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Management recommendations for invasive alien plants in a university arboretum of North Sumatra, Indonesia

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Abstract. *Ayuningtyas AJ, Afrianti S, Baba S, Basyuni M. 2025. Management recommendations for invasive alien plants in a university arboretum of North Sumatra, Indonesia. Biodiversitas 26: 5544-5555.* Invasive alien plants threaten biodiversity and ecosystem stability, yet studies in Indonesian arboreta remain limited. This study assessed the diversity, ecological characteristics, and management priorities of invasive alien plants in the Universitas Sumatera Utara (USU) Arboretum, North Sumatra, Indonesia. The objective of this study is threefold: first, to identify the diversity of invasive alien plants; second, to analyze their taxonomic relationships and interactions with native species; and third, to provide recommendations for effective management. A systematic nested plot design was implemented, entailing the utilization of 250 plots, each measuring 5 × 5 m, with subplots of 2 × 2 m. A total of 29 invasive species, classified into 16 families, were documented. The most prevalent species were *Asystasia gangetica* (1,361 individuals) and *Miconia crenata* (523 individuals), with a combined Importance Value Index (IVI) of 148.97%. The diversity, richness, and evenness indices were found to be moderate. The Jaccard Index ranged from 0.184 to 0.606, indicating weak interspecies similarity across plots. Three management strategies were proposed: (i) Site management for *A. gangetica* and *M. crenata*, (ii) Regular monitoring for six moderately invasive species, (iii) Limited control for 21 species of negligible risk. These findings provide a scientific basis for developing structured management and early detection systems to sustain biodiversity and ecological integrity in university arboreta and other ex-situ conservation sites.

Keywords: Arboretum management, ecological risk, Indonesia, invasive alien plants, taxonomic indices

INTRODUCTION

Indonesia has gained global recognition as a megabiodiversity country, distinguished by its diverse ecosystems and species that facilitate essential ecological functions and human well-being. To ensure the preservation of this biodiversity, a combination of in-situ and ex-situ strategies is imperative. This includes the establishment of arboreta as living laboratories for research, education, recreation, and conservation (Sadjati et al. 2022). Among ex-situ approaches, arboreta function as controlled environments where plant species can be observed, documented, and managed for long-term ecological sustainability.

The understory of the arboretum is home to a diverse array of herbs, shrubs, and lianas, which play pivotal roles in nutrient cycling, microclimatic regulation, and soil stabilization (Zaki et al. 2022). It is imperative to comprehend the taxonomic relationships and composition of these understory plants to monitor biodiversity and identify ecological disturbances effectively. However, the integrity of arboretum ecosystems is increasingly threatened by the spread of Invasive Alien Species (IAS). These plants have the capacity to outcompete native vegetation, alter habitat structures, and disrupt ecosystem processes, which can result in reduced biodiversity and ecological function (Yusuf and Arisoesilaningsih 2017).

The introduction of IAS is frequently facilitated by human-mediated pathways, including ornamental trade, transportation, and land-use change (Sitepu 2020). Once established, these species can proliferate rapidly due to the absence of natural predators or competitors. Prior studies in Indonesia have documented the presence of invasive plants in several conservation and educational sites, including the Gunung Burangrang Nature Reserve (Audrya et al. 2021), Universitas Tadulako (Iqbal et al. 2023), and Gunung Meja Nature Tourism Park in Manokwari (Yuliana and Lekitoo 2018). These findings underscore the pervasive and escalating nature of this threat. However, despite the growing awareness, no comprehensive study has specifically assessed the diversity and management implications of invasive alien plants in university arboreta, particularly within the Universitas Sumatra Utara (USU) Arboretum.

The USU Arboretum, situated in Deli Serdang, North Sumatra, constitutes a significant ex-situ conservation area that fosters education and research on tropical forest species. The composition of the site includes a multitude of thematic plots, each centered on a predominant tree species, and boasts a remarkable biodiversity of undergrowth flora. A preceding study identified 67 understory species from 33 families, with a total population of approximately 682,920 individuals (Ginting 2023). A significant proportion of these species possesses both medicinal and ornamental value, and the vast majority are classified as Least Concern according to conservation status. Notwithstanding the notable biodiversity present within the USU Arboretum, the management of invasive alien plants therein remains unstructured and devoid of scientific oversight. This condition has the potential to adversely impact the ecological balance and educational value of the arboretum over time.

Furthermore, anthropogenic pressures such as frequent human visitation, livestock grazing, and wildlife movement facilitate the unintentional introduction and dispersal of invasive plants. Absent effective monitoring and control strategies, these pressures could accelerate the spread of IAS and pose a threat to native biodiversity. Consequently, the development of a scientific understanding of invasive plant diversity, abundance, and ecological relationships is imperative for ensuring the ecological stability and conservation value of the arboretum.

However, despite the existence of previous inventories of undergrowth vegetation, no comprehensive study has specifically focused on identifying invasive alien plants and assessing their management implications in the USU Arboretum. Addressing this knowledge gap is essential for establishing evidence-based strategies that can guide sustainable arboretum management. The objective of this study is threefold: firstly, to identify the invasive alien plant species present in the USU Arboretum; secondly, to analyze their taxonomic relationships and ecological dominance; and thirdly, to propose management approaches to support long-term biodiversity conservation within the arboretum.

MATERIALS AND METHODS

Study area

This research was conducted from January to April of 2025 in the Arboretum of Universitas Sumatera Utara (USU), which is located in Bekala Village, Pancur Batu Sub-district, Deli Serdang District, North Sumatra, Indonesia (Figure 1). The process of plant identification was conducted at the Silviculture Laboratory, which is affiliated with the Faculty of Forestry. The verification of dry specimens was carried out at the Medanense Herbarium, which is part of the Faculty of Mathematics and Natural Sciences at Universitas Sumatera Utara.

Materials

The instruments employed in this study encompassed a Global Positioning System (GPS), stakes, plastic ropes, measuring tapes, cameras, writing implements, laptop computers, Microsoft Excel software, MVSP software, and guidebooks for the identification of invasive alien plants. The materials utilized in this study comprised 70% alcohol, herbarium samples, and field data sheets.

Vegetation analysis

The observation plots were established using systematic sampling with a random start method. Fifty transects, each measuring 50 meters in length, were meticulously arranged in a linear configuration across the designated arboretum. Along each transect, five quadrats measuring 5 × 5 m were placed alternately on the left and right sides at 5 m intervals, resulting in a total of 250 plots. Within each quadrat, a nested plot measuring 2 × 2 m was utilized to document the undergrowth vegetation.

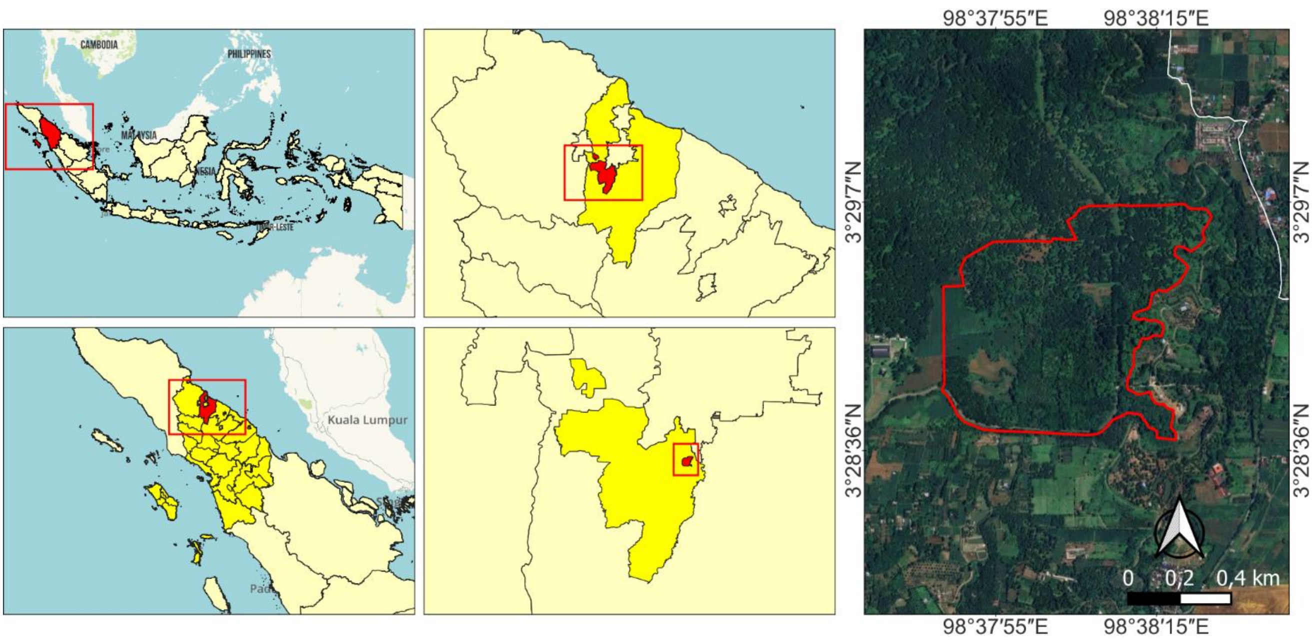

Figure 1. Map of the four sampling locations: North Arboretum, Central Arboretum, East Arboretum, and South Arboretum in Universitas Sumatera Utara (USU) Arboretum, Pancur Batu Sub-district, Deli Serdang, North Sumatra, Indonesia. Each site represents different habitat characteristics within the arboretum area, where 250 nested plots (5 × 5 m) were established for vegetation inventory and invasive alien plant assessment. The legend indicates spatial distribution, site codes, and accessibility routes, allowing clear visual interpretation of the sampling layout

Plant identification

The identification of plant species was conducted through morphological analysis, followed by verification using authoritative references on invasive alien plants in Indonesia (Setyawati et al. 2015; Tjitrosoedirdjo et al. 2016a). The invasive status of each species was determined according to the Regulation of the Minister of Environment and Forestry (PERMENLHK No. 94/2016) on the national list of invasive alien plants.

Questionnaire completion

A structured questionnaire was utilized to ascertain the risk value and management feasibility value for each invasive alien plant species. The questionnaire was developed in accordance with the Post Border Invasive Alien Plant Risk Analysis Guideline, a document formulated by the Forest Research and Development Center (KLHK) and FORIS Indonesia (Tjitrosoedirdjo et al. 2016b).

Ten respondents participated in the study, including seven lecturers from the Faculty of Forestry at USU, one invasive plant expert from Universitas Simalungun, and two staff members from the North Sumatra Natural Resources Conservation Center (BBKSDASU). To ensure the consistency of the data, the interviews were conducted directly.

Data analysis

Importance Value Index (IVI)

The vegetation data obtained were then subjected to analysis to calculate the Importance Value Index (IVI). The IVI value was derived from the sum of relative density and relative frequency, as previously defined by Indriyanto (2006).

Species diversity index

The diversity of invasive plant species can be calculated using the Shannon Diversity Index (H'). This index places a premium on species richness, accounting for the presence of species with a limited number of individuals. Its calculation is based on the methodology outlined by Odum (1993).

Species richness index

The Margalef Species Richness Index (Dmg) is a metric that can be used to calculate the species richness of invasive alien plants. This index can be calculated using the methodology outlined by Ludwig and Reynolds (1988).

Species evenness index

The level of evenness of plants is indicated by the species evenness index (evenness). This index is indicative of the distribution of individuals within a species. The calculation of this index is referred to in the work of Ludwig and Reynolds (1988).

Association index

The level of association between species was determined using the Jaccard Index (Jaccard 1901), which measures the similarity between two species based on their co-occurrence in sample plots.

$$\text{Ji} = \frac{a}{a+b+c} \quad [1]$$

Potential utilization and conservation status

The potential utilization of the plant material, including its application as feed, medicine, and ornamentals, was determined through a comprehensive literature review of scientific journals and reference books. The current conservation status of the species was verified using the International Union for Conservation of Nature (IUCN) Red List database.

Risk of invasive alien plants

The risk level of invasive alien plants was determined based on the interaction among three key criteria: invasiveness, impact, and potential distribution. Each criterion was standardized on a 0-10 scale prior to being multiplied to obtain a composite risk value, ranging from 0 to 1000, where higher scores indicate greater risk. This multiplication approach has been demonstrated to yield a wider score distribution and to reflect the interactive nature of invasion dynamics. In these dynamics, high invasiveness combined with wide distribution potential and strong ecological impact produces greater overall risk. This procedure was conducted in accordance with the post-border risk assessment framework delineated by Titrosoedirdjo et al. (2016b).

$$\text{Invasiveness value} = \frac{\text{total value of the scoring table}}{15} \times 10 \quad [2]$$

$$\text{Impact value} = \frac{\text{total value of the scoring table}}{19} \times 10 \quad [3]$$

Potential distribution value = total value of the scoring table [4]

Risk of invasive alien plants = invasiveness x impact x potential distribution [5]

Feasibility of invasive alien plant management

The Management Feasibility Index is a metric used to assess the practicality of controlling an invasive species. This index is calculated using B × DTI × P, where B is the cost of control, DTI is the distribution, and P is the persistence of the species. Each variable was standardized on a 0-10 scale, and the resulting feasibility value ranged from *0 to 1000*, with higher values denoting greater feasibility for management actions. This procedure was conducted in accordance with the post-border risk assessment framework delineated by Titrosoedirdjo et al. (2016b).

$$\text{Control cost value} = \frac{\text{total value of the scoring table}}{15} \times 10 \quad [6]$$

$$\text{Distribution value of invasive plants} = \frac{\text{total value of the scoring table}}{12} \times 10 \quad [7]$$

$$\text{Persistence value} = \frac{\text{total value of the scoring table}}{11} \times 10 \quad [8]$$

Feasibility of invasive alien plant management = control costs x distribution of invasive plants x persistence [9]

Priority recommendations for invasive alien plant management

After completing the questionnaire, the next step is to align the risk and management feasibility values using a priority matrix for invasive alien plant management (Table 1). This is based on the risk and feasibility matrix outlined in the Invasive Alien Plant Risk Analysis Guidelines (Tjitrosoedirdjo et al. 2016b), developed by the Center for Forestry Research and Development, the Ministry of Environment and Forestry, and FORIS Indonesia. This stage helps determine priority control actions for invasive plants at the USU Arboretum.

RESULTS AND DISCUSSION

Diversity of invasive alien plants in the USU Arboretum

The diversity of invasive alien plants recorded in the USU Arboretum is summarized in Table 2, which presents the families, species, origins, and total number of individuals identified across all observation plots. A total of 29 invasive alien plant species belonging to 16 families were documented, representing 4,143 individual plants recorded within the study area

Table 1. Matrix of guidelines for the management of invasive alien plants

Risk of invasive alien plants	Feasibility of invasive alien plant management					
	Ignored (> 113)	Low (56-112)	Medium (31-55)	High (14-30)	Very high (< 14)	
Ignored (< 14)	Limited action	Limited action	Limited action	Limited action	Monitor	
Low (15-38)	Limited action	Limited action	Limited action	Monitor	Monitor	
Medium (39-101)	Manage the site	Manage the site	Manage the site	Protect the site	Prevent spread	S T
High (102-192)	Manage invasive plants	Manage invasive plants	Protect the site	Prevent spread	Destroy investment	A N
Very high (> 192)	Manage invasive plants	Protect the site and manage invasive plants	Prevent spread	Destroy investment	Eradication	D B Y

Table 2. Diversity of invasive alien plants at the research site

Family	Latin name	Total	Origin
Acanthaceae	*Asystasia gangetica* (L.) T.Anderson **	1,361	India, Sri Lanka
	Thunbergia grandiflora (Roxb. ex Rottler) Roxb.***	3	India, South China, Myanmar
Alismataceae	*Limnocharis flava* (L.) Buchenau**	1	Tropical America
Asteraceae	*Struchium sparganophorum* (L.) Kuntze**	18	Tropical America
	Ageratum conyzoides L.**	19	Tropical America
	Elephantopus scaber L.**	102	Tropical Asia
	Synedrella nodiflora (L.) Gaertn.**	49	South America
	Acmella paniculata (Wall. ex DC.) R.K.Jansen**	51	Tropical America
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Schult.**	20	America
Commellinaceae	*Commelina communis* L.**	148	Asia
Convolvulaceae	*Ipomoea triloba* L.**	6	Tropical America
Cucurbitaceae	*Momordica charantia* L.*	1	India
Cyperaceae	*Cyperus rotundus* L.**	360	India, Africa
	Rhynchospora colorata (L.) H.Pfeiff.**	215	Asia
Fabaceae	*Calopogonium mucunoides* Desv.**	15	Tropical America, West India
	Mimosa pudica L.**	136	Tropical America
Lamiaceae	*Hyptis capitata* Jacq.**	75	Tropical America
Malvaceae	*Urena lobata* L.*	155	Asia
Melastomaceae	*Miconia crenata* (Vahl) Michelang. *	523	South America
	Melastoma malabathricum L.*	83	Asia
Piperaceae	*Piper aduncum* L.*	62	South America
Poaceae	*Setaria barbata* (Lam.) Kunth**	27	Africa
	Paspalum conjugatum P.J.Bergius**	190	Tropical America
	Panicum maximum Nees, 1841**	28	Tropical Africa
	Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.**	34	Africa, South Asia
	Axonopus compressus (Sw.) P.Beauv.**	350	Tropical America
Polypodiaceae	*Nephrolepis biserata* (Sw.) Desv.**	50	America
Verbenaceae	*Lantana camara* L.*	5	Tropical America
	Stachytarpheta indica (L.) Vahl*	56	Tropical America
16	29	4,143	

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

The invasive alien plants identified in the USU Arboretum originated from various regions across the world, with a preponderance of taxa from Tropical America and Asia. This finding is consistent with the conclusions of Foxcroft et al. (2017), who reported that the introduction of invasive alien plants into Indonesia was predominantly attributable to Asia (26%) and Tropical America (25%).

The number of species documented in this study was higher than the 27 species recorded by Mustika et al. (2024) in agricultural areas of Sukoharjo, yet lower than the 52 species reported by Sitepu (2020) in KHDTK Samboja, East Kalimantan. These variations can be attributed to differences in vegetation composition, land use types, and environmental conditions among the study sites.

In contrast to large protected forests, arboreta such as USU's exhibit limited spatial heterogeneity, a feature that has been shown to reduce ecological resistance and increase susceptibility to the dominance of certain invasive species. Comparative evidence from Gunung Meja, Manokwari (Yuliana and Lekitoo 2018) also demonstrates that even small-scale invasions in public conservation areas can disrupt native regeneration and visitor experiences. Consequently, adaptive management in arboreta should integrate taxonomic clustering with functional threat profiling to optimize monitoring and control. Integrating cluster-based risk assessment with national guidelines (Tjitrosoedirdjo et al. 2016a; PERMENLHK No. 94/2016) has been demonstrated to improve early detection and resource efficiency in managing invasive alien plants within ex-situ conservation areas.

Importance Value Index (IVI)

The research location was found to contain a total of 44 plant species, classified into the categories of shrub, understory, and liana. Of these, 29 were identified as invasive alien plants, while the remaining 15 were classified as non-invasive alien plants. Of the total, 148.97% is the accumulation of IVI from invasive alien plant types, while 51.03% is the accumulation of IVI from non-invasive plant types. The relatively high proportion of invasive alien plant dominance suggests that these types may have the capacity to exert a substantial influence on the composition of the undergrowth vegetation community within the USU Arboretum. The results of the IVI invasive alien species are presented in Table 3.

The Invasive Vegetation Index (IVI) of invasive alien plants in the shrub category exhibited a range of values from 0.12% to 22.52%. *Miconia crenata* (Vahl) Michelang., which belongs to the Melastomaceae family, exhibited the highest IVI, with a value of 22.52%. The species was identified in the majority of the observation plots. Concurrently, the lowest IVI value in the shrub category was obtained by *Momordica charantia* L., at 0.12%. The low IVI value for this species is attributable to its sporadic distribution within the arboretum, suggesting that it may have only recently begun to spread in the area. Le et al. (2018) have stated that *M. crenata* is an invasive plant that poses a significant threat to conservation, with a wide distribution across the Pacific and Indian Oceans. *Miconia crenata* has been observed to thrive in various locations across the study site, ranging from the interior of the arboretum to the roadside.

For the IVI of invasive alien plants in the understory category, the range is from 0.12% to 40.15%. *Asystasia gangetica* (L.) T.Anderson species, classified within the Acanthaceae family, exhibited the highest INP value of 40.15%. Concurrently, the lowest recorded INP concentration at the understory level was observed in *Limnocharis flava* (L.) Buchenau, reaching 0.12%. Odion et al. (2024) have stated that *A. gangetica* species is an invasive herb originating from India. *Asystasia gangetica* species is the most dominant and widespread in the study location. This species has been found to be more abundant in shaded areas. Asbur et al. (2024) posited that *A. gangetica* exhibits optimal growth in shaded environments relative to brightly illuminated settings.

For the IVI of invasive alien plants in the liana category, *Thunbergia grandiflora* (Roxb. ex Rottler) Roxb. was found at 0.36. This species is classified within the Achantaceae family. The species *T. grandiflora* is native to India, Southern China, and Myanmar. This species exhibits limited distribution within the study site, displaying a growth pattern characterized by twining and climbing on adjacent vegetation. Consequently, it possesses the capacity to impede the proliferation of the seedlings it envelops.

Species diversity index (H'), Species richness index (Dmg), and species evenness index (E)

The total H' value reached 1.99 in the interval 1 < H' < 3, indicating a moderate level of diversity. The total damage value was determined to be 3.35, and the E value was found to be 0.75. For Liana, all index values were 0 because only one species was found in this group (Table 4).

The total H' value of 1.99 indicates that the invasive alien plants found in the USU Arboretum fall into the moderate diversity category, which is characterized by a relatively large number of species and a fairly even distribution. This result aligns with the findings of Musyawir et al. (2021), who posited that a higher diversity index reflects a more heterogeneous community that is not dominated by one or a few species. The total Dmg value of 3.35 indicates that the species richness of invasive alien plants at the study site is within the moderate category. This finding is consistent with the conclusions of Wahyuningsih et al. (2019), who observed that an increase in the number of identified species corresponds to an increase in the richness index value. Conversely, the E value of 0.75 signifies a moderate evenness level, suggesting that individuals are distributed fairly uniformly across species, with some species exhibiting greater dominance than others. This finding indicates that the invasive alien plant community has become well-established in the USU Arboretum, which may have a potential impact on the composition and stability of the existing ecosystem.

Table 3. The IVI of invasive alien plant species and non-invasive alien plants in the shrub, understory, and liana categories at the research location

Family	Scientific name	RD (%)	RF (%)	IVI (%)	Plant status
Shrub					
Cucurbitaceae	*Momordica charantia* L.	0.02	0.10	0.12	Invasive alien
Malvaceae	*Urena lobata* L.	2.67	6.04	8.70	Invasive alien
Melastomaceae	*Miconia crenata* (Vahl) Michelang.	8.99	13.53	22.52	Invasive alien
	Melastoma malabathricum L.	1.43	3.95	5.38	Invasive alien
	Heterotis rotundifolia (Sm.) Jacq.-Fél.	0.89	0.73	1.62	Non-invasive alien
Moraceae	*Ficus hisbida* L.fil.	0.33	0.31	0.64	Non-invasive alien
Piperaceae	*Piper aduncum* L.	1.07	3.33	4.40	Invasive alien
Verbenaceae	*Lantana camara* L.	0.09	0.42	0.51	Invasive alien
	Stachytarpheta indica (L.) Vahl	0.96	2.19	3.15	Invasive alien
Vitaceae	*Leea indica* (Burm.fil.) Merr.	0.02	0.10	0.12	Non-invasive alien
	Total	16.47	30.7	47.16	
Understory					
Acanthaceae	*Asystasia gangetica* (L.) T.Anderson	23.40	16.75	40.15	Invasive alien
Alismataceae	*Limnocharis flava* (L.) Buchenau	0.02	0.10	0.12	Invasive alien
Amaranthaceae	*Cyathula prostrata* (L.) Blume	0.03	0.10	0.14	Non-invasive alien
Araceae	*Alocasia macrorrhizos* (L.) G.Don	0.69	2.60	3.29	Non-invasive alien
	Caladium biscolor (Aiton) Vent.	0.26	1.35	1.61	Non-invasive alien
Aspleniaceae	*Phegopteris connectilis* (Michx.) Watt	0.03	0.21	0.24	Non-invasive alien
	Diplazium esculentum (Retz.) Sw.	0.12	0.10	0.22	Non-invasive alien
	Christella dentata (Forssk.) Brownsey & Jermy	8.91	8.01	16.92	Non-invasive alien
	Asplenium nidus L.	0.02	0.10	0.12	Non-invasive alien
Asteraceae	*Struchium sparganophorum* (L.) Kuntze	0.31	0.52	0.83	Invasive alien
	Ageratum conyzoides L.	0.33	0.73	1.06	Invasive alien
	Elephantopus scaber L.	1.75	3.02	4.77	Invasive alien
	Synedrella nodiflora (L.) Gaertn.	0.84	1.25	2.09	Invasive alien
	Acmella paniculata (Wall. ex DC.) R.K.Jansen	0.88	0.83	1.71	Invasive alien
	Helianthus divaricatus L.	0.05	0.10	0.16	Non-invasive alien
Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Schult.	0.34	0.10	0.45	Invasive alien
Commellinaceae	*Commelina communis* L.	2.54	0.73	3.27	Invasive alien
Convolvullaceae	*Ipomoea triloba* L.	0.10	0.21	0.31	Invasive alien
Cyperaceae	*Cyperus rotundus* L.	6.19	2.50	8.69	Invasive alien
	Rhynchospora colorata (L.) H.Pfeiff.	3.70	2.50	6.19	Invasive alien
Fabaceae	*Calopogonium mucunoides* Desv.	0.26	1.04	1.3	Invasive alien
	Mimosa pudica L.	2.34	4.99	7.33	Invasive alien
Lamiaceae	*Hyptis capitata* Jacq.	1.29	3.23	4.52	Invasive Alien
Poaceae	*Setaria barbata* (Lam.) Kunth	0.46	0.42	0.88	Invasive alien
	Paspalum conjugatum P.J.Bergius	3.27	2.08	5.35	Invasive alien
	Panicum maximum Nees, 1841	0.48	0.52	1.00	Invasive alien
	Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	0.58	0.52	1.10	Invasive alien
	Axonopus compressus (Sw.) P.Beauv.	6.02	3.43	9.45	Invasive alien
	Lasiacis divaricata (L.) Hitchc.	5.11	2.29	7.40	Non-invasive alien
	Oplismenus undulatifolius (Ard.) P.Beauv.	1.12	0.52	1.64	Non-invasive alien
	Leersia virginica Willd.	2.24	0.52	2.76	Non-invasive alien
Polypodiaceae	*Nephrolepis biserata* (Sw.) Desv.	0.86	2.39	3.25	Invasive alien
Pteridaceae	*Adiantum latifolium* Lam.	8.96	5.20	14.16	Non-invasive alien
	Total	83.5	68.96	152.48	
Liana					
Acanthaceae	*Thunbergia grandiflora* (Roxb. ex Rottler) Roxb.	0.05	0.31	0.36	Invasive alien
	Total	0.05	0.31	0.36	
	Total IVI	100.00	100.00	200.00	

Note: RD: Relative Dominance, RF: Relative Frequency

Association between invasive alien plant species and non-invasive alien plants in the USU Arboretum

The Jaccard index analysis revealed the five most significant association pairs between invasive species, with JI values ranging from 0.397 to 0.606. The relationship between invasive and non-invasive species was further examined, revealing that the top five pairs exhibited lower JI values ranging from 0.184 to 0.273 (Table 5).

The Jaccard Index (JI) analysis (Table 5) demonstrates that associations among invasive alien plant species were, in general, stronger than those between invasive and non-invasive alien species. However, the overall association values remained low to moderate, indicating limited co-occurrence patterns within the arboretum plots. This finding indicates that invasive species tend to form small, loose clusters rather than tightly connected assemblages, and their interaction with non-invasive alien plants is relatively weak. These patterns imply a degree of niche separation between invasive and non-invasive species, where the latter may not yet occupy similar ecological spaces. These findings are consistent with those reported by Metananda et al. (2015), who underscored that low JI values (approaching 0) indicate weak associations and restricted ecological overlap among species.

Potential utilization and conservation status of invasive alien plants

Twenty-nine invasive alien plants found in the USU Arboretum consist of 13 species with Least Concern (LC) status and 16 species with Not Evaluated (NE) status. These species have various potential uses, including as medicinal plants, ornamental plants, and animal feed (Table 6).

The invasive alien plant species recorded in the USU Arboretum demonstrate a diverse potential for utilization, primarily as medicinal plants, with a smaller number serving as animal feed or ornamental species (Table 6). Despite this high potential, field observations revealed minimal actual utilization, suggesting that local communities are not yet aware of the benefits or appropriate processing methods for these plants. Concurrent findings were reported by Lengkong et al. (2021), who emphasized that limited public knowledge often hinders optimal plant utilization.

Table 4. Diversity, richness, and evenness index of invasive alien plant species in the shrub, understory, and liana categories at the study location

Categories of invasive alien plants	H'	Dmg	E
Shrub	0.54	0.88	0.28
Understory	1.45	2.47	0.47
Liana	0.00	0.00	0.00
Total	1.99	3.35	0.75

Table 5. Association between invasive alien plant species and non-invasive alien plants at the site

Species	Ji
Invasive alien species pair - Invasive alien species	
Paspalum conjugatum - Axonopus compressus	0.606
Rhynchospora colorata - Axonopus compressus	0.500
Rhynchospora colorata - Paspalum conjugatum	0.467
Miconia crenata - Asystasia gangetica	0.433
Mimosa pudica - Axonopus compressus	0.397
Invasive alien species - Non-invasive alien species pair	
Christella dentata - Asystasia gangetica	0.273
Setaria barbata - Helianthus divaricatus	0.250
Christella dentata- Miconia crenata	0.232
Adiantum latifolium - Asystasia gangetica	0.185
Urena lobata - Christella dentata	0.184

Table 6. Potential utilization and conservation status of invasive alien plants at the research location

Species	Status	Utilization	References
Acmella paniculata (Wall. ex DC.) R.K.Jansen	LC	Medicinal plant	(Sivaraj et al. 2024)
Ageratum conyzoides L.	LC	Medicinal plant	(Setiawan et al. 2023)
Asytasia gangetica (L.) T.Anderson	NE	Medicinal plant	(Lefi et al. 2024)
Axonopus compressus (Sw.) P.Beauv.	LC	Medicinal plant	(Puspitasari et al. 2016)
Calopogonium mucunoides Desv.	NE	Animal feed	(Dele et al. 2022)
Miconia crenata (Vahl) Michelang.	NE	Medicinal plant	(Junedi et al. 2023)
Commelina communis L.	NE	Medicinal plant	(Puspitasari et al. 2016)
Cyperus rotundus L.	LC	Medicinal plant	(Hema et al. 2013)
Drymaria cordata (L.) Willd. ex Schult.	NE	Medicinal plant	(Liao and Tzen 2022)
Elephantopus scaber L.	NE	Medicinal plant	(Francis et al. 2018)
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	NE	Animal feed	(Nuhaa et al. 2019)
Hyptis capitata Jacq.	NE	Medicinal plant	(To'bungan et al. 2022)
Ipomoea triloba L.	LC	Medicinal plant	(Nuraini et al. 2021)
Lantana camara L.	NE	Medicinal plant	(Komolafe et al. 2021)
Limnocharis flava (L.) Buchenau	NE	Medicinal plant	(Jamila et al. 2021)
Melastoma malabathricum L.	NE	Medicinal plant	(Safrida et al. 2024)
Mimosa pudica L.	LC	Medicinal plant	(Sasumana and Ray 2020)
Momordica charantia L.	NE	Medicinal plant	(Zhang et al. 2025)
Nephrolepis biserata (Sw.) Schott	LC	Medicinal plant	(Renjana et al. 2021)
Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs	NE	Animal feed	(López-Zerón et al. 2022)
Paspalum conjugatum P.J.Bergius	LC	Medicinal plant	(Puspitasari et al. 2016)
Piper aduncum L.	LC	Medicinal plant	(Mariani et al. 2023)
Rhynchospora colorata (L.) H.Pfeiff.	LC	Medicinal plant	(Dewi 2021)
Setaria barbata (Lam.) Kunth	NE	Animal feed	(Wulandari et al. 2025)
Stachytarpheta indica (L.) Vahl	LC	Medicinal plant	(Jumawardi et al. 2021)
Struchium sparganophorum (L.) Kuntze	LC	Medicinal plant	(de Madureira et al. 2002)
Synedrella nodiflora (L.) Gaertn.	NE	Medicinal plant	(Puspitasari et al. 2016)
Thunbergia grandiflora (Roxb. ex Rottler) Roxb.	NE	Ornamental plant	(Supriyatna et al. 2022)
Urena lobata L.	LC	Medicinal plant	(Silalahi et al. 2014)

Note: LC: Least Concern, NE: Not Evaluated. Conservation status according to IUCN status

With respect to the conservation status of these species, that the majority are designated as Not Evaluated (NE at 55.2%), and the rest were Least Concern (LC at 44.8%), in accordance with the IUCN Red List. This pattern suggests that the majority of species are not currently facing significant extinction threats. However, the high proportion of species with NE status underscores the paucity of ecological data and the need for continued monitoring. Maintaining ecological balance and safeguarding the integrity of native species within the USU Arboretum is contingent upon ensuring periodic assessment.

Risk of invasive alien plants

A total of 29 invasive alien plant species in the USU Arboretum were stratified into three risk levels based on a risk index calculated from invasiveness, impact, and distribution potential (Table 7). Two species, *M. crenata* (84.2) and *A. gangetica* (70.2), were classified as moderate risk, representing 6.9% of the total. Five species (17.2%) were categorized as low risk, with risk values ranging from 15.4 to 33.7. The remaining 22 species (75.8%) were classified as negligible risk, with values ranging from 0.0 to 14.

The predominance of negligible-risk species suggests that the majority of invasive alien plants in the arboretum currently pose a limited ecological threat. However, *M. crenata* and *A. gangetica,* the only two species with moderate risk, demonstrate high distribution potential (score = 10) and broad ecological adaptability, which may enable them to disseminate rapidly under favorable conditions. The risk composition, in its entirety, indicates that preventive management and regular monitoring should primarily focus on these species. Moreover, environmental changes, including shifts in climate and disturbances to habitats, have the potential to elevate the risk levels of species that currently exhibit low or negligible risk. Consequently, this risk assessment serves as a pivotal reference for determining management priorities and maintaining ecological balance within the USU Arboretum.

Feasibility of invasive alien plant management

A categorization system for evaluating the feasibility of invasive alien plant management was developed, encompassing five categories ranging from negligible to very high (Table 8). *Asystasia gangetica* was classified as negligible with a feasibility value of 138.9, indicating that its management is extremely difficult. Two species, *M. crenata* (111.1) and *Urena lobata* L. (75.8), were categorized as low feasibility. Four species exhibited moderate feasibility levels (32.3-50.5), while 17 species were classified as high (15.2-30.3). The remaining five species, including *Drymaria cordata* (L.) Willd. ex Schult. and *Ipomoea triloba* L., demonstrated very high feasibility, with values ranging from 8.3 to 13.9.

Table 7. Risk value of invasive alien plants at the research sites

Species	Risk value			Risk Indeks (%)	Risk categories
	Invasiveness	Impact	Potential distribution		
Acmella paniculata (Wall. ex DC.) R.K.Jansen	6.0	1.1	1.0	6.3	Ignored
Ageratum conyzoides L.	6.0	2.1	1.0	12.6	Ignored
Asystasia gangetica (L.) T.Anderson	6.7	1.1	10.0	70.2	Medium
Axonopus compressus (Sw.) P. Beauv.	5.3	0.5	2.0	5.6	Ignored
Calopogonium mucunoides Desv.	6.0	0.5	0.5	1.6	Ignored
Miconia crenata (Vahl) Michelang.	8.0	1.1	10.0	84.2	Medium
Commelina communis L.	4.7	0.5	0.5	1.2	Ignored
Cyperus rotundus L.	5.3	0.5	4.0	11.2	Ignored
Drymaria cordata (L.) Willd. ex Schult.	6.0	0.5	0.5	1.6	Ignored
Elephantopus scaber L.	6.0	1.6	2.0	18.9	Low
Eragrostis amabilis (Desv.) Steud.	5.3	0.5	0.5	1.4	Ignored
Hyptis capitata (L.) Poit.	6.7	0.5	4.0	14.0	Ignored
Ipomoea triloba L.	6.0	1.1	0.5	3.2	Ignored
Lantana camara L.	6.0	2.1	1.0	12.6	Ignored
Limnocharis flava (L.) Buchenau	6.0	0.0	0.5	0.0	Ignored
Melastoma malabathricum L.	8.0	1.1	4.0	33.7	Low
Mimosa pudica L.	4.7	1.1	6.0	29.5	Low
Momordica charantia L.	6.0	0.5	0.5	1.6	Ignored
Nephrolepis biserata (Sw.) Schott	4.0	0.5	1.0	2.1	Ignored
Panicum maximum Jacq.	5.3	0.5	0.5	1.4	Ignored
Paspalum conjugatum Bergius	5.3	0.5	2.0	5.6	Ignored
Piper aduncum L.	7.3	0.5	4.0	15.4	Low
Rhynchospora colorata (L.) Britton	5.3	0.5	4.0	11.2	Ignored
Setaria barbata (Lam.) Kunth	5.3	0.5	1.0	2.8	Ignored
Stachytarpheta indica (L.) Vahl	6.0	1.1	2.0	12.6	Ignored
Struchium sparganophorum (L.)	5.3	0.5	1.0	2.8	Ignored
Synedrella nodiflora (L.) Gaertn.	6.0	0.5	1.0	3.2	Ignored
Thunbergia grandiflora (Roxb. ex Rottler) Roxb.	6.0	0.5	0.5	1.6	Ignored
Urena lobata L.	7.3	0.5	6.0	23.2	Low

Table 8. Feasibility value of invasive alien plants at research sites

Species	Feasibility value			Feasibility index	Feasibility categories
	Control costs	Invasive distribution	Persistence		
Acmella paniculata (Wall. ex DC.) R.K.Jansen	3.3	2.1	2.7	18.9	High
Ageratum conyzoides L.	3.3	2.1	2.7	18.9	High
Asystasia gangetica (L.) T.Anderson	3.3	9.2	4.5	138.9	Ignored
Axonopus compressus (Sw.) P. Beauv.	3.3	2.5	4.5	37.9	Medium
Calopogonium mucunoides Desv.	2.7	1.3	4.5	15.2	High
Miconia crenata (Vahl) Michelang.	2.7	9.2	4.5	111.1	Low
Commelina communis L.	3.3	1.3	3.6	15.2	High
Cyperus rotundus L.	3.3	1.7	4.5	25.3	High
Drymaria cordata (L.) Willd. ex Schult.	3.3	0.9	2.7	8.3	Very high
Elephantopus scaber L.	3.3	3.3	2.7	30.3	High
Eragrostis amabilis (Desv.) Steud.	3.3	1.3	4.5	18.9	High
Hyptis capitata (L.) Poit.	3.3	3.3	2.7	30.3	High
Ipomoea triloba L.	2.7	0.9	4.5	11.1	Very high
Lantana camara L.	2.7	1.3	3.6	12.1	Very high
Limnocharis flava (L.) Buchenau	3.3	0.9	4.5	13.9	Very high
Melastoma malabathricum L.	2.7	3.3	4.5	40.4	Medium
Mimosa pudica L.	3.3	3.3	4.5	50.5	Medium
Momordica charantia L.	2.7	0.9	3.6	8.9	Very high
Nephrolepis biserata (Sw.) Schott	3.3	1.7	4.5	25.3	High
Panicum maximum Jacq.	2.7	1.3	4.5	15.2	High
Paspalum conjugatum Bergius	3.3	1.7	4.5	25.3	High
Piper aduncum L.	2.7	3.3	3.6	32.3	Medium
Rhynchospora colorata (L.) Britton	3.3	1.7	4.5	25.3	High
Setaria barbata (Lam.) Kunth	3.3	1.3	4.5	18.9	High
Stachytarpheta indica (L.) Vahl	3.3	2.5	2.7	22.7	High
Struchium sparganophorum (L.)	3.3	2.1	2.7	18.9	High
Synedrella nodiflora (L.) Gaertn.	3.3	2.1	2.7	18.9	High
Thunbergia grandiflora (Roxb. ex Rottler) Roxb.	2.7	1.3	4.5	15.2	High
Urena lobata L.	3.3	5.0	4.5	75.8	Low

The feasibility category is intended to provide a general overview of the relative ease with which management actions can be implemented for each species. A high feasibility value indicates greater difficulty and resource requirements for control, while lower values suggest that management can be carried out more efficiently. The substantial number of species classified in the "high" category indicates that the majority of invasive species in the arboretum can be effectively managed using the available resources. This finding aligns with recent studies highlighting the increasing dominance of invasive alien species in tropical arboreta and their potential disruption to native plant communities (Luo et al. 2022; Junaedi et al. 2023). These works emphasize that early detection and risk-based management frameworks are critical to preventing ecological imbalance and maintaining biodiversity integrity.

However, *A. gangetica* and *M. crenata* are noteworthy species that necessitate specialized and intensive management approaches due to their high persistence and wide distribution. These species possess a notable capacity for adaptation and reestablishment following removal, thereby rendering them primary targets for long-term control initiatives.

Presently, the management of invasive alien plants in the USU Arboretum remains constrained by limited financial resources and technical assistance. This finding is consistent with the conclusions of Tjitrosoedirdjo et al. (2016b, c), who underscored the importance of resource availability, effective control techniques, and stakeholder collaboration for successful management. The lack of consistent monitoring and institutional coordination has further hindered the implementation of invasive plant control measures.

Priority recommendations for invasive alien plant management

The management recommendations for the 29 invasive species were divided into three priority categories (Table 9): site management, monitoring, and limited action. Two species, *A. gangetica* and *M. crenata*, were prioritized for site management; six species were recommended for monitoring, and the remaining 21 species were designated for limited action.

The site management strategy for *A. gangetica* and *M. crenata* is focused on safeguarding pivotal ecological and social values within the arboretum. Both species demonstrate rapid growth and reproduction, necessitating intensive and coordinated management. The strategy emphasizes stakeholder capacity building and awareness through the principles of Integrated Management of Invasive Plants (PTIT). Mechanical control is recommended as the primary method due to its minimal environmental impact, a position that is supported by land use planning that considers microclimate and human activities.

Table 9. Recommendations for invasive alien plants management at research sites

Species	Risk of invasive alien plants	Feasibility management	Recommendation
Acmella paniculata (Wall. ex DC.) R.K.Jansen	Ignored	High	Limited action
Ageratum conyzoides L.	Ignored	High	Limited action
Asystasia gangetica (L.) T.Anderson	Medium	Ignored	Manage Site
Axonopus compressus (Sw.) P. Beauv.	Ignored	Medium	Limited action
Calopogonium mucunoides Desv.	Ignored	High	Limited action
Miconia crenata (Vahl) Michelang.	Medium	Low	Manage site
Commelina communis L.	Ignored	High	Limited action
Cyperus rotundus L.	Ignored	High	Limited action
Drymaria cordata (L.) Willd. ex Schult.	Ignored	Very high	Monitor
Elephantopus scaber L.	Low	High	Monitor
Eragrostis amabilis (Desv.) Steud.	Ignored	High	Limited action
Hyptis capitata (L.) Poit.	Ignored	High	Limited action
Ipomoea triloba L.	Ignored	Very high	Monitor
Lantana camara L.	Ignored	Very high	Monitor
Limnocharis flava (L.) Buchenau	Ignored	Very high	Monitor
Melastoma malabathricum L.	Low	Medium	Limited action
Mimosa pudica L.	Low	Medium	Limited action
Momordica charantia L.	Ignored	Very high	Monitor
Nephrolepis biserata (Sw.) Schott	Ignored	High	Limited action
Panicum maximum Jacq.	Ignored	High	Limited action
Paspalum conjugatum Bergius	Ignored	High	Limited action
Piper aduncum L.	Low	Medium	Limited action
Rhynchospora colorata (L.) Britton	Ignored	High	Limited action
Setaria barbata (Lam.) Kunth	Ignored	High	Limited action
Stachytarpheta indica (L.) Vahl	Ignored	High	Limited action
Struchium sparganophorum (L.)	Ignored	High	Limited action
Synedrella nodiflora (L.) Gaertn.	Ignored	High	Limited action
Thunbergia grandiflora (Roxb. ex Rottler) Roxb.	Ignored	High	Limited action
Urena lobata L.	Low	Low	Limited action

The monitoring strategy emphasizes regular observation of distribution changes and invasion intensity to enable early detection and timely control actions. This approach precludes the implementation of superfluous interventions for species that pose minimal threat, while ensuring preparedness for potential escalation.

The limited action strategy is applicable to 21 species that currently pose negligible risks. Control measures are implemented selectively when a significant spread threatens priority land use systems. It is imperative to note that actions are adapted to local conditions and available resources. This adaptation ensures efficiency and practicality.

Innovative utilization of invasive alien plants is also recommended to complement management. One potential solution is vegetative engineering, which involves the combination of invasive and local species to create new, economically valuable hybrids that retain adaptability while limiting invasiveness. The implementation of such innovations has the potential to generate new commodities and mitigate the risk of invasion.

This study also introduces a transferable model for university arboretum-based IAS management in tropical Asia, integrating taxonomic clustering, ecological impact indices, and management feasibility. The framework under discussion has been developed to support proactive monitoring and rapid-response strategies for small green spaces. In an era of accelerating urbanization and plant exchange, locally adapted yet globally informed management is essential to maintain biodiversity and ecological resilience in managed landscapes.

Conclusion, a total of 29 invasive alien plant species from 16 families were recorded in the USU Arboretum, with *A. gangetica* and *M. crenata* identified as the most dominant and ecologically influential species. Pursuant to ecological and management assessments, three priority actions were proposed: site management, monitoring, and limited action. It has been determined that only *A. gangetica* and *M. crenata* require intensive site management. In contrast, six species require regular monitoring, and the remaining species require limited intervention. This study proposes a pragmatic and replicable framework for the management of invasive alien plants in university arboretums across tropical Asia. The integration of ecological indices with management feasibility and the alignment of local practices with national IAS guidelines serve to strengthen early detection, prevention, and control strategies, thereby supporting broader biodiversity conservation efforts in academic and urban green spaces.

The study was limited to a single sampling season and relied on morphological identification and expert scoring without long-term monitoring or environmental variable integration. Future work should include multi-seasonal monitoring, remote-sensing mapping, and trials of different control methods, while integrating soil, ecological, and community-based management approaches for improved invasive species control.

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