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Habitat Characteristics of *Magnolia* Based on Spatial Analysis: Landscape Protection to Conserve Endemic and Endangered *Magnolia sulawesiana* Brambach, Noot., and Culmsee

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Abstract: Based on habitat preferences, in this study, we investigated the spatial distribution of the *Magnolia* genus in the northern part of Sulawesi. Habitat characteristics, especially temperature, precipitation, and topography, were determined using spatial analysis. The temperature and precipitation datasets were obtained from WorldClim BIO Variables V1, and topographical data were obtained from the Google Earth Engine. Data collection began in 2008–2009 and was completed in 2019–2020. In total, we analyzed 786 waypoints. The genus distribution was then predicted based on the most suitable habitat characteristics and mapped spatially. This study confirmed that *Magnolia* spp. distribution is affected by the annual temperature range, precipitation seasonality, and elevation. We discovered endemic and endangered species, *Magnolia sulawesiana* Brambach, Noot., and Culmsee, that were previously distributed exclusively in the central part of Sulawesi. Five waypoints of the endemic species were found in the conservation area of the Gunung Ambang Nature Reserve and on the border of Bogani Nani Wartabone Nation Park. In general, *M. sulawesiana* is distributed at higher elevations than other *Magnolia* species. This study provides a scientific basis for forest officers to develop in-situ and ex-situ conservation strategies and landscape protection measures to maintain the sustainable use of the genus, especially the sustainability of endemic species.

Keywords: endemic; landscape protection; conservation; *Magnolia sulawesiana*; habitat characteristic; spatial distribution

1. Introduction

Magnolia (Fam. Magnoliaceae) is a plant genus that consists of more than 300 species [1–5]. This genus has a wide distribution in subtropical and tropical Asia and America [2,4,5]. The Magnolia genus includes evergreen and deciduous trees and shrubs [2,4], and many species are prominently used as ornamental plants, timber, medicinal raw materials, cosmetics, and essential oils [2,3,6–10]. Despite Magnolia's crucial uses, the assessment in [2] using the International Union for Conservation of Nature (IUCN) criteria resulted in 147 species of *Magnolia* being categorized as threatened (Critically Endangered, Endangered, and Vulnerable) due to various threats such as continued deforestation, habitat destruction, and over-harvesting.

In Indonesia, there are 28 species of *Magnolia* distributed in Sumatra, Java, Lesser Sunda Islands, Sulawesi, Moluccas, and Papua [2,7,10]. Among these species, one species was categorized as Threatened, i.e., *Magnolia sulawesiana* Brambach, Noot., and Culmsee (Endangered); one as Near Threatened (*M. borneensis*); five under Least Concern; and the rest under Data Deficiency. Indonesia is one of the countries with the least amount of information on *Magnolia,* especially for the threatened taxa [11].

The endangered *M. sulawesiana* is an endemic species that grows naturally only in three locations within the mountain range in the central part of Sulawesi [12]. Considering the increasing rate of forest-cover loss in Sulawesi, which was 10.98% between 2000 and 2007 [13], as well as the species' current red-list status as Endangered [2], it is crucial to find this endemic species in other areas of Sulawesi. The central parts of Sulawesi, including the Central and West Sulawesi Province, where *M. sulawesiana* was found, face deforestation rates of 0.68 and 0.84%, respectively [13]. Deforestation is not the only threat to *Magnolia*; overharvesting, poor fruiting, and low natural regeneration [11] also add pressure to the endemic species' vulnerability in the wild.

In Indonesia, overharvesting might become a real threat since Magnolia species are commercially traded. This is especially true for *M. sulawesiana* because it is challenging to distinguish *M. sulawesiana* wood from other Magnolia woods on the market. Magnolia species have a long historical connection with the Minahasa tribe, one of the tribes in the northern part of Sulawesi. The *Magnolia* woods are known as *Cempaka* or *Wasian* and were used as material to construct Woloan, a traditional Minahasa wooden house [14–16]. In the 1970s, when forest concession rightsholder companies began to operate in the production forest, *Magnolia* wood became prominent because of its good quality. In response to the high demand for *Magnolia* wood, local communities started to plant *Magnolia* species [17,18]. Today, the Minahasa district is known to have the largest community plantation forest containing *Magnolia* species among the areas in Sulawesi [15,19,20].

There is also *Magnolia cubensis* in Cuba, which is a highly endangered and endemic species that requires conservation measures. The need for conservation action was determined based on the findings of studies on the influence of habitat fragmentation on the species' population structure and genetic diversity [21]. In Western Mexico, *Magnolia granbarrancae*, *M. pugana*, *M. talpana*, and *M. vallartensis* are also critically endangered species because their extent of occurrence (EOO) and area of occupancy (AOO) are below the limits set by the IUCN, and they also have a low genetic diversity [22].

The spatial distribution of plant species is not the result of a random event but is influenced by environmental variables, especially climate and topography characteristics [23,24], as well as soil, temperature, hydrology, and spatial constraints, which affect plant distribution [25–29]. Information on the distribution of *Magnolia* spp. in North Sulawesi is crucial for conservation strategies and landscape protection. Understanding the habitat preferences and suitability of *Magnolia* spp. is also important to determine the species' functions in its surrounding community, including the associated animals [30]. An assessment conducted in China using climate and terrain variables demonstrated differing habitat preferences among *Magnolia* species [8]. Despite its importance for conservation strategies, this type of assessment has never been used for *Magnolia* species in Indonesia.

This study aims to identify the distribution of *Magnolia* species in the northern part of Sulawesi, including the endemic *M. sulawesiana*. We distinguished the habitat preferences of *Magnolia* and combined them with spatial data to estimate the potential species distribution. The discovery of *M. sulawesiana* distribution in the northern part of Sulawesi will lead to a new record of this species' distribution in the Wallacea bioregion [29], which features high species endemism but is still poorly understood.

2. Materials and Methods

2.1. Study Area and Targeted Species

This study was conducted in the northern part of Sulawesi Islands, Indonesia, covering an area of 13,892 km^2 (Figure 1). Most of the topography in this area features hills and mountains that are more than 1000 m above sea level (m asl), with steep contour intervals of less than 12.5 m.

The following Magnolia species [5,19] are known to exist in North Sulawesi: *Magnolia tsiampacca*, *M. tsiampacca* var. *tsiampacca*, *M. vrieseana*, *M. lilliifera*, *M. champaca*, and *M. candollei*. The endemic *M. sulawesiana*, which closely resembles *M. tsiampacca* var. *tsiampacca* [12], is the most common species in the study areas. Even though it is challenging to distinguish all species in the field, *M. sulawesiana* can be easily differentiated by its golden leaf color. Local people sometimes refer to *M. sulawesiana* as "gold Cempaka Wasian" because of its leaf color. In all study areas, we specifically distinguished *M. sulawesiana* and grouped other Magnolia species that were found as *Magnolia* spp.

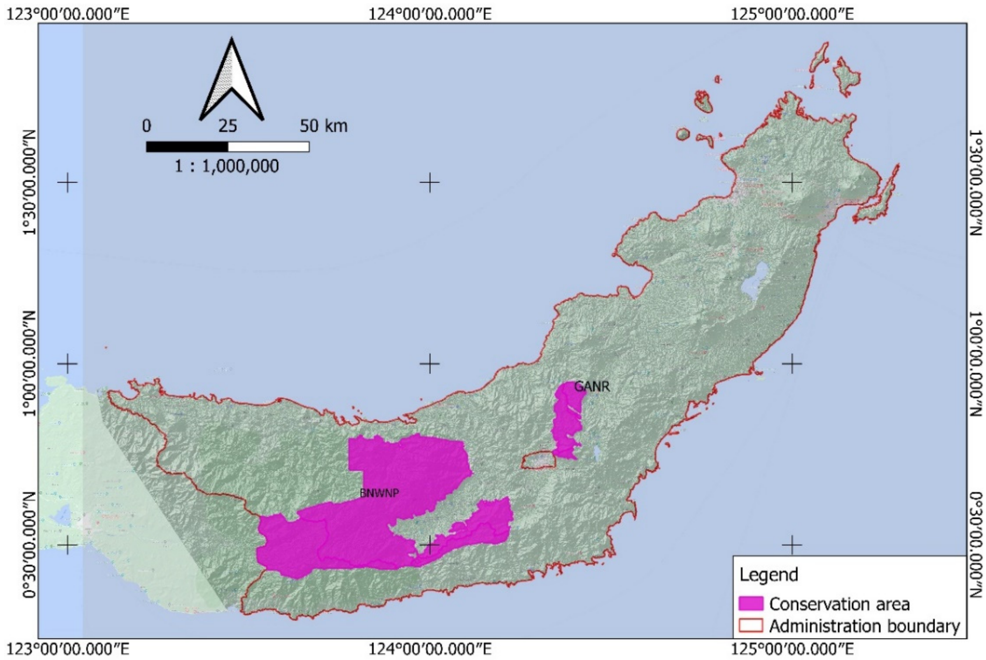

Figure 1. Study area in the northern part of Sulawesi: The purple color represents conservation areas of Bogani Nani Wartabone National Park (BNWNP) and the Gunung Ambang Nature Reserve (GANR).

A preliminary study was conducted to locate the *Magnolia* species in North Sulawesi by collecting information from the district forestry office, local herbarium data, local people, and the literature [19,31,32]. All information was subsequently mapped to produce a survey map. A field survey and ground check were then conducted twice to record the presence or absence of the genus. The first survey was conducted in 2008–2009, concentrating in the western part, and the second in 2019–2020 for the eastern part of North Sulawesi. In all locations in which *Magnolia* trees (diameter at breast height > 15 cm) were found, we recorded the geographical positioning system coordinates as waypoint data. Associated species found around *Magnolia* spp. were also recorded. We recorded 786 waypoints for *Magnolia* spp., 5 of which were for the endemic species *M. sulawesiana.*

2.2. Habitat Characteristics

Habitat characteristics were analyzed using a hierarchical approach with parameters for the criteria, indicators, and verifiers based on those in [8] as presented in Table 1. A flowchart of this methodology used in the present study is presented in Figure 2. The first parameter used was temperature, which was divided into several indicators as shown in Table 2 [33]. We also included land surface temperature (LST), which was derived from the MODIS_LST dataset. This dataset provides daily surface temperature information with a spatial resolution of 1 km [34]. The temperature data were collected from the WorldClim BIO Variables V1 dataset [35].

Table 1. Parameters analyzed in each data category.

Temperature	Precipitation	Topography
AMT	AP	E (Elevation)
DRT	PDM	S (slope)
MinT	PWM	A (Aspect)
MaxT	PCQ	
TAR	PWQ	
TS	PDQ	
LST	PWEQ	
Isot	PS	

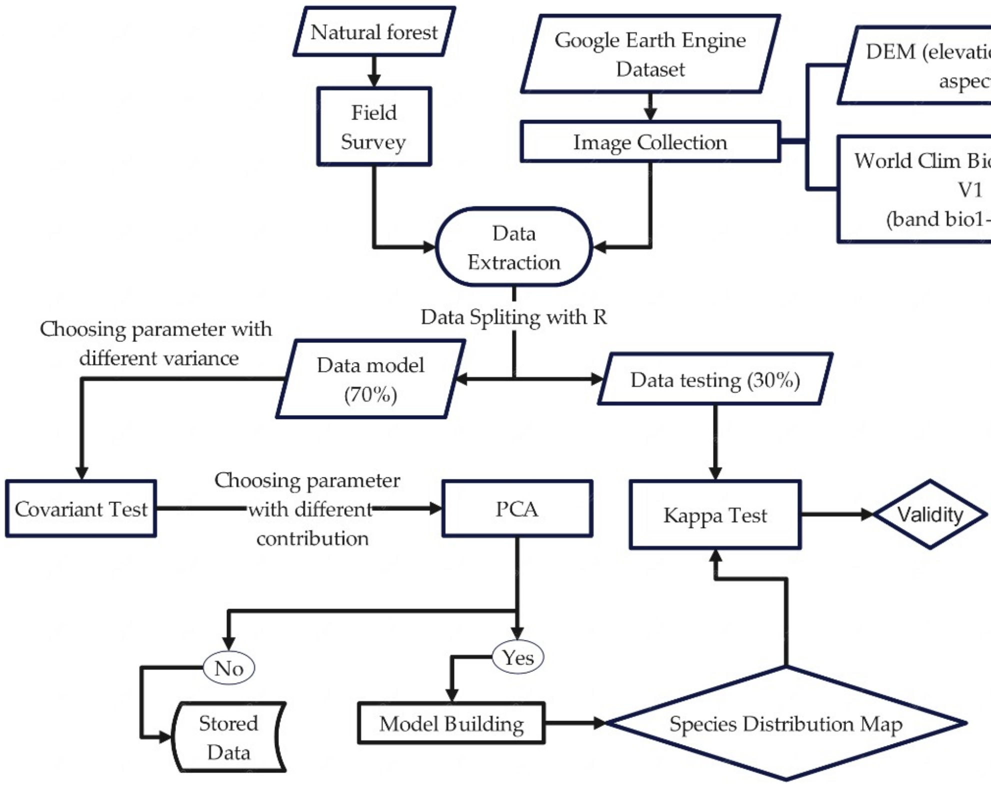

Figure 2. Flowchart of the methodology used to identify *Magnolia* and *M. sulawesiana* distribution.

Table 2. Classification of *Magnolia* spp. distribution prediction based on covariance model analysis.

Class	Description
1	Not a natural distribution area because the parameter values are out of range.
2	Possible distribution area of *Magnolia* spp. Because one of the parameter values is within range.
3	Possible distribution area of *Magnolia* spp. Because two of the parameter values are within range (elevation and temperature annual range).
4	Possible distribution area of *Magnolia* spp. Because two of the parameter values are within range (elevation and precipitation seasonality).
5	Possible distribution area of *Magnolia* spp. because two of the parameter values are within range (temperature annual range and precipitation seasonality).
6	High possible distribution area because all parameter values are within range.

Notes:

- Annual mean temperature (AMT) is the average temperature each year based on the ratio of energy obtained by the ecosystem and the duration of the covered times.
- Diurnal range temperature (DRT) records the daily temperature fluctuations obtained from the maximum and minimum daily temperature differences in a period.
- Maximum temperature (MaxT) is an indicator that states the highest daily temperature in the month with the hottest temperature in each season of the year.
- Minimum temperature (MinT) is the lowest temperature in the coldest month, which varies from year to year. As a result, the lowest temperature will be average.
- Temperature annual range (TAR) is an indicator that states the differences between MaxT and MinT.
- Temperature seasonality (TS) is a periodic temperature indicator of the daily average and deviation of temperature.
- Annual precipitation (AP) expressed in mm/year is the average yearly rainfall in the observation period.
- Precipitation of the driest month (PDM) and wettest month (PWM) record the average amount of rain in the driest month and rainy season, respectively.
- Precipitation of the coldest quarter (PCQ), the warmest quarter (PWQ), the driest quarter (PDQ), and the wettest quarter (PWEQ) indicate the average daily rain in the coldest quarter of a year, the warmest quarter of a year, the dry season quarter of a year, and the highest rainy quarter of a year, respectively. In Indonesia, PWQ and PWEQ are difficult to distinguish between since there are only two seasons, the rainy and dry seasons, between which the temperature differences are very narrow. Precipitation data were also collected from the WorldClim BIO Variables V1 dataset [35].
- Isothermality (Isot) is a thermodynamic process in which the temperature of a system remains constant.
- Aspect (A) is the compass direction or azimuth that a terrain surface faces.

2.3. Data Analysis

Magnolia spp. distribution was predicted based on the most suitable habitat characteristics. Since one of the *Magnolia* spp. found in North Sulawesi was *M. sulawesiana*, which is an endemic and endangered species [12,32,36], we predicted the suitable habitat characteristics for this particular species separately for conservation purposes.

For the spatial analysis, a covariance model was used to determine the species dependency [37] and to increase the prediction accuracy based on the species distribution [30,31]. The hypotheses used in the covariance test for each indicator were as follows:

Hypothesis H0. *There will be differences in variance for each indicator where the species grow (p-value* $< \alpha = 5\%$*).*

Hypothesis H1. *There are no differences in variance for each indicator where the species grow (p-value* $> \alpha = 5\%$*).*

The value interval of each indicator was calculated to determine the pattern of each waypoint. The contribution of each parameter and quadrant was then determined using a principal component analysis and a bi-plot contribution graph. To avoid the possibility of errors in classification, the required contribution should be close to 100%.

The classification of species distribution patterns depends on the indicator for the number of species present, where a higher score indicates a greater possibility for a species to be present. All the parameter data were overlayed with a spatial raster. The classes were then developed based on the presence/absence of tree species. If there is an n-parameter with the presence/absence of *Magnolia* spp. trees, then the number of classes becomes 2n if the species is present. A higher value of n indicates a higher possibility of *Magnolia* spp.

being present and vice versa. The interval between the highest and lowest n-value then indicates variations in the probability (Table 2).

Distribution classification testing was conducted using separated data testing based on the method in [38]. An accuracy test was then completed using the Kappa value [39], which was able to express accuracy in the classification [38]. The comparison matrix is presented in Table 3.

Table 3. Confusion matrix of the validation distribution test.

		Reference				
	Class	**1**	**2**	**..**	**m**	**∑**
Map	1	p_{11}	p_{12}	$p_{1.}$	p_{1m}	$p_{1.}$
	2	p_{21}	p_{22}	$p_{2.}$	p_{2m}	$p_{2.}$
	..	$p_{\cdot 1}$	$p_{.2}$	$p_{..}$	$p_{.m}$	$p_{..}$
	n	p_{n1}	p_{n2}	$p_{n.}$	p_{nm}	$p_{n.}$
	∑	$p_{\cdot 1}$	$p_{\cdot 2}$	$p_{\cdot n}$	$p_{\cdot m}$	1

$$p_0 = \sum_{i=1}^{m} pii \quad (1)$$

Here, p_0 is the probability of accuracy, which determines whether it is appropriate to locate the point in the polygon that indicates the presence of *M. sulawesiana* or *Magnolia* spp. and vice versa for the point that indicates that the polygon does not contain *M. sulawesiana* or *Magnolia* spp.

$$p_e = \sum_{i=1}^{m} pi.\ p.i \quad (2)$$

Here, p_e is the chance of error, which determines whether the point in the polygon that indicates that there is no *Magnolia* spp. or *M. sulawesiana* can be precisely determined and vice versa for the point that determines whether the polygon does not contain *Magnolia* spp. or *M. sulawesiana* when they exist in the polygon. The Kappa coefficient (κ) and standard error (σ_κ) were then measured using the following equation:

3. Results

3.1. Habitat Characteristics

M. sulawesiana and other Magnolias grow under a similar diurnal temperature range, land surface temperature, and isothermality but have different ranges for the rest of the indicators (Figure 3 and Table 4). *Magnolia* spp. grow at an annual average temperature of between 20 and 26.4 °C, with an average of 23 °C, while *M. sulawesiana* grows at 20–25 °C, with an average of 21°C. *Magnolia* spp. grow at minimum temperatures of between 15 and 22 °C, while *M. sulawesiana* can prevail at minimum temperatures of between 15 and 20 °C. Concerning the highest temperature, *Magnolia* spp. can grow at temperatures of 25–32 °C, with 25–30 °C for *M. sulawesiana*. Based on the temperature differences between the rainy and the dry season, *Magnolia* spp. grow in areas with a temperature difference of 2.2–3.8 °C. Meanwhile, *M. sulawesiana* grows in areas with a temperature difference of 2.3–2.5 °C.

Based on the precipitation data, *Magnolia* spp. and *M. sulawesiana* have a similar range only in annual precipitation (Figure 4 and Table 5). The average annual rainfall is between 1900 and 3000 mm. *Magnolia* spp. grow in areas with rainfall of between 2060 and 3034 mm/year, with an average annual rainfall of 2400 mm. Meanwhile, *M. sulawesiana* grows in areas with rainfall of 1900–2400 mm/year and an average of 2300 mm/year.

The topographical data (Figure 5 and Table 6) show that *Magnolia* spp. grow at elevations between 400 and 800 m asl. However, some trees are found at up to 1300 m asl. Meanwhile, *M. sulawesiana* grows at an elevation of 1000–1300 m asl, with most trees growing above 1200 m asl. *Magnolia* spp. and *M. sulawesiana* grow in an overlapping topography range from 1000 to 1300 m asl.

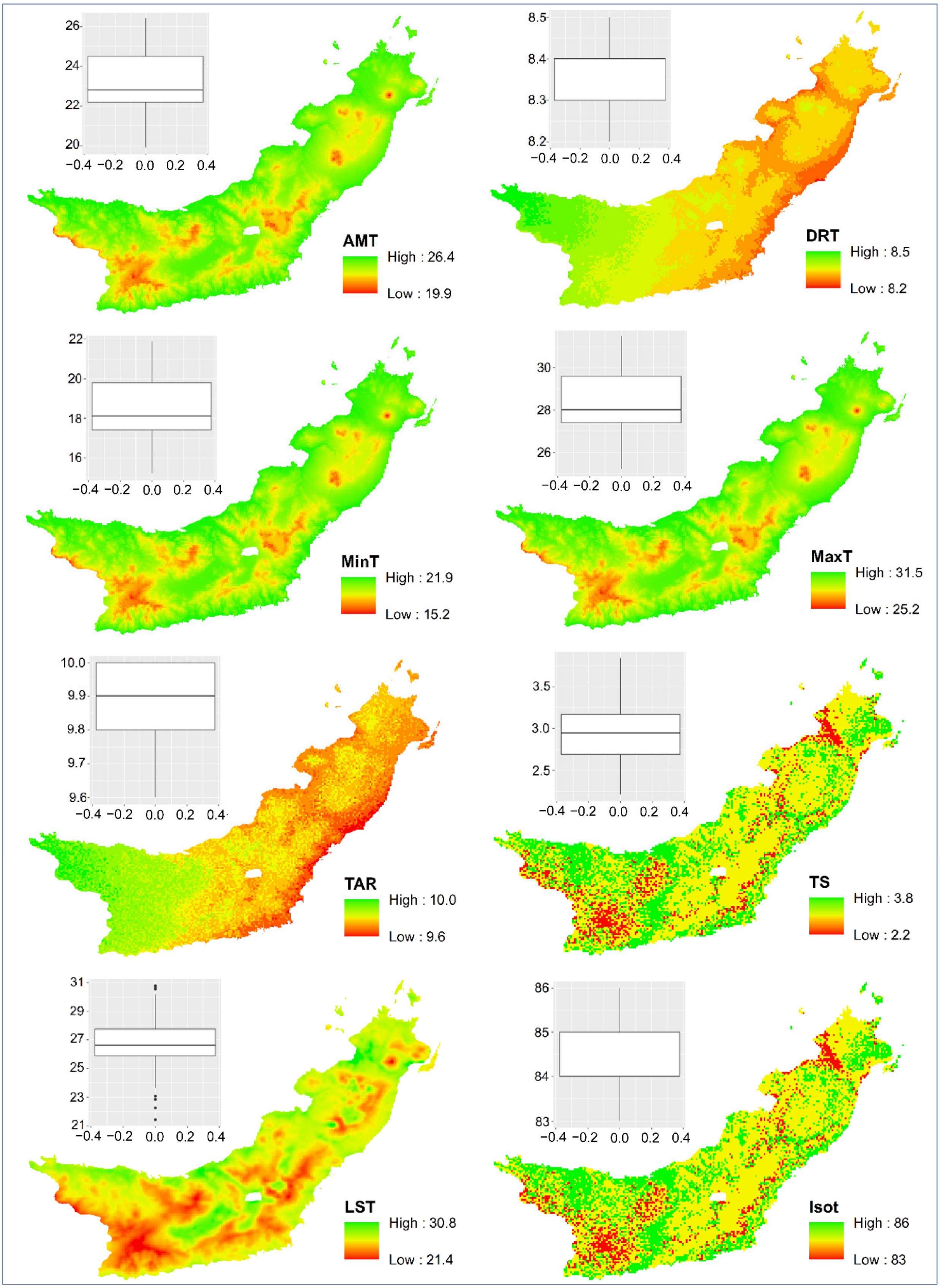

Figure 3. Temperature indicator images for *Magnolia* spp. in North Sulawesi.

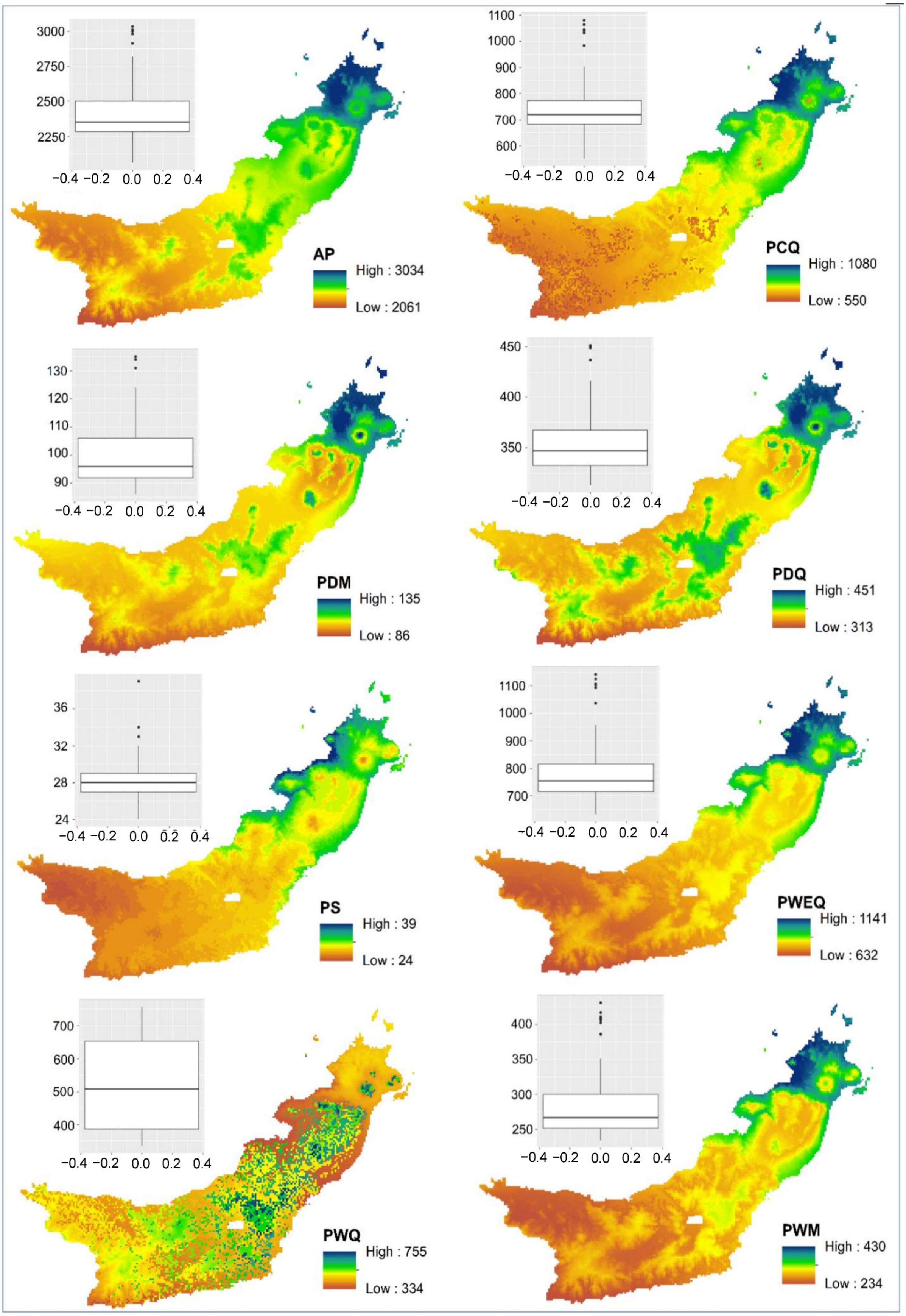

Figure 4. Precipitation indicator images for *Magnolia* spp. in North Sulawesi.

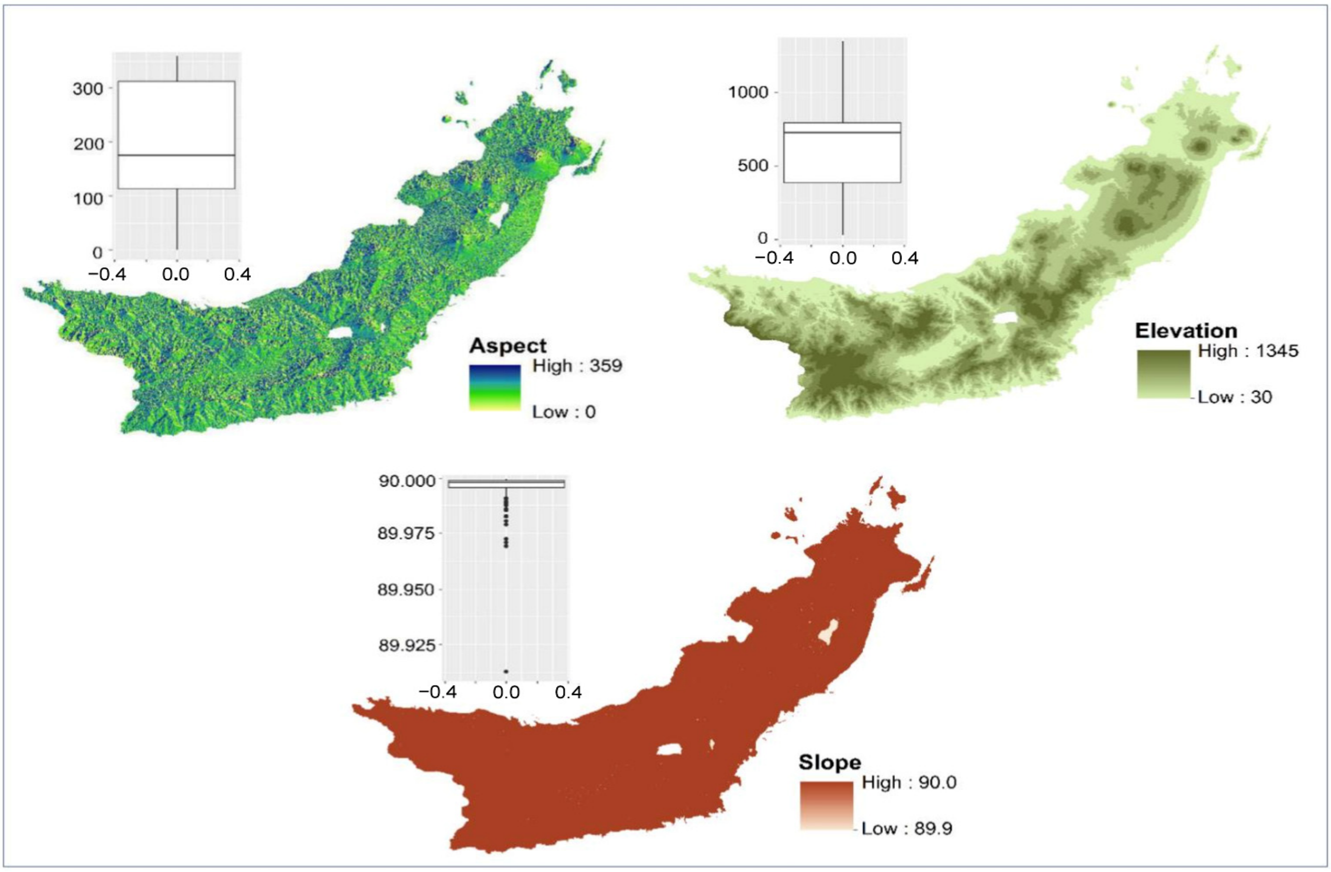

Figure 5. Topographical indicator images for *Magnolia* spp. in North Sulawesi.

The statistical analysis results (Table 6) indicate that *Magnolia* spp. can be found at an altitude of between 30 and 1345 m asl with a variation of up to 45%. Meanwhile, *M. sulawesiana* grows between 179 and 1414 m asl with a variation of 48%. The average *Magnolia* spp. and *M. sulawesiana* grow at 638 m asl and 1017 m asl, respectively. Meanwhile, both have similar preferences in terms of slope and aspect.

Table 4. Statistical descriptions for temperature indicators.

Variable	Tree Species	Average	Standard Deviation	Coefficient of Varian	Min	Max
AMT	*Magnolia* spp.	23	1.5	6.4	19.9	26.4
	M. sulawesiana	21	2.3	10.9	19.5	25.0
DRT	*Magnolia* spp.	8.4	0.06	0.8	8.2	8.5
	M. sulawesiana	8.4	0.05	0.7	8.4	8.5
MinT	*Magnolia* spp.	18.3	1.5	8.2	15.2	21.9
	M. sulawesiana	16.2	2.3	14.0	14.7	20.2
MaxT	*Magnolia* spp.	28.2	1.4	5.1	25.2	31.5
	M. sulawesiana	26.2	2.3	8.7	24.7	30.2
TAR	*Magnolia* spp.	9.9	0.09	0.9	9.6	10.0
	M. sulawesiana	10	0.0	0.0	10.0	10.0
TS	*Magnolia* spp.	2.9	0.3	10.1	2.2	3.8
	M. sulawesiana	2.4	0.1	4.7	2.3	2.5
LST	*Magnolia* spp.	26.5	1.8	6.7	21.4	30.8
	M. sulawesiana	25.3	1.9	7.4	22.6	27.4
Isot	*Magnolia* spp.	84.3	0.5	0.6	83.0	86.0
	M. sulawesiana	84.4	0.5	0.7	84.0	85.0

Table 5. Statistical descriptions for precipitation indicators.

Variable	Tree Species	Average	Standard Deviation	Coefficient of Varian	Min	Max
AP	*Magnolia* spp.	2414.0	171.7	7.1	2061.0	3034.0
	M. sulawesiana	2290.6	210.6	9.2	1915.0	2407.0
PDM	*Magnolia* spp.	101.7	11.2	11.0	86.0	135.0
	M. sulawesiana	103.4	6.5	6.3	92.0	108.0
PWM	*Magnolia* spp.	281.7	35.7	12.7	234.0	430.0
	M. sulawesiana	266.2	34.8	13.1	204.0	284.0
PCQ	*Magnolia* spp.	738.9	81.0	11.0	550.0	1080.0
	M. sulawesiana	474.2	57.2	12.1	427.0	551.0
PWQ	*Magnolia* spp.	512.8	129.0	25.2	334.0	755.0
	M. sulawesiana	553.8	74.3	13.4	421.0	592.0
PDQ	*Magnolia* spp.	358.6	32.7	9.1	313.0	451.0
	M. sulawesiana	377.2	37.2	9.9	311.0	398.0
PWEQ	*Magnolia* spp.	777.3	86.4	11.1	632.0	1141.0
	M. sulawesiana	705.6	65.3	9.3	589.0	742.0
PS	*Magnolia* spp.	27.9	2.1	7.4	24.0	39.0
	M. sulawesiana	23.6	0.5	2.3	23.0	24.0

Table 6. Statistical descriptions for topography parameter.

Variable	Tree Species	Average	Standard Deviation	Coefficient of Varian	Min	Max
Elevation	*Magnolia* spp.	638.49	288.50	45.18	30.00	1345.00
	M. sulawesiana	1017	487	47.93	179	1414
Slope	*Magnolia* spp.	89.996	0.00527	0.01	89.913	90.000
	M. sulawesiana	89.997	0.00177	0.00	89.995	89.999
Aspect	*Magnolia* spp.	202.15	106.01	52.44	0.00	359.40
	M. sulawesiana	197.1	123.9	62.84	54.4	329.0

Variation Test for Habitat Characteristics

The results of the F test showed that each category of habitat parameters featured variations among both *Magnolia* spp. and *M. sulawesiana*. The parameters of temperature annual range, precipitation seasonality, elevation, and slope showed significant differences in *Magnolia* spp. (Table 7).

The six temperature and seven precipitation indicators tested showed no differences for *Magnolia* spp. and *M. sulawesiana*, meaning that *Magnolia* spp. and *M. sulawesiana* have similar habitat preferences. Significant differences in preferences were observed in the gap between the maximum and minimum temperature (TAR) and the ratio between the standard deviations of annual rainfall (PS) (Table 7). While *Magnolia* spp. and *M. sulawesiana* have different ranges in elevation and slope, they both have the same variation in aspect, which is supported by the work in [40] showing that precipitation and annual mean temperature make critical contributions to endemic and critically endangered species in Kashmir Himalaya. Based on these results, we concluded that the habitat characteristics of *Magnolia* spp. and *M. sulawesiana* are influenced by the temperature annual range, precipitation seasonality, and elevation. This information serves as the basic information to predict the spatial distribution of *Magnolia* spp. and *M. sulawesiana*.

3.2. Species Distribution

3.2.1. Magnolia spp.

The variable contribution and bi-plot analysis of *Magnolia* spp. showed that the slope has a lower impact than the other key variables, including annual temperature range, precipitation seasonality, and elevation. In addition, the slope variable is also in the same quadrant as the annual temperature range (Figure 6). Therefore, the slope variable can be neglected when estimating the distribution of *Magnolia* spp.

The spatial distribution prediction map for *Magnolia* spp. is presented in Figure 7. There are six distribution classifications based on the range of TAR, PS, and elevation parameters (as shown in Table 2). The highest number of criteria (6, green color) represent the most suitable habitat, while the lowest number (3, yellow color) represents the least suitable habitat for *Magnolia* spp. In general, *Magnolia* spp. is spread in mountainous areas and follows the direction of the slopes with a concentric habitat pattern.

Table 7. F-test results for all habitat characteristic categories.

Categories		*p*-Value F Test
Temperature	Annual mean temperature (AMT)	0.09
	Diurnal range temperature (DRT)	0.87
	Temperature minimum (MinT)	0.11
	Temperature maximum (MaxT)	0.09
	Temperature annual range (TAR)	2.2×10^{-16} **
	Temperature seasonality (TS)	0.07
	Land surface temperature (LST)	0.72
	Isothermality	0.65
Precipitation	Annual Precipitation (AP)	0.39
	Precipitation of driest month (PDM)	0.29
	Precipitation of wettest month (PWM)	0.87
	Precipitation of coldest quarter (PCQ)	0.53
	Precipitation of warmest quarter (PWQ)	0.29
	Precipitation of driest quarter (PDQ)	0.54
	Precipitation of Wettest quarter (PWEQ)	0.63
	Precipitation Seasonality (PS)	0.02 **
Topography	Elevation (E)	0.04 **
	Slope (S)	0.04 **
	Aspect (A)	0.49

** significantly different.

3.2.2. *Magnolia sulawesiana*

The main characteristics of the *M. sulawesiana* species found in the northern part of Sulawesi are leaves with a coriaceous shiny-green top (pale greenish-brown to reddish-brown when dry) and a paler bottom (dark golden-brown to chestnut when dry). The tree bark is grey-brown, fissured, and lenticellate with a mealy texture and flakes off in large, irregular plates on older trees. Older trees feature silver-grey bark with fine longitudinal cracks (Figure 8). According to the species characteristics and identification key provided in [12], we are confident that the species found in the study area is *M. sulawesiana.*

The flowering and fruiting seasons of *M. sulawesiana* have irregular patterns in the five locations. This study identified two flowering and fruiting seasons, of February to April and August to September. The study also found that single-mother trees can have both a flowering and fruiting season (monoecious). Buds, young and mature flowers, and ripe fruits were observed together in one individual tree. We also observed very few seedlings around the mother tree, although closer observations of the reproduction strategy of this species must be conducted. Poor fruiting and low natural regeneration were reported in [11]. These findings will add to the knowledge of *M. sulawesiana* in the northern part of Sulawesi. The other location was the mountain forest of the Gunung Ambang Nature Reserve (GANR) and production forest (Figure 9), where we found four individuals of *M. sulawesiana* at an elevation of 1163–1378 m asl in a hilly primary forest dominated by Myristicaceae, Euphorbiaceae, and Calophyllaceae. Additionally, one individual was found in the slope area near Kotulidak River. The last individual found was located in the production forest at Bolaang Mongondow District (175 m asl). This production forest is part of a natural forest located near the boundaries of BNWNP. Based on the analysis of the results, this endemic species seems to have a wide distribution, from 179–1414 m asl to 1600–2200 m asl, as described in [12]. This wide range of elevation creates a greater possibility of finding this species in the mountainous area down to the lowland forest in Sulawesi.

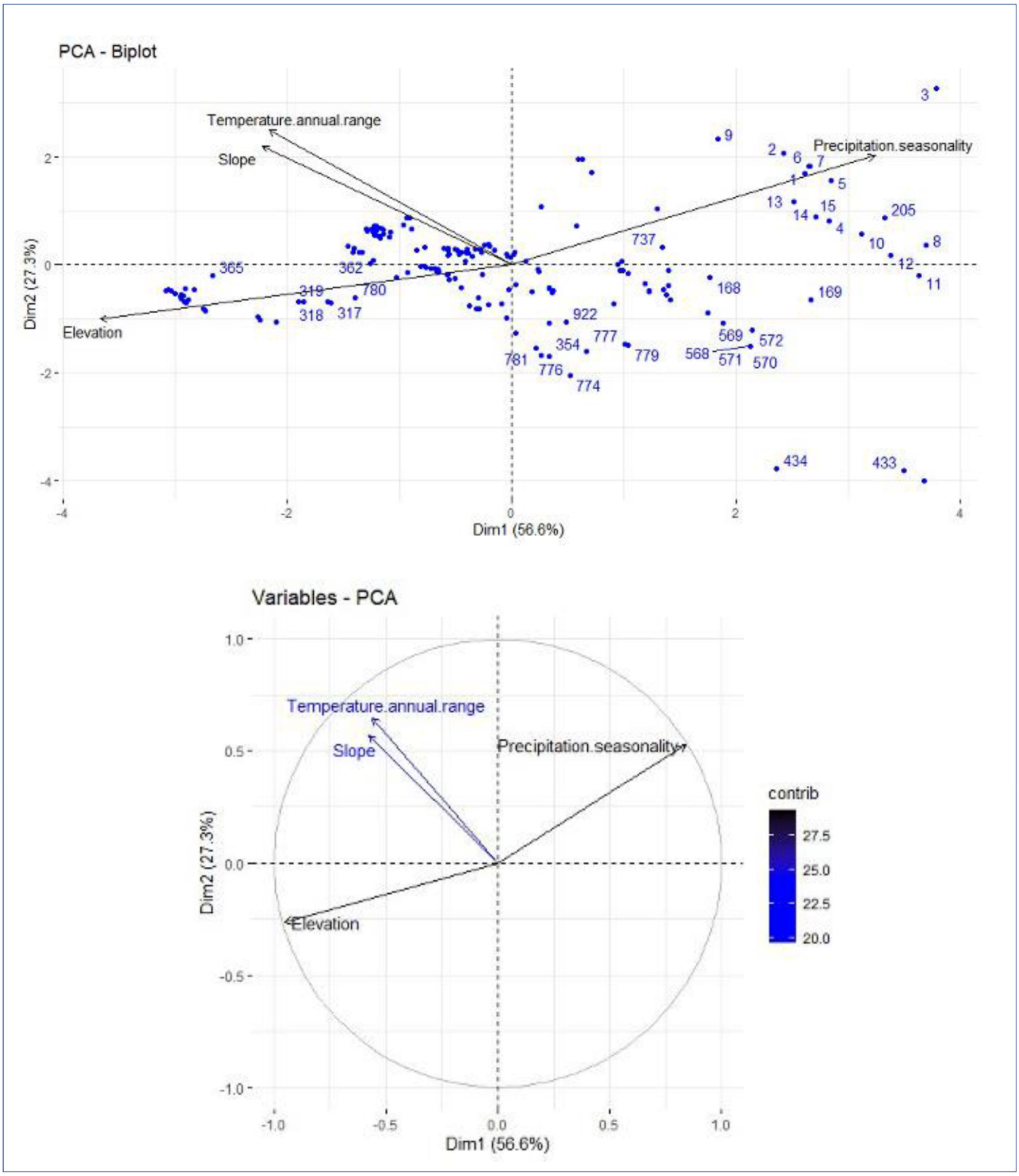

Figure 6. Variable contribution analysis and bi-plot of the annual temperature range, precipitation seasonality, elevation, and slope of *Magnolia* spp. Above: PCA—Biplot; below: Variables—PCA.

3.3. Accuracy Test Classification

The results of the accuracy test (Table 8) showed that the estimated kappa distribution was 100%; thus, the standard error was zero. A random selection of waypoints in the classification accuracy test was also conducted. The number of waypoints in the *Magnolia* spp. distribution test was 116. All points were of the highest class (6). Thus, the Kappa value was 100%, which means the classification accuracy is appropriate.

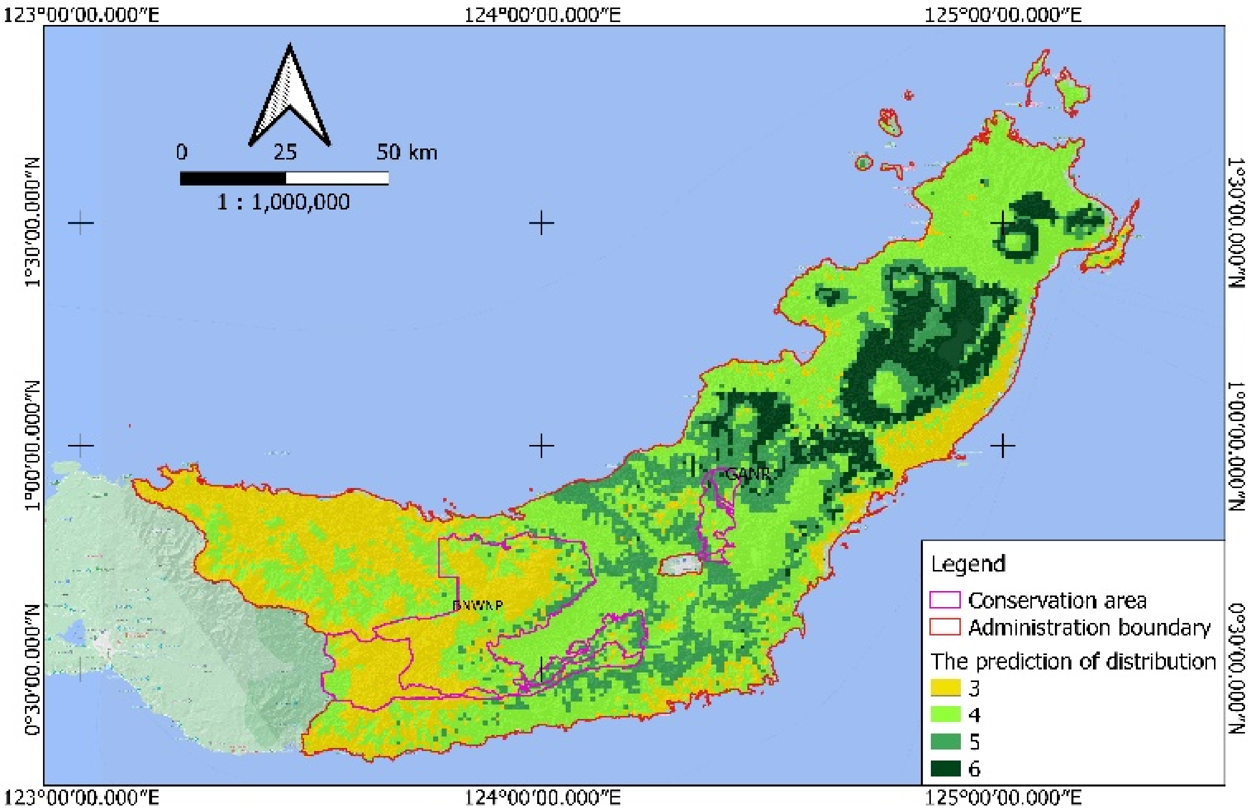

Figure 7. Distribution prediction patterns of *Magnolia* spp. in North Sulawesi, with the number representing habitat suitability, with 3 indicating the least suitable habitat and 6 representing the most suitable habitat. In the map, the darker the color (6), the more suitable the habitat for *Magnolia* spp.

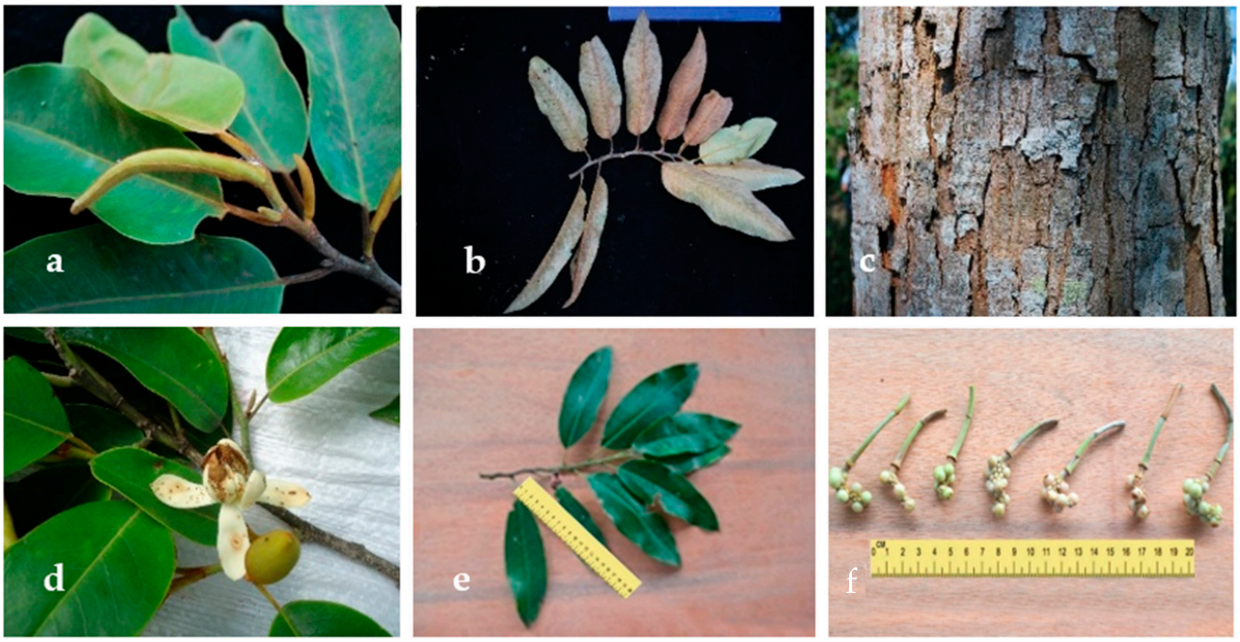

Figure 8. Morphological characteristics of *M. sulawesiana* found in the northern part of Sulawesi: (**a**) adaxial leaf; (**b**) abaxial leaf; (**c**) older tree bark; (**d**) leaves on twig with an open flower; (**e**) leaves on twig with fruit; (**f**) closer look at ripe fruits.

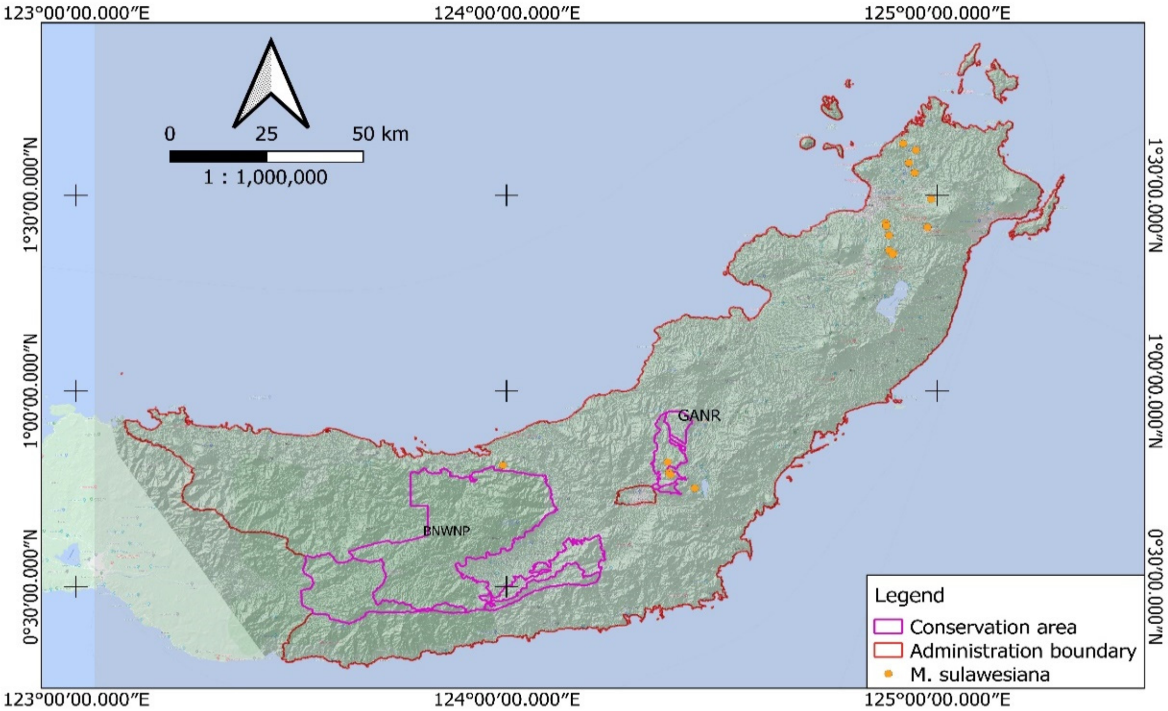

Figure 9. Distribution of *M. sulawesiana* found in GANP and the production forest at the border of BNWNP in North Sulawesi.

Table 8. Accuracy test classification results for *Magnolia* spp.

	Class	0	1	∑	p_0	p_e	κ	σ_κ
	0	0	0	0	0	1	100%	0
Magnolia spp.	1	0	116	116				
	∑	0	116	116				

4. Discussion

The spatial distribution of *Magnolia* in North Sulawesi Province is influenced by the annual temperature range, precipitation seasonality, and elevation. At the landscape scale in this extremely varied environment, topography and climate were reported to be significant determinants of species richness, endemic richness, and endemicity [23,24]. The influence of climate on *Magnolia* distribution demonstrates the species' vulnerability to climate changes [40]. *Magnolia* is also reported to have allopatric speciation [3]. Thus, geographical isolation [3], topography, and climatic factors [26] have led to the scarcity of this genus due to a lack of specific habitat suitability. On the other hand, changes in climatic parameters such as temperature can also lead to the distribution of a species outside of its native range, as shown in [41] for *M. grandiflora*.

Based on our results, despite the importance of climatic factors, elevation seems to have the largest influence on *Magnolia* species distribution in North Sulawesi Province. Elevation can have a 10% to 50% effect on plant distribution [27,42]. For *M. sulawesiana*, we found that this species has a wider elevation range due to the presence of outlier data. One individual was found at 175 m asl, while the rest of the individuals, including the individual recorded in [12], were found from 1100 to 2000 m asl. This is a very interesting result because the individual was identified as *M. sulawesiana* based on morphological characteristics [12] and located inside GANP, where it remains unclear if this species grows naturally. A closer study needs to be conducted to explain this phenomenon. There might be other factors that determine species distribution other than climatic and elevation factors. Other research shows that most of the endemic and endangered species of *Magnolia* are naturally found in tropical mountain forests and at high elevations. Examples include *M. schiedeana* in Mexico [43], *M. sinica* in Yunan (1339–1707 m asl) [44], *M. vovidesii* in Mexico (1520–1550 m asl) [21], and *M. granbarrancae* (1073–1215 m asl) [22].

The growing demand for *Magnolia* trees in the lumber market throughout the year has led to consequences such as the increasing rarity of this genus. To meet these needs, wood is harvested not only from *Magnolia* plantations but also from the species' natural habitat. This study demonstrated that the distribution of *Magnolia* spp. in production forests is decreasing. Without any effort to create a community development program to maintain the balance between different needs, *Magnolia* species will gradually become rare and, eventually, extinct. As a result, the existence of this genus is threatened. Scattered, small-scale *Magnolia* plantations managed by local people still exist in several areas in North Sulawesi. Examples include Rumoong Atas Village, South Minahasa District [17], and Kawatak Village, Minahasa District [18]. The plantation in Rumoong Atas village has existed for decades, and the Cempaka trees in the region were planted on inheritance land [17]. The plantations typically cover about 1–2 ha and is managed from generation to generation. While the local community in Kawatak village developed plantations under the Community Forestry Program, the local people planted several *Magnolia* species, including the endemic species, *M. sulawesiana.*

Habitat preference data will serve as the basic information for landscape management approaches to ensure the survival of the genus, including in-situ and ex-situ conservation. This approach is also expected to maintain the remaining natural population in the protected area while ensuring sustainable use through plantation and community forests. The *Magnolia* species, especially the endemic species, found inside conservation areas, need to be protected in-situ [22]. As an endemic and endangered species, *M. sulawesiana* also needs to be considered as a protected species. For this reason, conservation efforts were conducted at both the habitat and species level. The other *Magnolia* species found outside the conservation areas could also be proposed for protection to maintain their sustainability. Additionally, the area could be designated as a buffer zone. Using the same information, the ex-situ conservation of the species could be conducted through the development of plantations or community forests within the most suitable habitat preferences in collaboration with the local people. Community forest development could act as a buffer for the natural habitat of the species in the conservation area. Ex-situ conservation could also lessen the risk of extinction for threatened species and support in-situ conservation efforts [22]. The remaining forest in Sulawesi plays a crucial role as a life support system due to its geographical conditions, with extreme faults being prone to landslides. Rapid changes in land use create further difficulties for conservation efforts on this island. A spatial distribution map is crucial for the local forest district to develop landscape-scale protection [22], which is important not only for the targeted species but also for Wallace's unique wildlife and Sulawesi's fragile ecosystems more broadly [45].

To facilitate the effective implementation of conservation, especially for endemic species with unique habitats [46], further research needs to be conducted to determine the genetic diversity of all populations, and inbreeding and genetic diversity levels [22,46] could be used to determine protection priorities, especially at the landscape level. Information on the population size, phenological patterns, morphological variations [47,48], and population genetic diversity [49] in natural habitats, including the populations in the northern and central part of Sulawesi, will determine the actions that should be taken concerning conservation in natural habitats (in-situ). This conservation should involve the indigenous knowledge of "*Eluren Eng Kayobaan*" (keeping and maintaining the Earth) [50] to encourage the planting of Wasian trees on community lands.

5. Conclusions

The spatial distribution of *Magnolia* spp. is affected by climatic (temperature annual range and precipitation seasonality) and elevation variables. Among the discovered *Magnolia* spp., we located five sites featuring the endemic and endangered species, *Magnolia sulawesiana,* which was previously distributed exclusively in the central part of Sulawesi. The existence of this essential species alters the paradigm of landscape protection. In this study, we provided a scientific foundation from which to develop in-situ and ex-situ conservation strategies and landscape protection measures to maintain the sustainability of endemic species. Simultaneously, it is also important to ensure the sustainable use of other *Magnolia* species. Further research is required to strengthen conservation and plantation-management practices.

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