in *ex situ* collections (BGCI 2025).

To update the conservation status of *M. sumatrae*, population surveys were conducted in the previously known locations of the species. Additionally, new locations were reported, along with population data and associated habitat characteristics. During general vegetation surveys in the regencies of Bener Meriah and Aceh Tengah, Aceh Province, a *Magnolia* species whose vegetative and reproductive characteristics matched those of *M. sumatrae* was encountered. This finding becomes a new record for *M. sumatrae* and represents the northernmost distribution of the species. Here, the implication of this new record to the conservation status of the species is discussed. To ensure the future survival of *M. sumatrae*, plant materials of the species have been collected to serve as *ex situ* collections for the first time. Using species distribution modeling methods, the potential distribution of the species is also presented to assist future surveys and population recovery programs of the species.

Material and methods

Study sites

The search for *M. sumatrae* was conducted in the previously known locations of the species on Mount Leuser and Mount Bandahar in Gunung Leuser National Park in Aceh Province, as well as on Mount Singgalang and Mount Talamau in Sumatera Barat Province. For the newly recorded locations, vegetation surveys were initially conducted in 14 locations: seven locations (Bur Oregon, Mutiara Baru, Oregon Tingkem, Pantan Sile, Rembele, Radio Republik Indonesia tower, and Uning Tritit) in Bener Meriah Regency and seven locations (Burni Bias, Burni Pepanyi, Burni Lintang, Tapak Moge, Gegarang, Pantan Reduk, and Berawang Baro) in Aceh Tengah Regency (Fig. 1). All these locations fall within the Sumatran montane rainforests, an ecoregion that consists of forests above 1,000 m above sea level that run from the north to the south of Sumatra Island

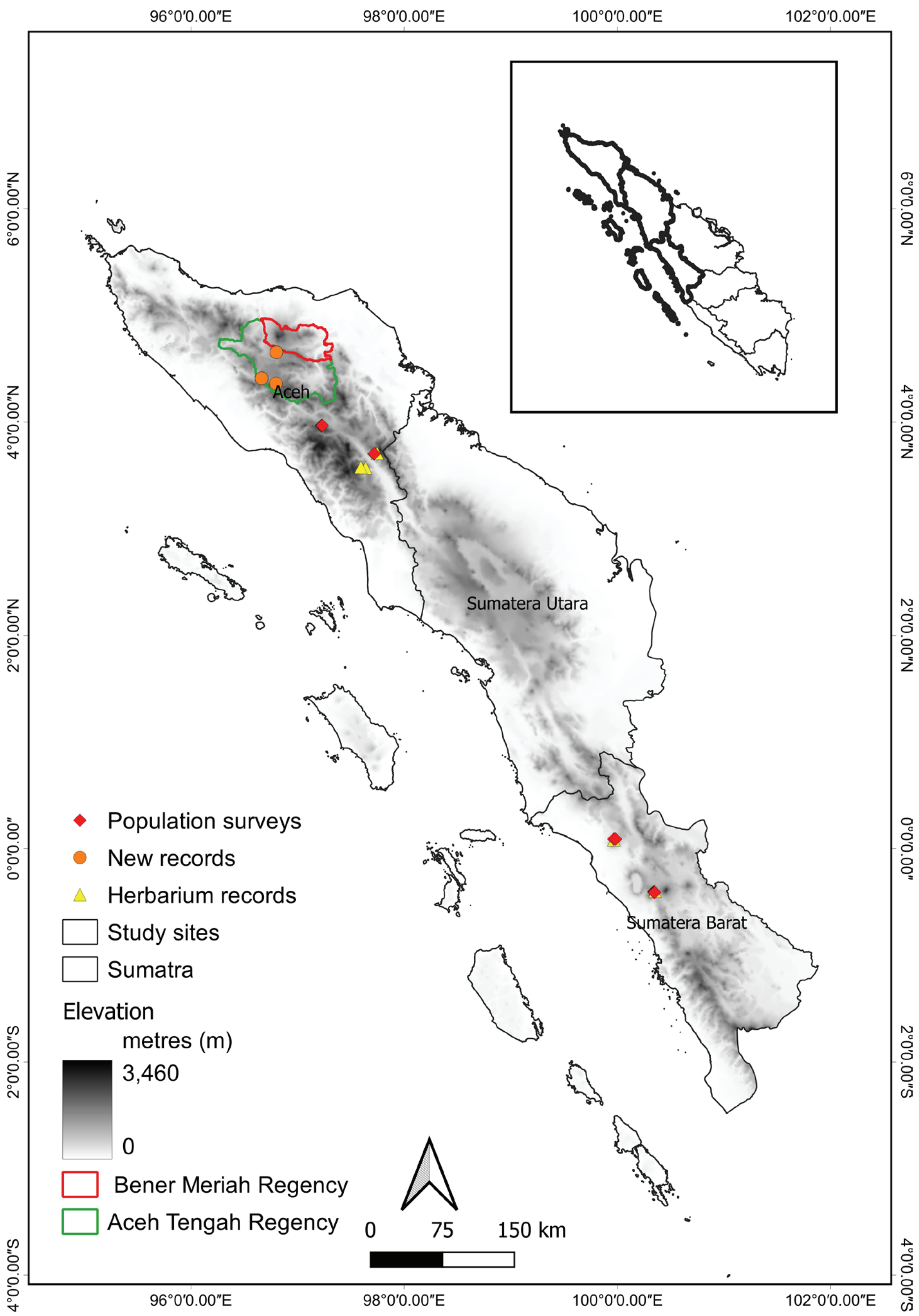

Figure 1. Study sites and distribution of *Magnolia sumatrae* in the provinces of Aceh and Sumatra Barat, Indonesia.

along the Barisan Mountain Range (Wikramanayake 2020). The ecoregion has mountainous topography, with the highest elevation of 2,600 m. It has an average air temperature of 21.38 °C and an average air humidity of 89.91% (BPS Kabupaten Bener Meriah 2021).

Population survey and plant material collection

For the newly recorded locations, the first individual of *M. sumatrae* was identified in Burni Pepanyi, Aceh Tengah Regency. Species identification was carried out using the identification key for Malesian *Magnolia* developed by Nooteboom (1988). Following this discovery, further population surveys were conducted using a focused survey method (Brewer 2013). When an individual of *M. sumatrae* was found, its location was recorded using a GPS receiver, and its diameter at breast height (dbh; cm) and height (m) were measured. The maturity of each individual was also assessed based on the presence of flowers or fruits. Additionally, the elevation (m), slope (°), and aspect (slope direction) of the site where the species was located were recorded. The same population and environmental variables were also measured at the previously known locations of the species. To support the conservation of *M. sumatrae*, plant materials were collected to serve as *ex situ* collections.

Conservation status assessment

Based on the findings, the conservation status of *M. sumatrae* was reassessed using Criterion B (geographic range) of the IUCN Red List, which includes two required subcriteria: number of locations and evidence of decline (IUCN 2012). The extent of occurrence (EOO) and area of occupancy (AOO) for Criterion B were calculated using the Geospatial Conservation Assessment Tool (GeoCAT; http://geocat.iucnredlist.org/; Bachman et al. 2011). A standard 2 × 2 km grid cell was used in these calculations.

Species distribution modeling

The potential distribution of *M. sumatrae* was predicted based on an ensemble model from Random Forest (RF) (Breiman 2001) and Support Vector Machine (SVM) (Noble 2006). A total of 94 occurrence records of *M. sumatrae* were used as the model input, which were obtained from the present study (89 records) and herbarium specimens (five records) stored in GBIF (2023). The environmental variables where the species was known to occur were used as inputs of the model; these include climate, topography, edaphic variables, and land cover. Five bioclimatic variables included annual mean temperature, mean diurnal range, temperature seasonality, precipitation of the wettest month, and precipitation seasonality, derived from the WorldClim 2.1 database (https://www.worldclim.org) with a spatial resolution of 30 arc-seconds (~1 km^2). These climate data represent conditions from 1970 to 2000 (Fick and Hijmans 2017). Topographic variables were derived from Shuttle Radar Topography Mission (SRTM) elevation data, also at a 30 arc-second (~1 km^2) resolution, obtained from the WorldClim platform (Fick and Hijmans 2017). The slope was subsequently calculated using these elevation data. The edaphic variables were derived from SoilGrids (http://soilgrids.org) at a 250 m spatial resolution. The soil properties collected included pH, soil organic carbon, nitrogen, and cation exchange capacity (Hengl et al. 2017). Land cover data were derived from the Moderate Resolution Imaging Spectroradiometer (MODIS), available at 500 m spatial resolution (Friedl and Sulla-Menashe 2019). All input variables were adjusted to 30 arc-seconds (~1 km^2) spatial resolution. The predictive map was then classified into two classes of habitat suitability: unsuitable and suitable. The areas of each class were calculated using QGIS tools. To determine which suitable areas overlapped with protected areas, the map of protected areas was derived from the Protected Planet database (UNEP-WCMC and IUCN 2025).

The modeling procedures were performed with the ‘sdm’ package in R (Naimi and Araújo 2016). Pseudo-absence data (*n* = 552) were generated because absence data are not available. The occurrence data were split at the following proportion: 80% for model training and 20% for testing. The model was run using a five-fold partition (Fielding and Bell 1997) to increase its accuracy. The area under the curve (AUC) evaluation metric and True Skill Statistics (TSS) were used to assess the performance of model predictions. The predictive map of current and future areas was classified into unsuitable (0–0.5) and suitable (0.51–1). The threshold value of 0.5 was derived from equal training sensitivity and specificity.

Results and discussion

Species identification and population status

Sumatra is a habitat for approximately 20 species of *Magnolia* (Mustaqim et al. 2021-onward; POWO 2025). The newly collected *Magnolia* from Aceh Tengah Regency can be differentiated from other Sumatran *Magnolia* and firmly identified as *M. sumatrae* using a combination of the following characters (Nooteboom 1988): i) flower buds arising on brachyblasts in the axils of the leaves, ii) petiole longer than 5 mm, iii) young twig hairy, iv) stipules free from petiole or adnate to its base only, v) brachyblast 3–7 mm, vi) leaves 9–13 by 2.3–4 cm, glaucous beneath, and vii) carpels *c.* 30. The species is morphologically similar to *M. philippinensis* P.Parm., which differs from the former species by shorter tepals and fewer carpels. In addition, *M. philippinensis* is only known from Thailand and the Philippines (Nooteboom 1988; POWO 2025). Fig. 2 shows the morphological appearance of *M. sumatrae* in the new localities.

During vegetation analysis at 14 locations in Bener Meriah and Aceh Tengah regencies, a total of 145 individuals of *M. sumatrae* were recorded from only three locations in Aceh Tengah Regency: 88 individuals in Burni Pepanyi, one individual in Pantan Reduk, and 56 individuals in Berawang Baro (Fig. 1). The species was not found in the other 11 locations. In these new locations, the largest individual observed had a height of up to 12 m and a dbh of up to 28 cm. In contrast, population surveys in the previously known locations recorded a total of 166 individuals: 21 on Mount Leuser, 62 on Mount Bendahara, 73 on Mount Singgalang, and 10 on Mount Talamau. Compared to those in the new locations, individuals in these areas were generally larger, with the largest observed individual having a dbh of up to 100 cm and a height of 25 m.

The majority of *M. sumatrae* individuals at all study sites are immature, with a dbh of less than 5 cm (Fig. 3). A total of 69 mature individuals were observed, with the highest number recorded on Mount Singgalang and in Berawang Baro, each with 23 individuals, followed by Burni Pepanyi with nine individuals, Mount Bendahara with seven individuals, Mount Leuser with five individuals, and Mount Talamau with two individuals. Fig. 3 shows that the population structure of *M. sumatrae* at all locations generally follows an inverse J-shaped pattern, indicated by a high number of individuals in the lower dbh classes, followed by a gradual decrease in the higher classes. This type of population structure is commonly observed in tree species of rainforests (Knight 1975; Rollet 1978) and indicates a good regeneration capacity of the population (Kimmins 1987). However, dis-

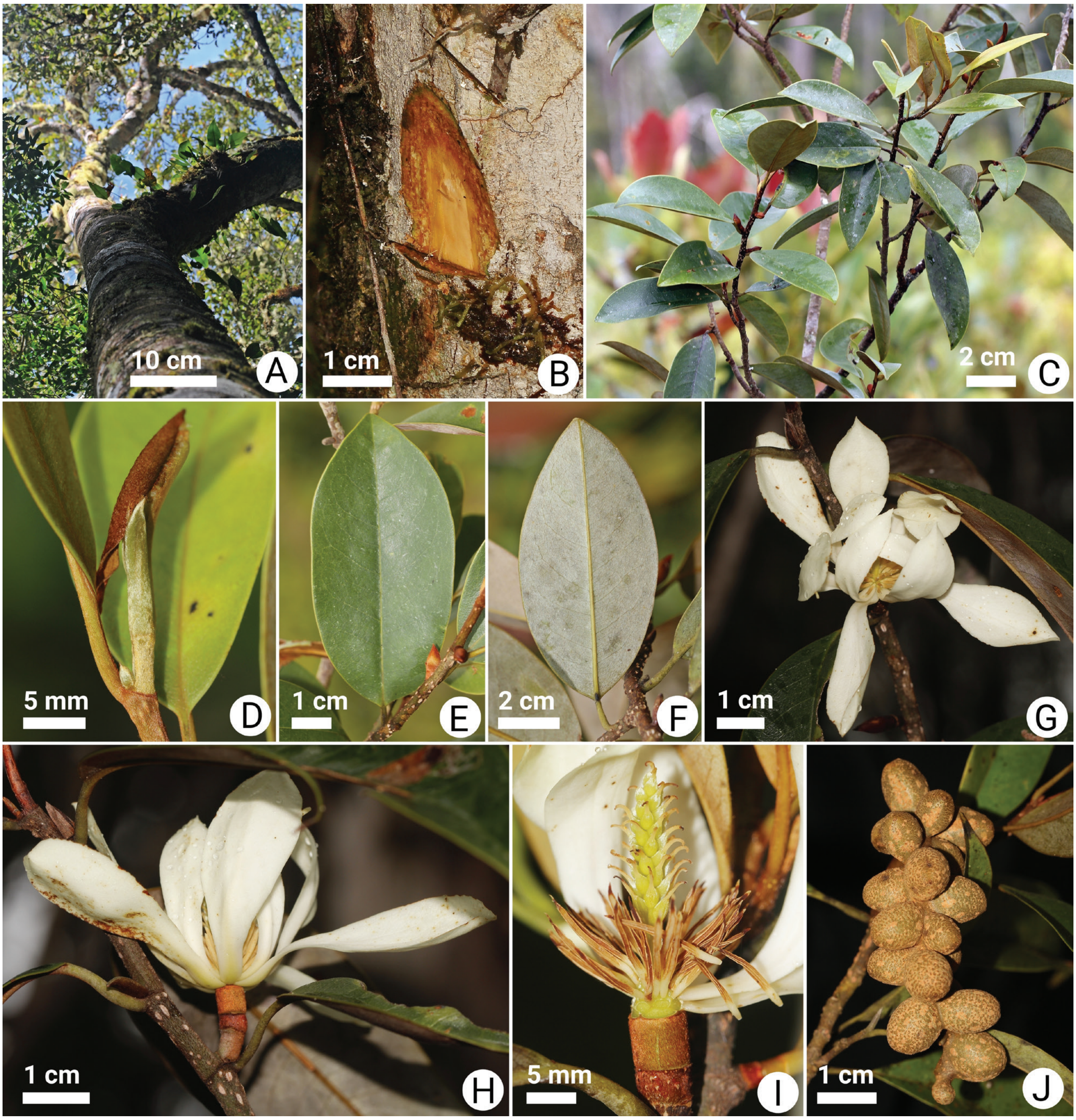

Figure 2. The morphological appearance of *Magnolia sumatrae*. **A.** Trunk; **B.** Slashed bark; **C.** Leafy twigs; **D.** Young twig and bud; **E.** Leaf, adaxial; **F.** Leaf, abaxial, with glaucous surface beneath; **G–H.** Flower; **I.** Stamens and pistils; **J.** Fruits. Photos: Wendy A. Mustaqim.

ruption of this pattern was observed in some populations, such as on Mount Talamau, which may be due to the influence of successional processes in the forest and disturbances that occurred there (e.g., D'Amato et al. 2008). Further studies are required to confirm the cause of the observed population structure.

While those in the previously known locations were found in montane forests at an elevation range of 1,769–2,461 m, all individuals of *M. sumatrae* in the new locations in Aceh Tengah Regency (Burni Pepanyi, Pantan Reduk, and Berawang Baro) were found in relatively flat tropical montane bogs with an elevation range of 1,415–1,732 m. These elevations are generally still within the elevation range (1,500–2,600 m) of the species recorded previously (Nooteboom

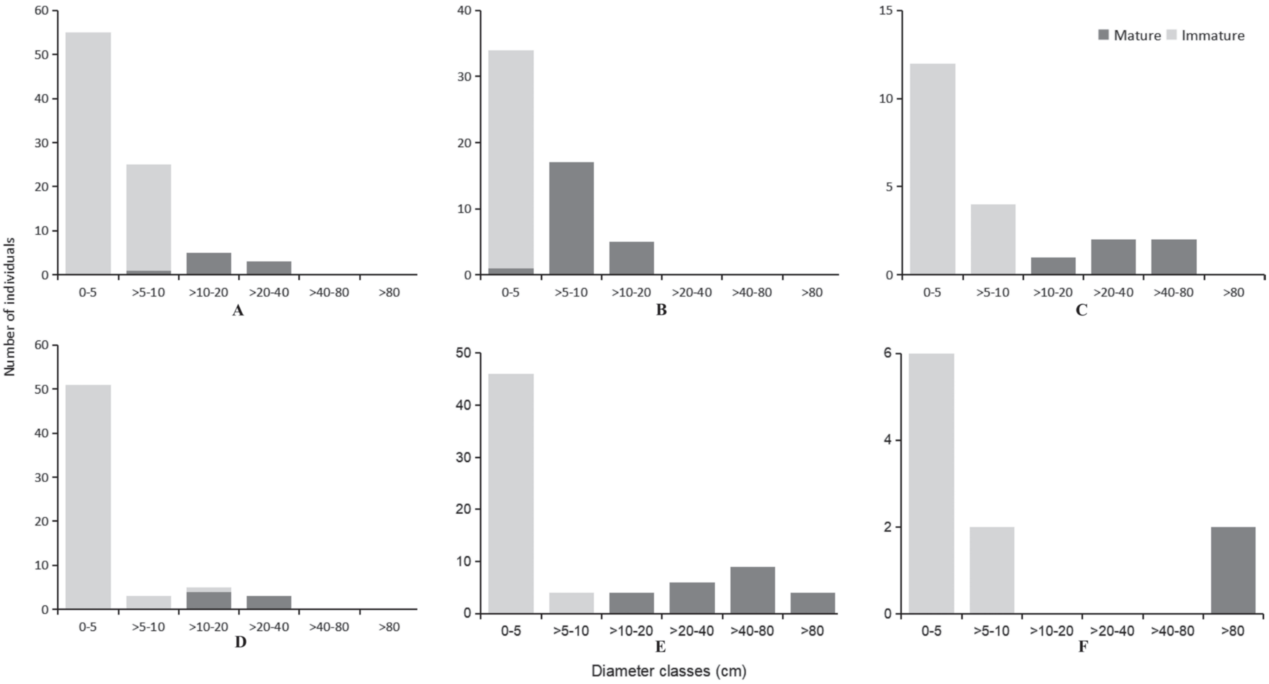

Figure 3. Population structure of *Magnolia sumatrae* based on the diameter at breast height (dbh) classes. **A.** Burni Pepanyi; **B.** Berawang Baro; **C.** Mount Leuser; **D.** Mount Bendahara; **E.** Mount Singgalang; **F.** Mount Talamau.

1988; Bijmoer et al. 2023), except for those in Berawang Baro, which are found at a slightly lower elevation of 1,415 m. Compared to other Sumatran endemic *Magnolia*, the elevation range of *M. sumatrae* is higher than that of *M. sumatrana* (Miq.) Figlar & Noot. (600–1,300 m) but similar to that of *M. calophylloides* Figlar & Noot. (2,000–2,200 m) (Nooteboom 1988) and *M. banghamii* (Noot.) Figlar & Noot. (1,100–1,750 m) (Robiansyah et al. 2023). Tropical montane bogs have not been mentioned as the habitat of *M. sumatrae* in previous publications (e.g., Dandy 1928; Nooteboom 1988; Figlar and Nooteboom 2004) and therefore become new information for the species. In addition to *M. virginiana* L., *M. sumatrae* is one of the only *Magnolia* species now known to grow in a bog habitat (Simmons and Strong 2002).

While forests in previously known locations are protected within either national parks (Mount Leuser and Mount Bendahara) or nature reserves (Mount Singgalang and Mount Talamau), the areas where *M. sumatrae* was found in Burni Pepanyi, Pantan Reduk, and Berawang Baro are currently not protected under national or local regulations. Forest degradation and conversion into agricultural fields and coffee plantations were observed as the main threats to the species in these new locations. In these areas, the species grows in small bog fragments that have been heavily degraded and are situated in the middle of vegetable fields and coffee plantations. The same threats were also reported to threaten *M. banghamii* (Robiansyah et al. 2023), a narrow endemic tree confined to Aceh Tengah Regency. Aceh Tengah, together with Bener Meriah, are two regencies with the highest arabica coffee production in Aceh Province (BPS Provinsi Aceh 2019), with more than 67,949 people engaged in coffee farming in 2012 (Hikmah et al. 2014). Increasing the protection level of the habitats is required in the long term to ensure the conservation of *M. sumatrae* and its habitats in Burni Pepanyi, Pantan Reduk, and Berawang Baro. In addition, *ex situ* conservation is needed to ensure the future survival of the species.

***Ex situ* conservation**

To support the conservation and future survival of *M. sumatrae*, a total of six wildings of the species have been collected to serve as *ex situ* collections for the first time at the Bogor Botanic Gardens. Fruits produced by the mature individuals were not collected during the fieldwork, as their seeds were still immature and could not be germinated. *Ex situ* collections of the species will serve as: i) a backup should the *in situ* populations disappear, ensuring the long-term preservation of the species' genetic material; ii) a material source for population reinforcement programs (Prance 1997; Maunder et al. 2001); and iii) effective material for public display and awareness campaigns (Hurka et al. 2003).

Conservation status assessment

Among the five criteria used in the IUCN Red List, Criterion B is considered the easiest to complete (Robiansyah and Wardani 2020). The criterion is based on occurrence data that can be obtained from herbarium records, flora databases, and published scientific papers. Using the occurrence records from the present study and previously collected herbarium specimens, the EOO and AOO of *M. sumatrae* calculated by GeoCAT are 18,989 km^2 and 56 km^2, respectively. The number of locations is considered eight: six locations (Mount Leuser, Mount Bendahara, Mount Mamas, Burni Pepanyi, Pantan Reduk, and Berawang Baro) in Aceh and two locations (Mount Talamau and Mount Singgalang) in Sumatra Barat. Therefore, under Criterion B, the species qualifies for the category of Vulnerable (VU) B2ab(iii)+2ab(iii), i.e., EOO <20,000 km^2 (Criterion B1), AOO <2,000 km^2 (Criterion B2), number of locations ≤10 (subcriterion a), and inferred continuing decline in the area, extent, and quality of habitat (subcriterion b(iii)). Under this category, *M. sumatrae* is considered facing a high risk of extinction in the wild.

In the present study, only Criterion B was used to assess the extinction risk of *M. sumatrae*. Although population information for the species is available from the new localities and most of the previously known locations, the data are not conclusive enough to assess the species using Criterion C (small population size and decline) and Criterion D (very small or restricted population). Further population surveys on Mount Mamas in Gunung Leuser National Park, the only additional known location that has not yet been surveyed, are required to acquire better population size estimates across the full geographic distribution range.

Potential distribution

The ensemble model, by integrating two machine learning algorithms (SVM and RF), performs better in predicting the potential distribution of *Magnolia sumatrae*. The value of AUC for those algorithms is above 0.90, indicating that the performance of the ensemble model is excellent, while the value of TSS for those algorithms is above 0.80, indicating that the ensemble model has high discrimination ability, which is good at distinguishing between presence and absence. The value of AUC can represent the categories of predictive model performance: a model with AUC in the range of 0.9–1 (excellent), 0.8–0.9 (good), 0.7–0.8 (fair), 0.6–0.7 (poor), and 0.5–0.6 (fail) (Krzanowski and Hand 2009). TSS statistics can be interpreted in several categories: values <0.4 are poor, 0.4–0.8 are useful, and >0.8 are good to excellent (Allouche et al. 2006). The index ranges from 0 to 1, with 0 indicating that none of the predictions corresponded to any observations and 1 indicating that predictions perfectly fit observations without any false negatives or false positives (Leroy et al. 2018). The use of the ensemble model is known to reduce uncertainties found in various single-model algorithms and thus provide more accurate predictions (Marmion et al. 2009; Grenouillet et al. 2011). This study found that the most prominent environmental predictor of *M. sumatrae* distribution is annual mean temperature, followed by elevation and precipitation seasonality (Fig. 5). Other variables contribute less to the suitable distribution of this species. Annual temperature is predicted as the most important variable that determines the potential distribution of this species. Commonly, *Magnolia* spp. are reported to grow at an annual average temperature of between 20 and 26.4 °C (Kinho et al. 2022), while *M. sumatrae* has an optimum temperature between 15 and 20 °C. *Magnolia sumatrae* will likely favor highland areas, with an elevation from 1,415 to 2,461 m above sea level based on direct field surveys. It is aligned with the ensemble model prediction, which predicts suitable habitats for *M. sumatrae* between 1,000 and 2,500 m, but the optimum required elevation is approximately 1,500 to 1,800 m above sea level. This is in line with the current distribution of the species, which is strongly associated with higher montane elevation (Nooteboom 1988; Bijmoer et al. 2023). The third most contributing variable is precipitation seasonality, with the value of precipitation seasonality for the suitable habitats between 25 and 45. It suggests that *M. sumatrae* is likely well adapted to environments with wet and moderately dry periods, such as tropical montane forests with short dry seasons or mist-fed ecosystems where seasonality is buffered by cloud cover. Tropical montane forests are typically at 1,500 to 3,300 m with high levels of cloud cover and abundant moisture.

The habitat suitability map of *M. sumatrae* (Fig. 4) shows that the species' niche occurs across the montane areas of Aceh, Sumatra Utara, and Sumatra Barat provinces. The total area of the current predicted distribution of the species is 2,103.76 km square, covering approximately 0.74% of the study sites in the three provinces. Aceh Province has the highest potential distribution of *M. sumatrae*, with a total area of approximately 1,136.03 ha, whereas Sumatra Utara and Sumatra Barat have total areas of 546.78 ha and 420.6 ha, respectively. Approximately 38% of the potential distribution of the species is located within protected areas. Gunung Leuser National Park, Kerinci Seblat National Park, Batang Gadis National Park, Barumun National Park, and Gunung Marapi Nature Recreation Park are predicted as suitable areas for *M. sumatrae*.

Conservation implications

The montane bog vegetation where the newly recorded specimens of *M. sumatrae* were collected is new habitat information for the species. The habitats are currently unprotected and under threat from coffee plantations. Increasing the protection level of these habitats is important to conserve and maintain the genetic diversity of *M. sumatrae*. Wildings of the species have been collected from the Mount Bendahara area to serve as *ex situ* collections and become the 11th Indonesian native *Magnolia* species available in the *ex situ* collections in the country (see Pusdatin BRIN 2025). These collections are effective media

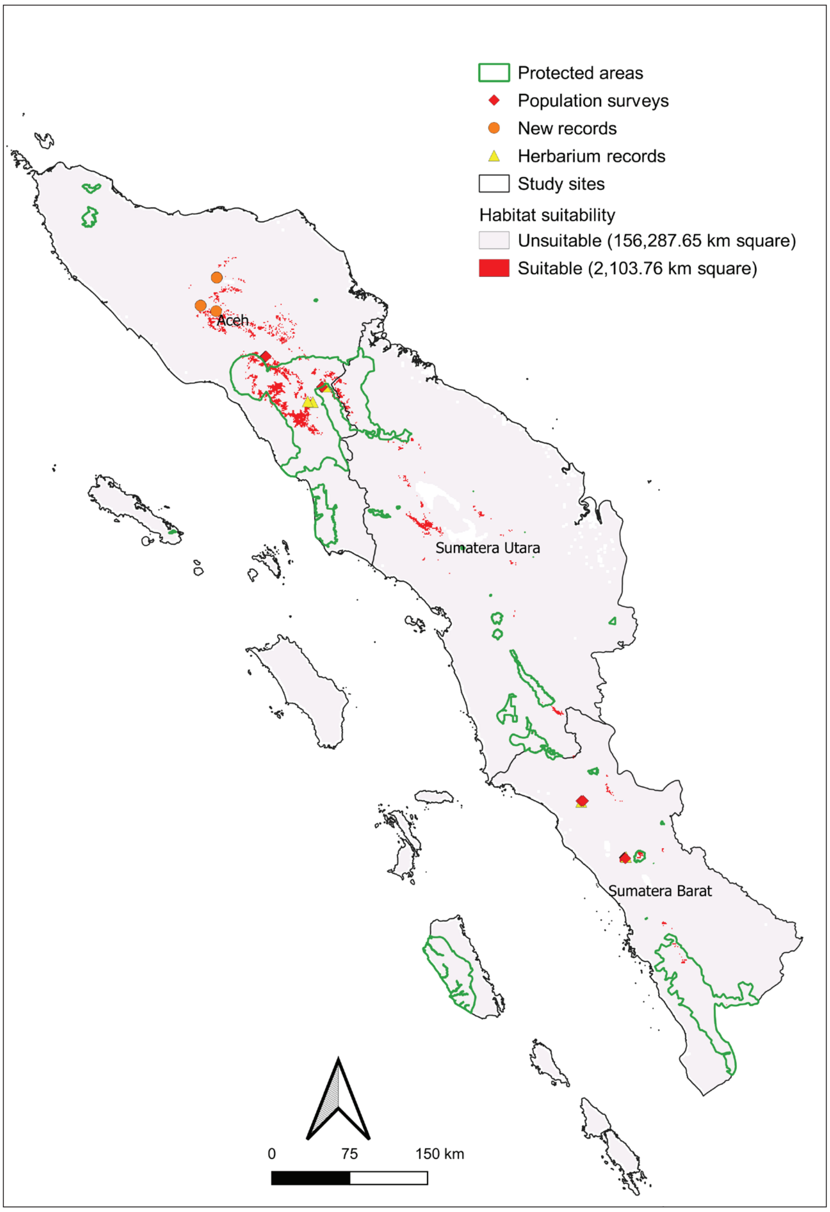

Figure 4. Predictive current potential distribution of *Magnolia sumatrae* using the ensemble model.

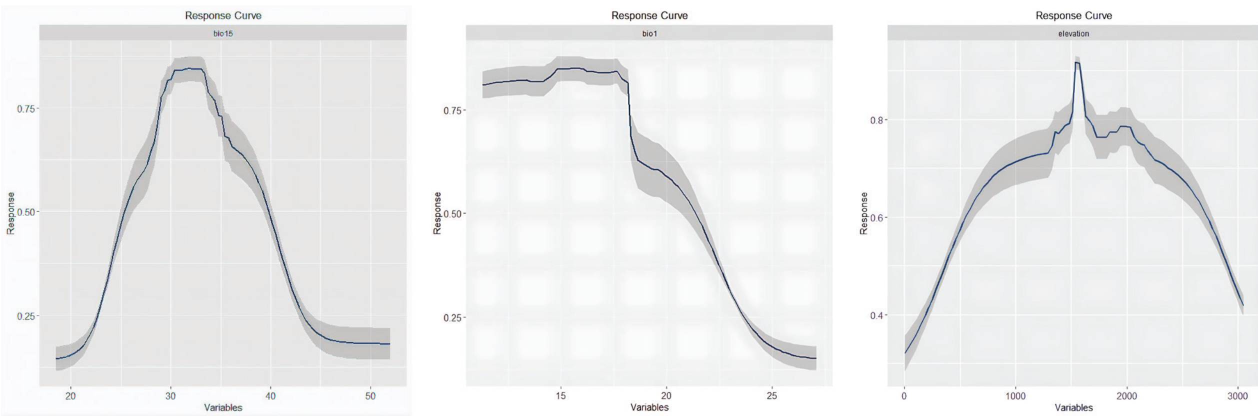

Figure 5. Response curve of the three most contributing factors for predicting the habitat suitability of *Magnolia sumatrae*. **A.** Annual mean temperature; **B.** Elevation; **C.** Precipitation seasonality.

for awareness campaigns regarding threatened plant conservation and their habitat. In addition, they can become material sources for propagation and future population reinforcement programs of the species.

Burni Pepanyi is part of the Burni Bias and Pepanyi Tropical Important Plant Areas (Mustaqim et al. 2025-onwards). *Magnolia sumatrae*, being a Sumatran endemic and potentially threatened species, should be listed as a priority species since the total number of individuals in this area comprises approximately 28.29%, which is above the threshold (≥10%) of the global population (Darbyshire et al. 2017). The population in Burni Pepanyi, for example, is also threatened by habitat conversion for agriculture and associated activities since it is located in privately owned forest fragments.

Concluding remarks and future plans

The results of the survey in the form of population data and threats, including the geographic records extension, successfully unearth the previously Data Deficient species, not only at the regional but also at the global level. This study is the second for Sumatran *Magnolia* after recent work in the northern part of the island, i.e., *Magnolia banghamii* (Robiansyah et al. 2023). The available data show a disjunct population of *M. sumatrae* in the northern and central parts of Sumatra. To determine whether the populations are truly distinct, further surveys in the Lake Toba area, especially the mountain range in the west, should be conducted due to its high potential for suitable habitats. Conservation of *M. sumatrae* can be achieved through formal *in situ* efforts, i.e., through the protected areas designated by the government, or by the involvement of local community initiatives that exist in its geographic range, i.e., local NGOs for the population in the northern Gayo Plateau. Further efforts to add *ex situ* collections should also be made, especially for the northern Gayo Plateau and Sumatera Barat populations.

Acknowledgments

The project was supported by research grants from the LPPM Universitas Samudra (Award Number 198/UN54.6/PT.01.03/2025); the Mohammed bin Zayed Species Conservation Fund (Award Number 232532157); the Atlanta Botanical Garden; the Magnolia Society International; LPPM Universitas Samudra; the American Rhododendron Society; and the International Association for Plant Taxonomy. The authors thank Taman Nasional Gunung Leuser, Cagar Alam Gunung Singgalang, and Dinas Kehutanan Provinsi Sumatera Barat for providing the research permit. Appreciation is also extended to the reviewers and editors for their constructive comments and suggestions.

References

Allouche O, Tsoar A, Kadmon R (2006) Assessing the accuracy of species distribution models: prevalence, kappa and the True Skill Statistic (TSS). Journal of Applied Ecology 43: 1223–1232. https://doi.org/10.1111/j.1365-2664.2006.01214.x

Bachman S, Moat J, Hill AW, De La Torre J, Scott B (2011) Supporting red list threat assessments with GeoCAT: Geospatial conservation assessment tool. ZooKeys 150: 117–126. https://doi.org/10.3897/zookeys.150.2109

BGCI (2025) PlantSearch. Botanic Gardens Conservation International. Richmond, U.K. https://plantsearch.bgci.org [Accessed 24 March 2025]

Bijmoer R, Scherrenberg M, Creuwels J (2023) Naturalis Biodiversity Center (NL) – Botany. Naturalis Biodiversity Center. https://doi.org/10.15468/ib5ypt [accessed via GBIF.org. Accessed 19 October 2023]

BPS Kabupaten Bener Meriah (2021) Kabupaten Bener Meriah dalam Angka 2021. https://benermeriahkab.bps.go.id/publication/2021/02/26/e15932ef08f007e5921cf6b8/kabupaten-bener-meriah-dalam-angka-2021.html [Accessed 6 October 2023]

BPS Provinsi Aceh (2019) Provinsi Aceh Dalam Angka 2019. Badan Pusat Statistik Provinsi Aceh, Aceh, Indonesia.

Breiman L (2001) Random forests. Machine Learning 45: 5–32. https://doi.org/10.1023/A:1010933404324

Brewer S (2013) How to survey an area for threatened tree species. Fauna & Flora International, Cambridge. http://arbnet.org/sites/arbnet/files/GTC-Brief-1-hi-res_0.pdf

D'Amato AW, Orwig DA, Foster DR (2008) The influence of successional processes and disturbance on the structure of *Tsuga canadensis* forests. Ecological Applications 18(5): 1182–1199. https://doi.org/10.1890/07-0919.1

Dandy JE (1928) Malayan Magnolieae. Bulletin of Miscellaneous Information 5: 183–193. https://doi.org/10.2307/4107183

Darbyshire I, Anderson S, Asatryan A, Byfield A, Cheek M, Clubbe C, Ghrabi Z, Harris T, Heatubun CD, Kalema J, Magassouba S, McCarthy B, Milliken W, de Montmollin B, Nic Lughadha E, Onana JM, Saïdou D, Sârbu A, Shrestha K, Radford EA (2017) Important plant areas: Revised selection criteria for a global approach to plant conservation. Biodiversity and Conservation 26: 1767–1800. https://doi.org/10.1007/s10531-017-1336-6

Fick SE, Hijmans RJ (2017) WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37(12): 4302–4315. https://doi.org/10.1002/joc.5086

Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24: 38–49. https://doi.org/10.1017/S0376892997000088

Figlar RB, Nooteboom HP (2004) Notes on Magnoliaceae IV. Blumea-Biodiversity, Evolution and Biogeography of Plants 49: 87–100. https://doi.org/10.3767/000651904X486214

Friedl M, Sulla-Menashe D (2019) MCD12Q1 MODIS/Terra+ aqua land cover type yearly L3 global 500 m SIN grid V006. [No Title]

GBIF (2023) GBIF Occurrence Download. https://doi.org/10.15468/dl.67qagy

Grenouillet G, Buisson L, Casajus N, Lek S (2011) Ensemble modelling of species distribution: the effects of geographical and environmental ranges. Ecography 34: 9–17. https://doi.org/10.1111/j.1600-0587.2010.06152.x

Hengl T, Mendes de Jesus J, Heuvelink GB, Ruiperez Gonzalez M, Kilibarda M, Blagotić A, Wei S, Wright MB, Geng X, Bauer-Marschallinger B, Guevara MA, Vargas R, MacMillan RA, Batjes NH, Leenars JGB, Ribeiro E, Wheeler I, Mantel S, Kempen B (2017) SoilGrids250 m: Global gridded soil information based on machine learning. PLoS ONE 12(2): e0169748. https://doi.org/10.1371/journal.pone.0169748

Hikmah, Hamzah A, Nasir M (2014) Analisis produksi dan ekspor komoditas kopi arabica di Kabupaten Bener Meriah dan Kabupaten Aceh Tengah. Jurnal Ilmu Ekonomi: Program Pascasarjana Unsyiah 2: 22–30.

Hurka H, Neuffer B, Friesen N (2003) Plant genetic resources in botanical gardens. In XXI International Eucarpia Symposium on Classical versus Molecular Breeding of Ornamentals-Part II 651, 35–44. https://doi.org/10.17660/actahortic.2004.651.2

IUCN (2012) IUCN red list categories and criteria. Version 3.1. IUCN. Gland, Switzerland.

IUCN (2025) The IUCN Red List of Threatened Species. Version 2024-2. https://www.iucnredlist.org [Accessed 24 March 2025]

Khela S (2014) *Magnolia sumatrae*. The IUCN Red List of Threatened Species 2014: e.T15116826A15116832. https://doi.org/10.2305/IUCN.UK.2014-1.RLTS.T15116826A15116832.en [Accessed 7 October 2023]

Kimmins JP (1987) Forest Ecology. Macmillan Publishing Company, New York, 531 pp.

Kinho J, Arini DID, Abdulah L, Susanti R, Irawan A, Yulianti M, Subarudi Imanuddin R, Wardani M, Denny D, Kalima T, Hardjana AK, Susilo A, Heriansyah I, Tampang A (2022) Habitat characteristics of *Magnolia* based on spatial analysis: landscape protection to conserve endemic and endangered *Magnolia sulawesiana* Brambach, Noot., and Culmsee. Forests 13(5): art.802. https://doi.org/10.3390/f13050802

Knight DH (1975) A phytosociological analysis of species-rich tropical forest on Barro Colorado Island, Panama. Ecological Monographs 45: 259–284. https://doi.org/10.2307/1942424

Krzanowski WJ, Hand DJ (2009) ROC Curves for Continuous Data. Chapman and Hall/CRC. https://doi.org/10.1201/9781439800225

Leroy B, Delsol R, Hugueny B, Meynard CN, Barhoumi C, Barbet-Massin M, Bellard C (2018) Without quality presence–absence data, discrimination metrics such as TSS can be misleading measures of model performance. Journal of Biogeography 45: 1994–2002. https://doi.org/10.1111/jbi.13402

Linsky J, Crowley D, Beckman Bruns E, Coffey EED (2022) Global Conservation Gap Analysis of *Magnolia*. Atlanta Botanical Garden, Atlanta. https://www.globalconservationconsortia.org/resources/global-conservation-gap-analysis-of-magnolia/ [Accessed 6 October 2023]

Marmion M, Parviainen M, Luoto M, Heikkinen RK, Thuiller W (2009) Evaluation of consensus methods in predictive species distribution modelling. Diversity and Distributions 15: 59–69. https://doi.org/10.1111/j.1472-4642.2008.00491.x

Maunder M, Higgens S, Culham A (2001) The effectiveness of botanic garden collections in supporting plant conservation: A European case study. Biodiversity & Conservation 10: 383–401. https://doi.org/10.1023/a:1016666526878

Mustaqim WA, Saputra R, Al Farishy DD, Tianara A, Ahmad RPP, Zainudin, Kartonagoro A, Ritonga YE, Sitepu BS, Randi A, Ardi WH (2021 [onwards]) Digital Flora of Indonesia. Facilitated by Tumbuhan Asli Nusantara Foundation. www.indonesiaplants.org

Naimi B, Araújo MB (2016) sdm: A reproducible and extensible R platform for species distribution modelling. Ecography 39(4): 368–375. https://doi.org/10.1111/ecog.01881

Noble WS (2006) What is a support vector machine? Nature Biotechnology 24(12): 1565–1567. https://doi.org/10.1038/nbt1206-1565

Nooteboom HP (1988) Magnoliaceae. Flora Malesiana ser I 10: 561–605. https://doi.org/10.26525/fpm23007

POWO (2025) Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. http://www.plantsoftheworldonline.org/ [Accessed 24 March 2025]

Prance GT (1997) The conservation of botanical diversity. In: Maxted N, Ford-Lloyd BV, Hawkes JG (Eds) Plant Genetic Conservation. The in-situ approach, Chapman & Hall, London, 3–14.

Pusdatin BRIN (2025) Manajemen Koleksi Kebun Raya Indonesia (MAKOYANA). Pusat Data dan Informasi, Badan Riset dan Inovasi Nasional. https://makoyana.brin.go.id/

Rivers M, Beech E, Murphy L, Oldfield S (2016) The Red List of Magnoliaceae – Revised and extended. Botanic Gardens Conservation International. Richmond. https://

www.bgci.org/resources/bgci-tools-and-resources/the-red-list-of-magnoliaceae [Accessed 6 October 2023]

Robiansyah I, Primananda E, Mustaqim WA, Fauzan YSA, Mahardhika AY, Arico Z, Persada AY, Linsky J (2023) Population study and conservation of *Magnolia banghamii*, a narrow endemic tree in Sumatra Island, Indonesia. Magnolia. The Journal of the Magnolia Society International 58: 14–19.

Robiansyah I, Wardani W (2020) Increasing accuracy: The advantage of using open access species occurrence database in the Red List assessment. Biodiversitas 21: 3658–3664. https://doi.org/10.13057/biodiv/d210831

Rollet B (1978) Description, functioning and evolution of tropical forest ecosystems: Organization Tropical Forest Ecosystems. Unesco, Paris, 112–142.

Simmons R, Strong M (2002) Fall line *Magnolia* bogs in the mid-Atlantic region. Magnolia 74: 19–21.

UNEP-WCMC and IUCN (2025) Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM) [Online], April 2025, Cambridge, UK: UNEP-WCMC and IUCN. www.protectedplanet.net

Wikramanayake E (2020) Sumatran Montane Rainforests. https://www.oneearth.org/ecoregions/sumatran-montane-rainforests/ [Accessed 27 September 2023]

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
AI was used exclusively as a supportive tool for language editing and clarifying academic writing during manuscript preparation (Grammarly). The authors verified, carefully checked, and take full responsibility for the final version of the manuscript.

Funding

The project was funded by research grants from the LPPM Universitas Samudra (Award Number 198/UN54.6/PT.01.03/2025); the Mohammed bin Zayed Species Conservation Fund (Award Number 232532157); the Atlanta Botanical Garden; the Magnolia Society International; the American Rhododendron Society; and the International Association for Plant Taxonomy.

Author contributions

ZA, WAM, EP, IR, and JL were involved in the conception and funding acquisition. IR supervised and led the first draft of the manuscript. ZA, WAM, EP, and IR performed material preparation and collected the data from the field. ADC and AP analyzed the modeling data. EP and IR analyzed the population structure data. WAM and EP prepared the morphological figure. IR, WAM, EP, and JL assessed the conservation status. All authors contributed to writing, commenting, and reviewing the manuscript.

Author ORCIDs

Z. Arico https://orcid.org/0000-0002-7526-0777
W.A. Mustaqim https://orcid.org/0000-0001-9902-830X
A.A. Condro https://orcid.org/0000-0002-2069-6223
A. Yudaputra https://orcid.org/0000-0002-5232-5662
D.S. Rinandio https://orcid.org/0000-0001-8938-9574
J. Linsky https://orcid.org/0000-0002-3657-9283
E. Primananda https://orcid.org/0000-0002-1197-3815
I. Robiansyah https://orcid.org/0000-0002-0503-458X

Data availability

All of the data that support the findings of this study are available in the main text.