RESEARCH ARTICLE

Vegetation structure of associated flora in *Amorphophallus gigas* Teijsm. & Binn. (Araceae) habitats, North Padang Lawas Regency, North Sumatra

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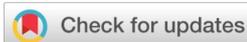
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Abstract

Amorphophallus gigas, a native aroid species found in the tropical forests of Sumatra, Indonesia, lacks robust population data despite previous spatial distribution studies. While not officially protected, *A. gigas* is considered rare in field documentation and faces potential habitat loss due to its proximity to the popular corpse flower. This 2023 study conducted in Halongonan District, North Padang Lawas Regency, North Sumatra, Indonesia, aimed to gather information on the habitat characteristics and associated flora of *A. gigas* to guide land conservation initiatives. The research focused on a forested area within three villages: Bargot Topong Julu, Napa Lancat, and Pangirkiran, utilizing a purposive random sampling approach. Plots covering 1 ha each were selected based on *Amorphophallus* in the generative phase across various land covers. Ecological analysis and indices were derived from collected vegetation data. The survey unveiled varying numbers of generative and vegetative *A. gigas* individuals across the three study sites. The understorey community at each site exhibited different levels of association with *A. gigas*, with *Selaginella willldenowii, Clidemia hirta*, and *Leersia virginica* showing strong positive correlations. The floral community in *A. gigas* habitats displayed diverse species richness and diversity across different growth stages and locations. Findings suggest that altitude, slope, pH, light intensity, air temperature, and humidity may influence *A. gigas* abundance in distinct ways. This study offers valuable insights into the biological and ecological factors influencing the distribution and abundance of *A. gigas* populations, providing guidance for conservation and management efforts.

Keywords

Introduction

Indonesia's flora is a significant component of the Malesian flora, which encompasses the diverse plant species found in the Malesian region. The Malesian region, also known as the Malesian floristic region, is a vast floral realm that includes Indonesia, Malaysia, the Philippines, Papua New Guinea, and parts of Thailand and Indochina. It is estimated to harbor approximately one-quarter of the world's flowering plant species. This

remarkable floral diversity establishes Indonesia as the seventh-largest nation in terms of species richness, boasting approximately 20,000 species (1). Of this staggering number, a notable 40% are considered endemic, exclusively native to Indonesia. Among the plant groups that thrive in Indonesia's lush landscapes is the Araceae family, which features a notable genus of interest, *Amorphophallus,* or the corpse flower species (2). This taxonomic group comprises over 200 species, ranging from West Africa to tropical Asia and northern Australia (3). The plants belonging to the genus *Amorphophallus* are distinguished by their significant size and are notorious for emitting a foul scent reminiscent of decomposing animals (4). *Amorphophallus* species have been acknowledged as economically important plants (5). They are cultivated in tropical and subtropical regions worldwide and play a crucial role in ensuring food security, as they are rich in glucomannan, a polysaccharide with diverse applications in the food, medicine, and chemical industries (6–9).

The available data on *Amorphophallus* plants in Indonesia suggests the existence of 25 different species, among which one falls within the rare category and has been designated for inclusion in the IUCN Red List, specifically *Amorphophallus titanum* (Becc.) Becc (10). Another notable species, *Amorphophallus gigas* Teijsm. & Binn., is found to grow naturally in North Sumatra (11,12). Despite its ecological significance, the diversity of *Amorphophallus* species in North Sumatra remains largely unexplored. The conversion of land poses a severe threat to the survival of corpse flowers, especially to *A. titanum,* while the public's awareness of their endangered status remains disconcertingly low (13). While *A. gigas* is not officially classified as a protected species, it is infrequently documented when it blooms in the field or forest, and its habitat is at risk of degradation or loss due to its coexistence with other habitats of the corpse flower. The species conservation has been prioritized through the strategic action plan for the conservation of rare *Amorphophallus* spp. flora, which spans from 2015 to 2025, similar to that of *Rafflesia* spp. One essential aspect of supporting conservation efforts is the systematic assessment of the wild population of *A. gigas,* particularly in habitats that intersect with anthropogenic activities. It is crucial to acknowledge that not all human activities inherently hinder growth and compromise the conservation status of this species. Consequently, recognizing the value of agroforestry as a harmonious strategy is imperative for communities to protect and sustainably utilize *A. gigas*.

Positive ecological interactions, such as commensalism, facilitation, and mutualism are pivotal for the functioning of plant communities (14). These interactions have a substantial impact as they ameliorate environmental stress, especially in the establishment of new seedlings and plant species constrained by limited adaptive mechanisms to cope with unfavorable environmental conditions (15). The presence of associated, associative, or nurse plants fosters resource acquisition and improves microenvironmental conditions, which, in turn, leads to enhanced growth and survival of plants (16). Thus, positive ecological interactions are indispensable for sustaining the resilience and diversity of plant communities, including *Amorphophallus* spp. One of the undocumented potentials of Halongonan District, North Sumatra, is the corpse flower, or *A. gigas*, locally known as *atturbung*. According to interviews with the residents of Bargot Topong Julu Village, the corpse flower blooms during the rainy season. This flower typically grows in the agroforestry areas of rubber and farmer gardens located along the riverbanks. Although the corpse flower can still grow in areas planted with oil palms, its growth is stunted due to the unsupportive habitat. The aim of this research is to assess the structure and composition of the vegetation that coexists with *A. gigas*, which may positively impact the growth and survival of the corpse flower. The interaction between the associated flora and *A. gigas* could indicate their mutual dependence on both biological and environmental factors, and this information could be valuable for the *in situ* and *ex situ* conservation of the species in the long term.

Materials and Methods

Study Area

The study was conducted in 2023 in Halongonan District, North Padang Lawas Regency, North Sumatra, Indonesia. The forested area within three villages, Bargot Topong Julu, Napa Lancat, and Pangirkiran, was selected as the sampling site for *A. gigas* and associated flora (Fig. 1). The total forest area spans 28,779 hectares, comprising 11,582 hectares of limited production forest, 7,746 hectares of permanent production forest, and 9,451 hectares of protected forest. The forest area encompasses a range of air temperature between 22 and 28°C throughout the year, with an average pluviosity of approximately 2750 mm. The forest exhibits characteristics of primary, secondary, and agroforestry, with varying degrees of slope. The placement of plots was intentionally carried out, focusing solely on *Amorphophallus gigas* in the generative phase across various land covers, using a purposive sampling approach. Each plot had an area of 1 ha and was square in shape. The determination of plot points was based on the presence of *A. gigas*. The population condition of the corpse flower was assessed through the analysis of the lower vegetation, including seedlings, poles, saplings, and trees. The placement of plots and sub-plots was nested (Fig. 2). During the study, vegetation data were collected by utilizing plots with various sizes to assess growth levels of different plant types. Mature trees with a diameter greater than 20 cm were evaluated on 20 × 20 m plots, while young trees with a diameter ranging from 10 to 20 cm were assessed on 10 × 10 m poles. Additionally, saplings with a height of more than 1.5 meters and young trees with a diameter less than 10 cm were evaluated on 5 × 5 m plots. Finally, seedlings and understory plants with a height less than 1.5 meters were analyzed on 2 × 2 m plots.
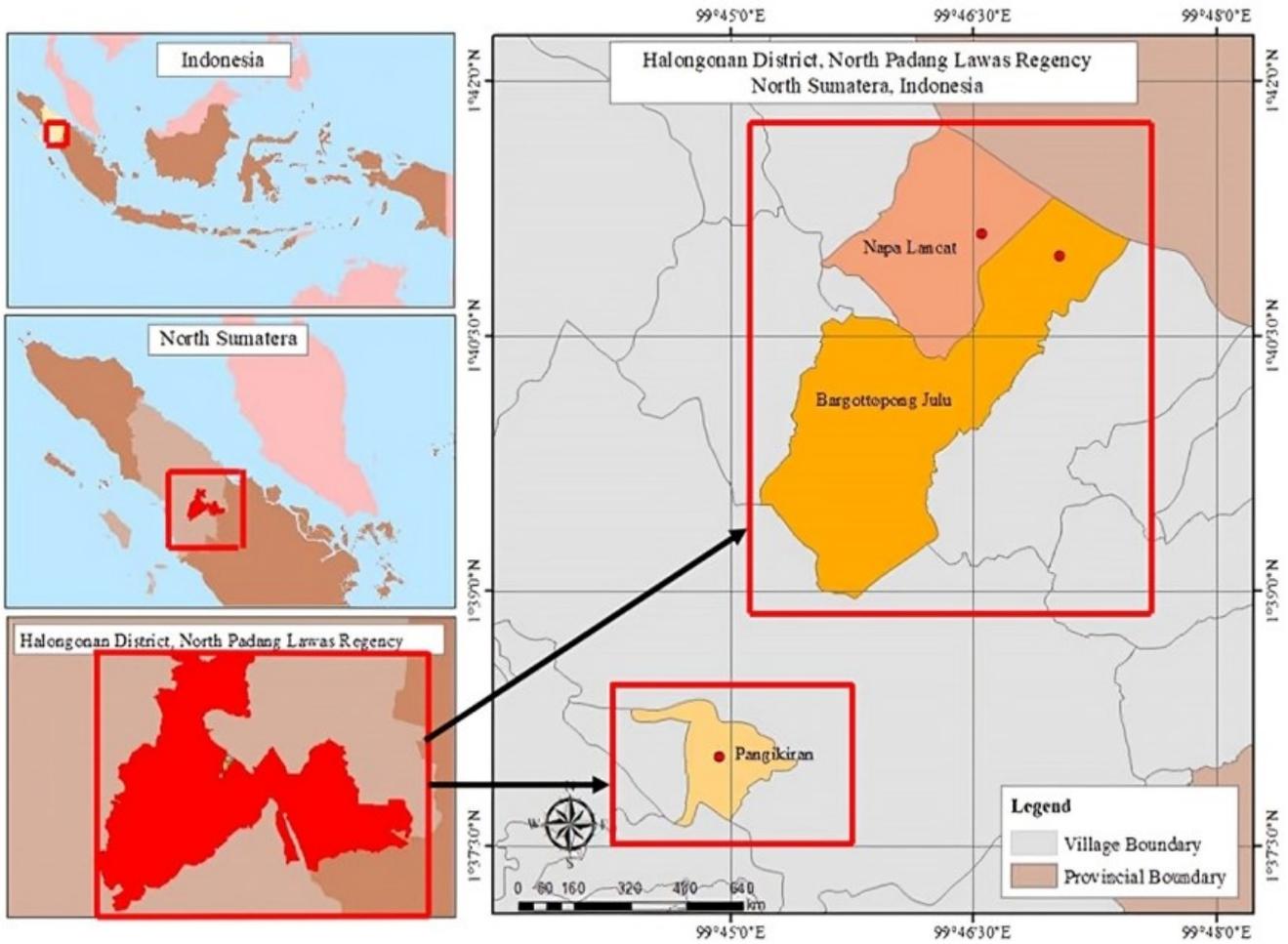
Figure 1. Location of Halongonan District as a survey site for *Amorphophallus gigas* and associated flora.
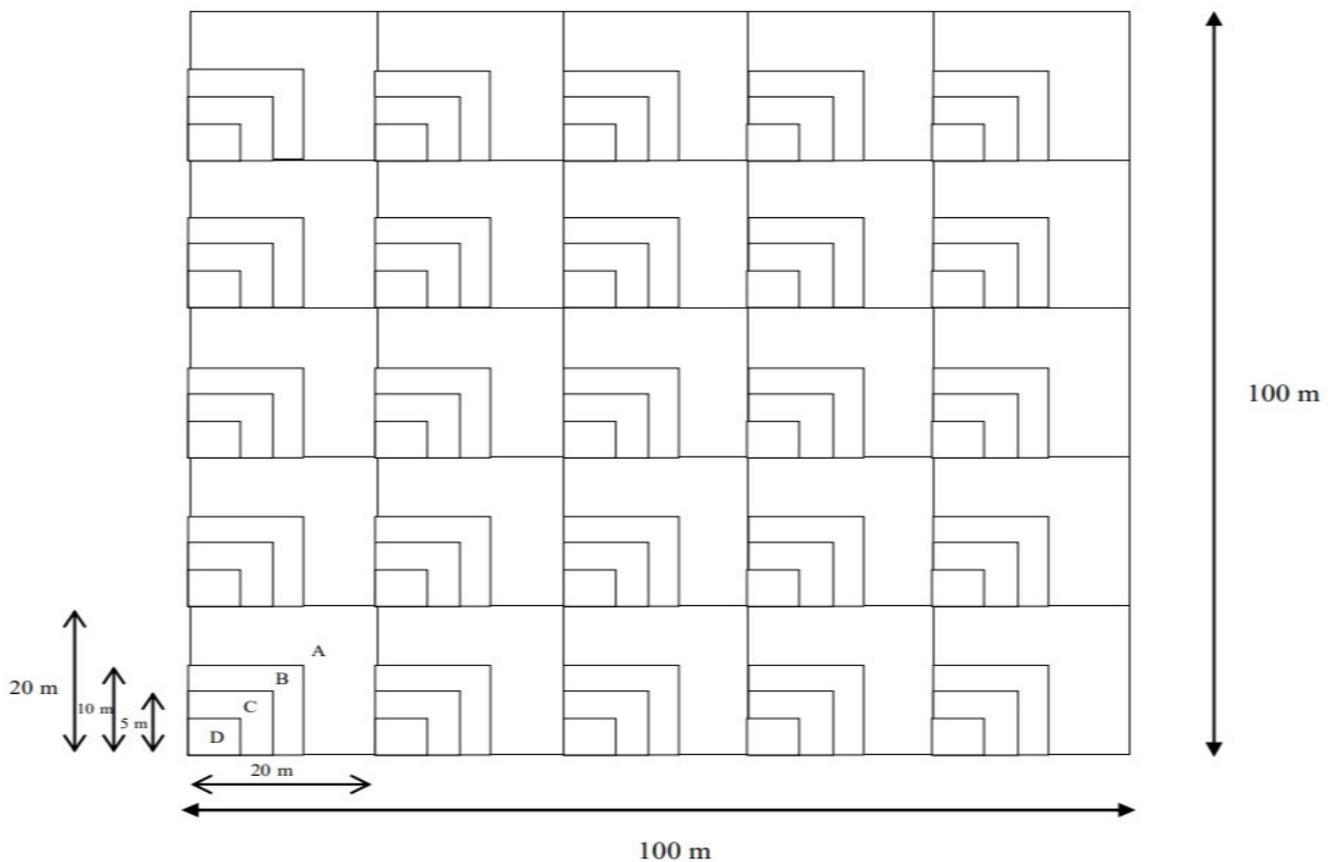

Figure 2. Schematic diagram of the nested plot for vegetation sampling.

Data Analysis

The vegetation data obtained from the study underwent various analyses, including but not limited to, density (ind/ha), relative density (%), frequency of occurrence, relative frequency (%), dominance or basal area (m^2/ha), relative dominance (%), importance value index (IVI), Shannon's diversity index (H'), evenness (J'), and Margalef's species richness index (D_{mg}) (17). The formulas for each parameter were described further:

$$Density = \frac{Number\ of\ Individuals\ of\ a\ species}{Area\ of\ sampling\ unit\ (ha)}$$

$$Relative\ density = \frac{Density\ of\ a\ species}{Total\ density\ of\ a\ species} \times 100\%$$

$$Species\ frequency = \frac{Number\ of\ plots\ of\ a\ recorded\ species}{Total\ number\ of\ plots}$$

$$Relative\ frequency = \frac{Frequency\ of\ a\ recorded\ species}{Total\ frequency} \times 100$$

$$Dominance\ (pole,\ tree) = \frac{Basal\ area\ of\ a\ species\ (m^2)}{Area\ of\ sampling\ unit\ (ha)}$$

$$Relative\ dominance = \frac{Dominance\ of\ a\ recorded\ species}{Dominance\ of\ all\ recorded\ species} \times 100$$

Importance Value Index (IVI) = $RD + RF + RDo*$

Note:

RD = Relative density

RF = Relative frequency

RDo = Relative dominance, exclusively to poles and trees

Shannon-Wiener's Diversity Index (H') = $-\sum [(Ni/Nt)\ \ln\ (Ni/Nt)]$

Note:

Ni = Number of individuals of the i-th species

Nt = Total number of individuals

Evenness (J') = $H'/\ \ln\ (S)$

Note:

H' = Shannon-Wiener's diversity index

S = Number of species

Margalef's species richness index (Dmg) = $(S-1)/\ \ln\ N$

Note:

S = Total number of genera

N = Total number of individuals in the area

To assess the interspecies relationship between *A. gigas* and other species, contingency tables with the Chi-square formula were utilized at a confidence interval of 5% as described below:

$$Chi\text{-}square = \frac{N\ (ad\text{-}bc)^2}{(a+b)\ (c+d)\ (a+c)\ (b+d)}$$

Note:

a = Number of plots where species-A and species-B were recorded

b = Number of plots where only species-A was encountered

c = Number of plots where only species-B was encountered

d = Number of plots where species-A and species-B were not recorded

N = Number of observation plots

Additionally, to ascertain the level of similarity between vegetation communities, three similarity indices, namely Ochiai, Dice, and Jaccard coefficients, were employed, utilizing species abundance data from each plot (18). Pearson's product moment correlation test was utilized to determine the correlation coefficient (r) between abiotic factors, such as altitude, slope, light intensity, air temperature, pH, and relative humidity (recorded during daylight hours), and biotic parameters, such as the number of generative and vegetative individuals of *A. gigas*. Altitude was determined using a Global Positioning System (GPS), while slope was assessed using an Abney level. Light intensity was measured with a lux meter, air temperature with a thermometer, and relative humidity with a hygrometer. pH levels were determined using a pH meter. Measurements for light intensity, temperature, and humidity were taken at three different time points throughout the day: in the morning (07:00 - 08:00), afternoon (12:00 - 14:00), and evening (16:00 - 17:00). After data collection, the measured values are averaged to obtain daily average data for light intensity, temperature, and humidity. Principal component analysis (PCA) was employed to visualize the interaction between biotic and abiotic factors contributing to the assemblage of *A. gigas* in the three villages and to identify highly correlated parameters using XLSTAT 2020.

Results and Discussion

In general, the Halongonan sub-district lies adjacent to the Barisan Hill, renowned for its numerous streams and rivers. *Amorphophallus gigas* naturally thrives in the area, particularly along riverbanks and in various land covers. The Napa Lancat population predominated exists within rubber agroforestry zones, nestled at an altitude of 94 meters above sea level (m asl), at the base of the Barisan hill, with slope ranging from 15 to 350 m asl. Other notable plants in the area include jengkol (*Archidendron pauciflorum*), matoa (*Pometia pinnata*), and mahang (*Macaranga* spp.). *A. gigas* population thrives beneath rubber trees amidst light intensities of 253 lux, an air humidity of 88%, and air temperature of 28.15^{o}C. In Pangirkiran Village, also situated along riverbank, rubber agroforestry dominates, providing a natural habitat for *A. gigas* and other plant species. The village lies at an altitude of 74 m asl, with a slope ranging from 10-17°. Air temperature average 27.6^{o}C, with humidity levels at 83.6% and light intensity measuring 170 lux. Bargot Topong Julu

Village, conversely stands at 70 m asl, with slopes ranging from 10-120°. In the area, land use predominantly revolves around rubber and durian plantations. *A. gigas* flourishes amidst these plantations, basking under a light intensity of 279 lux, with air temperature hovering around 27.6°C and air humidity levels at 85.6%. The survey conducted in Halongonan District unveiled a total of 286 *A. gigas* individuals in Napa Lancat Village, comprising 283 individuals in the vegetative phase and three individuals in the generative phase. In Bargot Topong Julu 52 individuals were recorded, with all individuals in the vegetative phase except for two individuals in the generative phase. Pangirkiran boasted 75 individuals, with 74 in the vegetative phase and only one in the generative phase. These findings underscore the varying presence of *A. gigas* across the study area and its adaptability to the prevailing environmental conditions, as evidenced by the abundance of individuals in the vegetative phase (Fig. 3).

The conversion of land for other purposes has led to a decline in the population of corpse flowers. These flowers thrive in shaded environment and typically exhibit a clustered distribution pattern in their natural habitat. Consequently, any disturbances to the land may result in the proliferation of corpse flowers in vulnerable areas (19). In a study on the population structure of corpse flowers, Hidayat and Yuzammi (20) documented the presence of 12 young and 22 mature individuals of *Amorphophallus* at the Air Ketapang site, Bukit Jufi, as well as at Air Terjun Datar Lebar, Bengkulu. Similarly, Nursanti (21) conducted a study in Muara Hemat Village, South Kerinci, where a total

of 83 individual corpse flowers were identified, exhibiting a clustered pattern of growth distribution. In another investigation by Arianto et al (22) across three research locations, namely Air Selimang, Tebat Monok, and Palak Siring; it was found that the total number of individual corpse flowers was 52, with 49 individuals in the vegetative phase and three individuals in the generative phase. The corpse flower populations were surrounded by various plant species such as *Artocarpus elasticus*, *Oreocnide rubescens*, *Syzygium pycnanthum*, *Pometia pinnata*, *Chionanthus cuspidatus*, and others. The presence of these plant species surrounding the corpse flower populations suggests a potential relationship between these species and their habitat requirements. The community structure of dominant vegetation surrounding *A. gigas* in the study area and its association indices are presented in Table 1.

We identified various associations for each growth stage (understorey, seedling, sapling, pole, tree) in each habitat using chi-square and association index results (Dice, Jaccard, Ochiai). Euphorbiaceae emerged as the predominant flora in the region, displaying consistence occurrence across all growth stages and distributed throughout the study sites or villages. The prevalence of *Hevea brasiliensis* in the study area may be attributed to intentional cultivation for latex harvesting by local communities or dispersal from nearby rubber plantations. In the understorey community of Napa Lancat, *Selaginella willdenowii* exhibited a significant and strong positive association with occurrence of *A. gigas*. While other plants also displayed varying degrees of association, ranging
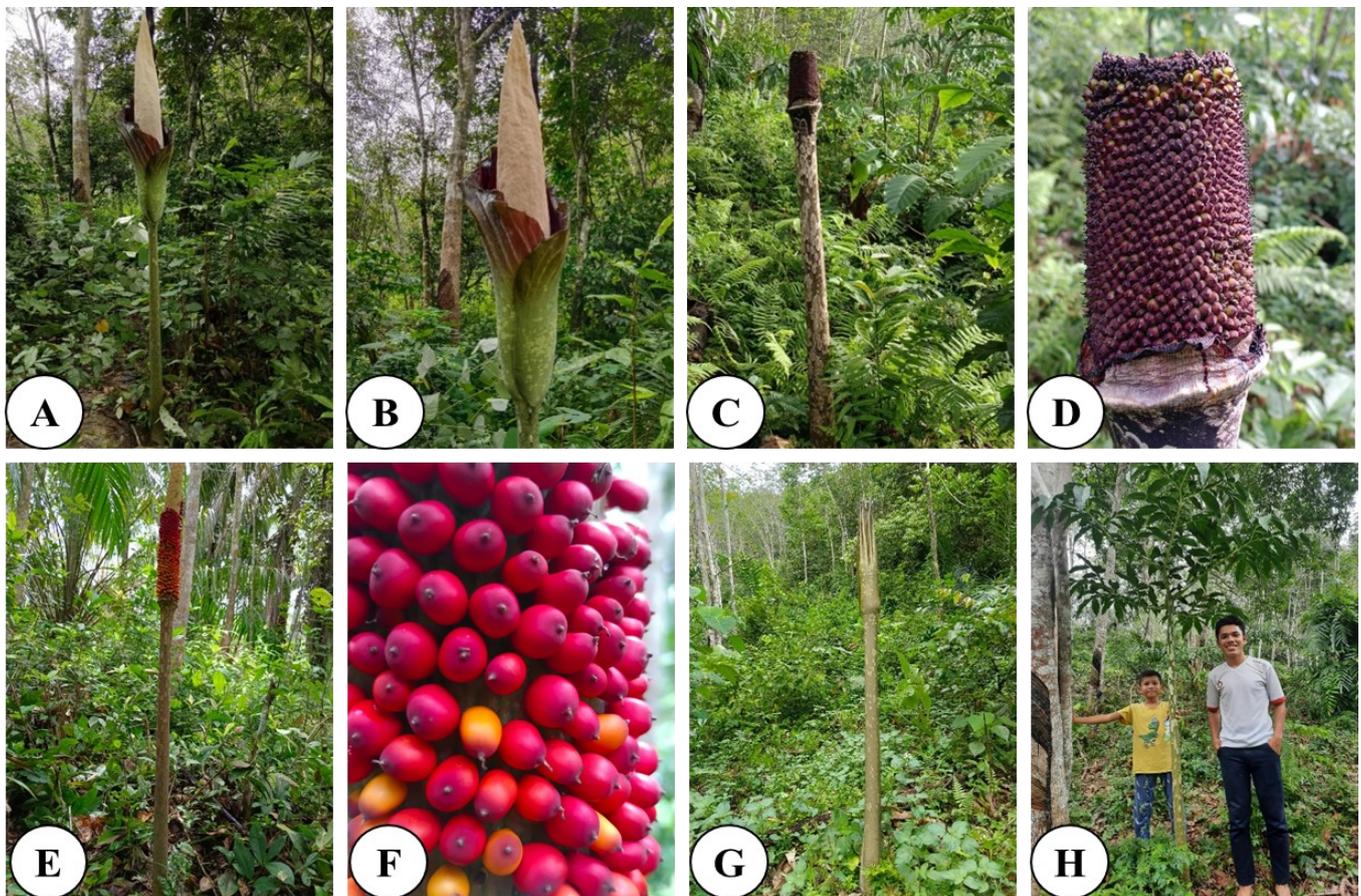

Figure 3. Documentation of *Amorphophallus gigas* in the study area. Inflorescence (A) and its closer look (B). Seed development (C) and its closer look (D) after blooming. Fruiting (E) and its closer look (F). Individual with unopened flowers (G) and its proportional height with human as a comparison (H).

Table 1. The association between *Amorphophallus gigas* and nearby flora at three research locations (Napa Lancat, Pangirkiran, Bargot Topong Julu) with five highest IVI (Importance Value Index) plant species across growth stage in North Padang Lawas Regency, North Sumatra.

Species	Family	IVI	Chi-square score		Association type	Association index			Association category
			X²	X² (Table)		OI	DI	JI	
Napa Lancat									
Understorey									
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	48.92	5.47	3.84	Significant	0.94	0.47	0.88	Very strong
Nephrolepis biserrata (Sw.) Schott	Nephrolepidaceae	17.85	1.33	3.84	Not significant	0.76	0.37	0.58	Strong
Asystasia gangetica (L.) T.Anderson	Acanthaceae	14.68	1.56	3.84	Not significant	0.58	0.26	0.36	Strong
Derris ellipitica (Wall.) Benth.	Fabaceae	12.83	1.33	3.84	Not significant	0.62	0.29	0.40	Strong
Oplismenus compositus P.Beauv.	Poaceae	10.77	2.21	3.84	Not significant	0.51	0.22	0.28	Strong
Seedling									
Symplocos rubiginosa Wall.	Symplocaceae	93.57	0.26	3.84	Not significant	0.46	0.17	0.21	Weak
Macaranga indica Wight	Euphorbiaceae	36.42	0.26	3.84	Not significant	0.46	0.17	0.21	Weak
Homalanthus populneus Pax	Euphorbiaceae	15.71	0.09	3.84	Not significant	0.29	0.08	0.08	Weak
Mallotus paniculatus Müll.Arg.	Euphorbiaceae	15.71	0.09	3.84	Not significant	0.29	0.08	0.08	Weak
Leea guineensis G.Don	Vitaceae	6.42	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak
Sapling									
Macaranga indica Wight	Euphorbiaceae	36.98	1.13	3.84	Not significant	0.65	0.31	0.44	Strong
Coffea canephora Pierre ex A.Froehner	Rubiaceae	35.03	0.49	3.84	Not significant	0.58	0.25	0.33	Strong
Homalanthus populneus Pax	Euphorbiaceae	25.37	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	22.26	0.33	3.84	Not significant	0.50	0.20	0.25	Strong
Leea guineensis G.Don	Vitaceae	19.43	0.33	3.84	Not significant	0.50	0.20	0.25	Strong
Pole									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	227.79	1.85	3.84	Not significant	0.82	0.40	0.67	Very strong
Macaranga indica Wight	Euphorbiaceae	28.87	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak
Archidendron pauciflorum (Benth.) I.C.Nielsen	Fabaceae	27.56	0.14	3.84	Not significant	0.35	0.11	0.13	Weak
Polyalthia stenopetala Finet & Gagnep.	Annonaceae	8.38	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak
Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	7.38	0.09	3.84	Not significant	0.29	0.08	0.08	Weak
Tree									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	184.33	0.49	3.84	Not significant	0.79	0.39	0.64	Very strong
Archidendron pauciflorum (Benth.) I.C.Nielsen	Fabaceae	86.46	0.41	3.84	Not significant	0.54	0.23	0.29	Strong
Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	11.02	0.04	3.84	Not significant	0,20	0,04	0,04	Very weak
Macaranga indica Wight	Euphorbiaceae	9.08	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak
Bischofia javanica Blume	Phyllanthaceae	9.08	0.04	3.84	Not significant	0.20	0.04	0.04	Very weak

Pangirkiran

Understorey

Species	Family								
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	49.19	0.04	3.84	Not significant	0.63	0.31	0.45	Strong
Asystasia gangetica (L.) T.Anderson	Acanthaceae	25.56	2.71	3.84	Not significant	0.68	0.33	0.50	Strong
Clidemia hirta D.Don	Melastomataceae	21.35	4.17	3.84	Significant	0.77	0.39	0.63	Very strong
Saurauia pendula Blume	Actinidiaceae	13.19	0.62	3.84	Not significant	0.53	0.25	0.33	Strong
Piper betle L.	Piperaceae	8.17	0.20	3.84	Not significant	0.38	0.17	0.21	Weak
Seedling									
Leea guineensis G.Don	Vitaceae	53.44	0.44	3.84	Not significant	0.42	0.20	0.25	Weak
Symplocos rubiginosa Wall.	Symplocaceae	51.07	0.04	3.84	Not significant	0.34	0.14	0.17	Weak
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	46.52	0.01	3.84	Not significant	0.44	0.21	0.26	Weak
Murraya koenigii (L.) Spreng.	Rutaceae	10.05	3.86	3.84	Significant	0.00	0.00	0.00	Very weak
Mallotus paniculatus Müll.Arg.	Euphorbiaceae	10.05	1.22	3.84	Not significant	0.35	0.11	0.13	Weak
Sapling									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	62.57	1.22	3.84	Not significant	0.73	0.36	0.56	Strong
Leea guineensis G.Don	Vitaceae	15.72	0.54	3.84	Not significant	0.47	0.18	0.22	Weak
Symplocos rubiginosa Wall.	Symplocaceae	15.72	0.54	3.84	Not significant	0.47	0.18	0.22	Weak
Mallotus paniculatus Müll.Arg.	Euphorbiaceae	14.99	0.54	3.84	Not significant	0.47	0.18	0.22	Weak
Piper aduncum L.	Piperaceae	13.37	0.30	3.84	Not significant	0.36	0.12	0.13	Weak
Pole									
Cephalomappa malloticarpa J.J.Sm.	Euphorbiaceae	246.73	0.09	3.84	Not significant	0.21	0.04	0.04	Very weak
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	53.37	0.41	3.84	Not significant	0.86	0.43	0.76	Very strong
Tree									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	207.32	1.44	3,84	Not significant	0.69	0.34	0.52	Strong
Garcinia parvifolia (Miq.) Miq.	Clusiaceae	30.89	0.09	3.84	Not significant	0.20	0.04	0.04	Very weak
Artocarpus heterophyllus Lam.	Moraceae	30.89	0.09	3.84	Not significant	0.20	0.04	0.04	Very weak
Litsea sp.	Lauraceae	30.89	0.09	3.84	Not significant	0.20	0.04	0.04	Very weak
Bargot Topong Julu									
Understorey									
Asystasia gangetica (L.) T.Anderson	Acanthaceae	24.66	0.69	3.84	Not significant	0.50	0.25	0.33	Strong
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	16.91	1.04	3.84	Not significant	0.14	0.07	0.07	Very weak
Elaeis guineensis Jacq.	Arecaceae	17.02	0.03	3.84	Not significant	0.36	0.18	0.21	Weak
Donax canniformis K.Schum.	Marantaceae	15.95	2.48	3.84	Not significant	0.56	0.28	0.38	Strong
Leersia virginica Willd.	Poaceae	17.84	4.17	3.84	Significant	0.57	0.27	0.36	Strong

Seedling									
Baccaurea motleyana (Müll.Arg.) Müll.Arg.	Phyllanthaceae	98.41	1.85	3.84	Not significant	0.33	0.10	0.11	Weak
Hibiscus tiliaceus L.	Malvaceae	25.40	1.85	3.84	Not significant	0.33	0.10	0.11	Weak
Leea guineensis G.Don	Vitaceae	25.40	1.85	3.84	Not significant	0.33	0.10	0.11	Weak
Coffea canephora Pierre ex A.Froehner	Rubiaceae	25.40	0.01	3.84	Not significant	0.19	0.08	0.09	Very weak
Lansium domesticum Corrêa	Meliaceae	25.40	0.59	3.84	Not significant	0.00	0.00	0.00	Very weak
Sapling									
Lansium domesticum Corrêa	Meliaceae	114.29	0.01	3.84	Not significant	0.19	0.08	0.09	Very weak
Durio zibethinus L.	Malvaceae	21.43	0.59	3.84	Not significant	0.00	0.00	0.00	Very weak
Grewia picta Baill.	Malvaceae	42.86	1.22	3.84	Not significant	0.00	0.00	0.00	Very weak
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	14.43	0.59	3.84	Not significant	0.00	0.00	0.00	Very weak
Pole									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	192.35	1.39	3.84	Not significant	0.38	0.17	0.20	Weak
Artocarpus integer (Thunb.) Merr.	Moraceae	64.73	1.85	3.84	Not significant	0.33	0.10	0.11	Weak
Baccaurea motleyana (Müll.Arg.) Müll.Arg.	Phyllanthaceae	42.92	0.59	3.84	Not significant	0.00	0.00	0.00	Very weak
Tree									
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	273.26	0.07	3.84	Not significant	0.38	0.19	0.24	Weak
Durio zibethinus L.	Malvaceae	26.74	1.39	3.84	Not significant	0.38	0.17	0.20	Weak

Note: OI = Ochiai index; DI = Dice index; JI = Jaccard index

from strong to very strong, they were either not statistically significant or showed negative associations. In Pangirkiran, *Clidemia hirta* from the understorey community similarly displayed a significant and very strong positive association with *A. gigas*, while *Murraya koenigii* exhibited a significant but weak association. Finally, in Bargot Topong Julu, *Leersia virginica* from the understorey community showed a strong positive association with the presence of *A. gigas*. *Clidemia hirta* is hypothesized to serve as a nitrogen supplier in the habitat of *A. gigas* due to its rapid leaf litter decomposition rate, which supports the growth of the corpse flower (23).

The second most prevalent plant species associated with *A. gigas* is *S. willdenowii*, a heterosporous lycophyte belonging to the *Selaginella* genus. These species possess functional ecological traits, including their megaspore size, which enables them to potentially thrive and spread alongside other exotic flora. The larger size of their megaspores provides resistance against desiccation and filters wind-borne particles, allowing them to thrive even under the forest canopy, where higher plants dominate and cover the majority of the area (24). Previous study by Arianto et al (22) and Hidayat & Yuzammi (20) have also highlighted the significance of *S. willdenowii* in *Amorphophallus* habitats. Additionally, Sari and Aryeni (25) documented the occurrence of both *S. willdenowii* and *C. hirta* in the habitat of *A. titanum* in Sibolangit forest, North Sumatra. Despite *Hevea brasiliensis* dominating three sites and the mature growth stage, it does not always reflect its direct contribution or at least association with *A. gigas*. According to the results of the chi-square test, a positive association indicates a beneficial relationship between the two species (26). Notably, all associated plants showing a strong association with *A. gigas* were from the understorey community, suggesting shared \ environmental preferences, such as humid air or soil conditions with certain levels of shade, favoring the growth of the corpse flower in all habitats (27,28).

While these findings offer a general trend, further investigation is necessary, particularly concerning the specific associations with understorey species identified in this study. Although most results indicated weak or negative associations, it's essential to note that these relationships may manifest through the community as a whole rather than specific individuals of a species. Plant species associations do not necessarily imply a harmonious relationship between them; they may compete for the same environmental resources by occupying the same strata as direct competitors, or they may rely on other species that can only thrive in certain niches created by trees as dependent species. Alternatively, different types of complementarity may exist, wherein species do not compete but instead occupy different strata or have different seasonal rhythms to thrive adequately (29). The results from the ecological analysis of associated flora in the *A. gigas* habitats are presented in Table 2.

Table 2. The diversity and ecological index of floral community in *Amorphophallus gigas* habitats.

Growth stage	Shannon's diversity index (H')	Category	Margalef's species richness (D_{mg})	Category	Evenness index (J)	Category
Napa Lancat						
Understorey	2.48	Moderate	20.85	High	0.12	Depressed
Seedling	1.19	Low	9.76	High	0.11	Depressed
Sapling	2.30	Moderate	13.78	High	0.16	Depressed
Pole	0.79	Low	4.74	Moderate	0.50	Unstable
Tree	1.02	Low	4.70	Moderate	0.20	Depressed
Pangirkiran						
Understorey	2.31	Moderate	3.65	Moderate	0.71	Stable
Seedling	1.68	Moderate	2.29	Low	0.77	Stable
Sapling	2.31	Moderate	4.27	Moderate	0.77	Stable
Pole	0.11	Low	0.53	Low	0.16	Depressed
Tree	0.39	Low	1.13	Low	0.07	Depressed
Bargot Topong Julu						
Understorey	2.71	Moderate	3.66	Moderate	0.20	Depressed
Seedling	1.30	Low	2.28	Low	0.98	Stable
Sapling	0.90	Low	1.52	Low	0.81	Stable
Pole	0.87	Low	1.06	Low	0.69	Unstable
Tree	0.14	Low	0.44	Moderate	0.20	Depressed

In Napa Lancat, moderate diversity (H' = 2.48 and 2.30, respectively) and high species richness (Dmg = 20.85 and 13.78, respectively) are observed in the understorey and sapling growth stages, while the pole and tree stages exhibit low diversity and moderate species richness. The evenness index is depressed for all growth stages except the pole stage, which is unstable. In Pangirkiran, moderate diversity and species richness (H' = 2.31 and 2.31; Dmg = 3.65 and 4.27, respectively) are noted in the understorey and sapling growth stages, while the seedling stage shows moderate diversity and low species richness (H' = 1.68 and Dmg = 2.29). The pole and tree stages exhibit low diversity and species richness. The evenness index is stable for all growth stages except the pole and tree stages, which are depressed. In Bargot Topong Julu, moderate diversity and species richness (H' = 2.71 and Dmg = 3.66) are observed in the understorey growth stage, while the seedling and sapling stages display low diversity and low species richness (H' = 1.30 and 0.90; Dmg = 2.28 and 1.52, respectively). The pole and tree stages exhibit low diversity and low to moderate species richness. The evenness index is depressed for all growth stages except the seedling stage, which is stable.

In summary, the findings suggest that the floral community within *A. gigas* habitats exhibits varying levels of diversity and species richness across different growth stages and locations. The ecological indices utilized offer insights into the structure and dynamics of the community, along with the environmental conditions influencing them. The prevalence of certain species dominating most growth stages and locations indicates potential disturbances or other ecological factors shaping community composition. Conversely, moderate to high species richness in select growth stages and locations signifies a diverse array of plant species contributing to ecosystem function and resilience. These findings align with ecological theories like the intermediate disturbance hypothesis, which posits that moderate disturbance levels can foster diversity and species coexistence in ecosystems (30). Furthermore, environmental variables recorded in Table 3 are investigated, and the correlation between these abiotic and biotic parameters is presented in Table 4. Additionally, Figure 4 visually illustrates the relationships among the examined parameters.

Table 3. The physicochemical parameters or environmental ranges in the *Amorphophallus gigas* habitats.

Location	Altitude (m asl)	Slope (°)	Light intensity (lux)	Air temperature (°C)	Soil pH	Relative humidity (%)
Napa Lancat	89-97	15-35	89-502	27.3-29.5	6.6-6.8	82-97
Pangirkiran	72-75	10-17	70-223	26.9-28.5	6.5-6.8	81-86
Bargot Topong Julu	68-72	10-12	127-425	27.0-27.6	4.7-5	83-90

Table 4. Pearson's correlation coefficient for physicochemical parameters and the number of generative and vegetative individuals of *Amorphophallus gigas* in the study region

Location	Altitude	Slope	Light intensity	Air temperature	Soil pH	Relative humidity	Vegetative phase	Generative phase
Altitude								
Slope	0.894							
Light intensity	0.233	0.480						
Air temperature	0.432	0.635	0.696					
Soil pH	0.607	0.534	-0.272	0.188				
Relative humidity	0.116	-0.270	-0.619	-0.361	0.030			
Vegetative phase	0.607	0.498	-0.212	-0.242	0.408	0.072		
Generative phase	0.226	0.210	-0.207	0.290	0.063	0.372	0.191	
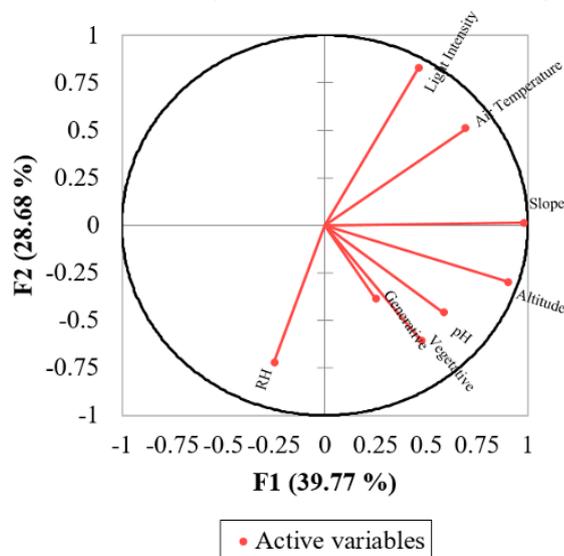
Figure 4. Relationship between the number of individuals of *A. gigas* and environmental parameters.

The correlation values, ranging from 0 to 1, indicate the strength of the relationship between variables, with values closer to 1 indicating stronger relationships. The results reveals a strong positive relationship ($r = 0.607$) between altitude and the total vegetative individuals, suggesting that higher altitudes corresponds to a greater number of individuals. Similarly, slope demonstrates a moderate positive relationship ($r = 0.498$) with the number of vegetative individuals, implying that steeper slopes harbor more individuals. The relationship between vegetative individuals and pH is moderate and positive ($r = 0.408$), while associations with light intensity and air temperature are weak and negative ($r = -0.212$ and -0.242, respectively). Conversely, the relationship with humidity, though less pronounced, is positive. These findings indicate that altitude, slope, pH, light intensity, air temperature, and humidity may influence the abundance of *A. gigas* individuals in various ways. Notably, the population at Napa Lancat, characterized by higher altitude and slope, exhibits a greater number of vegetative individuals compared to the populations at Pangirkiran and Bargot Topong Julu.

The moderate to strong positive correlation between soil pH and the abundance of vegetative *A. gigas* individuals suggests a preference for slightly alkaline soils. Conversely, the weak negative correlations between light intensity and air temperature with vegetative individuals imply that *A. gigas* may thrive less in areas with high light exposure or elevated temperatures. The less pronounced positive correlation between relative humidity and the number of individuals indicates a preference for higher humidity levels. Our findings align with those of Wulandari *et al.* (31), who observed similar weak correlations between environmental parameters such as air and soil temperature and relative humidity in *Amorphophallus* habitats in Mount Poteng, West Kalimantan. However, unlike studies on *A. konjac*, which suggested that altitudinal variation influences associated rhizospheric microbes and disease occurrence, our study in a lowland forest indicates a moderate yet significant correlation with altitude ($r = 0.607$) (32). Nonetheless, the impact of soil microbiomes on *A. gigas* remains uncertain in our study. Traditional forest management practices, particularly rubber planting and other economically valuable plants, inadvertently contribute to *A. gigas* presence in the study area. Complex agroforestry systems, while beneficial for biodiversity, cannot fully replace natural habitats crucial for maintaining wild biodiversity. Hence, integrating local knowledge, ongoing research, and monitoring is essential for informed management, involving active participation from farmers and local communities (33).

Conclusion

This study offers valuable insights into the environmental variables that could impact the spatial arrangement and population size of *A. gigas*, providing guidance for initiatives aimed at conserving and managing these habitats. Future investigations could delve into the fundamental mechanisms and drivers of these associations, along with their potential consequences for the ecosystemic functionality and resilience of *A. gigas* habitats. *Amorphophallus gigas* requires shade to support its growth, making it highly dependent on its habitat. Protecting the forests as its habitat will directly preserve the *A. gigas* species. Conservation strategies may include

in-situ conservation, preserving *A. gigas* in its natural habitat, as well as ex-situ conservation, which involves conservation outside its original habitat, such as in botanical gardens or arboreta located in North Sumatra, Indonesia. By identifying key environmental factors influencing *A. gigas* populations, this study provides valuable insights for developing effective conservation and management strategies for this unique plant species.

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Authors' contributions

RR was responsible for conceptualization, methodology, investigation, and writing the original draft. R provided supervision, validation, reviewed and edited the manuscript, and acquired funding. AR offered supervision and conducted the formal analysis. ESMN provided supervision, developed software, and curated data. D was in charge of visualization. TAA supplied the necessary resources. MHI contributed to methodology, developed software, and performed validation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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