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Research Article

Ecological Study of *Bidens pilosa* in Bandung, West Java, Indonesia

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ABSTRACT
Bidens pilosa has been widely distributed from tropical to temperate regions and is often reported as a weed in agriculture. It readily thrives in various environments, naturally spreading to open areas and artificial ecosystems, establishing new populations, emphasising the need for ecological studies to prevent its invasive potential. In this study, we focused on population study of *B. pilosa* and its distribution in Bandung as urban area. Survey was conducted using 1x1 m quadrate plots in eight locations (24 plots). Individual number of *B. pilosa*, the number of flowers in each individual, coordinates, and altitude of each plot were recorded to describe population structure and map this population in Bandung. Air temperature (°C), humidity (%), light intensity (Lux), and soil water content (%) were measured. Individual number and environmental condition are analysed using cluster analysis and PCA, then mapped using IDW (Inverse Distance Weighting). The highest population in AR (652 ind), followed by CG (626 ind), TR (253 ind), PA (135 ind), CW (78 ind), NR (39 ind), PU (28 ind), and PR (20 ind). On average, each *B. pilosa* individual produces 61 inflorescences, indicating a mature population with all developmental stages present across all locations. Ordination plots shows that *B. pilosa* has wide range of environmental condition from open to shade area with various environmental condition. Open areas, settlements, and agriculture host dense *B. pilosa* populations, and its biological traits suggest it may become invasive without proper control.

INTRODUCTION
Alien plants, also known as non-native or exotic species, originate from different areas and can thrive in new environments. When these foreign plants reach high populations and spread extensively, they become invasive, leading to ecological disturbances and contamination of ecosystems. Consequently, invasive species pose a significant threat to biodiversity and native species worldwide (Sunaryo & Tihurua 2012; Tjitrosedirdjo 2012).

One such species is *Bidens pilosa*, a cosmopolitan herbaceous plant native to Central and Tropical America. It has spread globally, especially in tropical and subtropical climates, often as a contaminant in agricultural seeds (US Forest Service 2018; Handayani et al. 2021). Concerns have arisen about *B. pilosa* becoming an invasive alien species that is difficult to control. It is listed among the 2000 exotic plant species in Indonesia and identified as invasive, also significantly affecting more than 30 crops in over 40 countries (Setyawati et al. 2015; WIKTROP 2023). The spread of *B. pilosa* in Indonesia has been facilitated by its presence as a weed from Africa and its prevalence in agricultural and plantation areas (Siagian et al. 2017; Paiman 2020). Additionally, *B. pilosa* has invaded several conservation areas in Indonesia, including Bromo Tengger-Semeru National Park, Lake Kalimpa'a Lore Lindu National Park, and National Baluran Park, where it has become the dominant foreign plant species (Megawati et al. 2017; Padmanaba et al. 2017; Abidin et al. 2019).

Urban environments have also been invaded by *B. pilosa*, particularly in Bandung, the largest and the most populous metropolitan city in West Java. Research by Rahmawati (2022) has revealed that *B. pilosa* is the most common invasive foreign herbaceous plant in Bandung. The proliferation of foreign plants in urban areas demands attention due to potential direct impacts on ecology, economy, and public health (Gaertner et al. 2017; Potgieter et al. 2022). *B. pilosa*'s presence in urban ecosystems poses a threat to local biodiversity, as it produces allelochemical compounds that inhibit the growth of other plants (Xuan & Khanh 2016). Moreover, the distribution of *B. pilosa* in urban areas near conservation sites can disrupt the structure and function of these areas, leading to biotic homogenisation (Gaertner et al. 2017). The plant also serves as a host and vector for plant parasites and viruses, reducing the productivity of various food crops (Galon et al. 2015; GISD 2023). Furthermore, *B. pilosa* can be a source of allergens or phototoxic toxins, causing allergic reactions in humans (Gaertner et al. 2017; PFAF 2022).

The availability of resources resulting from human activities and minimal competition and disturbance contribute to the proliferation of *B. pilosa* (Paiman 2020). The presence of roads, railroad crossings, canals, and waterways in urban areas acts as corridors that facilitate the rapid spread of *B. pilosa* propagules (Säumel & Kowarik 2010; Meek et al. 2010; Gaertner et al. 2017). Addressing the invasion of *B. pilosa* is essential to prevent future challenges. However, a comprehensive understanding of the interactions between biotic and abiotic factors determining the level of invasiveness is still lacking. Therefore, gathering ecological data, such as environmental information, distribution patterns, and the specific invasive potential of *B. pilosa* in Bandung, is crucial. Such information can help formulate effective strategies to mitigate the impact of this invasive alien species on both urban and conservation areas. By taking prompt and informed action, it is possible to protect native biodiversity and preserve the delicate balance of ecosystems in the face of invasive threats like *B. pilosa*.

MATERIALS AND METHODS

Materials

GPS was employed to record the coordinates and elevation of observation sites. Microclimate parameters, including air temperature (°C), air humidity (%), and light intensity (Lux) were measured using a sling psychrometer and a lux meter. Each observation plot underwent five repetitions, yielding 120 data points. Soil moisture content (%) was determined through core sampling, involving the collection of wet soil samples and subsequent drying at 105°C for 24 hours. Soil moisture content was calculated by subtracting the weight of the dry soil sample from the weight of the wet soil sample (after drying), dividing by the weight of the wet soil sample, and then multiplying by 100%.

Methods

Study area and period

This study was conducted between July 2022 until October 2022 in several locations in the administrative area of Bandung City, West Java Province, Indonesia. The research site was determined according to Rahmawati (2022), which identified sampling coordinates where significant colonies of *B. pilosa* were present (Figure 2). The geographic coordinates of the study area are located in S6°49' - 7°18' and E107°14' - 107°56'. Each observation site shows the results of measurements of different microclimatic and environmental settings. The study areas encompass altitudes ranging from 300 to 970 meters above sea level (asl). Air temperature values are between 21.5 - 27°C, relative humidity is between 45 - 90%, light intensity is between 200 - 1100 Lux (Table 1). Each observation site possesses a distinct environmental setting, encompassing agricultural landscapes, residential areas, open spaces, rice fields, transportation routes (including roads and railways), and riverbanks (Figure 3).

Data collection

Random sampling encompassed eight observation sites, each with three 1 x 1 meter square plots, totalling 24 plots. These plots were strategically positioned in areas with *B. pilosa* populations, and their coordinates and elevation were recorded using handheld GPS. Population structure and inflorescent count data were collected during three phases: seedling, reproductive, and non-reproductive stages. The count included main plants, excluding rhizomes that develop into new individuals, with each clump considered as one individual. Each individual is characterized by clear morphological features as shown in Figure 1, with reproductive individuals identified by those that have flowered or flowers that have developed into achenes.

For flower count, three random samples of flowering adult individuals were selected from each plot. *B. pilosa* inflorescences contain two types of florets: white ray flowers and yellowish disc flowers, with the count focused on ray flowers, representing one flower. Microclimatic parameters are measured to analyse the relationship between environmental factors and the population of *B. pilosa*. These measurements also sup-

Table 1. Habitat characteristics of *Bidens pilosa* at eight study sites in Bandung, West Java, Indonesia.

Study sites	Environmental Setting	Temperature (°C)	Relative Humidity (%)	Light Intensity (Lux)	Altitude (m asl)	Coordinates	
						X	Y
Cigadung (CG)	Contour residental area	23.61 – 25.83	48 – 65	870 – 1085	780	107.62237500	-6.87258056
Panyileukan Rail Road (PR)	Dry open area without canopy	23.33 – 24.17	72 – 82	270 – 380	625	107.70618889	-6.94688056
Tol Road Edge (TR)	Windy open area	24.44 – 26.11	50 – 80	236 – 407	600	107.70455833	-6.96681667
GBLA-near River (NR)	Humid riverbanks	24.72 – 26.39	65 – 88	289 – 610	615	107.70455833	-6.96681667
Panyileukan (PA)	Rice fields and settlement	24.72 – 25.83	59 – 72	632 – 845	651	107.71350000	-6.93407778
Cipadung Wetan (CW)	Flat residential areas	25.28 – 26.94	60 – 80	535 – 760	679	107.71288056	-6.93217778
Arcamanik (AR)	Open spaces	22.22 – 23.61	75 – 86	202 – 228	700	107.6764222	-6.91053056
Padasaluyu Utara (PU)	Agricultural landscapes	21.67 – 22.50	73 – 82	149 – 463	966	107.5933528	-6.84853889

port the creation of prediction maps for the distribution of *B. pilosa*.

Figure 1. Morphology of *B. pilosa*: flowers (1), *achene* (2), leaf (3), dan stem (4).

Data analysis

Population structure

Population structure, which pertains to the distribution of individuals by age and sex, plays a pivotal role in determining population size changes over time. While sex differentiation can be challenging in certain organisms like plants, age structure becomes a critical determinant of population growth. Younger individuals are more likely to contribute to population growth as they reach reproductive maturity, while older individuals face higher mortality rates, impacting overall population dynamics. Odum's (1993) population structure analysis involves examining the population size across various life stages, represented in diagram form. These diagrams can take different shapes:

A. An expansive pyramid shape signifies a growing population, dominated by the young.
B. A bell-shaped polygon denotes a stable population where no age group dominates.
C. A jug or urn shape suggests a declining population, with a prevalence of older or unproductive individuals.

These models visually depict the distribution of individuals across age or life stages, providing valuable insights into *B. pilosa*'s population dynamics.

Relationship between population and ecological factors

Principal Component Analysis (PCA) is employed to elucidate complex relationships between observed variables, specifically between *B. pilosa* populations seize and microclimatic parameters. This analysis seeks to identify essential data patterns while reducing complexity by transforming the data into a new coordinate system. The PCA analysis was conducted using IBM SPSS Statistics 26.

Cluster analysis groups observed objects (*B. pilosa* populations at each observation site) into smaller clusters based on the similarity of observed variables, resulting in a dendrogram representation. These variables include number of populations, temperature, relative humidity, light intensity, and altitude. The average linkage method is used for clustering, which groups based on the average distance between observations. The criterion used compares the average distance within a cluster to that of other clusters. This method follows the research by Paramadina et al. (2019) and was conducted using IBM SPSS Statistics 26.

Distribution map

A visual representation or distribution map was generated to give an overview of how the *Bidens pilosa* population is spread throughout Bandung city. This was achieved by employing the Inverse Distance

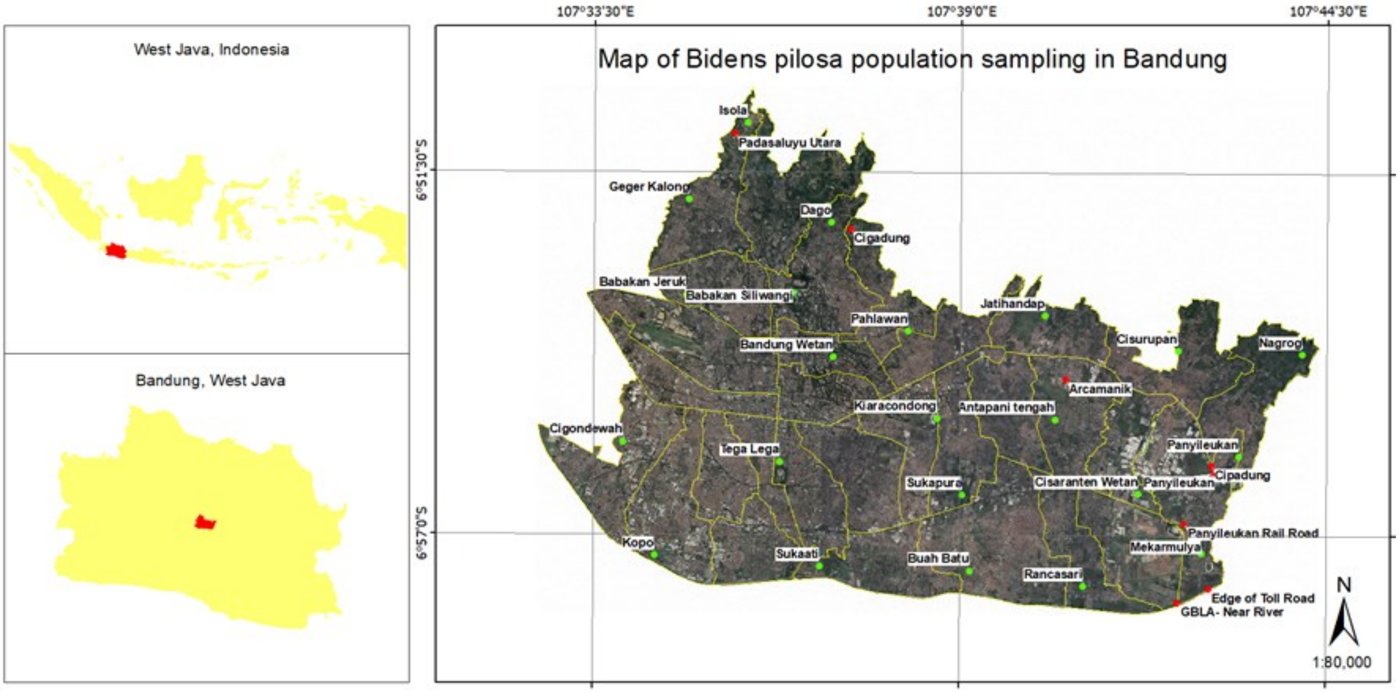

Figure 2. Map of study site in Bandung urban area, West Java, Indonesia; dot features represent site for sampling point collection. The sampling points conducted by Rahmawati (2022) are depicted with green dots, while the observation points in this study are represented by red dots.

Weighting (IDW) technique to create the distribution map for *Bidens pilosa*. The Inverse Distance Weighting (IDW) method assumes that each input point has a locally diminishing influence with distance. It is influenced by the inverse distance obtained from a mathematical equation, allowing us to adjust the relative influence of sample points. IDW interpolation is suitable for map creation when sample selection requires data on quantity, distribution, or density (Yudanegara et al. 2021).

The choice of the IDW method stems from the assumption that *B. pilosa* can be found across Bandung city due to its adaptability. Locations with significant *B. pilosa* concentrations are taken as indicative of broader areas where the plant could be present. Absence of *B. pilosa* at certain observation points is treated as a value of 0. The distribution map for *B. pilosa* in Bandung city was formulated by combining the total populations from each of the 8 observation sites, along with the population data for *B. pilosa* gathered by Rahmawati (2022) at these points. The IDW method involves estimating values at unsampled locations based on neighbouring data points, a process known as spatial interpolation. This distribution mapping was carried out using the ESRI ArcMap 10.8. software using IDW as an interpolation method. In the context of Geospatial Information Systems (GIS), interpolation is used to predict values in areas lacking direct measurements, aiding in map creation and value distribution projection across the observed region (Sejati 2019).

RESULTS AND DISCUSSION

B. pilosa has invaded Bandung city, with an average density of 76.2 individuals/m2 across all life stages (seedling, non-reproductive, and reproductive). *B. pilosa* was found in all observation sites with different environmental baselines and microclimatic conditions at each observation site (Table 1). Additionally, individual plants were capable of producing 20 to 120 inflorescences, resulting in an estimated annual seed yield of 2287 to 4575 per plant.

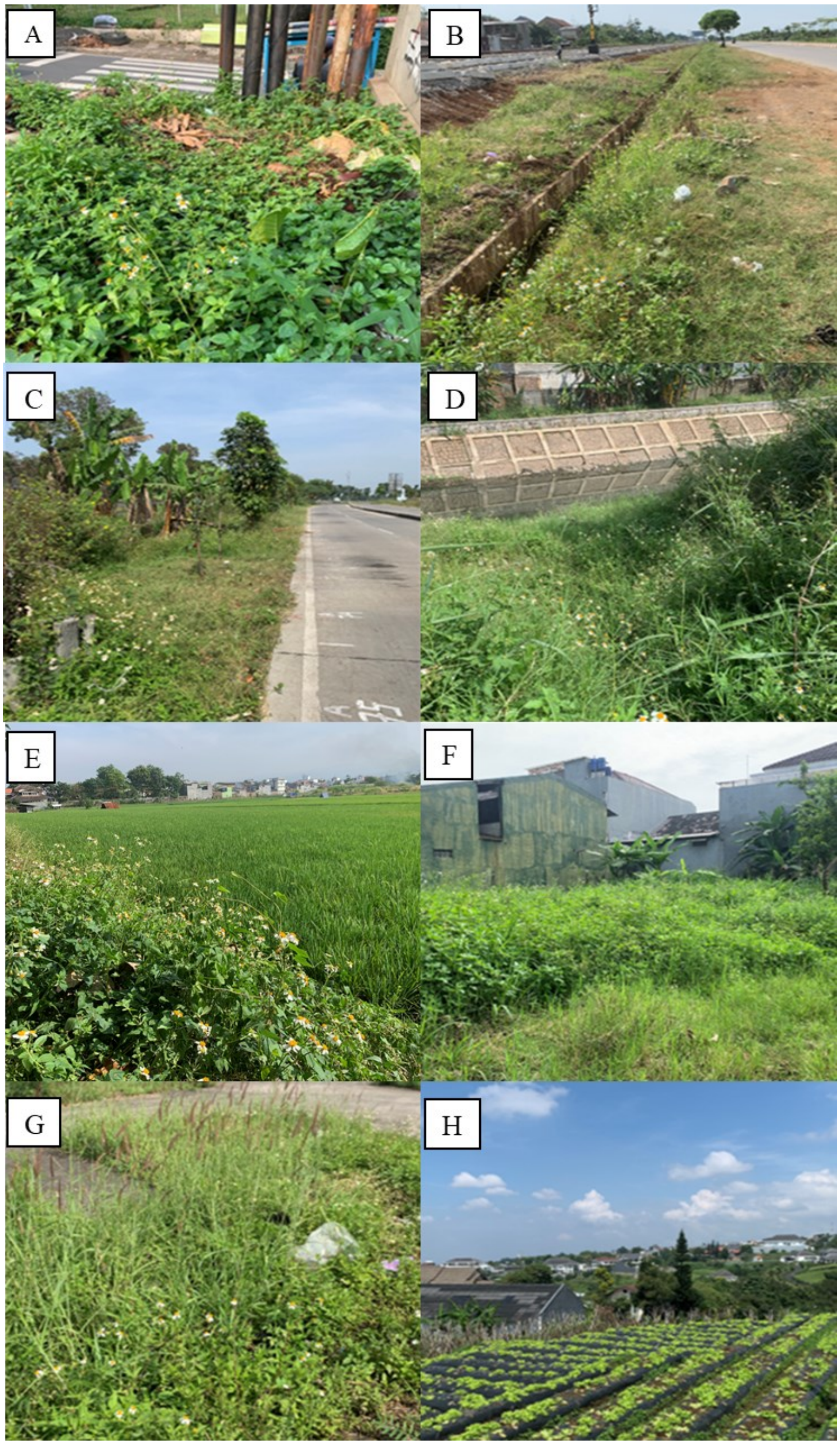

Figure 3. Various environmental settings can be observed at the eight research locations, listed from left to right: Cigadung/CG (A), Panyileukan Rail Road/PR (B), Edge of Toll Road/TR (C), GBLA-Near River/NR (D), Panyileukan/PA (E), Cipadung Wetan/CW (F), Arcamanik/AR (G), and Padasaluyu Utara/PU (H).

Population structures of *B. pilosa*

Based on our survey, the AR area exhibited the highest estimated number of *B. pilosa* individuals, with a total of 218 individuals per m^2, followed closely by the CG area with 209 individuals per m2. The areas with the highest number of individuals primarily consisted of individuals in the seedling stage. On the other hand, the PR area had the least estimated number of *B. pilosa* individuals, with only 7 individuals per m^2, and the PU area had 9 individuals per m^2 (Figure 3). In the PR area, the absence of seedlings was attributed to significant disturbance in the area, potentially due to control measures implemented near the railroad tracks to avoid disruption. The population in the PU area was also limited, likely due to competition with cultivated plants in dry land agricultural areas, which were actively managed by farmers.

The number of individuals recorded within a 24 m^2 observation area was 1.831, resulting in an average of 76.2 individuals per m2. Among the eight observation points, the dominant class is seedlings, with a total of 1.211 individuals and an average of 151 seedlings per m^2. On the other hand, the non-reproductive phase has the lowest proportion, averaging 27 individuals per m^2 (Figure 4). Based on the description of Figure 5, the visualization of the population distribution is expected to resemble an expansive pyramid shape. This suggests that there is a higher abundance of individuals in the seedling stage compared to other stages, gradually decreasing as they progress into reproductive phases.

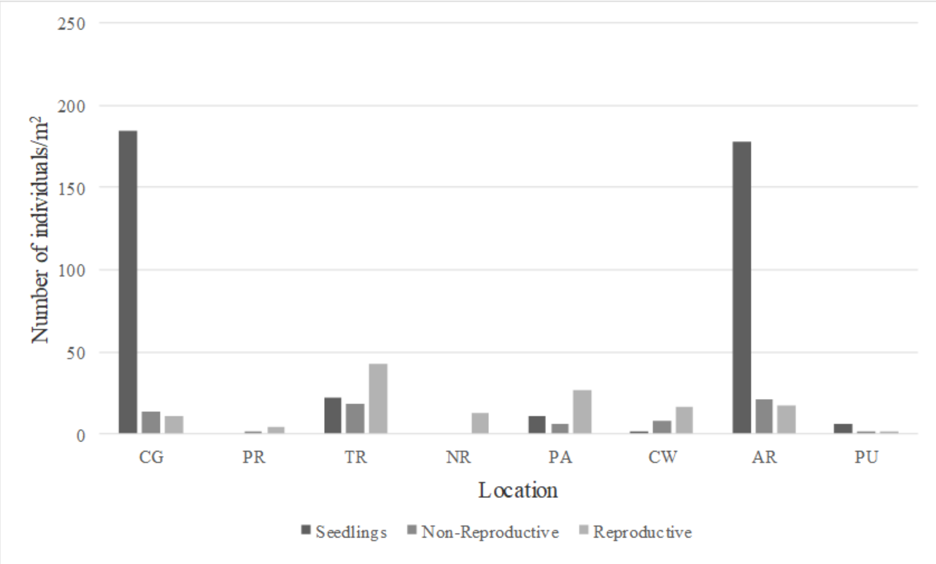

Figure 4. Population density of *B. pilosa* in research area.

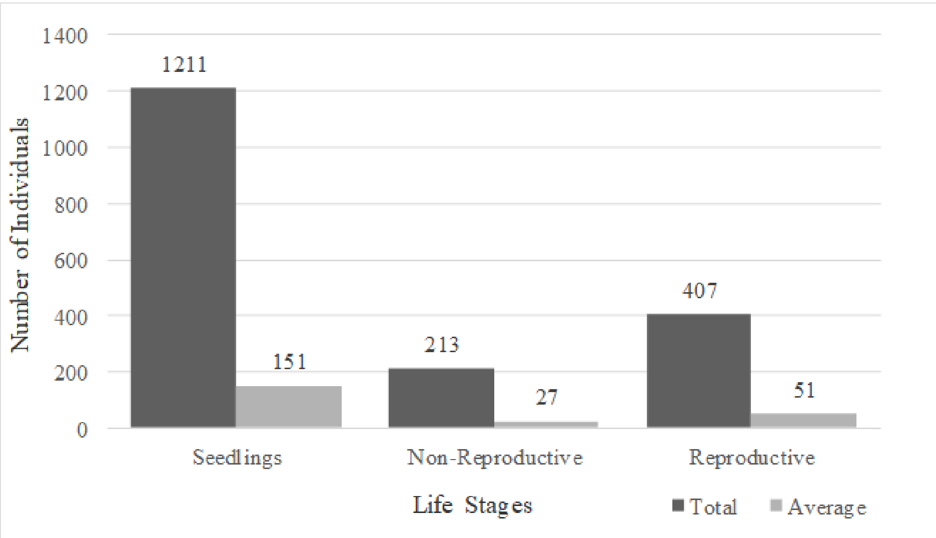

Figure 5. The proportion of the number of individuals between population classes.

Plant strategy

Referring to Table 2, the mean inflorescent yield per observed individual was 61. According to estimations derived from literature, a total of 4575 seeds per year can be produced from 61 flowers (assuming 4 generations annually). Success germination of *B. pilosa* can reach up to 74% (US Forest Service 2018; GISD 2023). Indicating that it is possible for each mature individual to generate 424 to 847 new individuals per generation. Massive seed production and high survival rate of this species show a benefit of population establishment.

Table 2. Reproductive characteristic of *B. pilosa*.

	Inflorescent/ flowers (per ind)	Seed production (per year)	Recruitments
Field Survey	61	2287 – 4575	424 – 846,56
(Waterhouse 1994; US Forest Service 2018; GISD 2023)	80	3000 – 6000	555 – 1110

Proximity between populations and their correlation with climatic factors

Based on Figure 6, the results indicated the presence of two major clusters within the *B. pilosa* population in Bandung city. The first cluster encompasses the P_5/PA Population, P_6/CW Population, P_3/TR Population, P_4/NR Population, and P_1/CG Population. The second cluster consists of the P_2/PR Population, P_7/AR Population, and P_8/PU Population (Figure 6). Among these clusters, the populations at P_5/PA and P_6/CW sites exhibited the highest degree of proximity, primarily due to their close geographical distance. The first cluster is believed to have formed due to variations in air humidity, while the second cluster appears to be influenced by the proximity of air temperature and light intensity factors, as indicated by the PCA ordination displayed in Figure 7.

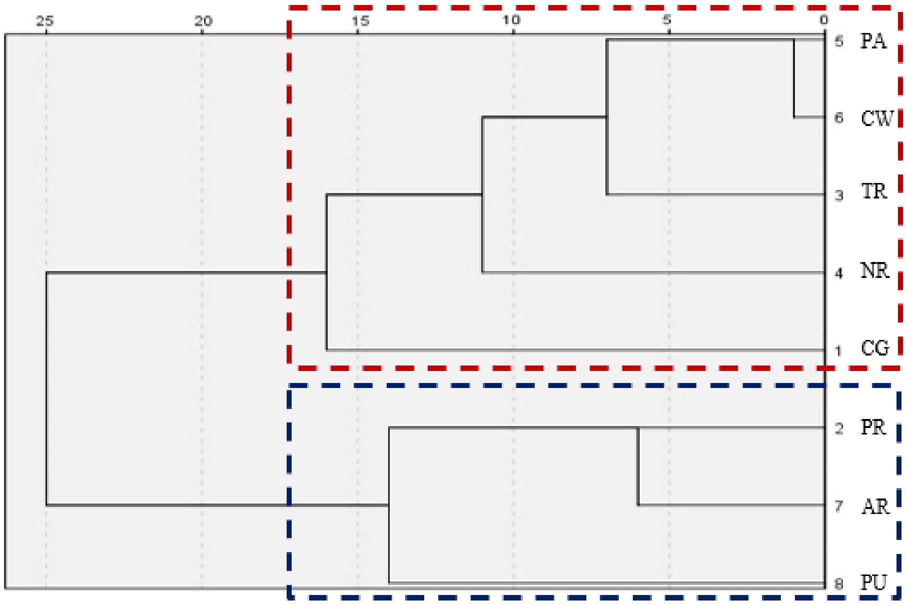

Figure 6. Clustering results for *B. pilosa* populations at eight observation sites; the red dashed rectangle is the first cluster, and the blue dashed rectangle is the second cluster.

Despite being included in the first cluster, the population at the P_1/CG site is located farthest away in the PCA ordination, suggesting a more distinct clustering pattern. This distinction is likely attributable to the population's growth in an environment characterized by the lowest humidity among all observed locations. On the other hand, the P_8/PU site represents the most remote point in the ordination, indicating that the population at this site thrives in the most distinct environment compared to all other observation points. Notably, site P_8 has the highest altitude and lowest temperature (Table 1).

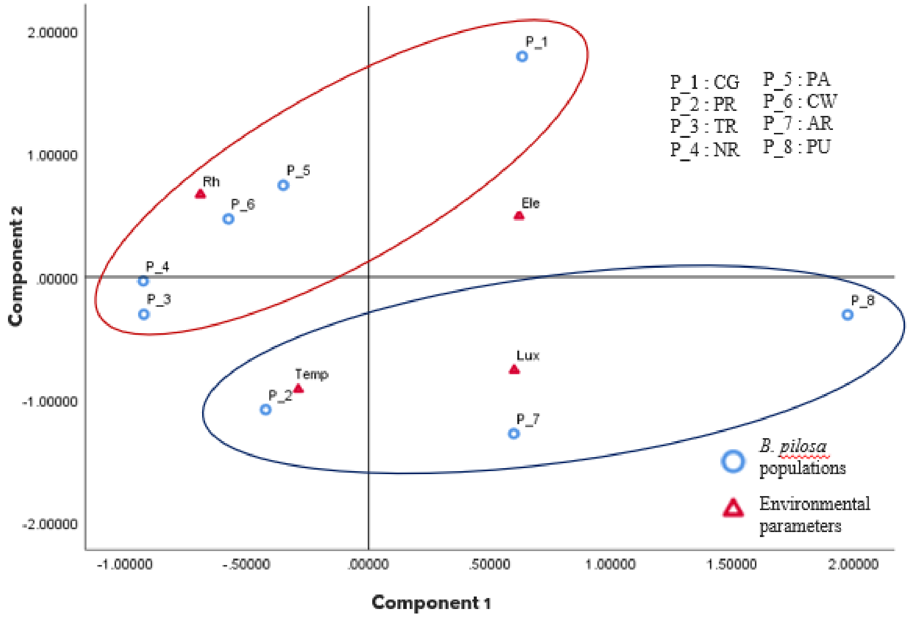

Figure 7. Result of PCA between *B. pilosa* populations and climatic factors; red circle is the first cluster, allegedly formed due to humidity factor; blue circle, The second cluster was allegedly formed due to the closeness of the air temperature and light intensity factors.

Distribution of *B. pilosa* by population density in the Bandung Area

B. pilosa thrives in diverse environments, forming large clusters, particularly in open areas with substantial human activity. The highest population estimates were observed in areas like rice fields, open residential spaces, and near dry land agriculture, highlighting its widespread presence in such environments (Figure 8).

Discussion

The locations with the highest number of *B. pilosa* individuals were predominantly in the seedling stage, indicating the presence of developing colonies. Such colonies, dominated by seedlings or tillers, tend to exhibit continued growth (Ansari et al. 2015). The height of individual seedlings reflects successful seed germination. The areas of Cigadung/CG and Arcamanik/AR had the highest seedling populations, suggesting widespread dispersal of *B. pilosa* seeds in these areas and favourable environmental conditions for germination, particularly due to relatively shaded light conditions compared to other locations. This finding is supported by Chauhan et al. (2019), who emphasized the influence of environmental factors, including light, on germination.

The Railroad/PR and GBLA-Near River/NR areas exhibited low populations of seedlings, likely due to relatively high temperatures and humidity compared to other locations, which hampered the germination process. Temperature and humidity are significant factors that impact seed germination. Certain herbaceous weed seeds have a broad temperature range and can easily germinate under various conditions, on the other hand, some seeds necessitate a specific temperature range to initiate germination. Additionally, weed seeds exhibit varying humidity requirements depending on their specific type (Chauhan et al. 2019). In the Padasaluyu/PU area, the small population of *B. pilosa* is suspected to result

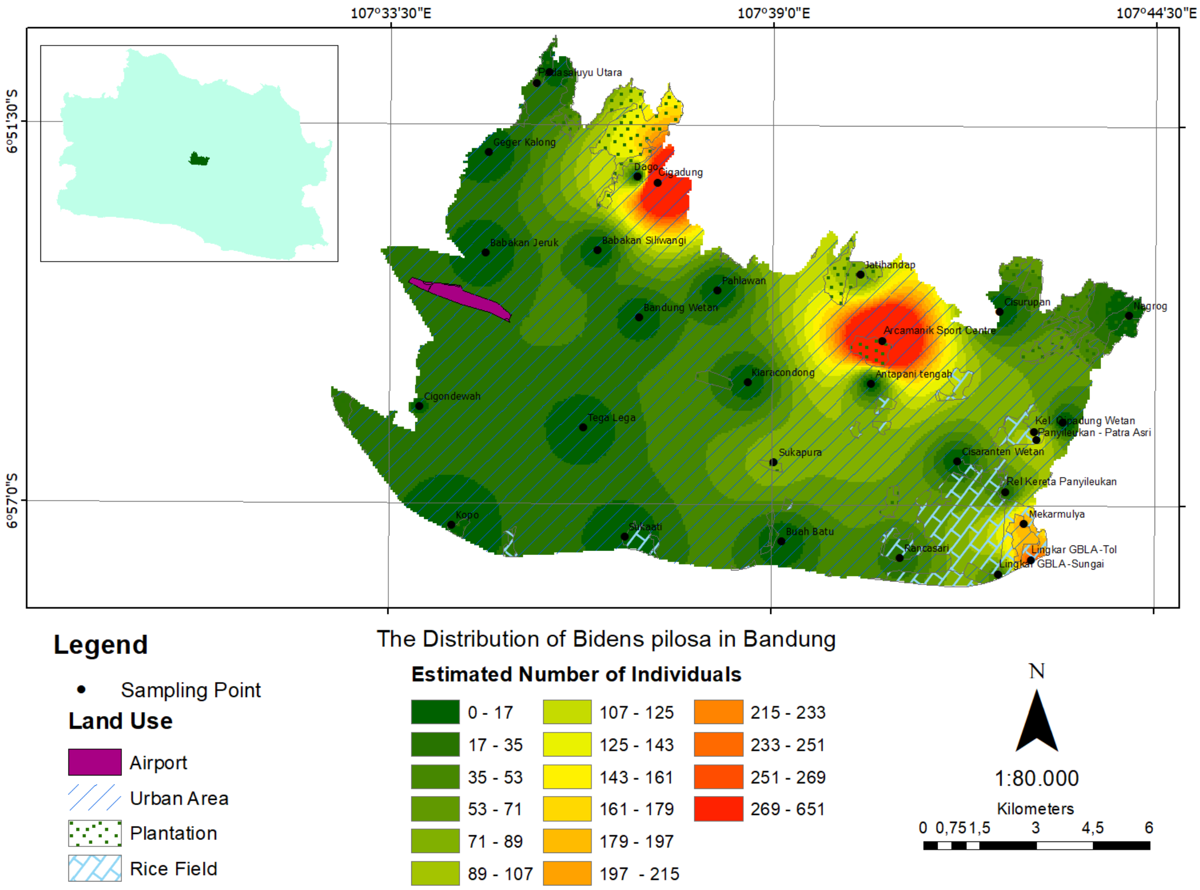

Figure 8. The overlay of the distribution of *Bidens pilosa* on the land use map, provides insights into the plant's preferences for specific habitats within the city of Bandung.

from seedlings being unable to survive due to competition with cultivated plants. Sebastian (2022) explained that biotic interactions, both between different species and within the same species, play a significant role in population growth, particularly at the seedling stage when plants have not yet fully adapted to their environment, making them relatively unstable.

The growth phase of a population is critical, with the seedling phase dominating in the case of *B. pilosa* due to its adaptability (LiYi et al. 2012). Population structure is influenced by factors such as birth rate, mortality, habitat, and human activity (Subahar 1998; Susanto & Halang 2019). *B. pilosa* exhibits a remarkable capacity to generate a substantial number of new individuals, estimated at approximately 555 to 1110 per generation per plant (Waterhouse 1994; US Forest Service 2018; GISD 2023). Environmental factors significantly impact its growth, particularly during the seedling stage (Sebastian 2022).

Flowers play a vital role in the survival of plants as they are essential for the reproductive process. The success of reproduction, including flowering, fruit maturity, and seed production, depends greatly on the developmental stages during the generative phase. Any failure at these stages can lead to reduced seed productivity and hinder the successful production of new offspring (Owens et al. 1991; Hidayat 2010). The flowering process is influenced by various factors, both internal and external. According to Hidayat (2010), internal factors such as genetics and hormones, as well as external factors like light, water, and temperature, significantly impact the flowering process and flower production.

B. pilosa exhibits adaptability to a diverse range of environmental factors, enabling its growth in various conditions. In Bandung, the colonies of *B. pilosa* thrive in multiple locations, each characterized by distinct environmental settings (Figure 7). Notably, these colonies show a preference for open areas that offer specific environmental conditions conducive to their growth and establishment (Figure 8). According to Pebriani (2017), *B. pilosa* is capable of growing in diverse habitat types, including disturbed areas, naturally disturbed environments, and those influenced by human intervention. It exhibits adaptability to a wide range of habitats, such as gardens, dry land agriculture, grasslands, vacant land, disturbed areas, open spaces in urban regions, and even roadside areas (Mahmoud et al. 2015; Silalahi et al. 2021). *B. pilosa* demonstrates tolerance to low humidity conditions, enabling its growth in relatively dry areas. Moreover, it can withstand moderately severe droughts and generally prefers locations with annual rainfall ranging from 500-3500 mm (Galinato et al. 1999; Rojas-Sandoval 2018). The species also exhibits a broad altitude range, spanning from lowlands to highlands up to 3,600 meters above sea level. It demonstrates a wide temperature tolerance, thriving in temperatures above 15°C and below 45°C. However, it is susceptible to frost, although its roots can survive and regenerate even after exposure to temperatures as low as -15°C (GISD 2023). Additionally, Ash-shiddiqqiyah et al. (2021) support this adaptability, highlighting *B. pilosa*'s ability to grow across various altitudes, ranging from lowlands (0 -100 m asl) to 200 m asl in Semarang City. These findings collectively demonstrate *B. pilosa*'s remarkable adaptability to diverse environmental settings within the city of Bandung.

B. pilosa, thriving in areas with high human activity, spreads through epizoochory, aided by hooked structures on its fruit (Paiman 2020). It readily colonizes disturbed habitats, whether natural or human-induced (Pebriani 2017). New introductions can cover distances exceeding 100 meters in less than 50 years (Richardson et al. 2000). The current distribution map of *B. pilosa* in Bandung requires further refinement using Ground Control Points (GCPs) for precise mapping (Susetyo & Gunarso 2018).

The population of *B. pilosa* in Bandung exhibits invasive characteristics, invading various land use systems due to factors like germination capability, competitive tolerance, canopy cover, and management practices (Tjitrosoedirdjo et al. 2016a). Its high reproductive potential, with over 1000 seeds/m2 and rapid growth from mature individuals, makes it a prolific invader (Tjitrosoedirdjo et al. 2016b). *B. pilosa* disperses widely across altitudes and environments, except for densely built urban areas, suggesting space constraints (McClure & Bartuska 2007). Prioritising control in colonized locations is essential to prevent further spread, given the complexities of urban ecosystems and the challenges posed by invasive species interactions (Gaertner et al. 2017). Managing these challenges in urban environments is crucial for future urban ecology and sustainability.

CONCLUSIONS

In conclusion, the estimated number of individual *Bidens pilosa* found in Bandung is around 1,831 individuals with an average of 76.2 individuals/m2. The most dominant is the young individual stage or seedlings (151 individuals/m2), then the reproductive stage (51 individuals/m2), and the non-reproductive stage (27 individuals/m2). Each individual can produce as many as 61 florets per individual. *B. pilosa* exhibits a remarkable tolerance to a wide range of environmental and climatic conditions, enabling its extensive distribution throughout Bandung, particularly in open areas with substantial human activity. It is anticipated that the population of *B. pilosa* in Bandung will experience exponential growth due to the high number of new recruits observed in all surveyed plots. Consequently, it is imperative to implement effective control measures to prevent the invasive establishment of this alien species within the region of Bandung.

AUTHOR CONTRIBUTION

D.P.O. designed the research, collected and analysed the data also wrote the manuscript. D.R. also designed the research, funded, and supervised all the process.

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CONFLICT OF INTEREST

There is no any conflict of interest regarding the research or the research funding.

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