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Spatial distribution of the ethnomedicinal plant *Aglaonema simplex* at the Sakaerat Environmental Research Station, Northeastern Thailand

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Abstract. *O-thong N, Tasen W, Marod D, Thinkampheang S, Phumphuang W. 2024. Spatial distribution of the ethnomedicinal plant* Aglaonema simplex *at the Sakaerat Environmental Research Station, Northeastern Thailand. Biodiversitas 25: 3043-3050. Aglaonema simplex* Blume (Araceae) is an evergreen herbaceous plant used ornamentally and in traditional medicine. Although the usefulness of this plant has been widely studied and reported, its ecology remains poorly understood. In this study, we examined the effects of various environmental factors on the spatial distribution of *A. simplex* in a Dry Evergreen Forest (DEF) at the Sakaerat Environmental Research Station (SERS) in Northeastern Thailand. All individual plants were counted; their positions were recorded within a 16-ha Forest Dynamics Plot (FDP), and their distribution pattern was analyzed using Ripley's K function. The spatial distribution of *A. simplex* was determined using a generalized linear model that incorporated plant density and topographic and edaphic variables within the 16-ha study plot. We found a total of 11,232 *A. simplex* individuals with a density of 702 individuals ha^{-1}, with a clumped distribution pattern. The modeling results showed that the spatial distribution of *A. simplex* was positively influenced by soil clay content, soil pH, exchangeable magnesium, and adult tree density; it was negatively influenced by sapling density and rocky outcrops. These findings contribute to the broader understanding of the ecological niche of *A. simplex*. They can be used to design integrated land management approaches that balance ecological conservation with economic development goals.

Keywords: *Aglaonema simplex*, generalized linear model, Ripley's K function, spatial distribution

Abbreviations: DEF: Dry Evergreen Forest; FDP: Forest Dynamics Plot; SERS: Sakaerat Environmental Research Station

INTRODUCTION

Understanding the relationships between organisms and environmental factors is an important aspect of ecology because environmental gradients play important roles in determining each organism's distribution, survival, and reproduction; they also reflect species ecological niches (Wang et al. 2016; Zhang et al. 2017; Murphy and Smith 2021). Species distribution patterns—generally classified as clumped, uniform, or random (Shen et al. 2017; Chen et al. 2021)—are influenced by the migration of individuals or populations away from their original location and their establishment in new habitats within an equivalent niche (Lowe and McPeek 2014; Hidasi-Neto et al. 2020). Investigations of a species' distribution are crucial for understanding its ecological interactions, population dynamics, and community structure (Husemann et al. 2016; He et al. 2022). For example, a clumped distribution can increase opportunities for cooperation, competition, and predator-prey dynamics within groups. Heterogenous spatial distributions are influenced by intra- and interspecific interactions and environmental conditions including edaphic and topographic factors (Borregaard et al. 2008; Hu et al. 2022). Thus, examinations of relationships among species distributions, ecological niches, and environmental gradients can provide insights into the mechanisms driving biodiversity patterns and inform conservation strategies to protect vulnerable species and ecosystems (Cornell and Harrison 2014; Gu et al. 2020; Ma et al. 2024).

Araceae is the third-largest monocot family. More than 140 genera and approximately 3,650 species have been classified in this family (Croat and Ortiz 2020). In Thailand, 30 genera and 210 species have been recorded, indicating high diversity within Southeast Asia (Boyce et al. 2012). Worldwide, 26 species within the genus *Aglaonema* have been reported, according to the Royal Botanic Gardens, Kew (2024) database, among which nine species are included in the Flora of Thailand (Boyce et al. 2012). Within Southeast Asia, *Aglaonema* species are highly valued as ornamental plants (Mayo et al. 1997; Yuzammi 2018); some species are also widely used in traditional medicine (Opryshko et al. 2019; Goni et al. 2021), especially *A. simplex*. Many Thai people consider the ripe fruit an elixir and an antiasthma medication, so its fruits are processed into expensive commercial products (Tilarux et al. 2022).

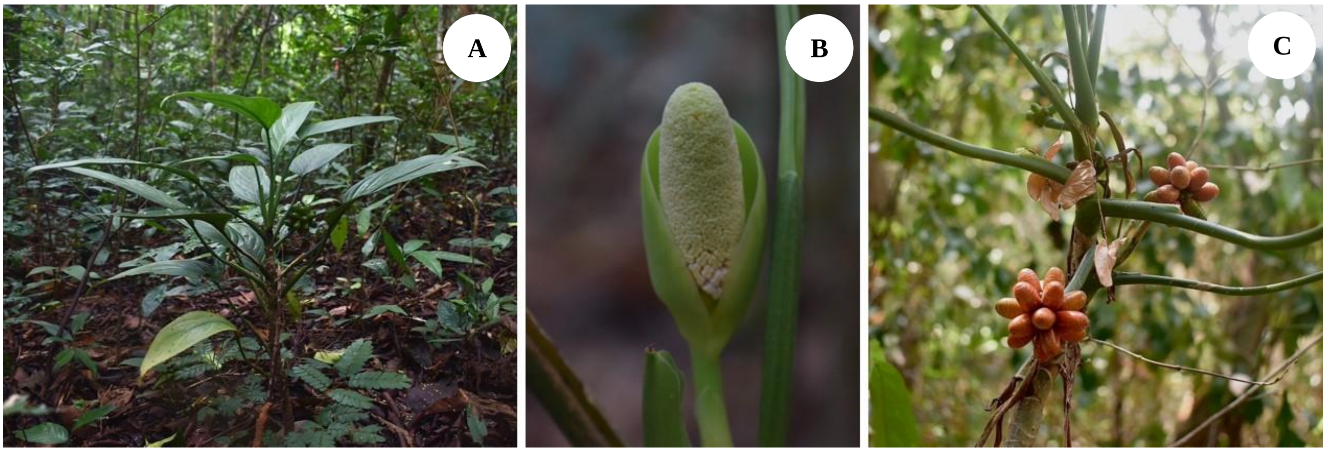

Figure 1. The characteristics of *Aglaonema simplex*: A. The habit of *A. simplex* with numerous leaves whorled at the tip of the shoot; B. The inflorescence of *A. simplex*; C. The ripe fruits of *A. simplex*

Aglaonema simplex Blume, an evergreen herbaceous plant (Figure 1), is commonly found in evergreen forests of Thailand and occasionally on limestones at altitudes ranging from 0 to 700 m. Its native distribution extends from Nicobar Island to Western Maluku and from Southwestern China to Java (Boyce et al. 2012). The *A. simplex* has an erect stem and numerous leaves clustered in a whorl at the tip of the shoot (Nicolson 1969). Its inflorescence consists of a spadix enclosed by a light green spathe and its unisexual flowers (Chai and Wong 2019). Its fruits change from green to orange or bright red during ripening (Mayo et al. 1997). Extracts from the roots, stems, leaves, and fruits of *A. simplex* contain phytochemical compounds with potential activities against atherosclerosis (Ismail et al. 2017), leukemia, and oral squamous carcinoma (Chee et al. 2005); they also represent a potential source of natural antioxidants (Kiatsongchai and Chitsomboon 2019). Furthermore, *A. simplex* has been used in ethnopharmacology by indigenous peoples of various countries in Southeast Asia and on Indian islands. These applications include using crushed leaves and stems to reduce pain and inflammation associated with liver problems (Dubost et al. 2019) or childbirth (Kamble et al. 2008).

According to the IUCN, *A. simplex* is currently categorized as the least concern (Allen 2011), but heavy disturbance, human utilization, and climate change could lead to a population decrease in the future (Boyce and Yeng 2012). Previous studies indicated that the species diversity and distribution of araceous plants are determined by various environmental factors (Sungkajanttranon et al. 2018; Croat and Ortiz 2020). Thus, ecological information is useful in various conservation and management decisions (Marod et al. 2022). However, ecological studies of the species have been rare (Allen 2011; Lestari and Asih 2017).

In the present study, we examined the effects of various environmental factors on the spatial distribution of *A. simplex* in a 16-ha Forest Dynamics Plot (FDP) at the Sakaerat Environmental Research Station (SERS), Northeastern Thailand. Our findings provide essential information for effective conservation planning, habitat management, and ecosystem restoration; they will ultimately contribute to preserving biodiversity and sustainable management of *A. simplex* as a natural resource.

MATERIALS AND METHODS

Study area

This study was conducted at the SERS in Sakaerat Biosphere Reserve, which is one of five biosphere reserves in Thailand located on Khorat Plateau, Wang Nam Khiao District (latitude 14°30'N, longitude 101°56'E), Nakhon Ratchasima Province, Northeastern Thailand (Figure 2). The SERS covers an area of approximately 81 km^2, with an elevation ranging from 250 to 762 masl. In a tropical climate, the mean temperature ranges from 16°C to 35°C, the mean annual temperature is approximately 26°C, and the annual precipitation is around 1,200 mm (Palakit et al. 2015). Most of the area consists of natural forests, with two dominant forest types: dry evergreen and deciduous dipterocarp forests (Dawwrueng et al. 2017). The soil can be classified into two types following the Thai soil series. First, Khoa Yai series (Ky) are deep soil and occur on shallow slope areas. Second, Tha Yang series (Ty) is the soil with few boulders or/and found rock outcrops. Most of the parent soil materials were weathering of sandstone and shale (Sakurai et al. 1998).

Therefore, a 16-ha FDP (400 m × 400 m) was established in 2010 in the Dry Evergreen Forest (DEF). All trees with a diameter at breast height (DBH, 1.30 m above soil surface) ≥4.5 cm were tagged, measured, and identified. Tree monitoring was done in 2015 and 2020; all trees with DBH ≥2 cm and DBH ≥1 were included, respectively. Previous studies showed that the characteristic of FDP is relatively flat, with an elevation difference of approximately 50 m. The soil texture is sandy loam with a predominance of sand particles and highly acidic soil conditions. The species diversity is high, and tree species composition with DBH ≥1 cm represents 204 species from 153 genera and 60 families. The top five dominant species include *Hydonocarpus ilicifolia* King, *Hopea ferrea* Laness., *Walsura pinnata* Hassk., *Memecylon ovatum* Sm., and *Aglaia elaeagnoidea* (A.Juss.) Benth., respectively (Phumphuang et al. 2024).

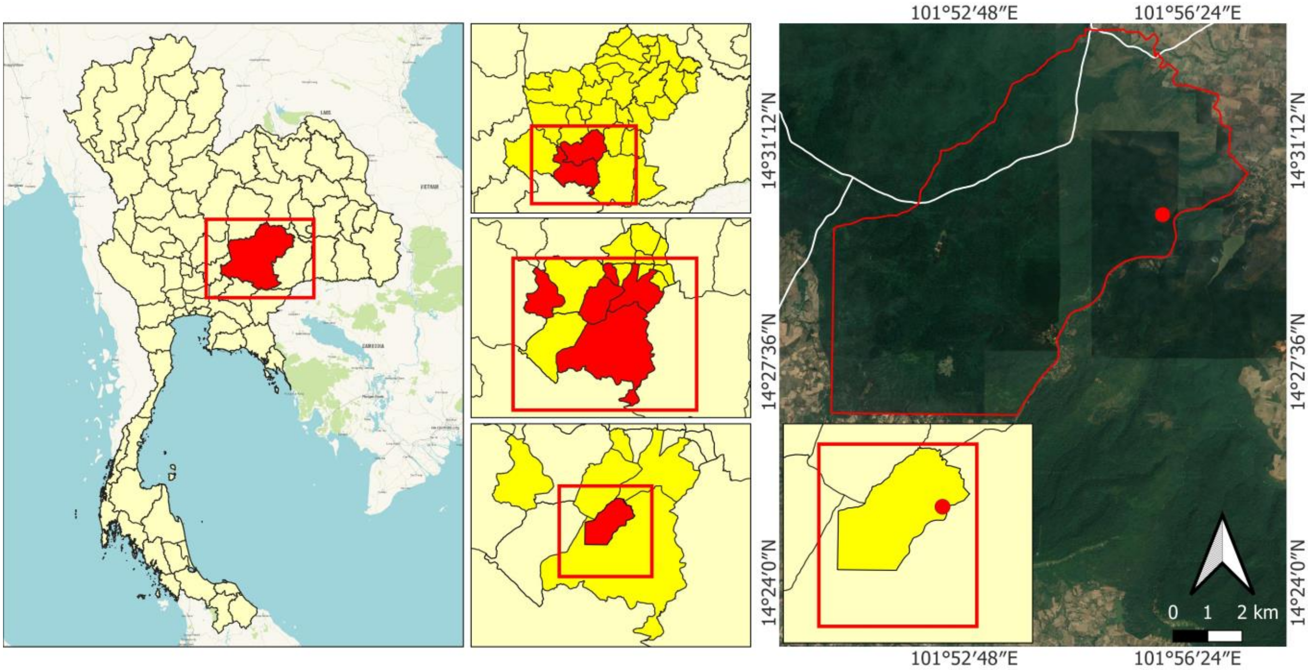

Figure 2. The location of the study area and 16-ha FDP in the Dry Evergreen Forest (DEF) at Sakaerat Environmental Research Station (SERS), Nakhon Ratchasima Province, Northeastern Thailand

Procedures

Aglaonema simplex *observation*

The *A. simplex* data was observed in DEF 16-ha FDP from 2 February 2023 to 18 March 2023. To identify *A. simplex* positions and ensure comprehensive coverage of the study area, the FDP was divided into smaller subplots measuring 10 m x 10 m each. This study counted the number of individuals, and their positions were recorded using grid coordinates (x, y) for all subplots.

Environmental variables collection

The 16-ha FDP was divided into 64 subplots at 50 m × 50 m for topographic collecting. Two topographic variables, elevation and slope, were analyzed. The elevation was calculated as the mean elevation of the four subplot corners, while the slope was determined as the average angle of the subplot from the horizontal. The "fgeo" package in R software version 4.3.1 (R Core Team 2023) was used to analyze the topographic variables.

For edaphic variables analysis, 64 soil samples were collected from each 50 m × 50 m subplot. In each sampling plot, four surface soil (0-15 cm depth) samples from each corner and one sample from the center were collected and combined into one composite soil sample. The physical and chemical properties of soil samples were analyzed. Soil textures (percentage of sand (SA), silt (SL), and clay (CL)) were measured using a hydrometer. Soil pH was measured using a pH meter (1:1 soil/water mixture). Organic Matter (OM) was estimated by wet oxidation (Walkley-Black) method. Exchange cations (K^+, Ca^{2+}, and Mg^{2+}) were analyzed by an atomic absorption spectrophotometer with 1N NH4Oac, while available Phosphorus (P) was measured by the Bray II method, respectively. All soil properties were analyzed at the Soil Fertilizer Environment Scientific Development Project, Department of Soil Science, Faculty of Agriculture, Kasetsart University (Bangkok, Thailand). In this study, all topographic and edaphic variables analysis methods were followed by Phumphuang et al. (2024). Additionally, rocky outcrops (Rock) in each subplot (10 m × 10 m) were visually estimated and averaged into a 50 m × 50 m scale.

The density of saplings (D_{sap}) and adult trees (D_{tree}) in 64 subplots of 16-ha FDP were assumed to be related to light transmittance to the forest floor. In this study, we used tree data from the latest monitoring in 2020 and categorized data into 2 size classes based on DBH: sapling (DBH<4.5 cm) and adult tree (DBH≥4.5 cm), respectively.

Data analysis

Therefore, to examine the spatial distribution pattern of *A. simplex*, Ripley's K function was used because it can describe the distribution characteristics of point data (event points recorded in two dimensions) at multi-distance scales (Wang et al. 2020a). The point pattern is interpreted as clustered or clumped, random, or uniform when the K-function value is above, equal to, or below the theoretical curve, respectively. To statistically test the significance of the deviation from the theoretical curve, the 95% confidence envelope of the null hypothesis was created using Monte Carlo simulations (99 replications) of Complete Spatial Randomness (CSR) (Hohl et al. 2017). This analysis was performed with the "spatstat" package (Gómez-Rubio 2016) in R software version 4.3.1 (R Core Team 2023).

As a statistical model, we used the Generalized Linear Model (GLM) technique to examine the relationship between environmental variables on *A. simplex* distribution (Sungkajanttranon et al. 2018). The dependent variable was the total number of individuals of *A. simplex*, while the independent variables were environmental variables. Poisson regression is commonly employed to describe the relationship between the count data to environmental variables. However, ecological data is often overdispersed, meaning that the variance of the response variable exceeds the mean. Consequently, Poisson regression is unsuitable for fitting the data (Harrison 2014). The GLM with a quasi-Poisson family and log links is therefore selected. The predicted variables were selected to fit the model using Pearson's correlation coefficient values ($r \geq 0.80$ or $r \leq -0.80$) (Marod et al. 2019). The model omitted the percentage of sand (SA) because this factor was highly dependent on other environmental variables. All predicters data were normalized (or scaled) by the Z-Score standardization technique using the scale function. The GLM analysis was performed with the "MASS" package in R version 4.3.1 (R Core Team 2023).

RESULTS AND DISCUSSION

The population of *A. simplex* at the 16-ha FDP

A total of 11,232 individuals of *A. simplex* were enumerated in the 16-ha FDP. Its density was 702 individuals ha^{-1} (or 0.07 individuals m^{-2}) and distributed throughout the FDP (Figure 3.A). Two characteristics of *A. simplex* were found: first, most individuals have erect stems and unbranching, and second, the stems lie parallel to the forest floor, resembling a decumbent. The density heatmap reveals a dense population in certain areas, particularly in the upper right corner of the FDP. In contrast, the upper left corner of the permanent plot exhibits a smaller population and lower density than other areas (Figure 3.B).

Distribution pattern

The distribution pattern of *A. simplex* was described using Ripley's K-function. The resulting graph showed that the K-function value (K(r)) for the observed data (solid line) is larger than the expected K value (red dashed line) and the upper confidence envelope of values obtained from simulations of CSR (shaded area) (Figure 4). This suggests that the distribution of *A. simplex* is clustered or clumped pattern for all distances distribution ($P<0.05$) up to 20 m. In addition, the trend of the solid line showed that if the distance increases, more *A. simplex* populations are likely to be found; this reflects that the distribution pattern of *A. simplex* is clustered or clumped at both small and large scales.

Relationship between spatial distribution and environmental variables

The GLM analysis with quasi-Poisson regression showed the high influence between the spatial distribution of *A. simplex* and environmental variables was detected (Table 1). It expressed six environmental variables that strongly influenced the presence of *A. simplex* ($P<0.05$) but differed among their correlation levels. The edaphic factors indicated that the percentage of clay (CL), soil pH, and exchangeable magnesium (Mg) were important in the distribution of *A. simplex*, which all factors had positively correlated. On the other hand, the presence of this species was negatively correlated with rocky outcrops (Rock). In addition, the vertical structure of the tree community also affected the distribution of *A. simplex*, even though it differed in directions. The density of the sapling (D_{sap}) was negatively correlated, contrasting with adult tree density (D_{tree}), which was positively correlated. Indicating the distribution assemblage of *A. simplex* had been influenced by the forest structure.

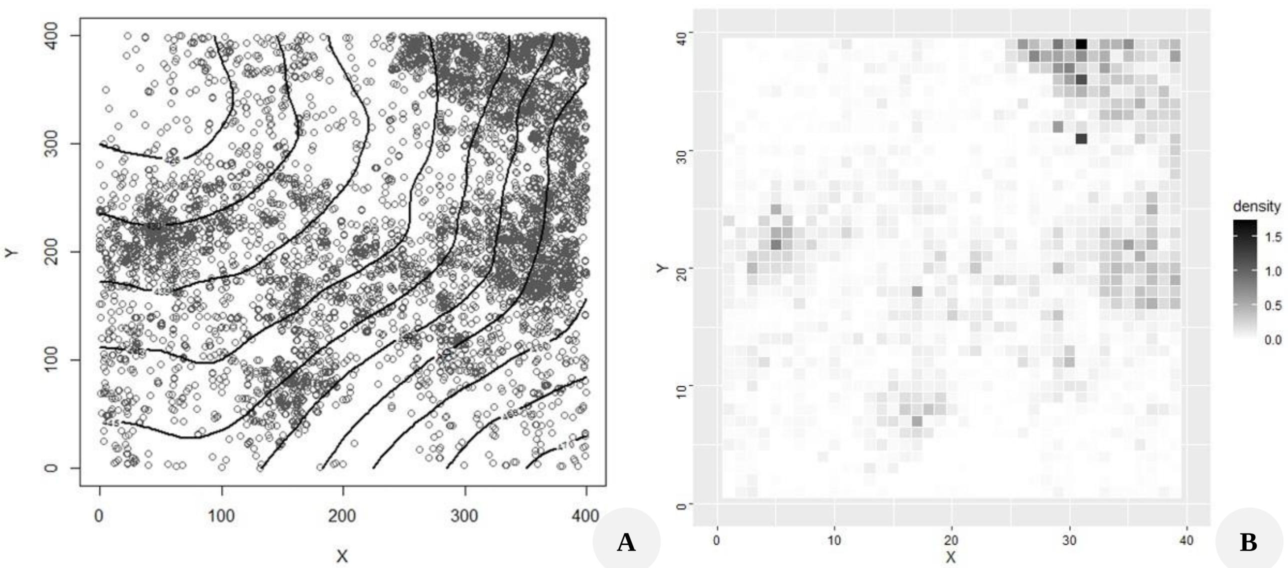

Figure 3. Distribution pattern of *A. simplex* in the 16-ha FDP in SERS: A. The distribution diagram of all individuals, where contours are shown at 5 m intervals; B. The density heatmap of all individuals of the 1,600 sub-plots of 10 m × 10 m

Table 1. The mean environmental variable values (±SD) and the estimate values (±SE) of a GLM analysis (with quasi-Poisson) describing the relationship between the spatial distribution of *A. simplex* and environmental variables in the DEF 16-ha FDP in SERS

Environmental variables	Mean value	Estimate value
Elev (m asl)	443.30 (±12.06)	0.2871 (±0.16) ns
Slp (°)	7.08 (±2.56)	0.0347 (±0.10) ns
SL (%)	23.25 (±4.21)	0.0294 (±0.12) ns
CL (%)	23.48 (±2.27)	0.6574 (±0.14) ***
Soil pH	4.77 (±0.33)	0.2266 (±0.11) *
OM (%)	4.33 (±0.83)	-0.1136 (±0.17) ns
P (mg/kg)	3.83 (±0.90)	0.1359 (±0.17) ns
K ($Cmol^+$/kg)	2.06 (±0.66)	-0.0562 (±0.15) ns
Ca ($Cmol^+$/kg)	20.45 (±12.57)	-0.1317 (±0.14) ns
Mg ($Cmol^+$/kg)	5.16 (±2.58)	0.3392 (±0.10) **
Rock (%)	18.26 (±20.32)	-0.4512 (±0.15) **
D_{sap} (trees/m^2)	0.39 (±0.09)	-0.3806 (±0.12) **
D_{tree} (trees/m^2)	0.14 (±0.02)	0.3931 (±0.07) ***

Note: *: P<0.05; **: P<0.01; ***: P<0.001; ns: P>0.05

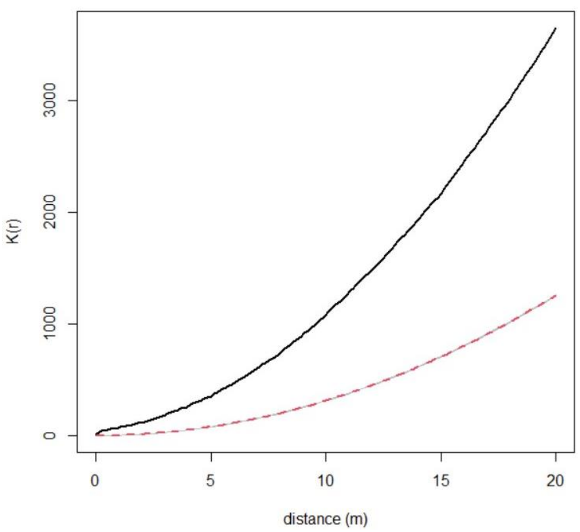

Figure 4. The plot of K-function value (K(r)) vs. distance up to 20 m for all individuals, and the solid line represents the value computed from observed data. The shading area indicates the 95% confidence envelope of values obtained from Monte Carlo simulations (99 replications) of Complete Spatial Randomness (CSR). The red dashed line shows the theoretical value for CSR

Discussion

According to the K function, *A. simplex* in the 16-ha study plot showed a clumped distribution; this result is consistent with a transect-based study in Indonesia (Lestari and Asih 2017), which showed a clustered or clumped distribution of *A. simplex* at altitudes lower than 400 m and a more uniform distribution with increasing altitude. Other studies have revealed clumped distributions for many species within the family Araceae (Tanesaka 2017; Sungkajanttranon et al. 2018; Matsumoto et al. 2020). Ecological factors associated with each species in this plant family, particularly reproductive strategy and/or seed dispersal, also determine individual species distribution patterns (Caughlin et al. 2014; Croat and Ortiz 2020; Matsumoto et al. 2020). Thus, our findings regarding the distribution of *A. simplex* may be partly attributable to its intrinsic ecological characteristics. Most *Aglaonema* species exhibit a nanophanerophyte life form, in which stems persist for many years (Boyce and Yeng 2012); even stems that break due to disturbances such as treefall or animal activity can survive to produce new shoots from bud primordia at the stem nodes, and stems separated from the parent plant can develop into new plants (Nicolson 1969). Seed dispersal limitation is another major factor influencing *A. simplex* distribution patterns. Its fruits are large, bright, red berries that aggregate as a bouquet, where each fruit produces a single seed. Although frugivorous birds mainly disperse the brightly colored fruits of many araceous plants (Mayo et al. 1997; Low 2024), those of *A. simplex* tend to fall from the plant when ripe and germinate close to the parent plant (Boyce and Yeng 2012; Lestari and Asih 2017; Chai and Wong 2019). Consequently, seedlings form a clumped distribution around the parent plant.

Plant distributions are influenced by environmental gradients, reflecting the distinctive ecological niche of each species (Walthert and Meier 2017; Marod et al. 2021). The results of our GLM analysis demonstrated that the distribution of *A. simplex* is significantly influenced by edaphic variables and plant density (Table 1), with a strong positive influence on soil clay content. This result differs from the findings from a study conducted in Doi Inthanon National Park, northern Thailand, which revealed that the distributions of dominant species including *Amorphophallus fuscus* Hett., *Amorphophallus yunnanensis* Engl., and *Arisaema consanguineum* Schott were negatively associated with soil clay particle content (Sungkajanttranon et al. 2018) due to the low soil moisture requirements of these species (Boyce et al. 2012). However, *Aglaonema* species generally thrive in humid habitats and are intolerant of long drought periods (Mansor et al. 2011; Yuzammi 2018). The soil texture in the permanent plot used in this study is sandy loam, mainly consisting of sand particles and exhibiting poor water absorption capacity (Lekprasoet et al. 2022) and lower nutrient levels than soil types with larger proportions of clay particles (Wang et al. 2018). Higher soil clay content increases water retention efficiency (Lekprasoet et al. 2022) and facilitates the retention and availability of nutrients (Kome et al. 2019).

Soil pH and exchangeable magnesium content also positively influenced the distribution of *A. simplex*, although to a lesser extent than clay content. Soil pH significantly affects soil properties and chemical processes, influencing plant physiological processes (Soti et al. 2015; Neina 2019; Penn and Camberato 2019). Acidic soil conditions are characteristic of tropical forest soils, such as those in the dry evergreen forest examined in this study. However, most nutrients become more available to plants under weakly acidic soil conditions than under neutral or alkaline soil conditions (Sela 2020; Wang et al. 2020b), such that acidic conditions promote growth rates and enhance reproductive system development (Gentili et al.

2018). Among soil macronutrients, magnesium is important in several plant physiological mechanisms such as chlorophyll formation, photosynthesis, nutrient absorption, and enzyme activation. It also improves plant resistance to disturbances such as stress, disease, and pests (Ahmed et al. 2023); this resistance may be essential for understory vegetation's strong competition in natural conditions. A lack of sufficient soil magnesium to meet plant requirements can reduce net carbon assimilation rates (Tränkner et al. 2018), decreasing plant productivity.

In the study plot, rocky outcrops acted as barriers to *A. simplex* migration, leading to lower population density in one corner that contained a creek with numerous continuous outcrops (Figure 3.B). The soil is shallower in areas with rocky outcrops (Sakurai et al. 1998), which limits species establishment due to a lack of space for root development.

Light is another crucial factor influencing plant growth and ecosystem processes. Light transmitted through the canopy to the forest floor is a vital resource for understory vegetation, and its quantity is determined by forest structure and species composition (Tinya and Ódor 2016; Sercu et al. 2017; Dormann et al. 2020). Light transmittance is related to plant density (Yang et al. 2014; Hovi and Rautiainen 2020); in our 16-ha study plot, areas with low tree density had vacant space for regeneration, which led to higher sapling density and consequently decreased light transmittance. This heterogeneous light transmittance based on plant density influenced the distribution of *A. simplex*, such that more individuals were present in areas with abundant adult trees and particularly high light conditions. Although *Aglaonema* species are generally intolerant of direct sunlight (Boyce and Yeng 2012; Yuzammi 2018), they can also survive under low-light conditions (Mayo et al. 1997). However, our results demonstrated that *A. simplex* required bright filtered light, with partial shade from the canopy, which is consistent with planting recommendations for many ornamental plants in the family Araceae, such as *Anthurium andraenum* Linden ex André, *Philodendron* spp., *Caladium* spp., and *Diefenbachia* spp. (Magar and Adhikari 2015).

In addition to the factors mentioned above, previous studies indicate that plant disease, especially root rot and leaf spot caused by anthracnose fungi, seriously damage *Aglaonema* species (Nicolson 1969). Furthermore, pollination may influence the distribution of the species. The inflorescence of *A. simplex* exhibits protogynous characteristics, with pistillate flowers becoming receptive before staminate flowers release pollen (Boyce et al. 2012); this characteristic promotes cross-pollination. However, *A. simplex* inflorescences have a specialist pollination system by drosophilid flies, resulting in lower pollination success and fruit set than species with a generalist pollination system (Chai and Wong 2019).

In conclusion, we found 11,232 *A. simplex* individuals (plant density, 702 individuals ha^{-1}) in a 16-ha dry evergreen forest plot at the Sakaerat Environmental Research Station, Northeastern Thailand. This species exhibited a clumped distribution pattern primarily attributed to its reproductive strategy and environmental factors (e.g., edaphic conditions and light transmittance). These findings contribute to the broader understanding of *A. simplex's* ecological niche; they can be used to design integrated land management approaches that balance ecological conservation with economic development goals for this species.

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REFERENCES

Ahmed N, Zhang B, Bozdar B, Chachar S, Rai M, Li J, Li Y, Hayat F, Chachar Z, Tu P. 2023. The power of magnesium: Unlocking the potential for increased yield, quality, and stress tolerance of horticulture crops. Front Plant Sci 14: 1285512. DOI: 10.3389/fpls.2023.1285512.

Allen DJ. 2011. *Aglaonema simplex*. The IUCN Red List of Threatened Species 2011. https://www.iucnredlist.org/species/194792/8902274.

Borregaard MK, Hendrichsen DK, Nachman G. 2008. Spatial distribution. In: Fath B (eds). Encyclopedia of Ecology. Elsevier, Oxford. DOI: 10.1016/B978-008045405-4.00659-5.

Boyce PC, Sookchaloem D, Hetterscheid WLA, Gusman G, Jacobsen N, Idei Y, Du NV. 2012. Araceae. Flora Thailand 11 (2): 1-221.

Boyce PC, Yeng WS. 2012. The Araceae of Malesia I: Introduction. Malays Nat J 64 (1): 33-67. DOI: 10.1080/00837792.2012.10670914.

Caughlin TT, Ferguson JM, Lichstein JW, Bunyawejchewin S, Levey DJ. 2014. The importance of long-distance seed dispersal for the demography and distribution of a canopy tree species. Ecology 95 (4): 952-962. DOI: 10.1890/13-0580.1.

Chai SK, Wong SY. 2019. Five pollination guilds of Aroid (Araceae) at Mulu National Park (Sarawak, Malaysian Borneo). Webbia 74 (2): 353-371. DOI: 10.1080/00837792.2019.1653425.

Chee C-F, Lee HB, Ong HC, Ho AHS. 2005. Photocytotoxic pheophorbide-related compounds from *Aglaonema simplex*. Chem Biodivers 2 (12): 1648-1655. DOI: 10.1002/cbdv.200590134.

Chen Y, Wu Y, Zhou J, Zhang W, Lin H-D, Liu X, Pan K, Shen T-J, Pan Z. 2021. Effectively inferring overall spatial distribution pattern of species in a map when exact coordinate information is missing. Methods Ecol Evol 12 (6): 971-984. DOI: 10.1111/2041-210X.13590.

Cornell HV, Harrison SP. 2014. What are species pools and when are they important? Ann Rev Ecol Evol Syst 45: 45-67. DOI: 10.1146/annurev-ecolsys-120213-091759.

Croat TB, Ortiz OO. 2020. Distribution of Araceae and the diversity of life forms. Acta Soc Bot Pol 89 (3): 8939. DOI: 10.5586/asbp.8939.

Dawwrueng P, Tan MK, Artchawakom T, Waengsothorn S. 2017. Species checklist of Orthoptera (Insecta) from Sakaerat Environmental Research Station, Thailand (Southeast Asia). Zootaxa 4306 (3): 301-324. DOI: 10.11646/zootaxa.4306.3.1.

Dormann CF, Bagnara M, Boch S, Hinderling J, Janeiro-Otero A, Schäfer D, Schall P, Hartig F. 2020. Plant species richness increases with light availability, but not variability, in temperate forests understorey. BMC Ecol 20: 43. DOI: 10.1186/s12898-020-00311-9.

Dubost JM, Phakeovilay C, Her C, Bochaton A, Elliott E, Deharo E, Xayvue M, Bouamanivong S, Bourdy G. 2019. Hmong herbal medicine and herbalists in Lao PDR: pharmacopeia and knowledge transmission. J Ethnobiol Ethnomed 15 (1): 27. DOI: 10.1186/s13002-019-0307-2.

Gentili R, Ambrosini R, Montagnani C, Caronni S, Citterio S. 2018. Effect of soil pH on the growth, reproductive investment and pollen allergenicity of *Ambrosia artemisiifolia* L. Front Plant Sci 9: 1335. DOI: 10.3389/fpls.2018.01335.

Gómez-Rubio V. 2016. Spatial point patterns: Methodology and applications with R. J Stat Softw: Book Rev 75 (2): 1-6. DOI: 10.18637/jss.v075.b02.

Goni O, Khan MF, Rahman MM, Hasan MZ, Kader FB, Sazzad N, Sakib MA, Romano B, Haque MA, Capasso R. 2021. Pharmacological insights on the antidepressant, anxiolytic and aphrodisiac potentials of *Aglaonema hookerianum* Schott. J Ethnopharmacol 268: 113664. DOI: 10.1016/j.jep.2020.113664.

Gu H, Li J, Qi G, Wang S. 2020. Species spatial distributions in a warm-temperate deciduous broad-leaved forest in China. J For Res 31 (4): 1187-1194. DOI: 10.1007/s11676-019-00928-7.

Harrison XA. 2014. Using observation-level random effects to model overdispersion in count data in ecology and evolution. PeerJ 2: e616. DOI: 10.7717/peerj.616.

He C, Jia S, Luo Y, Hao Z, Yin Q. 2022. Spatial distribution and species association of dominant tree species in Huangguan plot of Qinling mountains, China. Forests 13 (6): 866. DOI: 10.3390/f13060866.

Hidasi-Neto J, Bini LM, Siqueira T, Cianciaruso MV. 2020. Ecological similarity explains species abundance distribution of small mammal communities. Acta Oecol 102: 103502. DOI: 10.1016/j.actao.2019.103502.

Hohl A, Zheng M, Tang W, Delmelle E, Casas I. 2017. Spatiotemporal point pattern analysis using Ripley's K function. In: Karimi HA, Karimi B (eds). Geospatial Data Science Techniques and Applications. CRC Press, Boca Raton. DOI: 10.1201/b22052-7.

Hovi A, Rautiainen M. 2020. Spectral composition of shortwave radiation transmitted by forest canopies. Trees 34: 1499-1506. DOI: 10.1007/s00468-020-02005-7.

Hu D, Xu Y, Chai Y, Tian T, Wang K, Liu P, Wang M, Zhu J, Hou D, Yue M. 2022. Spatial distribution pattern and genetic diversity of *Quercus wutaishanica* Mayr population in Loess plateau of China. Forests 13 (9): 1375. DOI: 10.3390/f13091375.

Husemann M, Zachos FE, Paxton RJ, Habel JC. 2016. Effective population size in ecology and evolution. Heredity 117 (4): 191-192. DOI: 10.1038/hdy.2016.75.

Ismail Z, Ahmad A, Muhammad TST. 2017. Phytochemical screening of in vitro *Aglaonema simplex* plantlet extracts as inducers of SR-B1 ligand expression. J Sustain Sci Manag 12 (2): 34-44.

Kamble MY, Mane SS, Murugan C, Jaisankar I. 2008. Diversity of ethno-medicinal plants of tropical islands-with special reference to Andaman and Nicobar Islands. In: Sivaperuman C, Velmurugan A, Singh AK, Jaisankar I (eds). Biodiversity and Climate Change Adaptation in Tropical Islands. Academic Press, Cambridge, Massachusetts. DOI: 10.1016/B978-0-12-813064-3.00003-X.

Kiatsongchai R, Chitsomboon B. 2019. Phytochemicals and antioxidant properties of Wan Khan Mak (*Aglaonema simplex* BL.) fruit extract. Suranaree J Sci Technol 26 (1): 101-112.

Kome GK, Enang RK, Tabi FO, Yerima BPK. 2019. Influence of clay minerals on some soil fertility attributes: A review. Open J Soil Sci 9 (9): 155-188. DOI: 10.4236/ojss.2019.99010.

Lekprasoet R, Tuankrua V, Kheereemangkla Y. 2022. Some soil physical properties and soil water storage capacity in mixed deciduous forest and maize fields at Na Luang sub-watershed, Nan Province. Thai J For 41 (1): 90-101.

Lestari D, Asih NPS. 2017. Population structure, distribution pattern and microhabitat characteristics of *Aglaonema simplex* in Pasatan Protected Forest, Jembrana, Bali, Indonesia. Biodiversitas 18 (4): 1663-1668. DOI: 10.13057/biodiv/d180446.

Low SL. 2024. Avian frugivory and seed dispersal in *Amorphophallus paeoniifolius* and *Alocasia odora*. Trop Ecol 65: 321-329. DOI: 10.1007/s42965-024-00340-1.

Lowe WH, McPeek MA. 2014. Is dispersal neutral? Trends Ecol Evol 29 (8): 444-450. DOI: 10.1016/j.tree.2014.05.009.

Ma F, Wang S, Sang W, Zhang S, Ma K. 2024. Spatial distribution and sustainable development of living woody and coarse woody debris in warm-temperate deciduous broadleaved secondary forests in China. Plants 13 (5): 638. DOI: 10.3390/plants13050638.

Magar ABP, Adhikari D. 2015. Climate Requirements of Major Flowers in Nepalese Context. Floriculture Association Nepal (FAN): Kathmandu Nepal.

Mansor M, Boyce PC, Othman AS, Sulaiman B. 2011. The Araceae of Peninsular Malaysia. Penerbit Universiti Sains Malaysia, Pulau Pinang.

Marod D, Duengkae P, Sangkaew S et al. 2022. Population structure and spatial distribution of tree species in lower montain forest, Doi Suthep-Pui National Park, northern Thailand. Environ Nat Resour 20 (6): 644-663. DOI: 10.32526/ennrj/20/202200139.

Marod D, Hermhuk S, Sungkaew S, Thinkampheang S, Kamyo T, Nuipakdee W. 2019. Species composition and spatial distribution of dominant trees in the forest ecotone of a mountain ecosystem, northern Thailand. Environ Nat Resour 17 (3): 40-49. DOI: 10.32526/ennrj.17.3.2019.21.

Marod D, Phumphuang W, Wachrinrat C. 2021. Effect of environmental gradients on tree distribution in lowland dry evergreen forest, Northeastern Thailand. Agric Nat Resour 55 (5): 795-805. DOI: 10.34044/j.anres.2021.55.5.10.

Matsumoto TK, Hirobe M, Akaji Y, Miyazaki Y. 2020. Population structures and spatial patterns of two unpalatable *Arisaema* species (Araceae) with and without clonal reproduction in a riparian forest intensively grazed by Sika deer. J For Res 31: 155-162. DOI: 10.1007/s11676-018-0845-9.

Mayo SJ, Bogner J, Boyce PC. 1997. The Genera of Araceae. The Trustees Royal Botanic Gardens, Kew. London, UK.

Murphy SJ, Smith AB. 2021. What can community ecologists learn from species distribution model? Ecosphere 12 (12): e03864. DOI: 10.1002/ecs2.3864.

Neina D. 2019. The role of soil pH in plant nutrition and soil remediation. Appl Environ Soil Sci 2019: 5794869. DOI: 10.1155/2019/5794869.

Nicolson DH. 1969. A Revision of the Genus *Aglaonema* (Araceae). Smithsonian Institution Press, Washington. DOI: 10.5962/bhl.title.123257.

Opryshko M, Tkachenko H, Buyun L, Kurhaluk N, Góralczyk A, Tomin V, Osadowski Z. 2019. Evaluation of the antibacterial activity of ethanolic extracts obtained from *Aglaonema commutatum* Schott and its cultivars against *Citrobacter freundii*. Agrobiodivers Improv Nutr Health Life Qual 3: 154-164. DOI: 10.15414/agrobiodiversity.2019.2585-8246.154-164.

Palakit K, Duangsathaporn K, Siripatanadilok S, Lumyai P. 2015. Effect of climate variability on monthly growth of *Aglaia odoratissima* and *Hydnocarpus ilicifolia* at the Sakaerat Environmental Research Station (SERS), Northeastern Thailand. Environ Nat Resour 13 (1): 1-12. DOI: 10.14456/ennrj.2015.7.

Penn CJ, Camberato JJ. 2019. A critical review on soil chemical processes that control how soil pH affects phosphorus availability to plants. Agriculture 9 (6): 120. DOI: 10.3390/agriculture9060120.

Phumphuang W, Sungkaew S, Wachrinrat C, Thinkampheang S, Hermhuk S, Thongsawi J, Waengsothorn S, Lin L, Marod D. 2024. Environmental factors differentially influence species distributions across tree size classes in a dry evergreen forest in Sakaerat Biosphere Reserve, Northeastern Thailand. J For Res 2024: 1-9. DOI: 10.1080/13416979.2024.2314834.

R Core Team. 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Royal Botanic Gardens, Kew. 2024. Araceae: *Aglaonema* Schott. https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:2671-1.

Sakurai K, Tanaka S, Ishiduka S, Kanzaki M. 1998. Differences in soil properties of dry evergreen and dry deciduous forests in the Sakaerat Environmental Research Station. Tropics 8 (1/2): 61-80. DOI: 10.3759/tropics.8.61.

Sela G. 2020. Soil pH and Acidity. https://cropaia.com/blog/soil-ph-and-acidity/.

Sercu BK, Baeten L, van Coillie F, Martel A, Lens L, Verheven K, Bonte D. 2017. How tree species identity and diversity affect light transmittance to the understory in mature temperate forests. Ecol Evol 7 (24): 10861-10870. DOI: 10.1002/ece3.3528.

Shen T-J, Chen Y, Chen Y-F. 2017. Estimating species pools for a single ecological assemblage. BMC Ecol 17 (1): 45. DOI: 10.1186/s12898-017-0155-7.

Soti PG, Jayachandran K, Koptur S, Volin JC. 2015. Effect of soil pH on growth, nutrient uptake, and mycorrhizal colonization in exotic invasive *Lygodium microphyllum*. Plant Ecol 216: 989-998. DOI: 10.1007/s11258-015-0484-6.

Sungkajanttranon O, Marod D, Thanompun K. 2018. Diversity and distribution of family Araceae in Doi Inthanon National Park, Chiang Mai province. Agric Nat Resour 52 (2): 125-131. DOI: 10.1016/j.anres.2018.06.009.

Tanesaka E. 2017. Ethnobotanical survey on distribution of medicinal plants in the genus *Arisaema* in ruins of fortresses used in medieval Japan. J Med Plants Res 11 (18): 338-344. DOI: 10.5897/JMPR2017.6353.

Tilarux P, Suwanposri A, Tachai S, Sasivatchutikool P, Boonmee Y. 2022. Effect of plant hormones on growth of Wan Khan Mak (*Aglaonema tenuipes* Engl.) in vitro. J Sci Technol MSU 41 (5): 227-235.

Tinya F, Ódor P. 2016. Congruence of the spatial pattern of light and understory vegetation in an old-growth, temperate mixed forest. For Ecol Manag 381: 84-92. DOI: 10.1016/j.foreco.2016.09.027.
Tränkner M, Tavakol E, Jákli B. 2018. Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. Physiol Plant 163 (3): 414-431. DOI: 10.1111/ppl.12747.
Walthert L, Meier ES. 2017. Tree species distribution in temperate forests is more influenced by soil than climate. Ecol Evol 7 (22): 9473-9484. DOI: 10.1002/ece3.3436.
Wang H, Liu D, Munroe D, Cao K, Biermann C. 2016. Study on selecting sensitive environmental variables in modelling species spatial distribution. Ann GIS 22 (1): 57-69. DOI: 10.1080/19475683.2015.1114523.
Wang Y, Chen F, Zhang M, Chen S, Tan X, Liu M, Hu Z. 2018. The effects of the reverse seasonal flooding on soil texture within the hydro-fluctuation belt in the Three Gorges reservoir, China. J Soils Sediments 18: 109-115. DOI: 10.1007/s11368-017-1725-1.
Wang Y, Gui Z, Wu H, Peng D, Wu J, Cui Z. 2020a. Optimizing and accelerating space-time Ripley's K function based on Apache Spark for distributed spatiotemporal point pattern analysis. Future Gener Comput Syst 105: 96-118. DOI: 10.1016/j.future.2019.11.036.
Wang Z, Ul Hassan M, Nadeem F, Wu L, Zhang F, Li X. 2020b. Magnesium fertilization improves crop yield in production systems: A meta-analysis. Front Plant Sci 10: 1727. DOI: 10.3389/fpls.2019.01727.
Yang G-Z, Luo X-J, Nie Y-C, Zhang X-L. 2014. Effects of plant density on yield and canopy micro environment in hybrid cotton. J Integr Agric 13 (10): 2154-2163. DOI: 10.1016/S2095-3119(13)60727-3.
Yuzammi Y. 2018. The diversity of Aroid (Araceae) in Bogor Botanic Garden, Indonesia: Collection, conservation and utilization. Biodiversitas 19 (1): 140-152. DOI: 10.13057/biodiv/d190121.
Zhang S, Huang Y, Zang R. 2017. The assembly and interactions of tree species in tropical forests based on spatial analysis. Ecosphere 8 (7): e01903. DOI: 10.1002/ecs2.1903.