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Population structure and risk assessment of invasive species *Asystasia gangetica* in urban area of Bandung City, West Java, Indonesia

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Abstract. *Rosleine D, Khalishah AR. 2024. Population structure and risk assessment of invasive species* Asystasia gangetica *in urban area of Bandung Citry, West Java, Indonesia. Biodiversitas 25: 2374-2381. Asystasia gangetica* (L.) T. Anderson is a weed from Africa that has a high adaptation to wide ecological conditions. This research aims to assess the population structure of *A. gangetica* in Bandung City, West Java, Indonesia and to conduct risk assessment to determine management decisions. This research was conducted from January to February 2023 by establishing a total of 106 plots with size of 1 m^2 to measure the population structure at adult and juvenile stages, and number of fruits. Plot sized 0.4 m^2 was used to count the seed in a 10 cm soil depth. A risk assessment was conducted, which consisted of 12 questions of risk analysis (invasiveness, impact, and potential distribution) and 20 questions of management feasibility (control cost, distribution, and persistence). The results of principal component analysis and clustering analysis show three groups based on population structure (PC1 49.12% and PC2 28.44%). The first cluster consists of three sub-districts and shows a set of early colonized populations indicated by low juvenile stage, while the second cluster (14 sub-districts) and third cluster (13 sub-districts) show more established population yet still recently colonized, which is indicated with medium-high juvenile and reproductive (fruit) stage. The risk assessment results in 91.2 of the risk analysis score (medium) and 169.7 of the management feasibility score (negligible), implying the need to manage the site. Nevertheless, its wide-range of habitat tolerant and population characteristics potentially threaten biodiversity and harm the agricultural sector at once. Therefore, early countermeasure is needed as an effort to minimize greater risks in the future.

Keywords: *Asystasia gangetica*, introduced species, invasion process, principal component analysis, urban ecology

INTRODUCTION

Asystasia gangetica (L.) T. Anderson (ara sungsang/rumput israel) is one of herbaceous plants in the Acanthaceae family that is native to the African continent (Yap et al. 2021). This plant was firstly introduced to Malaysia in 1876 and 1923 as an ornamental plant (Asbur et al. 2019). In Indonesia, this plant has also been successfully introduced, and its population has now become a naturalized alien plant in certain areas (Westaway et al. 2016). The presence of *A. gangetica* has been reported in various regions such as in West Java, including in Bogor, Banten and Garut (Kumalasari et al. 2020). In Indonesia, this plant is well known as a cover crop and commonly found in agricultural lands and plantations, however it tends to be categorized as a weed plant (Asbur et al. 2018). *A. gangetica* is classified as an aggressive weed in oil palm plantations because of its ecological characteristics (Westaway et al. 2016).

Asystasia gangetica is classified as weed species because it can produce enormous amounts of seed along with its explosive fruits, making this species has high dispersal ability (Asbur et al. 2019). Management effort to control the population of *A. gangetica* in a particular area would be challenging if its population has invaded and reached the establishment stage (Yulia et al. 2022). *A. gangetica* can tolerate a wide range of environmental conditions, e.g. open or shaded areas and low soil fertility (Samedani et al. 2013), implying that it has wide range of habitat suitability. Furthermore, this plant is able to grow at an altitude of up to 2,500 m above sea level. Moreover, *A. gangetica* can reproduce new individual sexually and asexually at once. Its morphology is adapted into the form of segmented and branched stems that facilitates this plant to form additional roots. The formation of vegetative organs from the stem modification promotes its characteristic as a creeping weed (Asbur et al. 2019).

Aside from agricultural lands and plantations, *A. gangetica* is commonly found in urban settlement areas such as roadsides, riverbanks, open land, etc. (Yap et al. 2021). An urban area is a built-up environment of cities and towns that is characterized by a dense human population and heavily transformed infrastructures (Roy et al. 2023). Urban areas become hotspots for the entry and establishment of invasive species because of the high disturbances by humans as well as the higher propagule pressure (Roy et al. 2023). Such conditions will increase the invasion risk in urban areas including in constructed and industrial developments areas, human settlements, transport networks, etc. This condition also has an impact on the economic and human well-being (Guo et al. 2018).

On the other hand, urban areas are also not seen as priority areas for alien species management due to their limited ecological as well as conservation value in many cases (Roy et al. 2023). According to a previous study in Bandung urban area (Rahmawati and Rosleine 2023), *A. gangetica* was revealed as invasive plant which had the third-highest Importance Value Index (IVI). Many *A. gangetica* populations were found in urban green spaces, such as gardens, paddy fields, roadsides and city parks (Rahmawati and Rosleine 2023). The existence of this ruderal species that coexists with human settlements is closely related to the invasion process (Guo et al. 2018). Urban areas, in some ways, allow people to be disconnected from the surrounding environment, even from their neighborhood. Such social and environmental disconnects result in difficult to come to a consensus about the management actions (Gaertner et al. 2017).

Alien species that are found in urban areas mostly by intentionally introduced ornamental plants that escaped from cultivation (Roy et al. 2023). Transportation of people and commodities might result in high opportunities for propagules dissemination and introduction (Gaertner et al. 2017). In addition, waterways that are situated along urban areas also provide corridors for alien species dispersal through pathways such as trade, tourism, and horticulture (Gaertner et al. 2016). Therefore, high human activities, especially in urban areas, somehow facilitate the introduction of alien species which then become established and naturalized in new areas (Potgieter and Cadotte 2020). Meanwhile, anthropogenic disturbances, including clearing land for urban development and the conversion of forest into agricultural lands and plantations, can lead to open areas which facilitate alien species to colonize.

Thus far, studies on invasive species mostly tend to be conducted in conservation areas rather than in urban areas, due to limited ecological and conservation value, so that urban areas tend to be seen as low priority areas for alien species in many cases (Gaertner et al. 2017). It includes studies related to risk assessment analysis, such as those that have been carried out in Mount Merapi National Park, Baluran National Park and Gede Pangrango National Park (Tjitrosoedirjo et al. 2016). Nevertheless, invasive species in urban areas are as much as important to study as these areas are the 'gateway' or entry point for the introduction of various types of alien species. Therefore, this study aimed to assess the population structure of A. *gangetica* in Bandung City, West Java, Indonesia to determine the invasion process, as well as to conduct the risk assessment analysis as an effort to early detect its potential invasiveness in urban areas. This population structure and risk assessment can later be used as a reference for relevant stakeholders and parties to regulate post-border such countermeasure management so that the control costs required in the future would significantly be reduced.

MATERIALS AND METHODS

Study period and area

Survey was conducted from January to February 2023 in Bandung City, the capital of West Java Province which is an excellent example of urban ecosystem (Figure 1). Bandung City has an area of 167.31 km^2 that is located in 6.9021856°S 107.6187558°E and consists of 30 sub-districts. Bandung City is bordered with Bandung District and West Bandung District to the north, Cimahi City to the west, and Bandung District to the east and south. Types of land use in Bandung consist of settlement (46.54%), industrial buildings (10.53%), plantations (10.26%), shrubs/bushes (7.29%), fields (6.13%), urban green spaces (4.95%), open areas (4.6%), hardened surfaces (3.42%), sport facilities (3.14%), and paddy fields (3.13%) (Ningsih et al. 2022). The average altitude of Bandung is around 700 m above sea level with average temperature about 25.3°C. Annual precipitation is around 192.6 mm/month, while average humidity is around 66.6-75.8% (Central Bureau of Statistics of Bandung City 2023).

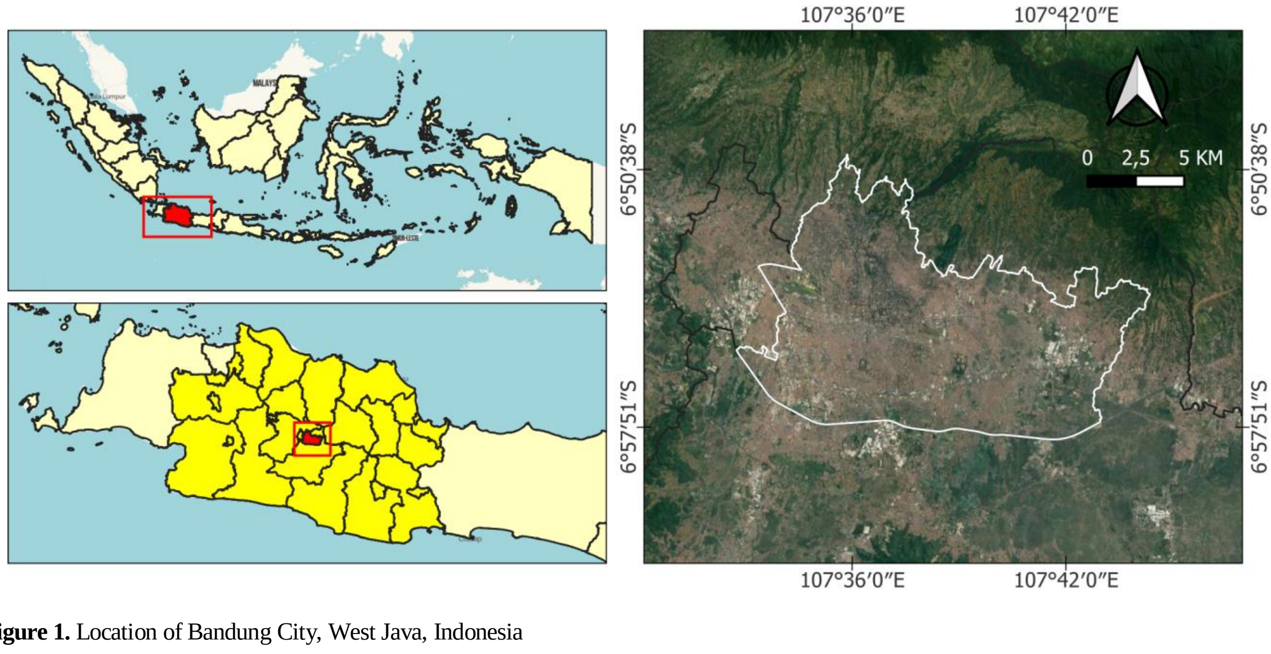

Figure 1. Location of Bandung City, West Java, Indonesia

Field survey

Population density

Vegetation survey was conducted using 1x1 m quadratic plots established across Bandung City with a total of 106 plots (Figure 1). Three to six plots were placed purposively based on the existence of *A. gangetica* in each sub-district to measure the whole population of each life stage (seedbank, juvenile, adult, and fruiting individual/reproductive stage). Environmental conditions were recorded at each plot including air temperature, light intensity, humidity, soil temperature, soil humidity, and soil pH. A smaller plot sized 0.2x0.2 m was placed within the same plot to count the seeds up to 10 cm depth as shown in Figure 2. The seedbanks were extracted manually by the sieving method (US mesh sized 3 or 6.73mm). This method overall will present the population density (Wheater et al. 2011).

Risk assessment

Risk assessment of *A. gangetica* was conducted by referring to A Modul for Risk Analysis of Alien Invasive Species by Indonesian Ministry of Environment and Forestry (KLHK) (Tjitrosoedirjo et al. 2016) and Australian Weed Risk Assessment Procedure (WRAP) by (Virtue 2008). This assessment consists of 22 questions with answer is in the form of score assigned based on literature reviews, recent field measurement, and additional information from related parties as well. There are two indices to calculate, namely weed risk index and feasibility of containment index, in which those indices will determine the management strategy priority. Weed risk index is related to invasiveness, impacts, and potential distribution, meanwhile the feasibility of containment index is related to control costs, current distribution, and persistence (Virtue 2008).

Data analysis

Principal Component Analysis (PCA) and K-means clustering were used to analyze the population density and clustering as well as the relation to the invasion process. Environmental condition and elevation of each plot were compared based on the sub-district clustering results. Moreover, the indices on the risk assessment were obtained from the following formula (Virtue 2008).

Risk score = invasiveness x impacts x potential distribution

Feasibility score = control costs x current distribution x persistence

Based on the calculation of the two indices, a total score was obtained and then classified to inform risk and feasibility categories as shown in Table 1 to determine the management strategy priority.

RESULTS AND DISCUSSION

Population structure and cluster of *Asystasia gangetica* and its relationship with environmental condition

The survey revealed that population of *A. gangetica* was found in all sub-districts across Bandung City, meaning that species is well naturalized in Bandung urban ecosystem. PCA result shows 90% of the variance within 3 dimensions with eigenvalues of 49.12% of Dim 1; 28.44% of Dim 2; and 13.22% of Dim 3, suggesting that Dim 1 and Dim 2 affected the cluster of *A. gangetica* in the study area (Figure 3.A). Juveniles represent the major influence on Dim-1 followed by non-reproductive which explain the invasion stage of the *A. gangetica* population. The juvenile life stage plays an important role in the colonization process by spreading and settling in a new area, also followed by the non-reproductive life stage which is relatively more established. Moreover, Dim-2 is represented by the reproductive life stage followed by seed density in the seedbank. These two components explain the gradation of land cover types in the *A. gangetica* habitat. Reproductive life stages play a role in the formation of seed banks in the soil that are able to influence vegetation cover type in the future.

Based on the clustering results of population density at each life stage, the *A. gangetica* population in Bandung comes into 3 clusters as presented in Figure 3.B.

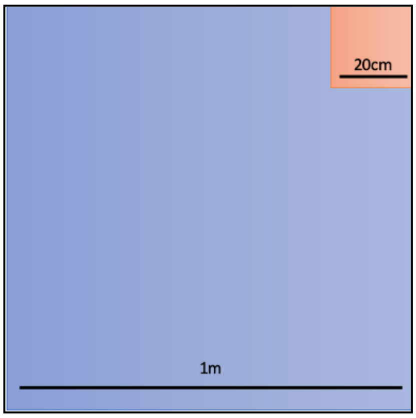

Figure 2. Diagram of plot measurement for population study of *Asystasia gangetica*

Table 1. Categories for risk index (*left*) and feasibility index (*right*)

Risk score	Risk category	Feasibility score	Feasibility category
> 192	Very high	> 113	Negligible
< 192	High	< 113	Low
< 101	Medium	< 56	Medium
< 39	Low	< 31	High
< 13	Negligible	< 14	Very high

Ordination in Dim-1 explains the colonization process of A. *gangetica*, while Dim-2 explains the gradation of land cover types in A. *gangetica* habitat. Cluster 1 (black color) consists of three sub-districts, namely Cinambo, Bojongloa Kaler, Batununggal. Cluster 1 which is scattered in quadrant-III is relatively an open area that can be categorized as a group of newly colonized *A. gangetica* population which is characterized by low percentage of the juvenile and reproductive stages due to hard to seek. Cluster 2 (red color) consists of fourteen sub-districts, including Cicendo, Andir, Bojongloa Kidul, Lengkong, Regol, Sumur Bandung, Ujung Berung, Panyileukan, Gedebage, Buah Batu, Bandung Kidul, Bandung Wetan, Coblong, and Sukasari. Cluster 2 which is mostly scattered in quadrant-II is an established population of *A. gangetica*, indicated by a high reproductive stage of the population that is found in residential areas. Cluster 3 (green color) consists of thirteen sub-districts, namely Kiaracondong, Cibeunying Kaler, Cidadap, Mandalajati, Antapani, Arcamanik, Sukajadi, Bandung Kulon, Babakan Ciparay, Astanaanyar, Cibeunying Kidul, Cibiru, and Rancasari. Cluster 3, which is mostly scattered across quadrant-I and quadrant-IV as an early establishment of *A. gangetica* population which characterized by higher juvenile stage compared to Cluster 2.

The percentage of population density (m^2) at each life stage in each district cluster is presented in Figure 4. The three clusters generally have adult and seed bank percentages that are relatively dominant among the other stages, indicating that *A. gangetica* is able to reproduce well in Bandung City.

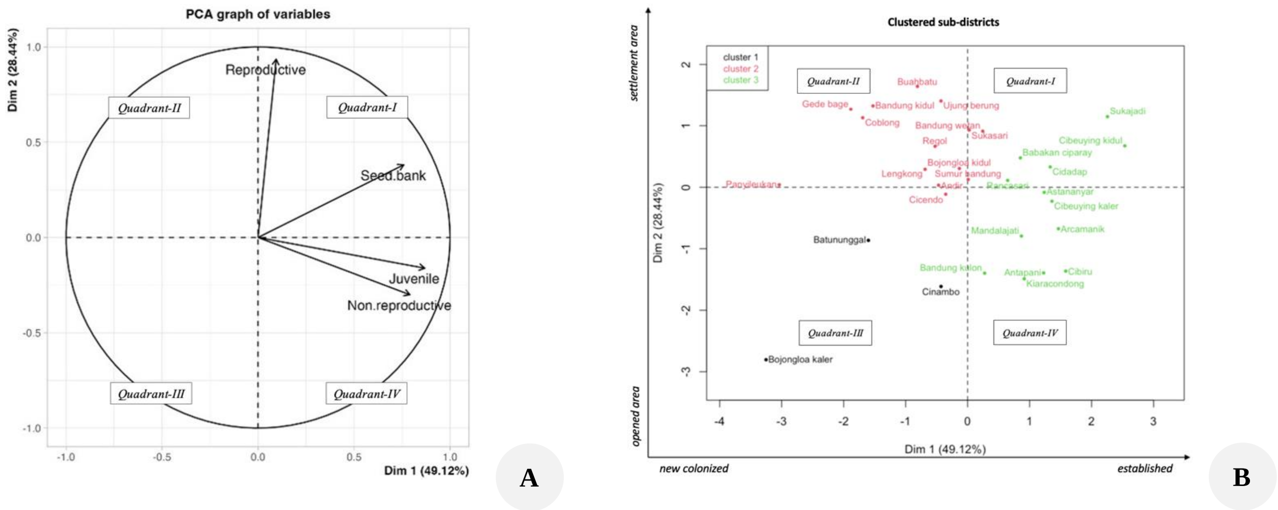

Figure 3. The result of PCA analysis showing the ordination of life stages (A) and the clustering of subdistricts (B)

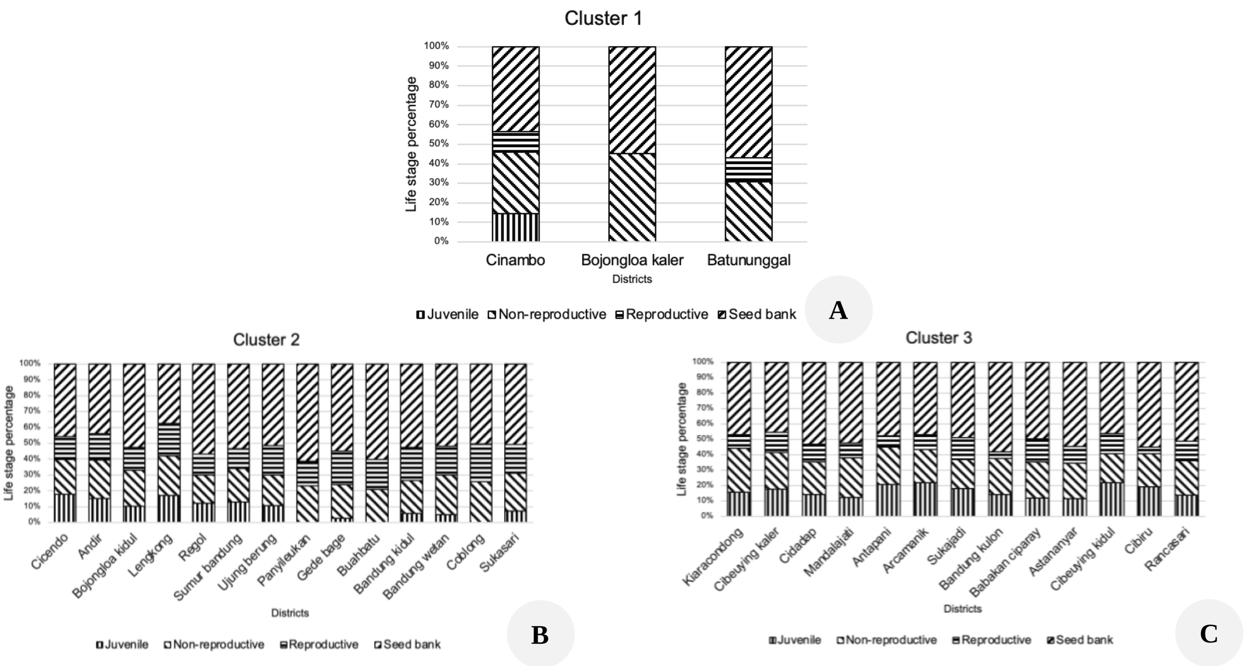

Figure 4. The proportion (density in m^2) of life stage of *Asystasia gangetica* in each cluster of the studied area

Looking at the overall population structure of *A. gangetica* in cluster 1, non-reproductive life stages as well as seeds in the soil (seedbank) were found in the population that was formed. The relatively high non-reproductive life stage was caused by the ability of this weed to reproduce asexually by forming modified stems in the form of stolon that propagate above the soil surface. However, juvenile and reproductive life stages were relatively difficult to find and have small populations compared to populations of other life stages. Apart from that, in Bojongloa Kaler subdistrict (cluster 1), a population of *A. gangetica* was found with incomplete life stages due to the ability of this population to produce new individuals through vegetative reproduction via stolon (Figure 4.A).

Cluster 2 (Figure 4.B) and 3 (Figure 4.C) generally were categorized as groups with a relatively more established population compared to the cluster 1. This was characterized by the reproductive life stage which is found to be higher than other life stages. Based on the data above, it is known that cluster 2 and cluster 3 have similar trends, however cluster 2 is relatively more established than cluster 3, as stated above based on the PCA graph (Figure 3.B). Cluster 3 had a higher proportion of juvenile stages and lower reproductive stages than cluster 2, indicating that cluster 3 was still in the initial phase of establishment otherwise juveniles that emerged from individuals resulting from germination. In contrary, cluster 2 showed a greater proportion of reproductive stages and fewer juvenile stages than cluster 3. Apart from that, the seed stage in the soil (seedbank) was found in greater numbers in cluster 2. This supported the estimation that the *A. gangetica* population in cluster 2 was relatively more established. The seedbank found showed that the *A. gangetica* population was regenerating well.

Environmental conditions in the three clusters are presented in Figure 5 (A-F). The air temperature generally ranged from 24.6-32°C with the highest average in the cluster 3 (28.4°C) as the areas are dominated by settlements, road sides and open areas. The light intensity varied from 4578.9 to 68557.8 Lux with the highest average in cluster 1 (23704.8 Lux) as settlement areas. The air humidity ranged around 56-90% with the highest average in clusters 2 and 3 in which both clusters consist of settlements and open areas. The soil temperature measured around 23.7-29.3°C with the highest average in cluster 1. The soil moisture ranged from 26.7-93% with the highest average in cluster 3 that are dominated by open areas. Soil pH ranged between 6.5-7.1 with the highest average in cluster 3.

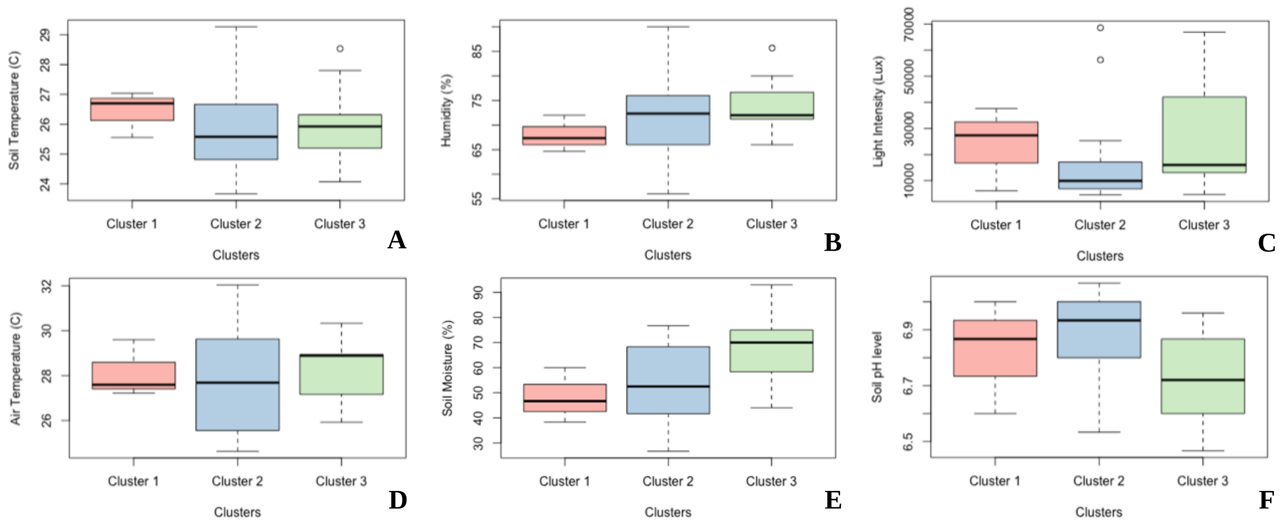

Figure 5. Environmental variables in each cluster: A. Air temperature, B. Light intensity, C. Humidity (c), D. Soil temperature, E. Soil moisture, F. Soil pH level

Table 2. Scoring summary of risk assessment of the invasion of *Asystasia gangetica* in Bandung City, West Java, Indonesia

Parameter		Number of questions	Max score	Current score	Total score (index)	Category outcome	Management option
Risk indices	Invasiveness	5	15	8.67	91.23	Medium	Managed sites (alert)
	Impact	6	19	2.63			
	Potential distribution	1	10	4			
Feasibility indices	Control cost	4	11	4	169.7	Very low (negligible)	
	Distribution	2	12	6.67			
	Persistence	4	11	6.6			

Risk assessment

A summary of risk assessment scoring is presented in Table 2. The risk index shows a score of 91.23, categorized as medium, meaning that the risk of *A. gangetica* to potentially invade the study area is at medium rate. The feasibility index shows a score of 169.7 which is in the very low (negligible) category, indicating the management practices have not shown a significant impact on the *A. gangetica* population. Based on the two indices and refers to the matrix in Table 3, management priority suggests to manage sites (alert) as an option.

Discussion

Population structure

Population structure of *A. gangetica* in Bandung City is currently in the invasion process between the early colonization and early establishment phases. It is characterized by the presence of seed banks across all populations, indicating that the population performs regeneration successfully. Seeds stored in the soil are able to maintain their viability up to 8 months before they are naturally destroyed (Hapsari et al. 2020). Additionally, juvenile density in the study sites indicates that the population is dominated by a relatively new generation through the germination process.

Based on the scheme of barriers that limits the spread of introduced species (Richardson et al. 2000), the population of *A. gangetica* in Bandung City is limited by local/regional barriers, which is indicated by their ability to establish, yet they are unable to invade/spread far from their populations. It might be due to the management and utilization efforts that are carried out periodically. Around residential areas, management effort such as removing/clearing practices is possibly carried out by the cleaning parties or the residents themselves. Meanwhile in abandoned open areas, *A. gangetica* population tends to be utilized as ruminants feed. However, if those management and utilization practices are not being performed properly, the dispersal process of *A. gangetica* population might occur since it is able to reproduce vegetatively.

Risk assessment

Invasiveness score contributes to risk index, because the scoring consists of questions about *A. gangetica* tolerance to the control efforts, then its long-distance dispersal. Moreover, *A. gangetica* is able to produce massive and explosive seeds within one month. Within the feasibility index, persistence score contributes more because the scoring consists of questions about the efficacy of *A. gangetica's* control effort which is low that led to population establishment. Thereafter, the regeneration time is relatively short, that is within two months. Lastly, the likelihood of ongoing propagule is facilitated by its dispersal ability.

The success of *A. gangetica* invasion depends on the propagules pressure, ecological characteristics, and environmental conditions (Vedder et al. 2021). In open areas, *A. gangetica* tends to produce more generative organs (Asbur et al. 2019). This species is able to produce flowers and seeds throughout the year with a total number of seeds around 27 million per hectare (Asbur et al. 2018). Generally, the newly produced seeds will not immediately germinate since the seed coat naturally protects the seeds, and will be dormant for about 7 days at 20-28°C (Akamine 1947). Subsequently, the seeds are able to germinate 7 days later after the fruit capsule has broken. The fruit capsule will explode which will hurl the seeds to 6 m away (Asbur et al. 2018). Through the generative organs, *A. gangetica* is able to disperse seeds within a month after producing flowers, and repeat the regeneration from germination to produce a number of seeds within 8 weeks (Hapsari et al. 2020). On the contrary, in shaded areas, *A. gangetica* produces more vegetative organs (Asbur et al. 2019). The stem of this plant is able to develop when it touches the ground, in order to modify the stem to form stolons. *A. gangetica* can produce early flowers within 10 weeks and then produce seeds through these modifications (Asbur et al. 2018).

A. gangetica has a relatively high tolerance to environmental conditions that are not suitable for its growth and this species has a particular strategy to exploit that condition (Asbur et al. 2019). The growth of *A. gangetica* is generally affected by shade which includes the number of branches per individual and the age of early flowering (Asbur et al. 2019). *A. gangetica* will produce more fruits in a high level light intensity (Asbur et al. 2019). Moreover, *A. gangetica* is also able to live in low light and low soil fertility conditions (Samedani et al. 2013), yet the process of photosynthesis is relatively hampered due to little light penetration, resulting in the growth process will also be hampered (Asbur et al. 2019).

Table 3. Matrix of management priorities of the invasion of *Asystasia gangetica* in Bandung City, West Java, Indonesiatable

Indices		Feasibility of containment				
		Negligible (≥ 113)	**Low (56-112)**	**Medium (31-55)**	**High (14-30)**	**Very high (0-13)**
Weed risk	Negligible (0-12)	Limited action	Limited action	Limited action	Limited action	Monitor
	Low (13-38)	Limited action	Limited action	Limited action	Monitor	Monitor
	Medium (39-100)	Manage sites (alert)	Manage sites (alert)	Manage sites (alert)	Protect sites (alert)	Contain spread (alert)
	High (101-191)	Manage weed (alert)	Manage weed (alert)	Protect sites (alert)	Contain spread (alert)	Destroy infestation (alert)
	Very high (≥ 192)	Manage weed (alert)	Protect sites & manage weed (alert)	Contain spread (alert)	Destroy infestation (alert)	Eradicate (alert)

Furthermore, the dense population tends to lessen the optimal growth since there is competition between individuals for light and nutrients (Craine and Dybzinski 2013). In this case, the high density of *A. gangetica* has the potential to suppress their population growth itself. *A. gangetica* tends to have a large number of shoots in high density and its vegetative organs (stolon) will continuously grow to fill the empty space (Asbur et al. 2019). On the contrary, populations that obtain sufficient amounts of light, such as in open area, tend to produce a high number of flowers (Asbur et al. 2019).

The risk of invasion of *A. gangetica* as an agricultural weed as well as its ability to adapt to a wide range of environmental conditions require appropriate management strategy. Managing the sites based on the result of the risk assessment aims to maintain the environmental and socio-economic condition in Bandung City through the improvement of the weed management system in general (Virtue 2008). Several management alternatives that are possible to implement such as improving the principles of IWM (integrated weed management) application, expanding the focus beyond invasive issues such as utilizing the *A. gangetica* abundance intentionally, and paying more attention to periodic clearing effort around the residence areas (Virtue 2008).

A. gangetica has many benefits, including as an ethnomedicine or traditional medicine that is commonly used for various diseases such as heart disease (Mugabo and Raji 2013), stomachache, rheumatism, asthma treatment, inflammation, anthelmintic, etc. (Kumar et al. 2021). *A. gangetica* extract contains antifungal compounds that can treat mouth/skin diseases (Hamid et al. 2011) and has a high antibacterial activity against *Salmonella paratyphi* (Daffodil et al. 2013). Additionally, in Nigeria, the crude aqueous extract of this plant is used as an anti-diabetic and hypolipidemic concoction, later on being used as like herbal tea on the market that able to enhance the properties of nutrients, antioxidants, and body immune system (Odoh et al. 2022). In East Africa, *A. gangetica* is used as the medicinal antidote to snake bites (Enenebeaku et al. 2018).

Moreover, *A. gangetica* is commonly used as ruminants feed since its fast-growing ability (Westaway et al. 2016), its high nutritional contents especially protein (Kamaruddin et al. 2021), and high digestibility (Ali et al. 2021) which is the main attraction for ruminants. In general, the leaves of *A. gangetica* have a better nutritional value than the stems (Kumalasari et al. 2019). Kacang goats are ruminants that like to consume this plant both as sole feed and supplementary feed on low-quality feed as well (Ali et al. 2021).

A. gangetica can also be used to remediate areas contaminated with heavy metals since it is reported as a good bio-monitor and phytoremediator for heavy metals Ni, Pb and Zn (Yap et al. 2021). This species is also possibly used as a candidate for future study in developing a weed management system as it has phytotoxic activity that will inhibit the growth of certain herbs (Suzuki et al. 2019).

Other than utilizing the *A. gangetica*, another option to reduce the spread of its population is to carry out periodic weed clearing/removal. There are several potential biocontrol agents that are capable of suppressing *A. gangetica* population growth such as 20% extracts of Taro tuber (*Collocasia escluenta* L.) and 30% extract of Yam tuber (*Discorea hispida* Dennst.) which are reported to inhibit 100% of *A. gangetica* germination (Yulia et al. 2022). These extracts are able to utilize the allelochemical compounds contained as organic herbicides (Tan and Tow 1994). Moreover, there are pathogenic fungi that are able to control the population of *A. gangetica*, which are *Fusarium* sp. and *Colletotrichum dematium*. *Fusarium* sp. causes the discoloration on *A. gangetica* leaves as the result of the toxins it produces (Yulia et al. 2022) while *C. dematium* attacks the leaves to cause necrosis and stunted plant growth (Tan and Tow 1994; Yulia et al. 2022).

In conclusion, population structure of *A. gangetica* in the urban area of Bandung explains the invasion stage between early colonization to establishment which is shown by the discovery of seed banks and also other life stages (juvenile, reproductive, adult) with relatively high in density. Furthermore, the risk index and feasibility index from the risk assessment were 91.2 (medium) and 169.7 (negligible), so that the priority management option is site management (alarms). The current population of *A. gangetica* still requires good attention in management to reduce high control costs in the future and reduce its potential to threaten biodiversity and harm the agricultural sector if it is not managed properly.

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