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Autecology of *Amorphophallus gigas* in Batang Natal Watershed, North Sumatra, Indonesia

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Abstract. *Rambey R, Rahmawaty, Suratman MN, Rauf A, Nababan ESM, Delvian, Aththorick TA, Ismail MH, Gendaseca S. 2024. Autecology of* Amorphophallus gigas *in Batang Natal Watershed, North Sumatra, Indonesia. Biodiversitas 25: 2887-2900. Amorphophallus gigas* Teijsm. & Binn., a member of the Araceae family, is distributed across Sumatra, particularly within the Batang Natal watershed of Mandailing Natal District. This plant population thrives significantly under the forest canopy in high-humidity environments, such as a watershed, despite being exposed to certain challenges. The Batang Natal Watershed, spanning 70.5 km and originating in the Batang Natal Sub-district, is frequently subjected to mining activities. Therefore, this study aimed to explore the autecology of *A. gigas* in the watershed, focusing on factors such as occurrence, associated plant species, vegetation composition, and soil characteristics. The occurrences of *A. gigas* were identified through direct interviews with the local community, complemented by field collection of coordinate points in five villages. The vegetation around *A. gigas* habitats was then analyzed using nested sampling with a plot size of 1 ha. There was no *A. gigas* in Aek Garingging Village despite the reported presence in 2020, while there were nine individuals in each village of Rao-Rao and Lubuk Bondar Panjang and six and three individuals in Bangkelang and Aek Nangali, respectively. There were 63 tree and 39 understory species recorded around the *A. gigas* habitat. Lubuk Bondar was dominated by *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. across several strata, with generally low to very low associations. Bangkelang was characterized by *Gmelina arborea* Roxb. ex Sm. in the pole and tree strata, with similarly low associations. In Rao-Rao, *Coffea canephora* Pierre ex A.Froehner was prominent in the seedling and sapling strata, showing low but consistent associations, and *Selaginella willdenowii* (Desv.) Baker in the understorey had a high positive association. The dominant species in each site typically had low to very low associations with other species, indicating limited ecological connectivity with *A. gigas*. The spatial distribution of *A. gigas* suggested a clumped pattern to ensure *A. gigas* preservation in the Batang Natal Watershed, it is essential to designate the plant's natural habitat as an in situ conservation area.

Keywords: Aroid, association, autecology, vegetation

INTRODUCTION

Plant species richness and distribution are primarily influenced by geographical and environmental factors, resource availability, ecological interactions, and species adaptability (Ridgwell 2002; Willig et al. 2003; Rahmawaty et al. 2019, 2020; Yang et al. 2022). At the local level, species diversity is shaped by micro-environmental conditions and biological processes (Mayor et al. 2023). Water availability plays a critical role in limiting vegetation growth and driving plant diversification by affecting water requirements and physiological adaptations (Bykova et al. 2019). Within the Soil-Plant-Atmosphere Continuum (SPAC), water facilitates nutrient circulation, impacting soil properties and plant growth, which in turn influences species distribution and diversity (Silva and Lambers 2020). Natural disturbances and ecological succession further affect distribution patterns by altering habitats and species composition (Lambers et al. 2008).

A watershed is defined as a landscape consisting of both natural and artificial ecosystems where rainfall and runoff flow into a common water body, such as river and lake (Cantonati et al. 2020). Watershed appears in the form of complex units with interconnected biophysical, social, economic, and cultural aspects (Aglanu 2014). Effective planning of watersheds is crucial for conserving sensitive plant species that rely on certain resources. This must account for the contextual influences on the major physical, chemical, and biological processes governing wetlands and stream functions. By understanding and managing these processes, better protection can be provided to the critical habitats and ecosystem services supporting certain vulnerable plant species (Flotemersch et al. 2016).

Amorphophallus, initially found in tropical regions spanning from Africa to the Pacific Islands, has extended its range to temperate areas such as China and Japan (Sumarwoto 2005). The genus is distributed from Africa, Madagascar, and India to Southeast Asia, Malesia, and northeastern Australia. Notably, Southeast Asia and West Malesia are recognized for their exceptional species diversity within this genus (Handayani et al. 2020). *Amorphophallus gigas* Teijsm. & Binn. is described as the second-largest carrion flower globally, featuring the highest inflorescence in the Amorphophallus genus. *A. gigas* is native to Sumatra Island, yet there is a lack of comprehensive information regarding the distribution and habitat characteristics. While several species from this genus have conservation concerns due to being threatened with extinction, *A. gigas* is not yet listed in the IUCN Redlist and the Regulation of the Minister of Environment and Forestry No. 20 of 2018 (Rugayah et al. 2017).

Amorphophallus gigas is a tuber-producing plant with significant potential for medicinal and food uses (Nababan et al. 2024). The tubers are rich in glucomannan, leading to being valuable in food, pharmaceutical, and chemical industries (Rambey et al. 2024). *A. gigas* belongs to the same genus as other well-studied species including *Amorphophallus muelleri* Blume (*porang*) and *Amorphophallus paeoniifolius* (Dennst.) Nicolson (*suweg*), which tends to possess similar phytochemical profiles (Dey et al. 2016; Yuzammi et al. 2018), but further investigations are needed for confirmation. In Java, local communities actively use *Amorphophallus*, particularly *suweg* (*A. paeoniifolius*), as a food source (Mutaqin et al. 2020a; 2020b). The young flowers and leaf stalks serve as vegetables, providing a rich source of carbohydrates, protein, minerals, vitamins, flavonoids, and fiber (Fontarum-Bulawin et al. 2023). *A. muelleri*, an alternative carbohydrate source, possesses the highest glucomannan content among various Amorphophallus species in Indonesia (Ashan et al. 2023).

The *Amorphophallus* population, including *A. gigas* has consistently declined over the years, and neglecting this trend poses a significant risk of extinction in the natural habitat (Yuzammi 2014). This species tends to have a scattered-to-clump distribution, contributing to the rarity of the local presence on the spatiotemporal scale (Rambey et al. 2021, 2022, 2023a). Numerous records indicate that the distribution closely associated with water sources, including watersheds (Mutaqin et al. 2023; Wulandari et al. 2022). Batang Natal Watershed in North Sumatra, Indonesia, presents significant environmental challenges due to its geological and hydrological characteristics. The region's alluvial fan deposits, formed during the Pleistocene-Early Holocene period, are known to contain valuable minerals like gold, further complicating conservation efforts. The watershed is heavily impacted by illegal gold mining, which has severely degraded water quality in the Batang Natal River, affecting around 30 villages along a 50 km stretch (Nasution et al. 2022). Considering the importance of watersheds on the existence and possibility of ecological connectivity with *A. gigas* populations, this study aimed to investigate the ecology of this species in the Batang Natal Watershed, North Sumatra Province, Indonesia, providing comprehensive information for species management and conservation. A deep exploration of the autecological aspects, such as environmental characteristics, elevation, and the associations of *A. gigas* with other plants will be conducted to highlight the ecological significance of this species.

MATERIALS AND METHODS

Study period and area

This study was conducted from 2022 to 2024 using vegetation analysis and exploratory surveys to investigate *A. gigas* presence by consulting the local community and recording the species distribution coordinates in the Batang Natal Watershed, Mandailing Natal District, North Sumatra Province, Indonesia. Five identified locations of *A. gigas* included Aek Garingging, Lubuk Bondar, Aek Nangali, Rao-Rao, and Bangkelang Village. Moreover, the Batang Natal Watershed spans 70.5 km and it traverses three subdistricts (Figure 1). The current condition of the Batang Natal River is critically compromised due to illegal gold mining activities (Nasution et al. 2022; Nasution et al. 2022), transforming the clear appearance of the water into a turbid state.

The watershed upstream area is situated in the Batang Natal District with natural conditions consisting mainly of mountains and hills as well as high rainfall (2500-4000 mm per year), intersected by the Batang Natal River. This part has steep slopes (above 64%) with shallow soil layers. Land use management is dominated by agroforestry managed by the local community especially in steep terrain, allowing various forest tree species to grow and prevent landslides. Additionally, the upstream portion is characterized by shallow and rocky soil layers, making it susceptible to landslides.

Sampling procedure

Population data for *A. gigas* were collected through a census method inside a 1-hectare nested plot consisting of 25 subplots (Figure 2), considering land use, elevation, soil pH, air humidity, air temperature, light intensity, and the vegetation surrounding *A. gigas* (Stohlgren et al. 1995; Rambey et al. 2023). Trees with a diameter greater than 20 cm were recorded in 20×20 m plots, while saplings with a diameter between 10 and 20 cm were assessed in 10×10 m plots. Seedlings taller than 1.5 m with a diameter of less than 10 cm were evaluated in 5×5 m plots, then seedlings and understory plants shorter than 1.5 m were recorded in 2×2 m plots. Soil samples were collected as a composite at three points from 0 to 20 cm depth at each *A. gigas* habitat (Purwowidodo 2004) and transported to the laboratory, while the measured parameter was the population count. The selection of observation plots was intentional by focusing only on *A. gigas* locations. The surrounding plant species were directly identified in the field, with those unknown being analyzed using identification books.

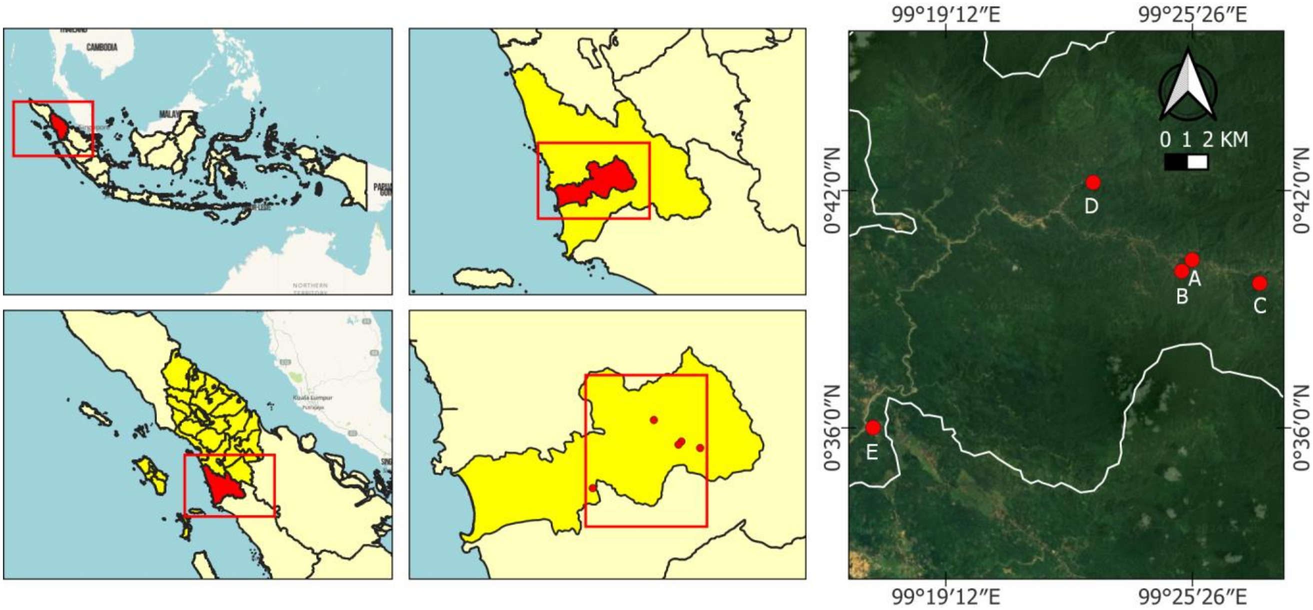

Figure 1. Map of the study location of *Amorphophallus gigas* in Batang Natal Watershed, Mandailing Natal District, North Sumatra Province, Indonesia. A. Rao-Rao, B. Aek Bangkelang, C. Aek Nangali, D. Lubuk Bondar, E. Aek Garingging

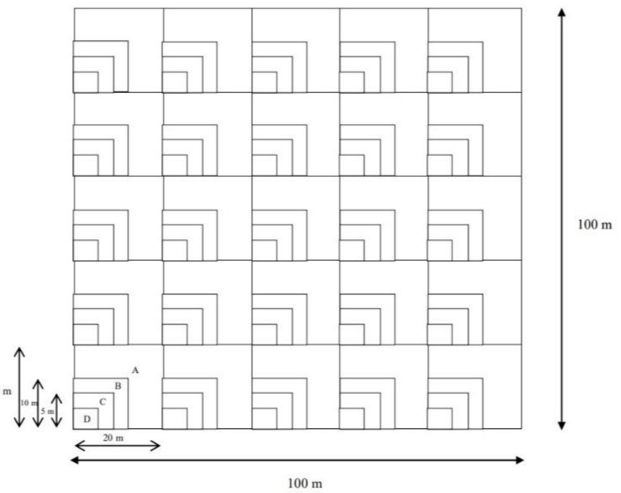

Figure 2. Diagram of nested sampling plot for vegetation analysis

Data analysis

Descriptive analysis was conducted on ecological parameter data, including land use, elevation above sea level, air humidity, air temperature, light intensity, physical and chemical properties of soil, and plant species growing around *A. gigas*. A Canonical Correspondence Analysis (CCA) was performed with CANOCO software to visualize the interaction between abiotic and biotic factors.

Importance value index

The dominant plant parameters were measured using the Importance Value Index (IVI) defined as the sum of relative density, relative dominance, and relative frequency. The IVI is a quantitative parameter used to express the dominance or control level of species in a plant community, and was calculated using the formula:

For pole and tree levels:

$$IVI = RD + RF + RDo$$

For seedling and sapling levels:

$$IVI = RD + RF$$

Where: RD: Relative Density; RF: Relative Frequency; RDo: Relative Dominance.

Species diversity

Species diversity showing stability level of vegetation community was determined using Shannon-Wiener diversity index following the formula by Odum (1996) as follow:

$$H = - \sum [(ni/Nt) \ln (Ni/Nt)]$$

Where: H: Shannon-Wiener diversity index; Ni: number of individuals of the i-th species; Nt: total number for all individuals.

The criteria for the diversity index value according to Magurran (1988) are low ($H<1$), moderate $1<H<3$ and high ($H>3$).

Morisita's spread index

Morisita's Index in this study was used to determine *Amorphophallus* distribution pattern, with no effect on the sampling area size. It has good ability to compare population distribution patterns (Brower et al. 1989) and the formula is as follows:

$$I_d = N \left[\frac{\sum x^2 - \sum x}{(\sum)x^2 - \sum x} \right]$$

Where: Id: Morisita's Distribution Index; N= ∑f(X) = number of frequencies of observation results; N: total number of individuals in (n); ∑X2: square of the number of individuals per observation point.

The distribution was classified into random (Id=1), uniform (Id<1) and clustered/clumped (Id>1).

Species richness index

Species richness index is a metric used to determine the number of species in a community, with higher richness signifying a greater variety (Magurran 1988). The richness index is calculated with Margalef Index (R), while the species diversity index is a parameter for assessing the stability of a community or the ability to maintain stability against disturbances faced by the components (Indrianto 2008). The richness of vegetation types was determined using the richness index (Ludwig and Reynold 1988) with the following formula:

$$R = \frac{S - 1}{In\ (N)}$$

Where: R: Species richness index; S: number of Species; N: total Number of Individuals; An R1<3.5 indicates low species richness, R1 between 3.5- .0 signifies moderate species richness, and R1>5.0 is high.

Species evenness index

The evenness of vegetation species was determined using the Evenness Index (Ludwig and Reynold 1988) with the following formula:

$$E = \frac{H'}{In\ (S)}$$

Where: E: Species Evenness Index; H': Species Diversity Index; S: Number of Species.

The evenness index value ranges from 0-1 with the following categories: low or depressed community (0<E≤0.4), moderate or unstable community (0.4<E≤0.6) and high or stable community (0.6<E≤1.0).

Ochiai index

Association studies were conducted to analyze the relationship of *A. gigas* with certain plants in the habitat based on Ochiai Index using the following formula (Ludwig and Reynolds 1988):

$$Oi = \frac{a}{\sqrt{a + b}\sqrt{a + c}}$$

Where: *a*: the number of plots where both species (A and B) are found; *b*: the number of plots containing species A but lacking B; *c*: the number of plots where species B is present but A is not.

The Ochiai Index ranges from 0 to 1, reflecting the degree of association between the two species. Values of 0.75 to 1.00 suggest a very high association, and 0.74 to 0.49 represents high, while 0.48 to 0.23 signify a low association, and 0.23 or less denotes very low. Additionally, the index is useful for understanding the closeness of the association between different ecological types within the studied plots.

RESULTS AND DISCUSSION

Overview of *Amorphophallus gigas* populations in Batang Natal watershed

Initially, we targeted five villages for data collection as described in the methods. However, this study then focused specifically on three villages: Bangkelang, Lubuk Bondar Panjang, and Rao-Rao. The village of Aek Nangali was excluded since it shared similar ecological conditions with Lubuk Bondar Panjang due to its comparable altitude. Aek Garingging was also excluded from the exploration due to recent land use changes; it has been entirely converted to residential areas since 2022, leaving insufficient site for proper vegetation analysis. The prevalence of *A. gigas* across three villages of Batang Natal Watershed is presented in Table 1 and Figure 3. The community structure of understorey and tree species is presented in Tables 2 and 3, while Table 4 shows that *A. gigas* thrives under agroforestry canopies in the landscape of the Batang Natal watershed. Surveys of *A. gigas* and its associated flora have provided some preliminary insights.

Table 1. Distribution of *Amorphophallus gigas* in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Sites (village)	Altitude (masl)	Number of *A. gigas*/ha	Description
Rao-Rao	623	9 vegetative, 1 generative	Forest under Forest Management Unit/*KPH*
Bangkelang	384	6 vegetative	Durian agroforestry
Lubuk Bondar Panjang	240	9 vegetative	*A. gigas* bloomed in 2020 according to community information, but it was not found during the 2022 study due to land transformation from rubber agroforestry to moorland
Aek Nangali	244	3 vegetative	Rubber agroforestry
Aek Garingging	35	1 generative was spotted in 2020 but no longer recorded since 2022	

There are 39 species of undergrowth and 66 species of trees (Table 3) found around *A. gigas* in the Batang Natal Watershed (Table 2). According to Wahidah et al. (2021), the natural growth of *Amorphophallus* Blume ex Decne. is influenced by biotic factors, including human and animal activities, as well as microorganisms in an ecosystem. Abiotic factors that play critical roles in determining the growth are soil conditions, water availability, air, light intensity, temperature, soil pH, and nutrient levels. The *A. gigas* habitat within the Batang Natal Watershed has an altitude of 35-623 masl with temperature ranges from 22.73 to 24.67°C, air humidity around 87.33 to 98% and light intensity ranging from 11 to 96.67 lux. Additionally, the soil is predominantly clay, with a low bulk density value, signaling low soil density and suggesting organic soil. The habitat condition of *A. gigas* growing in an agroforestry setting in this study differs from Wahyu et al. (2022) results in the Sub Watershed of Kokok Tojang, East Lombok, where *A. paeoniifolius* grew under temperature of 19.4-30.3°C, humidity of 64.4-81.4%, light intensity of 60.3-22,526.8 lux and the highest elevation of 438 meters above sea level (masl) and the lowest at 24 masl. In addition, the study conducted by Munawaroh and Yuzammi (2018) showed that *A. titanum* specifically grows at elevation of 100-1100 masl. *A. gigas* thrives on extremely steep mountain slopes (64.90-91.08%), corresponding to the exploration of Amorphophallus habitat by Komsiati and Achyani (2021), where *A. titanum* was located in steep areas ranging from 30 to 60%. Soil conditions of each *A. gigas* habitat are presented in Table 5, and this species is abundant under tree stands such as agroforestry, secondary forests, open land, yards, gardens, and on the edge of rice fields (Mursyidin and Hernanda 2021; Mutaqin et al. 2021; Mutaqin et al. 2020b). Furthermore, *A. gigas* grows in secondary vegetation, shrubs, secondary forests, as well as moorlands (Saputro et al. 2022).

Table 2. Understorey community around *Amorphophallus gigas* habitat in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Local name	Botanical name	Family	Presence		
			Rao-Rao	Lubuk Bondar	Bangkelang
Atturbung	*Amorphophallus beccarii* Engl	Araceae	+	+	+
Atturbung besar	*Amorphophallus gigas* Teijsm. & Binn.	Araceae	+	+	
Rumput Manis	*Hierochloe odorata*	Poaceae		+	
Sanduduk Rubaton	*Melastoma malabathricum* L.	Melastomataceae	+	+	
Ria-ria	*Carex muskingumensis* Schwein.	Cyperaceae		+	
Pandan	*Pandanus amaryllifolius* Roxb. Ex Lindl	Poaceae		+	
Pakis	*Nephrolepis biserrata* (Sw.) Schott	Nephrolepidaceae	+	+	+
Asoli	*Crassocephalum crepidioides* f. *luteum* (Steen.) Belcher	Cyperaceae			
Sirungguk	*Selaginella willdenowii* (Desv.) Baker	Selaginellaciae	+	+	+
Lantoyung	*Solanum ferox* Burm.f.	Polypodiaceae	+		
Suat	*Colocasia esculenta* (L.) Schott	Araceae	-		+
Sanduduk Bulu	*Clidemia hirta* (L) D.Don	Melastomataceae	+	+	+
Sirih Majo	*Piper crocatum* Ruiz & Pav.	Piperceae	+		
Singkut	*Saurauia pendula* Blume	Actinidiaceae	+	+	+
Ayub-ayub	*Sanchezia speciosa* Leonard	Acanthaceae	+		
Bon Ban	*Donax canniformis* (G.Forst.) K.Schum.	Marantaceae	+	+	
Sirih Hutan	*Piper aduncum* Vell.	Piperceae	+	+	
Bunga Rubaton	*Impatiens balsamina* L.	Balsaminaceae	+		
Anggur-Anggur	*Ageratum conyzoides* Sieber ex Steud.	Asteraceae	+		
Ambolung	*Alocasia alba* Schott	Araceae	+		
Rimbang	*Solanum torvum* Sw.	Solanaceae	+		
Siala	*Phaleria macrocarpa* (Scheff.) Boerl.	Thymelaeceae	+		
Keladi	*Caladium bicolor* (Aiton) Vent	Araceae	+		
Bayang Aek	*Elatostema platyphyllum* Wedd.	Urticaceae.	+		+
Pogu Tano	*Lindernia viscosa* (Hornem.) Bold	Linderniaceae	+		
Salak	*Salacca zalacca* (Gaertn.)Voss	Arecaceae		+	
Aren	*Arenga pinnata* (Wurmb) Merr.	Arecaceae		+	
Paku tiang	*Dicksonia antarctica* Labill.	Thyrsopteridaceae		+	
Bunga kelelawar hitam	*Tacca chantrieri* Andre	Dioscoreaceae		+	
Homalomema	*Homalomena pontederifolia* Griff. Ex Hook.f.	Araceae		+	
Begonia	*Begonia* sp	Begoniaceae		+	
Lalang	*Imperata cylindrica* (L.) Raeusch.	Poaceae		+	
Jahe-jahean	*Etlingera coccinea* (Blume) S.Sakai & Nagam	Zingiberaceae		+	
Pakis halus	*Nephrolepis falcata* (Cav.)C.chr.	Nephrolepidaceae		+	+
Pakis sayur	*Diplazium esculentum* (Retz.) Sw	Athyriaceae			+
Pinang	*Areca catechu* L.	Arecaceae			+
Rotan	*Calamus polystachis*	Arecaceae			+
Rumput israel	*Asystasia gangetica* (L.) anderson	Acanthaceae			+
Rumput karet	*Oplismenus compositus* f. *Glabratus* F.Br.	Poaceae			+

Table 3. Tree community around *Amorphophallus gigas* habitat in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Local name	Botanical name	Family	Presence		
			Rao-Rao	Lubuk Bondar	Bangkelang
Alngit	*Neonauclea calycina* (Bartl. Ex DC.) Merr.	Rubiaceae	+		
Amadie	*Alseodaphne nigrescens* (Gamble) Kosterm.	Lauraceae	+		
Andarasi	*Ficus glandulifera* (Miq.)Wall. Ex King	Moraceae	+		
Andis	*Tamarindus indica* L.	Fabaceae	+		
Kapundung	*Baccaurea racemosa* (Reinw.) Mull.Arg.	Phyllanthaceae		+	
Arodan	*Artocarpus communis* J.R.Forst. & G.Forst.	Moraceae	+	+	
Hayu Orsik	*Quercus gamelliflora* Blume	Fagaceae	+		
Hayundolok	*Syzygium racemosum* (Blume) DC.	Myrtaceaea	+	+	
Bungle	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	+		
Damar	*Agathis alba* (Rumph. Ex Valmont) Foxw.	Dipterocarpaceae	+		
Daun Salam	*Syzygium polyanthum* Thwaites	Myrtaceaea	+		
Durian	*Durio zibethinus* L.	Malvaceae		+	+
Jelatang	*Laportea aestuans* (L.) Chew	Orticaceae		+	+
Karet	*Hevea brasiliensis* (Willd. Ex A. Juss.) Mull.Arg	Euphorbiaceae		+	+
Ketapang	*Terminalia catappa* L.	Combretaceae	+		
Mayang susu	*Palaquium rostratum* (Miq.) Burk	Sapotaceae	+		
Modang	*Litsea odorifera* Valeton	Lauraceae	+		
Meranti	*Shorea* sp	Dipterocarpaceae	+	+	
Modang Congke	*Garcinia parvifolia* (Miq.) Miq.	Clusiaceae	+		
Modang Sauh	*Litsea ferruginea* (Blume) Blume	Lauraceae	+		
Modang Tano	*Litsea cubeba* (Lour.) Pers.	Lauraceae	+		
Monton	*Antidesma bunius* (L.) Spreng.	Phyllanthaceae	+		+
Hoteng	*Castanopsis javanica* (Bllume) A.DC.	Fagaceae	+		
Petai	*Parkia speciosa* (Hassk)	Fabaceae		+	+
Salik	*Aglaia elliptica* (C.DC.) Blume	Meliaceae	+		
Simarkopi-kopi	*Porterandia anisophylla* (Jack ex Rob.) Ridl.	Rubiaceae	+		+
Sitarak	*Macaranga indica* Wight	Euphorbiaceae		+	+
Tarutung Karangan	*Durio graveolens* Becc.	Malvaceae			+
Tinggiran	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	+		
Torop	*Artocarpus elasticus* Reinw. Ex blume	Moraceae	+		+
Kase	*Pometia pinnata* J.R.Forst. & G.Forst.	Sapindaceae	+	+	+
Kopi	*Coffea canephora* Pierre ex A.Froehner	Rubiaceae	+	+	
Incop-incop	*Leea guineensis* G.Don	Leeaceae	+	+	+
Mayang Aek	*Palaquium leiocarpum*	Sapotaceae	+		
Barangan	*Castanopsis inermis* (Lindl.) Benth, & Hook.f.	Fagaceae	+		
Bayur	*Pterospermum Blumeanum* Korth.	Malvaceae	+		
Capot	*Macaranga indica* Wight	Euphorbiaceae	+		
Dap-dap	*Erythrina fusca* Lour.	Fabaceae	+	+	+
Garunggung	*Cratoxylum arborescens* (Vahl) Blume	Guttiferae	+		
Kayu Manis	*Cinnamomum burmanni* (Nees & T.Nees) Blume	Lauraceae	+	+	+
Lancat Body	*Baccaurea lanceolata* (Miq.) Mull.Arg.	Phyllanthaceae	+		
Lagan	*Dipterocarpus elongatus* Korth.	Dipterocarpaceae	+		
Mayang Tarutung	*Palaqium gutta*	Sapotaceae	+		
Sidulas	*Knema latifolia* Warb.	Myristicaceae	+		
Simarbakkudi	*Beilschmiedia tawa* (A.Cunn.) Kirk	Gnetaceae	+		
Kemiri	*Aleurites moluccana*	Euphorbiaceae		+	
Waru pucuk merah	*Sapium baccatum* Roxb.	Euphorbiaceae		+	
Manggis	*Garcinia mangostana* L.	Clusiaceae		+	
Mangga	*Mangifera indica* L.	Anacardiaceae		+	+
Jengkol	*Archidendron pauciflorum* (Benth.) I.C. nielsen	Fabaceae		+	+
Pohon sirih	*Piper aduncum* Vell.	Piperaceae		+	
Langsat	*Lansium domesticum* Correa	Meliaceae		+	
Kuini	*Mangifera odorata* Griff.	Clusiaceae		+	+
Kari	*Murraya koenigii*	Rutaceae		+	
Coklat	*Theobroma cacao* L.	Malvaceae		+	+
Rambutan	*Nephelium lappaceum* L.	Sapindaceae		+	+
Dong-dong	*Laportea stimulans* (L.f.) Miq	Urticaceae		+	
Bacang	*Mangifera foetida* Lour.	Clusiaceae		+	
Hapesong	*Pangium edule* Reinw	Achariaceae			+
Jati putih	*Gmelina arborea* Roxb. Ex Sm.	Verbenaceae			+
-	*Homalanthus populneus* Geiseler Kuntze	Euphorbiaceae		+	
Cempedak	*Artocarpus integer* (Thunb.) Merr.	Moraceae		+	
-	*Pimelodendron griffithianum* (J. Mueller-Arg.) Benth	Euphorbiaceae	+		
-	*Ratoxylum arborescens* (Vahl) Blume	Hypericaceae	+		
-	*Dipterocarpus apterus* Fexw	Dipterocarpaceae	+		

Table 4. Topographic, land condition, and environmental variables of *Amorphophallus gigas* habitat in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Sites	Altitude (masl)	Lux	T (ºC)	RH (%)	Soil texture	BD (%)	BD category	Slope (%)	Slope category	Land use
Lubuk Bondar	240.67	96.67	22.73	90.67	Clay	0.89	Low	86.92	Extreme steep slopes	Agroforestry
Bangkelang	384	43	24.67	98	Clay	0.73	Low	91.08	Extreme steep slopes	Agroforestry
Rao-Rao	623.33	11	22.93	87.33	Clay	0.74	Low	64.90	Extreme steep slopes	Forest management unit

Note: T: Temperature, RH: Humidity, BD: Bulk Density

Table 5. Soil physicochemical characteristics in *Amorphophallus gigas* habitat in Batang Natal watershed, Batang Natal District, North Sumatra, Indonesia

Sites	pH	Organic-C (%)	N-Kjeldahl (%)	P (%)	Available P (mg/kg)	CEC	K-Exc	Ca-Exc	Mg-Exc	Na-Exc	Base saturation
Lubuk Bondar	5.00A	2.47M	0.25M	0.54VL	170.28VH	13.37L	0.09L	2.72L	1.20M	0.43S	33.21L
Bangkelang	4.91VA	4.16H	0.40M	0.63VL	243.29VH	23.25M	0.08H	3.31L	0.82M	0.85H	21.76L
Rao-rao	4.95A	3.62H	0.31M	0.61VL	131.47VH	14.79L	0.14L	4.52L	1.00L	0.92H	44.49M

Note: A; Acid, VA: Very acid M: Moderate, H: high, L; Low, VH; Very high

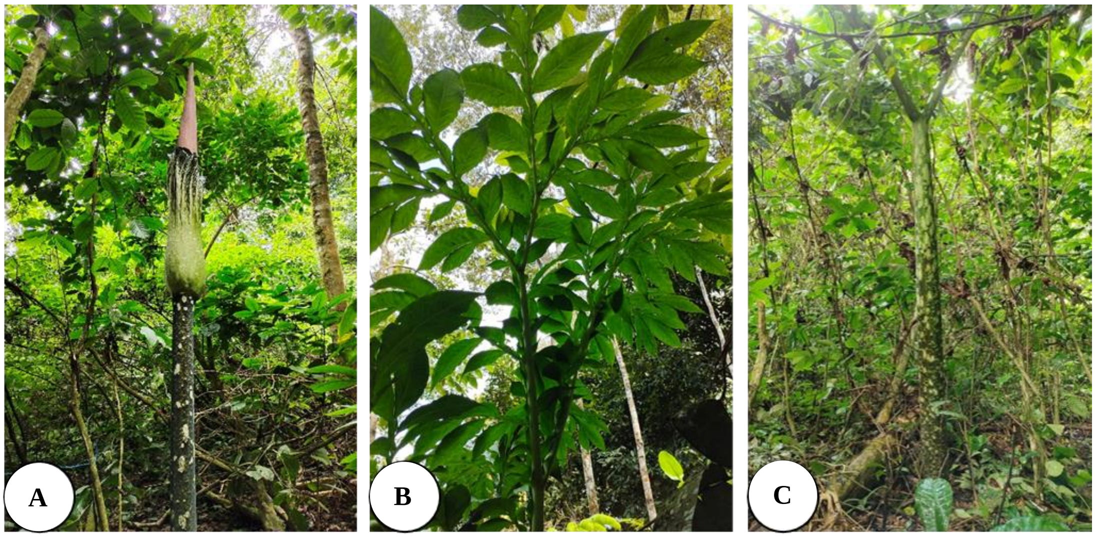

Figure 3. *Amorphophallus gigas* in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia. A. Generative state; B. Vegetative state; C. *A. gigas* under canopy shade

Abiotic factors influencing the distribution of *Amorphophallus gigas* populations

Soil chemical properties show ion activity that remains imperceptible to the naked eye but can be assessed through chemical testing. These play a crucial role in determining the fertility level (Gerge 2015), while plants are known to require both macronutrients and microelements for growth and survival. The essential macronutrients include Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), Calcium (Ca), and Magnesium (Mg). Within the habitat of *A. gigas* in the Batang Natal Watershed, the organic C content is categorized as moderate to high. Elements i.e., N, P, Ca, Mg, and Na content are classified as medium, high, low, low to medium, and medium to high, with low to high cation exchange capacity as well as base saturation ranging from low to moderate. Moreover, soil analysis at three locations, including Lubuk Bondar, Rao-Rao, and Bangkelang, showed distinct differences in properties. The pH values at Lubuk Bondar and Rao-Rao are acidic, while Bangkelang has very acidic soil. Other characteristics observed include organic carbon content, which is moderate at Lubuk Bondar and high at Bangkelang. Nitrogen levels and phosphorus content are moderate across all locations, but available phosphorus is very high. Cation exchange capacity, a key indicator of soil fertility, is low at Lubuk Bondar and Rao-Rao, but moderate at Bangkelang. Potassium exchange (K-Exc) is low at Lubuk Bondar and Rao-Rao and high at Bangkelang, while Calcium Exchange (Ca-Exc) is consistently low at all locations. Magnesium Exchange (Mg-Exc) is moderate at Lubuk Bondar and Bangkelang, but low at Rao-Rao, nearly similar to Sodium Exchange (Na-Exc) which is moderate at Lubuk Bondar but high at Bangkelang and Rao-Rao. Base saturation is low at Lubuk Bondar and Bangkelang, but moderate at Rao-Rao.

Soil properties significantly influence the distribution of *A. gigas* and its related species within the Araceae family, including various edible types. In Gowa District, South Sulawesi, nine edible Araceae species across four genera were identified in coastal, lowland, and highland regions (Hafsah 2018). Light intensity was a key factor affecting the distribution of *Xanthosoma* and *Alocasia*, while altitude, soil organic matter, and moisture were important for *Colocasia*. The distribution of *Amorphophallus*, on the other hand, was primarily determined by soil pH (Hafsah 2018). These findings support ecological theory of niche, which suggests that species distributions are shaped by environmental conditions and resource availability (Pulliam 2000). Based on ecological gradient theory, the distribution of species across various landscapes is influenced by interactions between abiotic factors such as light, temperature, and soil characteristics, with altitude further impacting these variables (Dyakov 2016). To visualize these interactions, a gradient analysis was performed through CCA using CANOCO software ver 5. (Lepš and ˇSmilauer 2003; Sutomo and Darma 2011), where vegetation and environmental data were converted (LogX+1) before the analysis. Predictor effect was tested for all constrained axes, and unrestricted permutations were perfomed with 499 number of permutations. The results showed that axes 1 and 2 could explain 85 and 73% of all the data variations.

Figure 4 shows the significant role of air Relative Humidity (RH) in shaping vegetation composition. Species located on the right side of the RH axis are adapted to lower humidity levels, while those on the left side thrive in higher RH environments. Particularly, *A. gigas* prefers clay or dusty compared to sandy soil textures and is often found in locations characterized by low air RH, as well as soil characteristics including high potassium (K) content, elevated pH, and low moisture.

Figure 5 further signifies that each sampling location is uniquely influenced by distinct environmental variables. The plots in Rao-Rao Village are predominantly affected by soil characteristics, such as a higher proportion of clay and dusty textures, along with elevated K content. However, Bangkelang plots are more influenced by air temperature and RH, along with high CEC and Na content. Bondar plots are influenced by high Bulk Density (BD) and soil pH, as well as low moisture. These variations present the diverse environmental conditions across the different locations and the impact on vegetation distribution.

Figure 6 shows that each of the sample locations are distinctive by both environmental variable and species composition. Furthermore, Rao-Rao contains species such as the *A. gigas*, *Castanopsis javanica* (Bllume) A.DC., *Dipterocarpus apterus* Fexw, *Pometia alnifolia* (Blume) King, *Palaquium leiocarpum*, *Baccaurea lanceolate* (Miq.) Mull.Arg., and *Ratoxylum arborescens* (Vahl) Blume. Bangkaleng consists of *Diplazium esculentum* (Retz.) Sw, *Antidesma bunius* (L.) Spreng., *Oplismenus compositus* f. *Glabratus* F.Br., *Gmelina arborea* Roxb. Ex Sm., *Erythrina variegate* L, *Parkia speciosa* (Hassk), *Artocarpus elasticus* Reinw. Ex blume, *Pangium edule* Reinw, *Elatostema platyphyllum* Wedd., *Leea indica* (Burm.fil.) Merr. Meanwhile, Lubuk Bondar comprises of *Nephrolepis falcata*, *Clidemia hirta*, *Selaginella willdenowii*, *Nephrolepis biserrata*, *Arenga pinnata*, *Amorphophallus beccarii*, *Macaranga indica*, *Homalanthus populneus*, *Hevea brasiliensis*, *Lee guineensis*, *Durio zibethinus*, *Nephelium lappaceum*, and *Piper aduncum.*

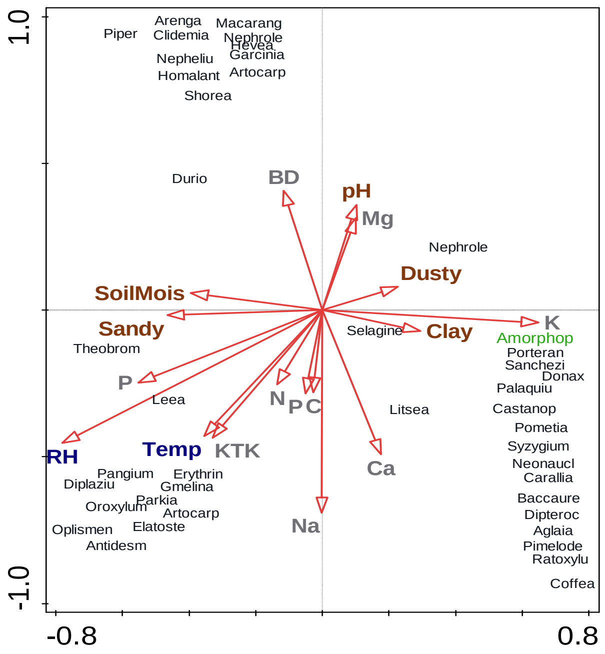

Figure 4. Biplot of plant species along the environmental gradients

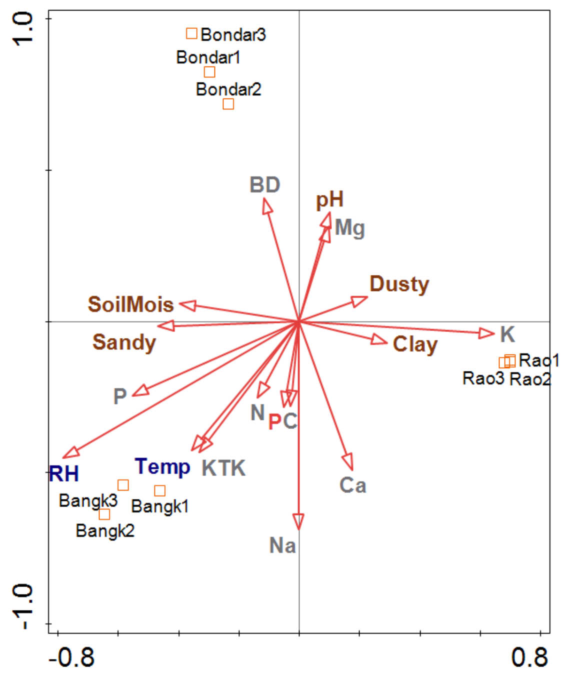

Figure 5. Biplot of sample locations and environmental variables

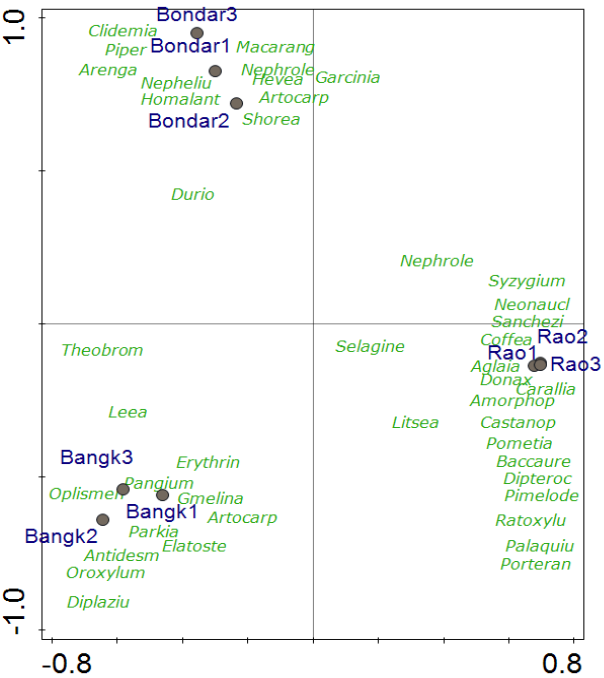

Figure 6. Biplots of species and sample plots

Importance value index of the surrounding plant community

IVI is a parameter that shows the role of species in a community or at a study location (Sundarapandian and Swamy 2000). Species dominating an area can be stated to have broad adaptability and tolerance to environmental conditions (Dharma et al. 2022). In Lubuk Bondar, the understorey plant species dominating the understorey vegetation include *Nephrolepis falcata* (Cav.) C. Chr (24.99), *Clidemia hirta* D.Don (21.49), *Selaginella willdenowii* (Desv.) Baker (18.65), *Nephrolepis biserrata* (Sw.) Schott (18.01), *Arenga pinnata* (Wurmb) Merr. (13.50), *Amorphophallus gigas* Teijsm. & Binn (10.55), and *Amorphophallus beccarii* Engl (10.55). The dominant seedling species in Lubuk Bondar Village are *Macaranga indica* Wight (36.57), *Homalanthus populneus* Pax (29.46), *Hevea brasiliensis* Willd. ex A.Juss.) Müll.Arg (25.52), *Lee guineensis* G. Don (23.11), and *Garcinia mangostana* L (17.52). At the sapling level, the dominant species are *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. (31.45), *Macaranga indica* Wight (18.85), *Artocarpus integer* (Thunb.) Merr. (18.85), *Garcinia mangostana* L (15.18), *Piper aduncum* L (15.18). The dominance of the pole stage population includes *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. (135.757), *Theobroma cacao* L, (40.249), *Durio zibethinus* Murr (23.193), *Nephelium lappaceum* L (21.970), and *Macaranga indica* Wight (13.609). Additionally, the highest IVI at the tree stage is attributed to *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. (151.75), *Durio zibethinus* Murr (82.90), *Garcinia mangostana* L (13.05), *Shorea* sp (12.83) and *Nephelium lappaceum* L. (10.80) (Table 6).

In Bangkelang Village, the dominant understorey species includes *Elatostema platyphyllum* Wedd. (45.95), *Selaginella willdenowii* (Desv.) Baker (37.36), *Oplismenus compositus* P.Beauv. (28.59), *Diplazium esculentum* (Retz.) Sw (17.99), *Amorphophallus gigas* Teijsm. & Binn. (11.72), and *Nephrolepis biserrata* (Sw.) Schott (9.81). Dominant seedling population comprises *Leea indica* (Burm.fil.) Merr (122.17), *Pangium edule* Reiwn (70.66), and *Theobroma cacao* L (7.16). At the sapling level, the most identified population consists of *Theobroma cacao* L. (67.82), *Gmelina arborea* Roxb (41.72), *Antidesma bunius* (L.) Spreng (25.09), *Pangium edule* Reiwn (12.75), and *Durio zibethinus* Murr (6.83). *Gmelina arborea* Roxb is predominant at the pole level (145.66), followed by *Oroxylum indicum* (L.) Vent (31.11), *Theobroma cacao* L (23.86), *Erythrina variegata* L (15.94), and *Durio zibethinus* Murr (10.37). At the tree level, *Gmelina arborea* Roxb (102.69) is majorly found along with *Artocarpus elasticus* Reinw (27.94), *Oroxylum indicum* (L.) Vent (21.39), *Litsea odorifera* Valeton (17.91), and *Parkia speciosa* Hassk (18.28).

Rao-Rao Village contains understorey plant species dominated by *Nephrolepis biserrata* (Sw.) Schott (41.61), *Sanchezia speciosa* Leonard. (36.42), *Selaginella willdenowii* (Desv.) Baker (25.29), *Donax canniformis* (G.Forst.) K.Schum (16.77), *Melastoma Malabathricum* L (10.02), *Amorphophallus beccarii* Engl and (13.06) and *Amorphophallus gigas* Teijsm. & Binn. (6.31). The seedling population mostly consists of *Coffea canephora* Pierre ex A.Froehne (120.40), *Palaquium leiocarpum* Boerl (25.27), *Porterandia anisophylla* (Jack ex Roxb.) Ridl (10.56), *Castanopsis javanica* (Blume) A.DC (7.54), and *Pometia pinnata* J.R.Forst. & G.Forst. (7.19). At the sapling level, the dominant species are *Coffea canephora* Pierre ex A.Froehne (73.76), *Palaquium leiocarpum* (25.14), *Pometia alnifolia* (Blume) King (21.33), *Syzygium racemosum* Blume (8.69), and *Porterandia anisophylla* (Jack ex Roxb.) Ridl (8.43) (Table 6). The pole level mainly includes *Litsea odorifera Valeton* Valeton (32.15), *Neonauclea calycina* Merr (31.80), *Carallia brachiata* (Lour.) Merr (22.50), *Baccaurea lanceolata* (20.08), and *Aglaia elliptica* Blume (18.02). The tree population comprises *Dipterocarpus apterus* Fexw (26.82), *Pometia alnifolia* (Blume) King (26.62), *Neonauclea calycina* Merr (25.56), *Pimelodendron griffithianum* (J.Mueller-Arg.) Benth (24.01), and *Ratoxylum arborescens* (Vahl) Blume (23.77).

Table 6. Importance Value Index (IVI) of plant community surrounding *Amorphophallus gigas* habitat in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Stratum	Family	IVI	Ochiai index	Association category	Association
Lubuk Bondar					
Understorey					
Amorphophallus gigas Teijsm. & Binn	Araceae	10.55			
Amorphophallus beccarii Engl	Araceae	10.55			
Nephrolepis falcata (Cav.) C. Chr	Nephrolepidaceae	24.99	0.43	Low	+
Clidemia hirta (L) D.Don	Melastomaceae	21.49	0.14	Very Low	-
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	18.65	0.31	Low	+
Nephrolepis biserrata (Sw.) Schott	Nephrolepidaceae	18.01	0.46	Low	+
Arenga pinnata (Wurmb) Merr.	Arecaceae	13.50	0.40	Low	+
Seedling					
Macaranga indica Wight	Euphorbiaceae	36.57	0.00	Very low	-
Homalanthus populneus Pax	Euphorbiaceae	29.46	0.00	Low	-
Hevea brasiliensis Willd. ex A.Juss.) Müll.Arg	Euphorbiaceae	25.52	0.27	Low	+
Lee guineensis G. Don	Vitaceae	23.11	0.22	Very Low	+
Garcinia mangostana L	Clusiaceace	17.52	0.44	Very low	+
Sapling					
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	31.45	0.13	Very Low	-
Macaranga indica Wight	Euphorbiaceae	18.85	0.31	Low	+
Artocarpus integer (Thunb.) Merr.	Moraceae	18.85	0.31	Low	+
Garcinia mangostana L	Clusiaceace	15.18	0.17	Very Low	-
Piper aduncum L	Piperaceae	15.18	0.17	Very Low	-
Pole					
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	135.75	0.38	Low	-
Theobroma cacao L	Malvaceae	40.24	0.15	Very Low	-
Durio zibethinus Murr	Malvaceae	23.19	0.19	Very Low	-
Nephelium lappaceum L	Sapindaceae	21.97	0.22	Very Low	+
Macaranga indica Wight	Euphorbiaceae	13.60	0.00	Very Low	-
Tree					
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	151.75	0.36	Low	-
Durio zibethinus Murr	Malvaceae	82.90	0.13	Very Low	-
Garcinia mangostana L	Clusiaceace	13.05	0.00	Very Low	-
Shorea sp	Dipterocarpaceae	12.83	0.27	Low	+
Nephelium lappaceum L	Sapindaceae	10.80	0.00	Very Low	-
Bangkelang					
Understorey					
Amorphophallus gigas Teijsm. & Binn.	Araceae	11.72			
Nephrolepis biserrata (Sw.) Schott	*Nephrolepidaceae*	9.81	0.41	Very Low	+
Elatostema platyphyllum Wedd.	Urticaceae	45.95	0.14	Low	-
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	37.36	0.41	Low	+
Oplismenus compositus f. Glabratus F.Br.	Poaceae	28.59	0.41	Low	+
Diplazium esculentum (Retz.) Sw	Athyriaceae	17.99	0.41	Low	+
Seedling					
Theobroma cacao L	Malvaceae	7.16	0.41	Low	+
Leea guineensis G. Don	Vitaceae	122.17	0.00	Very Low	-
Pangium edule Reiwn	Achariaceae	70.66	0.00	Very Low	-
Sapling					
Durio zibethinus Murr	Bombaceae	6.83	0.00	Very low	-
Pangium edule Reiwn	Achariaceae	12.75	0.00	Very Low	-
Theobroma cacao L	Malvaceae	67.82	0.00	Very Low	-
Gmelina arborea Roxb	Verbenaceae	41.72	0.37	Low	+
Antidesma bunius (L.) Spreng	Phyllanthaceae	25.09	0.17	Very Low	-
Pole					
Theobroma cacao L	Malvaceae	23.86	0.20	Very Low	+
Erythrina variegata L	Fabaceae	15.94	0.47	Low	+
Durio zibethinus Murr	Bombaceae	10.37	0.00	Very Low	-
Gmelina arborea Roxb	Verbenaceae	145.66	0.25	Very Low	-
Oroxylum indicum (L.) Kurz	Bignoniaceae	31.11	0.00	Very Low	-
Tree					
Gmelina arborea Roxb	Verbenaceae	102.69	0.32	Low	+
Oroxylum indicum (L.) Kurz	Bignoniaceae	21.39	0.17	Very Low	+
Litsea odorifera Valeton	Lauraceae	17.91	0.47	Low	+
Parkia spesiosa (Hassk)	Fabaceae	18.28	0.24	Very Low	+
Artocarpus elasticus Reinw	Moraceae	27.94	0.55	High	-

Rao-Rao					
Understorey					
Amorphophallus gigas Teijsm. & Binn.	Araceae	6.31			
Amorphophallus beccarii Engl	Araceae	13.06			
Nephrolepis biserrata (Sw.) Schott	Nephrolepidaceae	41.61	0.22	Very Low	-
Donax canniformis (G.Forst.) K.Schum	Marantaceae	16.77	0.18	Very Low	-
Selaginella willdenowii (Desv.) Baker	Selaginellaceae	25.29	0.71	High	+
Sanchezia speciosa Leonard	Acanthaceae	36.42	0.00	Very Low	-
Melastoma Malabathricum L	Melastomataceae	10.02	0.22	Low	+
Seedling					
Palaquium leiocarpum	Sapotaseae	25.27	0.38	Low	+
Coffea canephora Pierre ex A.Froehne	Rubiaceae	120.40	0.25	Low	-
Castanopsis javanica (Blume) A.DC	Fagaceae	7.54	0.00	Very Low	-
*Porterandia anisophylla (*Jack ex Roxb.) Ridl	Rubiaceae	10.56	0.00	Very Low	-
Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	7.19	0.00	Very Low	-
Sapling					
Coffea canephora Pierre ex A.Froehne	Sapindaceae	73.76	0.34	Low	-
Pometia alnifolia (Blume) King	Sapindaceae	21.33	0.33	Low	+
Palaquium leiocarpum	Sapotaceae	25.14	0.18	Very Low	-
Syzygium racemosum Blume	Myrtaceaea	8.69	0.00	Very Low	-
Porterandia anisophylla (Jack ex Roxb.) Ridl	Rubiaceae	8.43	0.25	Low	+
Pole					
Neonauclea calycina Merr	Rubiaceae	31.80	0.00	Very Low	-
Baccaurea lanceolata	Phyllanthaceae	20.08	0.25	Low	+
Litsea odorifera Valeton Valeton	Lauraceae	32.15	0.00	Very Low	-
Aglaia elliptica Blume	Meliaceae	18.02	0.00	Very Low	-
Carallia brachiata (Lour.) Merr	Anisophyllaceae	22.50	0.00	Very Low	-
Tree					
Neonauclea calycina Merr	Rubiaceae	25.56	0.18	Very Low	-
Ratoxylum arborescens (Vahl) Blume	Hypericaceae	23.77	0.00	Very Low	-
Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	26.62	0.33	Low	+
Dipterocarpus apterus Fexw	Dipterocarpaceae	26.82	0.00	Very Low	-
Pimelodendron griffithianum (J.Mueller-Arg.) Benth	Euphorbiaceae	24.01	0.00	Very Low	-

Araceae and Euphorbiaceae are commonly found across all vegetation strata due to their high adaptability and broad ecological niches. Species within these families exhibit a wide range of morphological traits, enabling them to thrive in various light conditions, from understory to canopy. Their flexible reproductive strategies, including asexual propagation and prolific seed production, further support their widespread colonization (Zhang and Zhang 2007). As ecological generalists, they can occupy diverse habitats and are resilient to environmental disturbances, allowing them to persist across different strata (Gibernau et al. 2010). Additionally, their mutualistic relationships with pollinators and seed dispersers enhance their ability to establish and regenerate in varied ecological conditions. The coexistence of Araceae and Euphorbiaceae species in tropical forests is driven by multiple ecological mechanisms. Although habitat preferences and niche partitioning play a role in the spatial distribution of Euphorbiaceae species, they only offer a partial explanation for their species richness (Debski et al. 2002). In contrast, for Araceae, distinct reproductive strategies, such as variation in flowering periods and specific pollinator associations, help mitigate competition and enable sympatric species to coexist more effectively (Moreno-Betancur and Cuartas-Hernández 2022).

Vegetation diversity and distribution patterns of the surrounding plant community

Healthy ecosystems show high biodiversity, and diversity in a forest is known to be influenced by competition, regeneration, and selection. Shannon-Wiener index is appropriate for calculating species diversity (Suratissa and Rathnayake 2016). Moreover, the evenness index expresses the relationship between abundance and the maximum possible species diversity, showing that as species become more diverse, the potential of identifying individuals reduces (Naidu and Kumar 2016). Morisita's Dispersion Index measures the spatial distribution pattern of a species or population, being independent of distribution types, sample sizes, and mean values. Therefore, this index yields relatively stable results, not depending on population density and sample size (Widiyanti et al. 2021). Detailed values of the Shannon-Wiener, Margalef, Evenness, and Morisita's Index for *A. gigas* population at various elevations in North Sumatra can be found in Table 7.

Table 7. Ecological parameters of vegetation found in *Amorphophallus gigas* habitat in Batang Natal Watershed, Batang Natal District, North Sumatra, Indonesia

Village	Number of species	*H'*	Category	D_{mg}	Category	*J*	Category	Morisita	Category
Lubuk Bondar									
Understorey	25	2.69	Moderate	4.35	Moderate	0.85	High	2.16	Clumped
Seedling	15	2.21	Moderate	3.62	Moderate	0.84	High	3.42	Clumped
Sapling	20	2.63	Moderate	4.39	Moderate	0.89	High	2.00	Clumped
Pole	13	1.87	Moderate	3.15	Low	0.75	High	6.09	Clumped
Tree	10	1.40	Moderate	2.3	Low	0.64	High	8.61	Clumped
Bangkelang									
Understorey	16	1.88	Moderate	2.50	Moderate	0.69	High	5.27	Clumped
Seedling	3	0.67	Low	0.69	Low	0.97	High	14.02	Clumped
Sapling	14	1.90	Moderate	2.98	Moderate	0.74	High	5.63	Clumped
Pole	16	0.98	Low	3.82	Moderate	0.36	Moderate	7.68	Clumped
Tree	16	0.86	Low	3.61	Moderate	0.32	Moderate	4.85	Clumped
Rao-Rao									
Understorey	21	2.29	Moderate	3.34	Low	0.76	High	3.64	Clumped
Seedling	13	1.17	Moderate	0.43	Low	0.47	Moderate	14.73	Clumped
Sapling	22	2.14	Moderate	4.29	Moderate	0.70	High	5.72	Clumped
Pole	22	2.82	Moderate	5.515	High	0.92	High	1.46	Clumped
Tree	25	2.94	Moderate	5.77	High	0.92	High	1.30	Clumped

Note: *H':* Shannon's diversity index, D_{mg}: Margalef's species richness index, *J:* evenness index

In the Lubuk Bondar population, all growth stages have moderate diversity (Table 7), with the species richness or margalef index for the understorey (0.85), seedlings (0.84), and sapling (0.89) being considered moderate, while other growth stages show low values. The evenness index observed for all growth stages is significantly high (stable community), along with a clustering pattern. In the Bangkelang population, the understorey and pole levels have moderate diversity, while other growth stages are considered low. The margalef richness index values are mostly moderate across all growth stages, except for seedlings, which are classified as low. The evenness index values for the understorey, seedlings, and poles are high (stable community), but moderate for poles and trees (unstable community). The Rao-Rao population has generally moderate species diversity, with high Margalef's richness index values for the pole and tree levels but low to moderate for other growth stages. The evenness index values for all growth stages are high, except for seedlings, which are considered low. The spatial distribution of Amorphophallus in the study location, as shown by Morisita's Index, suggests a clumped pattern, consistent with Nursanti (2019) observation that Amorphophallus in the South Kerinci location tended to grow in clumped.

Conservation strategies of *Amorphophallus gigas* populations

Based on our survey, *A. gigas* has varying population sizes across different locations, which are influenced by distinct habitat conditions. Therefore, essential conservation initiatives for *A. gigas* should include both in situ and ex situ methods. In situ conservation would focus on preserving the natural habitat to facilitate the natural growth of the species, while ex situ conservation required measures conducted outside the native habitat. In situ conservation of endangered plants involves safeguarding and managing populations within their natural environments to preserve evolutionary dynamics (Heywood 2014). Nonetheless, this approach encounters difficulties when habitat loss and degradation occur rapidly (Yadav 2016; Rahmawaty et al. 2022). A combined ex situ and in situ conservation strategy has been suggested, which includes maintaining plant collections in natural or semi-natural conditions to conserve both neutral and adaptive genetic diversity (Volis et al. 2009). Ex situ conservation methods, such as propagation in legally sanctioned locations like the Bogor Botanical Garden, present a viable option for preserving *A. gigas*, as has been successfully applied to various aroid species across Indonesia (Yuzammi 2018). Tissue culture technology also provides a faster alternative for ex situ conservation, particularly for species with small populations in the wild (Yadav 2016). While in situ conservation enables species to adapt gradually to environmental changes, integrating both in situ and ex situ approaches may offer the most effective strategy for conserving endangered plants (Volis et al. 2009; Heywood 2014). Even though aroids were found with dominant occurrence in the study locations, which signified persistence on thriving in moist, shaded environments with rich organic soils, these habitats should be optimally conserved. Protecting the diverse aroids associated with *A. gigas* would support its conservation due to possessing similar habitat characteristics. Comprehensive data collection across the entire habitat would be necessary to assess and understand the population dynamics in each specific location, guiding effective conservation strategies.

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