ASIAN JOURNAL OF FORESTRY
Volume 9, Number 2, December 2025
Pages: 332-345
E-ISSN: 2580-2844
DOI: 10.13057/asianjfor/r090215

Diversity of invasive alien plants in the Universitas Sumatera Utara Arboretum, Deli Serdang, Indonesia

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Manuscript received: 26 August 2025. Revision accepted: 15 November 2025.

Abstract. *Nathaniel G, Basyuni M, Tarigan AA, Baba S. 2025. Diversity of invasive alien plants in the Universitas Sumatera Utara Arboretum, Deli Serdang, Indonesia. Asian J For 9: 332-345.* Invasive alien plants are one or more plant species that are introduced into a different ecosystem and become dominant, disrupting the local ecosystem. In Indonesia, there are more than 300 species of invasive plants. The aim of this study is to analyze species diversity, examine morphological relationships, and analyze the distribution of invasive alien plants. This research was designed using a quantitative approach. Data collection was conducted through vegetation analysis using the "systematic sampling with random start" technique. The results of the study identified a total of 4,143 individual invasive alien plants belonging to 29 species from 16 families. The diversity index of invasive alien plants in the arboretum was calculated at 1.99, the evenness index was 0.5895, and the species richness index was 3.35. The highest importance value index at the shrub level was found in *Clidemia hirta* (Melastomaceae) with a value of 40.18%, while at the ground cover level it was *Asystasia gangetica* (Acanthaceae) with a value of 72.07%. Several species showed very close morphological relationships, indicated by a similarity index of 1. These included *C. hirta* with *Melastoma malabathricum*, *Elephantopus scaber* with *Ageratum conyzoides*, *Eragrostis amabilis* with *Panicum maximum*, *Cyperus rotundus* with *Rhynchospora colorata*, and *Caladium bicolor* with *Alocasia macrorrhizos* and *Limnocharis flava*. The distribution of invasive alien plants was found primarily on flat and gently sloping terrain, at distances ranging from 0 to 150 meters from the arboretum road, and from 0 to 375 meters from the river.

Keywords: *Clidemia hirta*, distribution, Indonesia, morphological relationship, species diversity

INTRODUCTION

Invasive alien species are a major driver of global change, impacting biodiversity, ecosystem services, and human livelihoods (Bacher et al. 2025). Global Impacts Dataset of Invasive Alien Species (GIDIAS) includes more than 22,000 records of impacts caused by 3,353 invasive alien species (plants, vertebrates, invertebrates, microorganisms) from all continents and realms (terrestrial, freshwater, marine), extracted from over 6,700 sources (Bacher et al. 2025).

Indonesia is a country rich in the diversity of flora and fauna species. However, along with the passage of time, threats to biodiversity have continued to increase. One of the main threats is the invasion of alien species that can disrupt local ecosystems. Invasive species are those originating from outside their native range, either intentionally or unintentionally introduced to a new area. Invasive plants, in particular, can upset the balance of ecosystems by dominating specific areas, ultimately reducing environmental quality and negatively impacting biodiversity. The loss of native species reduces the natural functioning of these ecosystems (Mustika et al. 2024).

The existence of forests in Indonesia is not only threatened by land conversion due to human activities but also by other threats that are actually quite evident, yet often overlooked. These threats come from several types of animals and plants, particularly invasive plants. Currently, various invasive plant species are growing and spreading beyond their native habitats, thereby threatening ecosystems, including the existing flora and fauna. The presence of invasive plants, which are not native species, has become a concerning issue, as these species are beginning to replace local ones, especially in conservation areas (Aleng et al. 2024).

Invasive alien plants are introduced plant species that take over and disrupt the balance of the local ecosystem. The introduction of invasive alien plants can occur through vectors such as animals, wind, water, or human activity. Invasive species possess several characteristics that make them highly robust, but they often have negative impacts on native species. Generally, invasive plants have no economic value, tend to dominate and take over new areas or ecosystems, and are difficult to control. In addition, invasive plants can also affect certain native animals (Daniansyah and Badi'ah 2024).

An arboretum is a place or area used to collect plants, which can grow naturally or be cultivated in an artificial habitat that mimics the original environment of the plant species (Sinampu et al. 2019). In general, an arboretum serves as a collection site for various types of trees and plays an important role in understanding the diversity of plant morphological traits. Over time, arboreta have developed multiple functions, ranging from storing plant collections as resources for scientific research, education, and biodiversity conservation technologies, to plant production and services (Destrianto and Afroda 2023).

Research related to the diversity of invasive alien plants has been widely conducted in Indonesia, such as spatial distribution of invasive plants in Bandung, West Jawa (Rahmawati and Rosleine 2023), invasive alien species in Mount Gede Pangrango National Park, West Java (Uji et al. 2019), and vegetation analysis and utilization potential of invasive plants in the rice fields of Blang Crum Village, Lhokseumawe, Aceh (Fathiya et al. 2024). However, these studies have not yet addressed the morphological relationships among invasive plants. Moreover, research on the diversity of invasive plants in the Arboretum of the Universitas Sumatera Utara (USU) has never been conducted.

The Arboretum of the Universitas Sumatera Utara, as one of the areas with a diverse flora collection, has the potential to become a habitat for invasive alien plants that could negatively affect ecosystem balance. Therefore, this study aims to investigate the diversity, distribution, importance value, and morphological relationships (based on morphology) of invasive alien plant species in the USU Arboretum.

MATERIAL AND METHODS

Study area

The research was conducted at the Arboretum of the Universitas Sumatera Utara, located in Bekala, Pancur Batu Sub-district, Deli Serdang District, North Sumatra, Indonesia (Figure 1). Data identification and processing were carried out at the Forest Cultivation Laboratory, Faculty of Forestry, while the identification of dried herbarium specimens was conducted at the Medanense Herbarium Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara. The research was carried out from January 2025 to March 2025.

Materials

The tools used in this research include a Global Positioning System (GPS) Garmin montana 680, raffia string, wooden stakes, measuring tape, machete, scissors, ziplock plastic bags, camera, name labels, duct tape, newspaper, cardboard, ruler, black cloth, sprayer, writing supplies, laptop, Microsoft Excel, MVSP software, ArcGIS 10.8 software, and identification books. The materials required include samples of understory plant species, 70% alcohol, Digital Elevation Model (DEM) data, and vector data for distance from roads and distance from rivers.

Vegetation analysis

The data collection method used in this research is vegetation analysis. The placement of observation plots was carried out using the systematic sampling with random start method, in which the first plot was determined randomly, and subsequent plots were placed systematically based on a predetermined interval. Observations were conducted using the quadrat method. A total of 250 observation plots were established, consisting of 50 transects, each containing 5 nested plots measuring 5×5 meters, within which a 2×2 meters observation subplot was placed in a systematic left-right (zigzag) pattern at 5-meter intervals. Each transect had a length of 50 meters, laid out from bottom to top (Figure 2). The types of plants observed in the 2×2 meter observation plots included shrubs, herbs, ferns, lianas, and grasses.

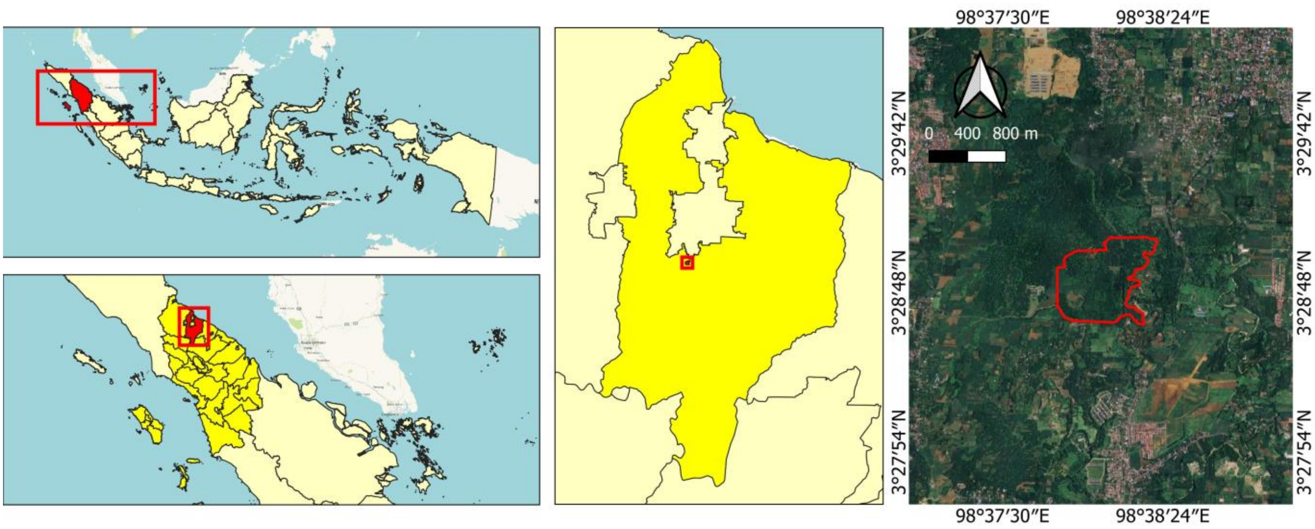

Figure 1. Research location map

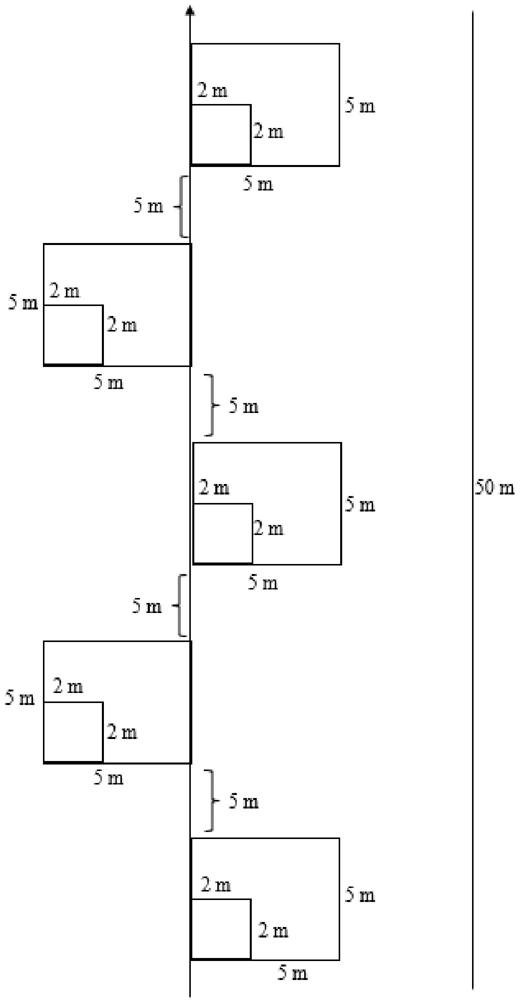

Figure 2. Sampling plot design

To minimize potential detection bias among plant species, all plots were observed with equal sampling effort and observation duration. Each transect was surveyed by two observers to ensure consistent identification and recording, particularly for small or hidden understory species growing beneath shrub layers. To minimize potential bias toward easily accessible areas, transects were distributed across various topographic positions (flat, gentle, and moderate slopes) and at varying distances from roads and rivers, guided by DEM and vector spatial data. Although accessibility influenced initial plot placement, efforts were made to ensure representative coverage of environmental gradients within the arboretum.

Plants collected were photographed, key characteristics were recorded, specimens were collected, and name labels were attached for further identification. Collected plants were photographed against a black cloth with a 30 cm ruler as a scale reference. Specimen preservation was done by preparing dried herbarium samples.

Plant identification

Specimens collected in the field will be identified based on the similarities and differences in the morphological characteristics of each plant species. A Plant species was categorized as an Invasive Alien Species (IAS) if it met two criteria: (i) it is non-native to Indonesia, originating from outside the Indonesian biogeographical region, and (ii) it shows evidence of naturalization and ecological dominance within the study site, characterized by species that occur in a large number of sampling plots. All identified plant species will then be classified as invasive or not by referring to books and checking against the invasive alien plant species database. Invasive alien plants in Indonesia are determined according to the list established by the Regulation of the Indonesian Minister of Environment and Forestry No. 94 of 2016. The reference literature used for identification includes: A Guide Book to Invasive Alien Plant Species in Indonesia (Setyawati et al. 2015), 75 Important Invasive Plant Species in Indonesia (Tjitrosoedirdjo et al. 2016a), *Pedoman Analisis Resiko Tumbuhan Asing Invasif* (Post Border) (Tjitrosoedirdjo et al. 2016b), *Tumbuhan Invasif dan Pendekatan Pengelolaannya* (Tjitrosoedirdjo et al. 2016c).

Data analysis

Plant species diversity level

Plant species diversity can be calculated using the Shannon–Wiener Diversity Index (H’). According to Ludwig and Reynolds (1988), this index can be calculated using the formula:

$$H' = -\Sigma \frac{ni}{N} log \frac{ni}{N}$$

Where:
H’: Shannon–Wiener Diversity Index
Ni: Number of individuals of species *i*
N: Total number of individuals of all species

The Shannon–Wiener Diversity Index values are categorized into three levels: H’<1: Low species diversity, 1<H’<3: Moderate species diversity, H’>3: High species diversity

Plant species evenness level

The evenness level is indicated by the Species Evenness Index (E). This index reflects the distribution of individuals among species. The index can be calculated using the following formula (Zulharman 2017):

$$E = \frac{H'}{\ln S}$$

Where:
H’: Shannon–Wiener Diversity Index
S: Number of species
E: Species Evenness Index

The Species Evenness Index values are categorized into three levels: E<0.31: Low species evenness, 0.31<E<1: Moderate species evenness, E>1: High species evenness

Species richness index

The species richness of invasive alien plants can be calculated using the Margalef Species Richness Index (Dmg). This index can be calculated using the following formula (Wahyuningsih et al. 2019):

$$Dmg = \frac{(S - 1)}{ln\ N}$$

Where:
Dmg: Margalef Species Richness Index
S: Number of species found
N: Total number of individuals of all species

The Margalef Species Richness Index values are categorized into three levels: D<2.5: Low species richness, 2.5<D<4: Moderate species richness, D>4: High species richness. The evenness (E) and species richness (Dmg) indices were calculated at the community level by combining all recorded plant growth forms (shrubs, understory herbs, and lianas) into a single dataset. All individuals were analyzed collectively to represent the overall invasive alien plant diversity within the arboretum.

Importance Value Index (IVI)

The vegetation data obtained were analyzed to calculate the Importance Value Index (IVI). The IVI value is derived from the sum of Relative Density (RD), Relative Frequency (RF) and Relative Dominance (RDo), based on Indriyanto (2006). Data analysis to calculate the IVI can use the following formulas:

Density

Density of an individual species (D) = $\frac{\textbf{abundance of an individual species}}{\textbf{observation plot area}}$

Relative Density of an individual species (RD) = $\frac{\textbf{density of an individual species}}{\textbf{density of all spescies}}$ x 100%

Frequency

Frequency of an individual species (F) = $\frac{\sum \textbf{number of plots where a species found}}{\sum \textbf{number of total observation plots}}$

Relative Frequency of an individual species (RF) = $\frac{\textbf{frequency of an individual species}}{\textbf{frequency of all species}}$ x 100%

Dominance

Dominance of an individual species (Do) = $\frac{\textbf{total basal area of a species}}{\textbf{observation plot area}}$

Relative Dominance of an individual species (RDo) = $\frac{\textbf{dominance of a species}}{\textbf{total dominance of all species}}$ x 100%

Importance Value Index (IVI)

IVI = RD + RF + Rdo

The Importance Value Index (IVI) was calculated separately for each plant growth form, including shrubs, understory herbs, and lianas. For each stratum, IVI was derived from the sum of relative density, relative frequency, and relative dominance, resulting in a standardized total IVI value of 300. This approach follows standard ecological procedures and ensures that IVI reflects dominance patterns within each vegetation layer rather than across mixed growth forms.

Similarity index

Data in the form of morphological traits or characteristics were scored as binary data to standardize the dataset and avoid subjectivity in character weighting. The scoring system and list of characters have been added as Table S1. The morphological characteristics are analyzed using the Sorensen similarity index formula:

$$S = \frac{2C}{A + B} \times 100\%$$

Where:
S: Similarity index
A: Number of characters possessed by species A
B: Number of characters possessed by species B
C: Number of shared characters between species A and B

Each character was coded into binary (has the trait = 1, does not have the trait = 0) depending on the variable type. The dataset was analyzed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm based on Euclidean distance to generate a similarity matrix. The dendrogram was produced using Multivariate Statistical Package (MVSP) software. The data obtained through this application were in the form of percentage levels of kinship between local plants and invasive alien plants and a dendogram showing kinship clusters between species.

Slope map creation

The slope map was created from Digital Elevation Model (DEM) data downloaded from the website https://tanahair.indonesia.go.id. The data were then processed using ArcMap software with the slope and reclassify tools to produce the slope map.

Road distance map creation

The road distance map was created using the Euclidean Distance method, which calculates the straight-line distance from each pixel to the nearest road, using vector data downloaded from https://tanahair.indonesia.go.id. Euclidean Distance is a distance calculation method used to measure the distance between two points in Euclidean space (Pribadi et al. 2022).

River distance map creation

The river distance map was created using the Euclidean Distance method, which calculates the straight-line distance from each pixel to the nearest river, using vector data downloaded from https://tanahair.indonesia.go.id. This process was carried out using ArcMap software. Habitat association analysis was conducted descriptively to provide an initial indication of possible relationships between invasive species distribution and environmental characteristics.

RESULTS AND DISCUSSION

Diversity of invasive alien plants

Vegetation analysis was conducted at the Arboretum of Universitas Sumatera Utara, covering an observation area of approximately 50 hectares with a sampling area of 5% (about 2.5 hectares). During data collection, 44 plant species from 22 families were recorded, totaling 5,816 individuals. Among these, 29 species were classified as invasive alien plants from 16 families, with a total of 4,143 individuals. The most abundant species found were Israel grass (*Asystasia gangetica*) with 1,361 individuals, Koster's curse (*Clidemia hirta*) with 523 individuals, and nutsedge (*Cyperus rotundus*) with 360 individuals (Table 1).

Based on Table 1, it is known that the invasive alien plants obtained originate from outside Indonesia, specifically from India, Sri Lanka, Southern China, Myanmar, Tropical America, South America, Asia, and Africa. This aligns with the statement by Foxcroft et al. (2017), which explains that invasive alien plants introduced into Indonesia come from all over the world, namely Asia 26%, Tropical America 25%, the Americas and surrounding areas 15%, Africa 12.8%, Europe 9%, Australia and New Zealand 4%, and 8.2% are unknown.

Species diversity index (H')

Table 1 shows that the diversity index value of invasive alien plants at the research site is 1.99, which falls into the moderate category. According to the Shannon-Wiener criteria, if H'≤1, the species diversity is low; if 1≤H'≤3, the species diversity is moderate; and if H'≥3, the species diversity is high. The diversity (H′) values showed moderate variation among habitat types, with higher diversity generally occurring in semi-open or moderately disturbed areas compared to dense forest and highly exposed zones. According to Harahap et al. (2021), the diversity index (H') is used to determine the stability level of species diversity in a community within a stand. The higher the H' value, the higher the stability level of the forest vegetation community. A community with H'<1 is considered unstable, an H' value between 1 and 2 indicates a stable community, and H'>3 indicates a very stable community.

Table 1. Diversity of invasive alien plants at the research site

Family	Scientific Name	Total	H'	Origin
Acanthaceae	*Asystasia gangetica* (L.) T.Anderson**	1,361	0.340	India, Sri Lanka
	Thunbergia grandiflora (Roxb. ex Rottler) Roxb.***	3	0.004	India, South China, Myanmar
Alismataceae	*Limnocharis flava* (L.) Buchenau**	1	0.001	South America
Asteraceae	*Struchium sparganophorum* (L.) Kuntze**	18	0.018	South America
	Ageratum conyzoides L.**	19	0.019	South America
	Elephantopus scaber L.**	102	0.071	Tropical Asia
	Synedrella nodiflora (L.) Gaertn.**	49	0.040	South America
	Acmella paniculata (Wall. ex DC.) R.K.Jansen**	51	0.042	South America
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Schult.**	20	0.020	America
Commellinaceae	*Commelina communis* L.**	148	0.093	Asia
Convolvulaceae	*Ipomoea triloba* L.**	6	0.007	South America
Cucurbitaceae	*Momordica charantia* L.*	1	0.001	India
Cyperaceae	*Cyperus rotundus* L.**	360	0.172	India, Africa
	Rhynchospora colorata (L.) H.Pfeiff.**	215	0.122	Asia
Fabaceae	*Calopogonium mucunoides* Desv. **	15	0.015	South America, West India
	Mimosa pudica L.**	136	0.088	South America
Lamiaceae	*Hyptis capitata* Jacq.**	75	0.056	South America
Malvaceae	*Urena lobata* L.*	155	0.097	Asia
Melastomaceae	*Clidemia hirta* (L.) D.Don*	523	0.217	South America
	Melastoma malabathricum L.*	83	0.061	Asia
Piperaceae	*Piper aduncum* L.*	62	0.048	South America
Poaceae	*Setaria barbata* (Lam.) Kunth**	27	0.025	Africa
	Paspalum conjugatum P.J.Bergius**	190	0.112	South America
	Panicum maximum Nees, 1841**	28	0.026	Tropical Africa
	Eragrostis amabilis (L.) Wight & Arn.**	34	0.030	Africa, South Asia
	Axonopus compressus (Sw.) P.Beauv.**	350	0.169	South America
Polypodiaceae	*Nephrolepis biserrata* (Sw.) Desv.**	50	0.041	South America
Verbenaceae	*Lantana camara* L.*	5	0.006	South America
	Stachytarpheta indica (L.) Vahl*	56	0.045	South America
16	29	4,143	1.99	
Evenness Index (E)	0.5895			
Species Richness Index (Dmg)	3.35			

Note: *: Invasive alien plants in the shrub category, **: Invasive alien plants in the understory category, ***: Invasive alien plants in the liana category

Species Evenness Index (E)

The Species Evenness Index of invasive alien plants at the research site is 0.5895 (Table 1) which is moderate, caused by the dominance of some species with a higher number of individuals and uneven distribution among species. This aligns with Baderan et al. (2021), who explained that the evenness index represents the degree of equality in richness or abundance of individuals among species. If each species has the same number of individuals, the community reaches maximum evenness. However, if the evenness value is low, the community has minimal evenness. The evenness value ranges from 0 to 1; if E<0.31: Low species evenness, 0.31<E<1: Moderate species evenness, E>1: High species evenness. Evenness index (E) values indicated that species distribution was relatively balanced in shaded habitats, whereas open areas tended to be dominated by a few fast-growing species.

Species richness index (Dmg)

The species richness index at the research site was analyzed using the Margalef index, with a value of 3.35 for invasive alien plants (Table 1). This result indicates that the species richness at the research site is in the moderate category (2.5<D<4). This aligns with Wahyuningsih et al. (2019), reported that the species richness index is used to determine the number of species in a community; the more species found in the community, the higher the species richness index. Margalef's Richness Index (Dmg) similarly reflected habitat heterogeneity, suggesting that structural and environmental variation supports higher species turnover (Wahyuningsih et al. 2019).

Importance Value Index

The Importance Value Index (IVI) of invasive alien plants at the research site varies at each level. This can be seen in Table 2 for invasive alien plants at the shrub, understory, and liana levels at the research site.

Based on Table 2, it is known that there are 44 plant species from 22 families categorized as shrubs, understory plants, and lianas, which are divided into 29 invasive alien plants and 15 non-invasive alien plants. It is also known that invasive alien plants have a total Importance Value Index (IVI) of 231.68%, while non-invasive alien plants have a total IVI of 68.32%. Based on Table 2, it is also known that there are 5 families and 7 species of invasive alien shrubs in the arboretum, 11 families and 21 species of invasive alien understory plants, and only 1 species of liana. The difference in species numbers across shrubs, understory plants, and lianas is due to the different types of plants observed: shrub-level plants include shrubs and bushes; understory plants include herbs, ferns, and grasses; and lianas are climbing plants.

The importance value index of invasive alien shrubs ranges from 0.30% to 40.18%. The species *C. hirta* (Melastomaceae) has the highest importance value index of 40.18%. This species is widely found in the arboretum, occurring in half of the total observation plots, namely 130 plots. According to Khoiriyah et al. (2024), *C. hirta* is a plant from the Melastomataceae family. It is also known as an invasive alien plant with high competitiveness.

In research by Pelu and Djarami (2021), *C. hirta* is described as a species easily found in open areas and sometimes grows covering forest edges, even becoming a weed. This plant also prefers moist places and soil with high humus content. Sunaryo et al. (2012) explained that *C. hirta* is an invasive plant that has spread across various islands in the Indian Ocean, such as parts of Micronesia, the Malay Peninsula, and Indonesia. Its local spread is mainly facilitated by fruit-eating birds. The exact mode and range of its invasion into other countries remain unclear, possibly through its introduction as an ornamental plant.

The dominance of *C. hirta* causes marked ecological impacts, including the formation of dense shrubs that inhibit the regeneration of native species through competition for light and growing space, the production of allelopathic compounds that suppress the germination and growth of local species, and the resulting homogenization of vegetation and decline in biodiversity (Mandala and Darmawan 2025). In the current study, these effects were not directly tested under field or laboratory conditions, rather the inference was made based on their observed dominance, abundance, and coverage patterns in the study area.

The importance value index of invasive alien understory plants ranges from 0.13% to 72.07%. The species *A. gangetica* (Acanthaceae) has the highest importance value index of 72.07%. This species belongs to the Acanthaceae family and is the most frequently found species in the observation plots, appearing in 161 plots. This aligns with the findings of Ginting (2023), who found that the understory plant dominating the USU Arboretum is *A. gangetica* with an importance value index of 18.11%. According to Naufal and Susintowati (2024), *A. gangetica* is a herbaceous plant commonly known as creeping foxglove, Israeli grass, or Chinese violet. This plant species grows quickly and is commonly found in tropical regions.

The study by Solfiyeni et al. (2016) reported that *A. gangetica* was present and fairly dominant in the Lembah Anai Nature Reserve, with an important value index of 26.68%. In the study by Ihsan et al. (2022), this species was also found and ranked as the third most dominant species, with an important value index of 14.57%, occurring in the Sungai Buluh Peat Protection Forest. Furthermore, Ulfah et al. (2020) reported that this species dominated in four reclamation sites, with important value indices of 10.40%, 26.96%, 57.76%, and 13.41%, respectively.

The dominance of these species has clear negative impacts on biodiversity by suppressing native species, which can lead to a loss of species richness and a simplification of community structure. However, there is an ecological paradox, particularly concerning *A. gangetica*, where under certain management contexts, this species can provide ecological benefits, such as increasing water infiltration rates and soil organic matter content. This indicates that the ecological impact of an invasive species is highly dependent on context and human intervention (Khalida et al. 2021).

Table 2. Importance Value Index of invasive alien plant species and non-invasive plant species at the shrub, understory, and liana levels at the research site

Family	Scientific name	RD (%)	RF (%)	RDo (%)	IVI (%)	Plant status
Shrubs						
Cucurbitaceae	*Momordica charantia* L.	0.02	0.10	0.18	0.30	Invasive alien
Malvaceae	*Urena lobata* L.	2.67	6.04	24.56	33.27	Invasive alien
Melastomaceae	*Clidemia hirta* (L.) D.Don	8.99	13.53	17.66	40.18	Invasive alien
	Melastoma malabathricum L.	1.43	3.95	0.31	5.69	Invasive alien
	Heterotis rotundifolia (Sm.) Jacq.-Fél.	0.89	0.73	0.10	1.72	Non-invasive alien
Moraceae	*Ficus hispida* L.fil.	0.33	0.31	0.07	0.71	Non-invasive alien
Piperaceae	*Piper aduncum* L.	1.07	3.33	5.81	10.21	Invasive alien
Verbenaceae	*Lantana camara* L.	0.09	0.42	0.01	0.52	Invasive alien
	Stachytarpheta indica (L.) Vahl	0.96	2.19	0.02	3.17	Invasive alien
Vitaceae	*Leea indica* (Burm.fil.) Merr.	0.02	0.10	0.38	0.50	Non-invasive alien
	Total	16.47	30.7	49.1	96.27	
Understory plants						
Acanthaceae	*Asystasia gangetica* (L.) T.Anderson	23.40	16.75	31.92	72.07	Invasive alien
Alismataceae	*Limnocharis flava* (L.) Buchenau	0.02	0.10	0.04	0.16	Invasive alien
Amaranthaceae	*Cyathula prostrata* (L.) Blume	0.03	0.10	0.01	0.14	Non-invasive alien
Araceae	*Alocasia macrorrhizos* (L.) G.Don	0.69	2.60	15.01	18.30	Non-invasive alien
	Caladium bicolor (Aiton) Vent.	0.26	1.35	0.51	2.12	Non-invasive alien
Aspleniaceae	*Phegopteris connectilis* (Michx.) Watt	0.03	0.21	0.01	0.25	Non-invasive alien
	Diplazium esculentum (Retz.) Sw.	0.12	0.10	0.01	0.23	Non-invasive alien
	Thelypteris dentata (Forssk.) E.P.St.John	8.91	8.01	0.48	17.40	Non-invasive alien
	Asplenium nidus L.	0.02	0.10	0.01	0.13	Non-invasive alien
Asteraceae	*Struchium sparganophorum* (L.) Kuntze	0.31	0.52	0.02	0.85	Invasive alien
	Ageratum conyzoides L.	0.33	0.73	0.04	1.10	Invasive alien
	Elephantopus scaber L.	1.75	3.02	0.25	5.02	Invasive alien
	Synedrella nodiflora (L.) Gaertn.	0.84	1.25	0.74	2.83	Invasive alien
	Acmella paniculata (Wall. ex DC.) R.K.Jansen	0.88	0.83	0.02	1.73	Invasive alien
	Helianthus divaricatus L.	0.05	0.10	0.01	0.16	Non-invasive alien
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Schult.	0.34	0.10	0.01	0.45	Invasive alien
Commellinaceae	*Commelina communis* L.	2.54	0.73	0.56	3.83	Invasive alien
Convolvulaceae	*Ipomoea triloba* L.	0.10	0.21	0.01	0.32	Invasive alien
Cyperaceae	*Cyperus rotundus* L.	6.19	2.50	0.08	8.77	Invasive alien
	Rhynchospora colorata (L.) H.Pfeiff.	3.70	2.50	0.03	6.23	Invasive alien
Fabaceae	*Calopogonium mucunoides* Desv.	0.26	1.04	0.01	1.31	Invasive alien
	Mimosa pudica L.	2.34	4.99	0.33	7.66	Invasive alien
Lamiaceae	*Hyptis capitata* Jacq.	1.29	3.23	0.13	4.65	Invasive alien
Poaceae	*Setaria barbata* (Lam.) Kunth	0.46	0.42	0.03	0.91	Invasive alien
	Paspalum conjugatum P.J.Bergius	3.27	2.08	0.06	5.41	Invasive alien
	Panicum maximum Nees, 1841	0.48	0.52	0.04	1.04	Invasive alien
	Eragrostis amabilis (L.) Wight & Arn.	0.58	0.52	0.02	1.12	Invasive alien
	Axonopus compressus (Sw.) P.Beauv.	6.02	3.43	0.16	9.61	Invasive alien
	Lasiacis divaricata (L.) Hitchc.	5.11	2.29	0.10	7.50	Non-invasive alien
	Oplismenus undulatifolius (Ard.) P.Beauv.	1.12	0.52	0.02	1.66	Non-invasive alien
	Leersia virginica Willd.	2.24	0.52	0.04	2.80	Non-invasive alien
Polypodiaceae	*Nephrolepis biserrata* (Sw.) Desv.	0.86	2.39	0.02	3.27	Invasive alien
Pteridaceae	*Adiantum latifolium* Lam.	8.96	5.20	0.18	14.34	Non-invasive alien
	Total	83.5	68.96	50.91	203.37	
Liana						
Acanthaceae	*Thunbergia grandiflora* (Roxb. ex Rottler) Roxb.	0.05	0.31	0.05	0.41	Invasive Alien
	Total	0.05	0.31	0.05	0.41	
	Total IVI	100.00	100.00	100.00	300.00	

Based on Table 2, it can be seen that the invasive alien plants dominating the area belong to the families Asteraceae and Poaceae, each with 5 species. This is similar to the study by Susilo (2018), who reported that invasive alien plants in Meru Betiri National Park are most commonly found in the families Asteraceae (13 species) and Poaceae (7 species). In the research by Abywijaya et al. (2014), the invasive alien plant families with the most species found were Poaceae (3 species) followed by Asteraceae (2 species).

According to Indraswara and Suwarna (2023), the large number of species and the ability of the Asteraceae family are well known as plants that cause damage, and many species are listed among the world's 100 most harmful invasive species. According to Amandari et al. (2023), the Poaceae family is easily found in every study area because its seeds disperse quickly and the plants grow rapidly.

Similarity index

The morphological relationship analysis of 44 invasive alien and local plant species was conducted using the Sorensen similarity index calculation based on 30 morphological characters. The morphological relationships based on the morphological characters of the 44 observed species are presented in a dendrogram (Figure 3).

From the dendrogram, it was known that the 44 plant species are divided into 2 clusters: Cluster I and Cluster II. Cluster I consists of *Urena lobata*, *Momordica charantia*, *Thelypteris dentata*, *Leersia virginica*, *Asplenium nidus*, *Diplazium esculentum*, *Phegopteris connectilis*, *Nephrolepis biserrata*, *Adiantum latifolium*, *Drymaria cordata*, *C. rotundus*, *Rhynchospora colorota*, *Caladium bicolor*, *Alocasia macrorrhizos*, *Limnocharis flava*, *Commelina communis*, *Oplismenus undulatifolius*, *Paspalum conjugatum*, *Lasiacis divaricata*, *Axonopus compressus*, *Eragrostis amabilis*, *Panicum maximum*, *Setaria barbata*, *Calopogonium mucunoides*, *Ipomoea triloba*, *Elephantopus scaber*, *Ageratum conyzoides*, *Struchium sparganophorum*, *Helianthus divaricatus*, *Acmella paniculata*, *Synedrella nodiflora*, and *Heterotis rotundifolia*. Meanwhile, Cluster II includes *Mimosa pudica*, *Leea indica*, *Piper aduncum*, *Cyathula prostrata*, *A. gangetica*, *Thunbergia grandiflora*, *Hyptis capitata*, *Stachytarpheta indica*, *Lantana camara*, *Ficus hispida*, *Melastoma malabathricum*, and *C. hirta*.

The clustering observed in the dendrogram does not merely reflect taxonomic relationships but rather indicates morphological similarity and functional convergence. This is consistent with the theory of ecomorphology, which states that organisms with similar ecological roles may develop comparable morphological adaptations even if they belong to different families. Furthermore, Anthony and Mathew (2010) demonstrated that community patterns can represent either morphological clustering or overdispersion resulting from similar ecological adaptations or competition across taxonomic lineages. Therefore, the similarity results should be interpreted as a representation of the morphological structure and ecological functions of the invasive community, rather than as a direct reflection of taxonomic relatedness."

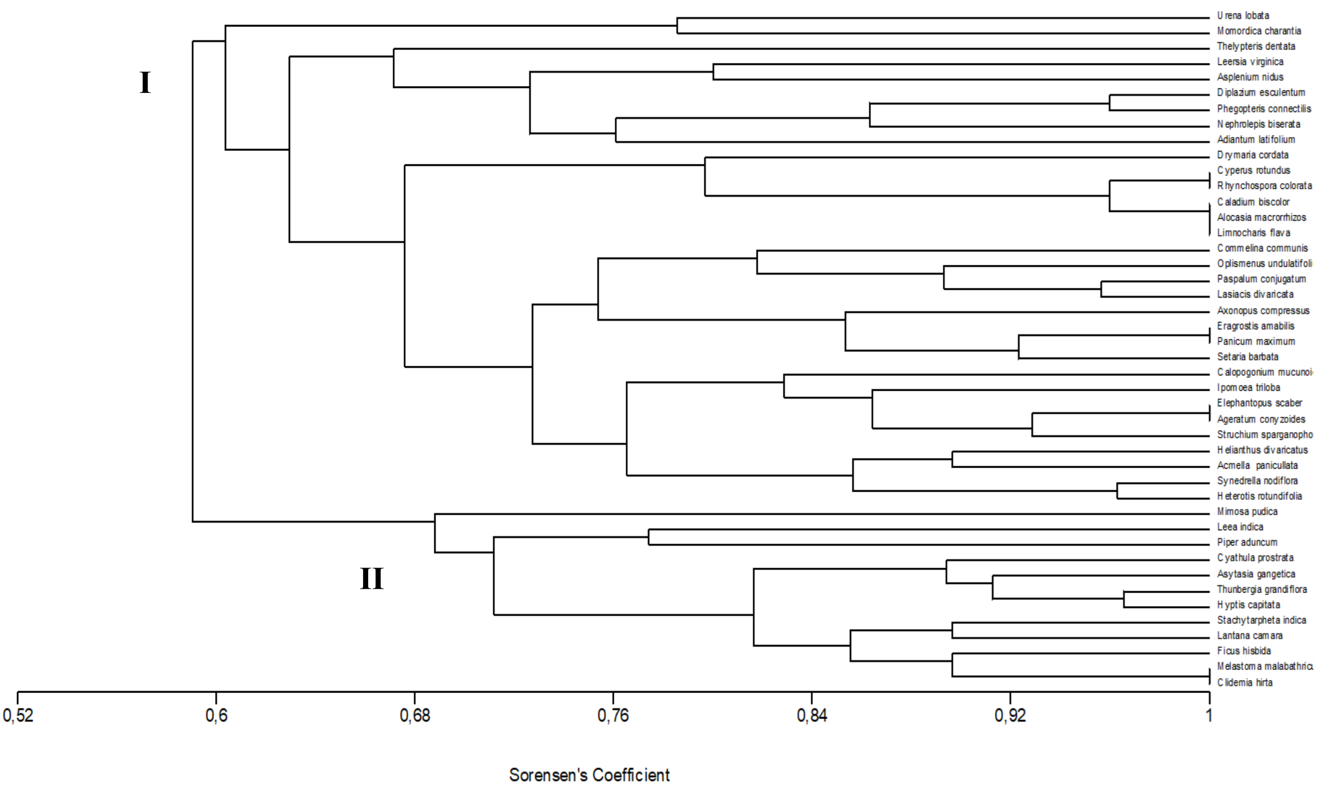

Figure 3. Dendrogram of the morphological relationships between invasive alien plants and local plants

Based on the dendrogram results, it can be seen that *C. hirta* and *M. malabathricum* have a very close morphological relationship with a coefficient of 1, as they both belong to the same family. These two species are also closely related to *F. hispida*, and all three are closely related to *L. camara* and *Stachytarpheta indica*. This is due to the fact that the observed morphological characteristics of these plant organs are nearly identical, resulting in a high similarity index.

The dendrogram also shows that *E. scaber* and *A. conyzoides* share a very close morphological relationship, with a similarity coefficient of 1. Both species belong to the same family, Asteraceae. This close relationship is reflected in similarities in root, stem, leaf, and flower morphology. According to Setyaningtyas et al. (2018), a key characteristic of the Asteraceae family is the presence of compound flowers densely arranged in a disk-like structure, commonly referred to as a capitulum.

A very close morphological relationship is also shared among *Caladium bicolor*, *A. macrorrhizos*, and *L. flava*, which have a similarity index of *C. bicolor* and *A. macrorrhizos* belong to the same family, Araceae, while *L. flava* belongs to the Alismataceae family. These three species have nearly identical morphological traits in terms of roots, stems, leaves, and flowers. Araceae and Alismataceae are taxonomically classified within the same order, Alismatales, although they belong to different families. This morphological proximity explains why they share a number of similar morphological characteristics. According to Viranda and Anggraini (2023), general characteristics of the Araceae family include being herbaceous plants erect-growing plants with tubers, shield-shaped leaf blades, fibrous roots, complete leaves with sheaths and petioles, lobed leaves, pinnate venation, and a perennial life cycle.

The dendrogram also shows that *E. amabilis* has a very close morphological relationship with *P. maximum*, and *C. rotundus* is closely related to *Rhynchospora colorata*, with a similarity index of 1. This is due to both pairs belonging to the same families. From the cluster analysis, it is also revealed that the combination of Cluster I and Cluster II shows a distant morphological relationship, with a similarity index of 0.590. According to Cahyarini et al. (2004), a similarity level is considered distant if it is below 0.60 or 60%. The closer the value is to 1, the more similar the relationship; the closer it is to 0, the more dissimilar the species are.

Species that share similar vegetative traits tend to exhibit the same strategies of dispersal and habitat dominance, such as rapid growth, the ability to cover the ground with broad leaves, and vegetative reproduction through rhizomes or stolons. This explains why some invasive species are able to thrive together in an ecosystem despite not being closely related taxonomically.

Nevertheless, it must be acknowledged that there are limitations in using only morphological characters in similarity analysis. Morphology can be influenced by environmental factors, so genetically distinct species may appear similar in their vegetative form. According to Hawari et al. (2022), environmental factors such as light, temperature, pH, and altitude can affect plant growth and development.

Distribution map of invasive alien plant species

Mapping of invasive alien plant species was conducted to determine their overall distribution within the USU Arboretum area. The distribution mapping was carried out through inventory and recording of invasive alien plant locations at the research site. Distribution data were collected in the form of coordinates using a GPS device, which were then overlaid onto the research site map including the slope map, road distance map, and river distance map of the USU Arboretum. The distribution maps of invasive alien plant species are shown in Figures 4 to 6.

In Figure 4, it can be seen that invasive alien plant species are predominantly found and distributed in areas with flat to gently sloping terrain (slope class 0-15%). These slope levels support a higher density of invasive plant growth. According to Saparung et al. (2024), environmental factors, especially land slope, strongly influence plant presence and growth. Sloped land is more susceptible to surface soil erosion (topsoil) due to runoff and leaching, which reduces granular structure, organic matter content, and soil nutrient levels.

In Figure 5, it can be seen that invasive alien plant species are found and spread within a distance of approximately 0-150 meters from the arboretum road. A large number of invasive species were observed in areas close to the road. This finding is consistent with the statement by Hermawan et al. (2017), who explained that roads are one of the pathways for human activities that can accelerate the spread of invasive species. Roads also provide conditions that facilitate this spread, such as optimal sunlight availability, which supports the growth of invasive plants. Descriptively, the results showed a clear tendency for invasive alien plants to occur more frequently in flat areas and near roads.

In Figure 6, it can be seen that invasive alien plants are not only found near river streams but also widely spread in areas farther away from the rivers. According to Ikhsani et al. (2023), the farther the distance from the river, the number of medicinal plants tends to increase. Priyono and Susilo (2022) explain that the factors most influencing the presence of invasive alien plants are sunlight intensity, temperature and air humidity, elevation, and vegetation openness.

In conclusion, invasive alien plants found in the observation plots amounted to 4,143 individuals, comprising 29 species from 16 families. The diversity index of invasive alien plants in the arboretum was 1.99, the evenness index was 0.5895, and the species richness index was 3.35. The highest importance value index at the shrub level was for *C. hirta* (Melastomaceae) at 40.18%, and at the understory plant level was *A. gangetica* (Acanthaceae) at 72.07%. Very close morphological relationships with a similarity index of 1 were found in five groups: *Clidemia hirta* with *M. malabathricum*, *E. scaber* with *A. conyzoides*, *E. amabilis* with *P. maximum*, *C. rotundus* with *R. colorata*, and *Caladium bicolor* with *A.*

macrorrhizos and *L. flava*. The distribution of invasive alien plants was found on flat and gentle slopes, at distances from the arboretum road of approximately 0-150 meters, and at distances from the river of around 0-375 meters.

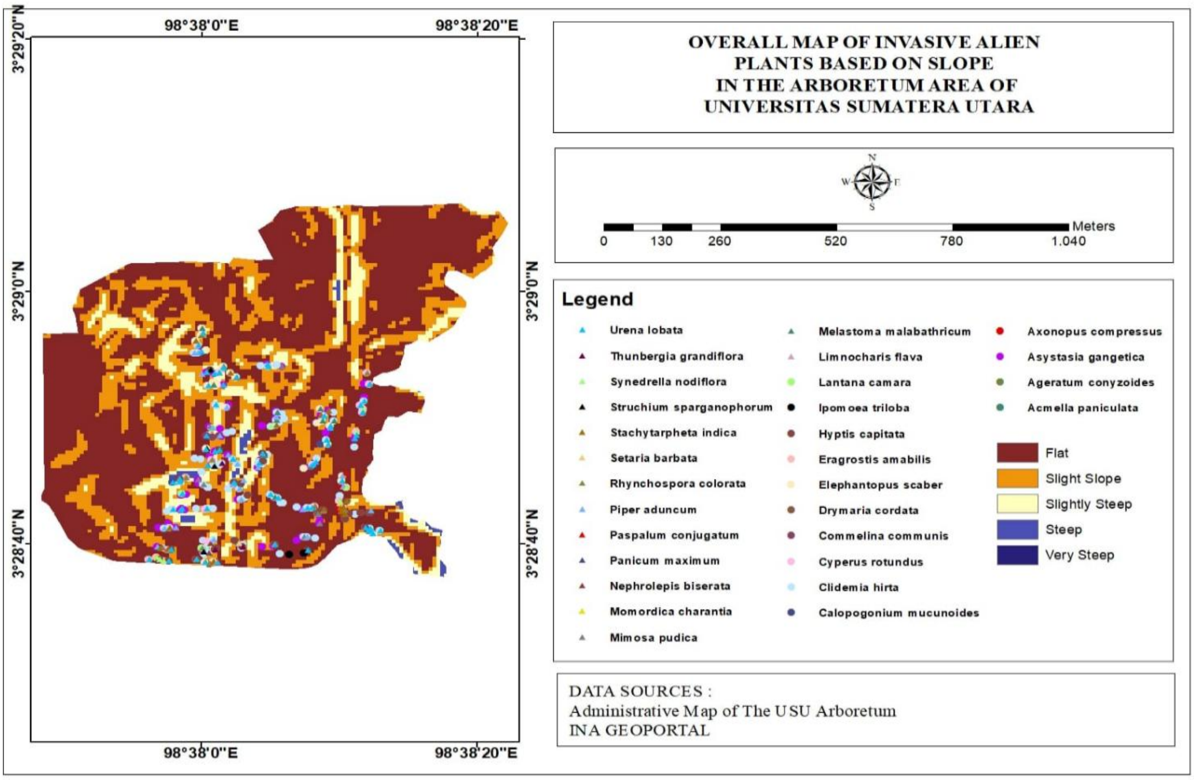

Figure 4. Distribution map of invasive alien plant species based on slope

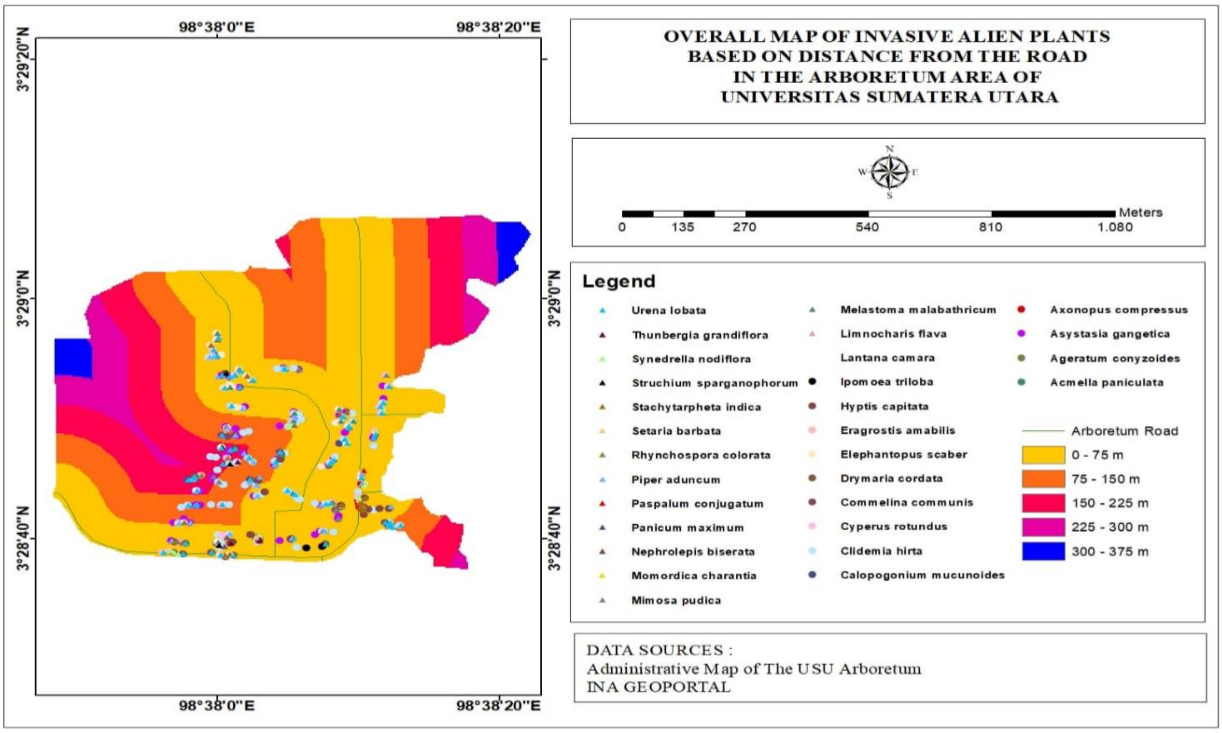

Figure 5. Distribution map of invasive alien plant species based on distance from roads

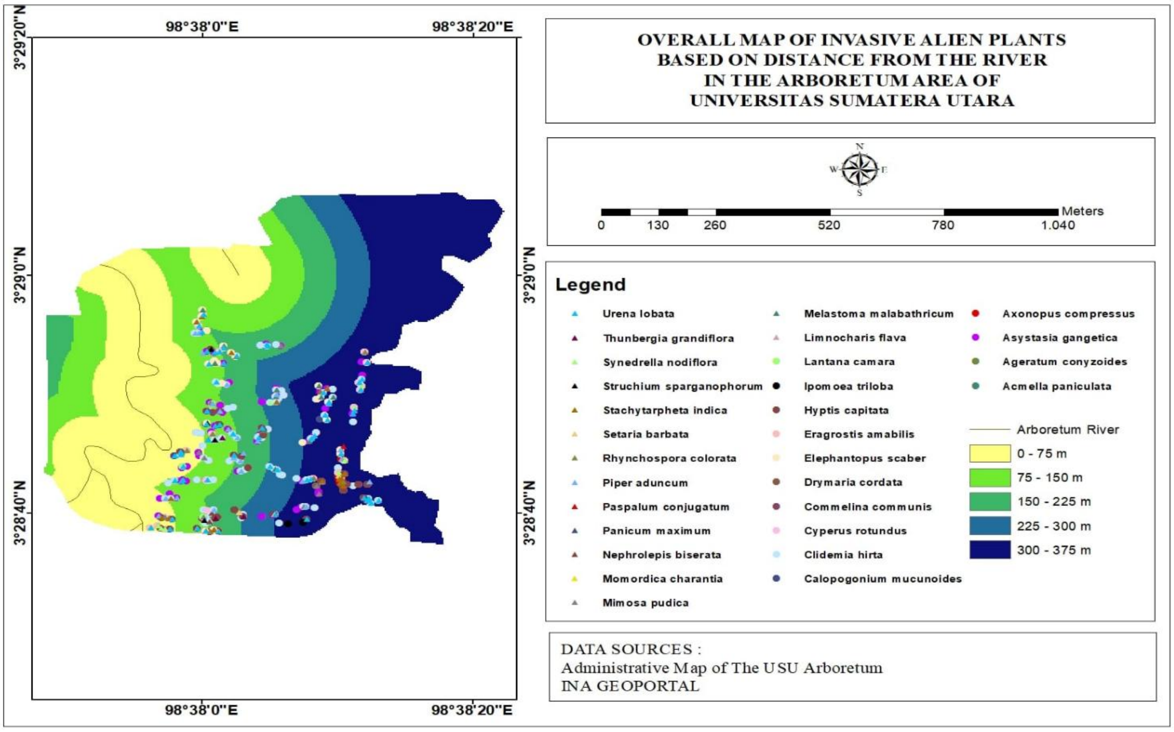

Figure 6. Distribution map of invasive alien plants based on distance from rivers

From a management perspective, these findings underscore the need to prioritize monitoring and control efforts on dominant invasive species while simultaneously implementing preventive measures to reduce further introductions. This recommendation is supported by the study results, which showed that several invasive species exhibited high Importance Value Index (IVI) scores and wide distribution across sampling plots, indicating strong ecological dominance. Strengthening invasive plant management in the arboretum is therefore essential to maintain ecological balance, conserve native biodiversity, and support the arboretum's function as a biodiversity conservation and education site.

ACKNOWLEDGEMENTS

This research was supported by the Center of Excellence for Mangrove, Universitas Sumatera Utara, Medan, Indonesia, through grants from the Ministry of Education, Culture, Research and Technology 2024.

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Table S1. Morphological characteristics of shrubs, understory plants, and lianas at the study site

Observed characteristics	Plant species																				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Fibrous roots	0	0	1	0	0	0	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1
Taproot	1	1	0	1	1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
Woody stem type	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Herbaceous stem type	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
Hairy stem surface	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
Spiny stem surface	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Smooth stem surface	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Light green young stem	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
Dark green young stem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Light brown mature stem	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dark brown mature stem	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
Stem diameter < 10 cm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
The stem contains latex/sap	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Leaves are arranged alternately	0	0	0	1	0	1	1	1	0	0	0	1	0	0	1	1	0	1	1	1	1
Leaves are arranged oppositely	1	1	1	0	1	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0
Leaves are lanceolate	0	0	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0
Leaves are elliptical/oblong	1	1	0	0	1	1	1	1	0	0	0	0	1	1	0	1	0	0	1	1	1
Leaves are palmate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leaf length 7–20 cm	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
Leaf margin serrated	0	0	0	0	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	0	0
Leaf margin entire	1	1	1	1	0	0	0	0	1	0	0	0	1	0	1	1	1	1	1	1	1
Leaf surface is hairy	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0
Leaf surface is glabrous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Pinnate venation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Palmate venation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leaf apex acuminate	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Leaf apex acute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Flower type: solitary	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Flower type: inflorescence	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Flowers are hermaphroditic	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Note: 0: Does not have the trait, 1: Has the trait. 1: *Clidemia hirta*, 2: *Melastoma malabathricum*, 3: *Heterotis rotundifolia*, 4: *Piper aduncum*, 5: *Hyptis capitata*, 6: *Struchium sparganophorum*, 7: *Ageratum conyzoides*, 8: *Elephantopus scaber*, 9: *Synedrella nodiflora*, 10: *Acmella paniculata*, 11: *Helianthus divaricatus*, 12: *Ipomoea triloba*, 13: *Asystasia gangetica*, 14: *Thunbergia grandiflora*, 15: *Calopogonium mucunoides*, 16: *Mimosa pudica*, 17: *Limnocharis flava*, 18: *Setaria barbata*, 19: *Lasiacis divaricata*, 20: *Oplismenus undulatifolius*, 21: *Paspalum conjugatum*

Table S1. Morphological characteristics of shrubs, understory plants, and lianas at the study site (*continued*)

Observed characteristics	Plant species																						
	22	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Fibrous roots	1	1	0	1	1	1	0	0	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1
Taproot	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0
Woody stem type	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Herbaceous stem type	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1
Hairy stem surface	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0	1
Spiny stem surface	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smooth stem surface	1	1	1	1	1	0	0	0	0	1	0	0	0	1	1	0	1	1	1	0	0	1	0
Light green young stem	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	0	1	1	1
Dark green young stem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Light brown mature stem	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1
Dark brown mature stem	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0
Stem diameter < 10 cm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
The stem contains latex/sap	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
Leaves are arranged alternately	1	1	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1
Leaves are arranged oppositely	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0
Leaves are lanceolate	1	1	1	0	0	0	0	0	1	0	1	0	1	1	1	1	0	0	1	0	1	0	0
Leaves are elliptical/oblong	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Leaves are palmate	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Leaf length 7-20 cm	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Leaf margin serrated	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0	0
Leaf margin entire	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	1	1
Leaf surface is hairy	1	1	1	0	0	1	1	1	0	0	1	1	0	0	1	0	0	0	1	1	1	0	0
Leaf surface is glabrous	0	0	0	1	1	0	0	0	1	1	0	0	1	1	0	1	1	1	0	0	0	1	1
Pinnate venation	0	0	0	1	0	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Palmate venation	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Leaf apex acuminate	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Leaf apex acute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flower type: solitary	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Flower type: inflorescence	1	1	1	1	1	0	1	1	1	0	0	1	0	0	0	0	1	1	1	1	1	1	0
Flowers are hermaphroditic	1	1	1	1	1	0	1	1	1	0	0	1	0	0	0	0	1	1	1	1	1	1	1

Note: 0: Does not have the trait, 1: Has the trait. 22: *Panicum maximum*, 23: *Eragrostis amabilis*, 24: *Axonopus compressus*, 25: *Rhynchospora colorata*, 26: *Drymaria cordata*, 27: *Momordica charantia*, 28: *Lantana camara*, 29: *Stachytarpheta indica*, 30: *Commelina communis*, 31: *Adiantum latifolium*, 32: *Nephrolepis biserrata*, 33: *Urena lobata*, 34: *Phegopteris connectilis*, 35: *Diplazium esculentum*, 36: *Thelypteris dentata*, 37: *Asplenium nidus*, 38: *Alocasia macrorrhizos*, 39: *Caladium bicolor*, 40: *Leea indica*, 41: *Ficus hispida*, 42: *Cyathula prostrata*, 43: *Cyperus rotundus*, 44: *Leersia virginica*