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DIVERSITY AND DISTRIBUTION PATTERNS OF UNDERSTORY INVASIVE PLANT SPECIES IN THE CISOROG BLOCK, MOUNT TILU NATURE RESERVE

KEANEKARAGAMAN DAN POLA DISTRIBUSI TUMBUHAN BAWAH SPESIES INVASIF DI BLOK CISOROG, CAGAR ALAM GUNUNG TILU

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Abstract

Invasive plants can reduce biodiversity, particularly in understory vegetation, by altering ecosystem composition and dynamics. Conservation areas, such as the Mount Tilu Nature Reserve (NR) in Bandung Regency, play a vital role in maintaining ecological balance. One of its blocks, Cisorog Block, consists of open areas directly adjacent to public activities, which support the growth and spread of invasive species. This study aims to analyze the diversity, distribution patterns, and environmental factors influencing invasive understory species in Cisorog Block. Vegetation analysis and principal component analysis were conducted within a 47-hectare area at three sampling points. A total of 39 invasive species from 21 families were identified. Species with the highest Important Value Index (IVI) included *Cyrtandra grandis* (93.714%) at station 1, *Cyperus odoratus* (33.927%) at station 2, and *Commelina benghalensis* (15.353%) at station 3. The invasive evenness index was relatively high (0.65–0.85), while the diversity index was moderate (1.05–2.96). All species exhibited clumped distribution patterns.The environmental factors most strongly associated with invasive species distribution were light intensity and air humidity. These results emphasize the importance of developing management strategies based on environmental factors to control invasive plants and conserve biodiversity in the Mount Tilu Nature Reserve.

Keywords: Biodiversity; Cisorog Block; Distribution; Invasive plants

Abstrak

Tumbuhan invasif berpotensi menurunkan keanekaragaman hayati, terutama pada vegetasi bawah, dengan mengubah komposisi dan dinamika ekosistem. Kawasan konservasi, seperti Cagar Alam (CA) Gunung Tilu di Kabupaten Bandung, berperan penting menjaga keseimbangan ekosistem. Salah satu bloknya, Blok Cisorog, memiliki wilayah terbuka dan berbatasan langsung dengan aktivitas publik, sehingga mendukung pertumbuhan serta penyebaran tumbuhan invasif. Penelitian ini bertujuan mengetahui keanekaragaman, pola distribusi, dan faktor lingkungan yang berhubungan dengan keberadaan tumbuhan bawah invasif di Blok Cisorog. Metode yang digunakan adalah analisis vegetasi dan principal component analysis pada area 47 ha dengan 3 titik sampel. Hasil penelitian menemukan 39 spesies invasif dari 21 famili. Spesies dengan Indeks Nilai Penting (INP) tertinggi ialah Cyrtandra grandis (93,714%) di stasiun 1, Cyperus odoratus (33,927%) di stasiun 2, dan Commelina benghalensis (15,353%) di stasiun 3. Indeks kemerataan invasif tergolong tinggi (0,65–0,85) dan keanekaragaman sedang (1,05–2,96). Semua spesies menunjukkan pola distribusi mengelompok. Faktor lingkungan yang paling memengaruhi distribusi adalah intensitas cahaya matahari dan kelembapan udara. Hasil ini menegaskan perlunya strategi pengelolaan invasif berbasis faktor lingkungan untuk menjaga keanekaragaman hayati CA Gunung Tilu.

Kata Kunci*: Blok Cisorog; Distribusi; Keanekaragaman; Tumbuhan invasif*

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INTRODUCTION

The distribution of invasive plant species in various ecosystems in Indonesia is one of the primary factors contributing to the decline of biodiversity (Abduh et al., 2021). According to the International Union for Conservation of Nature and Natural Resources (IUCN), invasive plants are defined as foreign plants that grow and spread outside their natural environment, posing a threat to ecosystems, habitats, or other species (Putra, 2022). Invasive plant species have the potential to alter the global environment, imperil biodiversity, and impact nutrient cycles, hydrology, and energy balance (Priyono et al., 2022).

Approximately 50% of Indonesia's total national parks have been invaded by around 2,809 invasive plant species (Pambudi & Purwaka, 2019). Several examples of invasive species that have had negative impacts on conservation areas in Indonesia include the invasion of *Acacia decurrens*, which displaced native plant species in burned areas in Mount Merbabu National Park (Purwaningsih, 2010) and Mount Merapi (Gunawan et al., 2015). The invasion of *Casia Tora*, *Austroeupatorium inulifolium,* and *Lantana camara* in the grazing land of Alas Purwo National Park, and the invasion of *Acacia nilotica* in savanna ecosystems in Baluran National Park (Abywijaya et al., 2014). Additionally, cases of invasion in West Sumatra Province commonly occur in understory vegetation (Solfiyeni et al., 2023).

Invasive species tend to be more abundant in understory vegetation, and the success of an invasion is more likely to occur in competition with the understory vegetation compared to competition among adult plants (Swandi et al., 2020). Understory vegetation includes grasses, herbs, shrubs, vines, and ferns (Nikmah et al., 2016). Understory vegetations are involved in interspecies interactions such as interspecies competition, allelopathy, and symbiosis (Sulfayanti et al., 2023).

Conservation areas worldwide are vulnerable to disturbances and threats, including the spread of invasive plants (Yuliana & Lekitoo, 2018). Mount Tilu Nature Reserve is the second-largest protected area in West Java (Efendi et al., 2022), which plays a crucial role in preserving the diversity of mountain plants in the region (Nordiansyah et al., 2016). Cisorog is one of the blocks within Mount Tilu Nature Reserve, which has a more open canopy than others. Cisorog borders directly with a frequently used road by residents (Tarigan, 2023), where environmental conditions become conducive to the growth and spread of invasive understory species (Sahira et al., 2016). Therefore, research on invasive understory species diversity and distribution patterns is needed to understand how diversity, distribution patterns, and environmental factors are related to the distribution of invasive understory species in Mount Tilu Nature Reserve.

MATERIALS AND METHODS

The research was conducted from January to March 2024 at Cisorog Block, Mount Tilu Nature Reserve (Figure 1). Mount Tilu was designated as a nature reserve with an area of 7479.8 ha through the Minister of Forestry Decision Number SK. 1873/Menhut-VII/KUH/2014 issued on March 25, 2014. Geographically, the area is located between 7° 2' 17–7° 16' 5'' LS and 107° 27'–107° 32' BT. Mount Tilu Nature Reserve has an elevation range of 1,150–2,434 masl, with a slope angle of 5–10% and air temperature varying between 18–25 °C. Cisorog Block itself has an elevation range of 1,600–1,700 masl with an area of 47 ha.

Based on the Comprehensive Forest Inventory (CFI) guidelines, which state that the sampling intensity should be more than 0.05% (P.5/Menhut-II/2011, 2011). The sampling intensity for this research is 0.07% of the area, with a size of 47 ha. According to these guidelines, the study was conducted using the quadrat transect method (Audrya et al., 2021), with three transects. The transects were determined based on the variation in canopy cover (Diana & Andani, 2020). Each transect consisted of 3 plots, each measuring 20 × 20 m, with 100 subplots measuring 2 × 2 m, as per the method used in the study (Hoffmann et al., 2019). Each plot was separated by a distance of 5 m, as per the study (Abywijaya et al., 2014).

The understory plants were identified using reference materials such as the guide book to “Invasive Alien Plant Species in Indonesia” (Setyawati et al., 2015), “A Picture Guide of Forest Plants in Mount Gede Pangrango National Park, Indonesia” (Toyama et al., 2018), “The Mountain Flora of

Java" (Steenis, 2006), and the online platform https://identify.plantnet.org/id. The results of the identification process were then validated by a team of experts from the Indonesian Institute of Sciences (BRIN). The status of the invasiveness of the plants was based on the guidebook to "Invasive Alien Plant Species in Indonesia" (Setyawati & Zubaidah, 2021) and the website Invasive.org. The environmental factors observed included climatic factors such as temperature, light intensity, humidity, and elevation. Temperature and humidity were measured using a thermometer and a hygrometer, respectively, while light intensity was measured using a lux meter. Elevation was determined using a GPS.

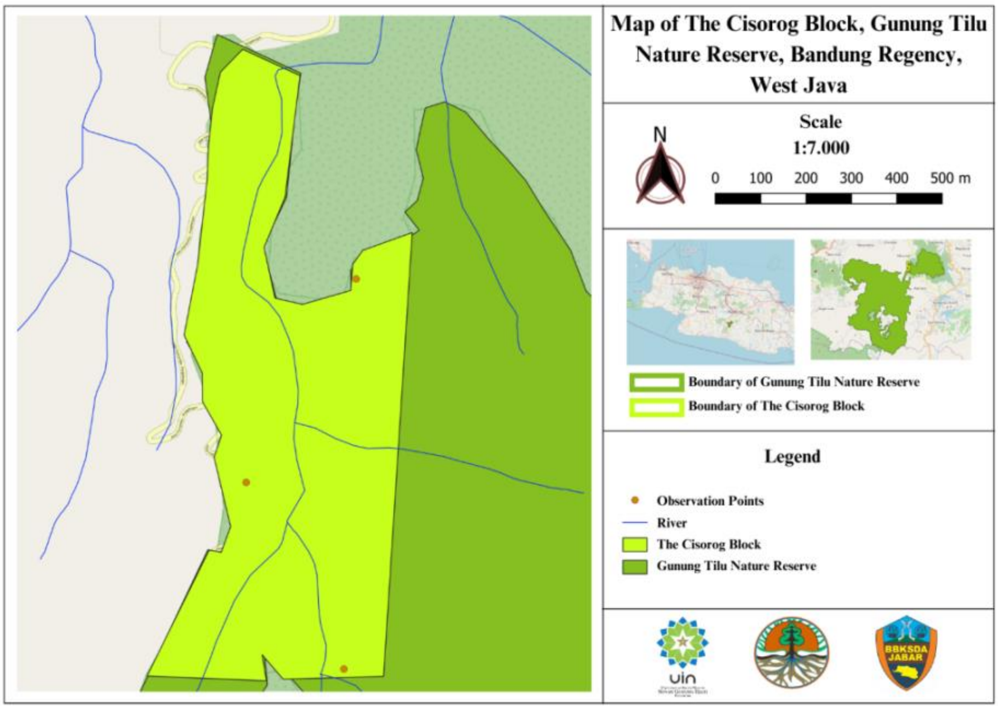

Figure 1. Location map of research at Cisorog Block, Mount Tilu Nature Reserve

One of the data analysis methods used is the Index of Important Value (IVI) (Ali et al., 2022). To calculate the species diversity index, the Shannon-Wiener index is used (Tarsius et al., 2019). Criteria for the Shannon-Wiener index of diversity are divided into three categories. If $H < 1$, the level of diversity is low; $1 < H < 3$, the level of diversity is medium; and for $H > 3$, the level of diversity is high. Further data analysis includes the index of evenness. The criteria for evaluating the evenness index are divided into three categories: if $0 < E \leq 0.4$, the evenness is low; if $0.41 < E \leq 0.6$, the evenness is medium; and if $0.6 < E \leq 1$, the evenness is high (Wahyuningsih et al., 2019). The distribution pattern of invasive species is determined using the Morphisita index (Audrya et al., 2021). The distribution pattern of a population can be determined by the Standardized Morisita Index (IP). The value of IP can be used to conclude the distribution pattern as follows: if Ip 0, the distribution is random; if Ip >0, the distribution is clumped; and if Ip <0, the distribution is uniform. The relationship between environmental factors and the spread of invasive plants can be determined using correlation tests (Jabnabillah & Margina, 2022). To identify the environmental factors most related to the spread of invasive plants at the research location, correlation tests and Principal Component Analysis (PCA) were used on IBM SPSS Statistics (Abywijaya et al., 2014).

RESULTS

Based on the research conducted at Cisorog Block, Mount Tilu NR, 39 invasive plant species belonging to 21 families were found (Table 1; Figure 2). Among all species, five species (4 families) were found at transect 1 with a large canopy cover, 11 species (9 families) at transect 2 with a medium canopy cover, and 32 species (15 families) at transect 3 with a small canopy cover. The family with the most species is *Asteraceae* (9 species), followed by *Poaceae* (5 species) and *Melastomataceae* (3 species).

Table 1. The composition and dominance of invasive understory plant species at the research location

No.	Family	Species	Habitus	Natural distribution	IVI/transect (%)		
					1	2	3
1.	*Acanthaceae*	*Asystasia gangetica*[1)2)]	Herb	India and Ceylon			2.94[*26]
2.	*Amaranthaceae*	*Amaranthus* sp.[1)2)]	Herb	Latin America			1.40[*31]
3.	*Araceae*	*Syngonium podophyllum*[2)]	Herb	Central and South America		24.21[*4]	
4.	*Asparagaceae*	*Ophiopogon* sp.[2)]	Herb	Central and South America	25.71[*4]		
5.	*Asteraceae*	*Ageratum conyzoides*[1)2)]	Herb	Central and South America			3.89[*24]
6.		*Bidens* sp.1[1)2)]	Herb	South Africa			11.44[*3]
7.		*Bidens* sp.2[1)2)]	Herb	South Africa			8.77[*8]
8.		*Chromolaena odorata*[1)2)]	Herb	Central and South America			2.08[*29]
9.		*Conyza* sp.[1)2)]	Herb	Tropical America			5.58[*17]
10.		*Crassophalum crepidioides*[1)]	Herb	Tropical Africa			5.63[*16]
11.		*Emilia sonchifolia*[1)2)]	Herb	Tropical Africa			4.57[*22]
12.		*Sphagneticola trilobata*[1)2)]	Herb	Tropical Amerika			11.18[*4]
13.		*Spilanthes iabadicensis*[1)]	Herb	Central and South America			8.16[*9]
14.	*Balsaminaceae*	*Impatiens balsamina*[1)2)]	Herb	India dan Asia Tenggara		29.01[*2]	3.28[*25]
15.	*Commelinaceae*	*Commelina benghalensis*[1)2)]	Herb	Tropical Asia			15.35[*1]
16.	*Cyperaceae*	*Carex baccans*[1)2)]	Herb	Southeast Asia and Central Asia		13.03[*8]	6.88[*13]
17.		*Cyperus odoratus*[1)2)]	Shrub	Southeast Asia and Central Asia		33.93[*1]	7.29[*11]
18.	*Euphorbiaceae*	*Austroeupatorium inulaefolium*[1)]	Shrub	Tropical America			2.77[*28]
19.	*Gesneriaceae*	*Cyrtandra sandei*[2)]	Herb	Southeast Asia	36.57[*2]		
20.		*Cyrtandra grandis*[2)]	Herb	Southeast Asia	93.71[*1]		
21.	*Lamiaceae*	*Marsypianthes chamaedrys*[2)]	Shrub	South America			10.02[*6]
22.		*Nepeta cataria*[2)]	Herb	Eropa dan Asia			5.93[*15]
23.	*Malvaceae*	*Sida rhombifolia*[2)]	Shrub	South America	10.86[*5]		
24.	*Melastomataceae*	*Clidemia hirta*[1)]	Shrub	South America		20.71[*5]	6.02[*14]
25.		*Melastoma* sp.1[2)]	Shrub	Asia		15.53[*7]	4.92[*20]
26.		*Melastoma* sp.2[2)]	Shrub	Asia			5.44[*18]
27.	*Oxalidaceae*	*Oxalis latifolia*[2)]	Shrub	South America		16.23[*6]	
28.	*Plantaginaceae*	*Plantago major*[2)]	Shrub	Europe		6.20[*10]	
29.	*Poaceae*	*Cynodon dactylon*[2)]	Herb	Souteast Asia			7.22[*12]
30.		*Digitaria* sp.[1)2)]	Herb	Africa		26.96[*3]	5.37[*19]
31.		*Isachne* sp.[1)2)]	Herb	South America			7.32[*10]
32.		*Panicum* sp.[1)2)]	Herb	Tropical Africa			8.82[*7]
33.		*Setaria* sp.[1)2)]	Herb	Europe			4.15[*23]
34.	*Polygonaceae*	*Polygonum nepalense*[2)]	Shrub	Southeast Asia			12.79[*2]
35.	*Rubiaceae*	*Borreria* sp.[1)]	Herb	Tropical America			11.05[*5]
36.	*Selaginellaceae*	*Selaginella* sp.[2)]	Ferns	Southeast Asia		3.32[*11]	0.71[*32]
37.	*Solanaceae*	*Brugmansia* sp.[1)2)]	Herb	Southeast Asia and America	33.14[*3]	10.86[*9]	4.76[*21]
38.	*Verbenaceae*	*Lantana camara*[1)2)]	Vines	Tropical America			2.82[*27]
39.		*Stachytarpheta* sp.[1)]	Herb	Tropical America			1.45[*30]

Note: Status of invasive plants based on the book "A Guide Book to Invasive Plant Species in Indonesia" (Setyawati et al., 2015); status of invasive plants according to the website Invasive.org

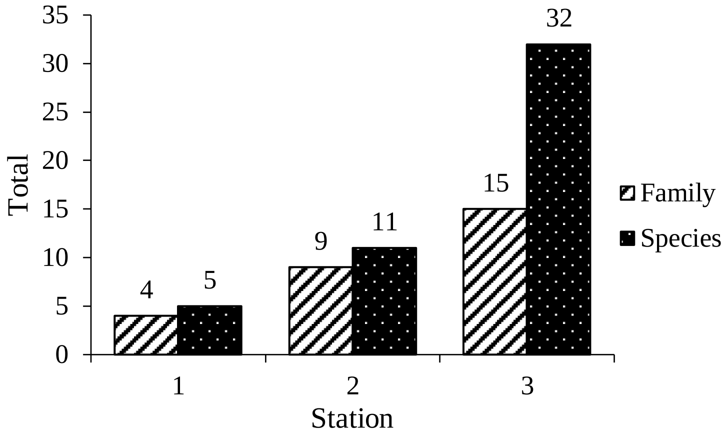

Figure 2. The composition of invasive understory plant species in Cisorog Block, Mount Tilu Nature Reserve

The invasive understory plant species from the *Asteraceae* family at the research location are shown in Figure 3 below. The results of Shannon-Wiener diversity index (H') calculations and species evenness index provide significant insights into the diversity and distribution of invasive understory plants in Cisorog Block, Mount Tilu NR. Based on the research findings, it is known that the diversity of invasive understory plant species in the three different transects shows moderate diversity, as indicated by the Shannon-Wiener diversity index values falling within the range of $1 \leq H' \leq 3$. The index of diversity and evenness of invasive understory plant species in Block Cisorog, Mount Tilu NR, is shown in Table 2.

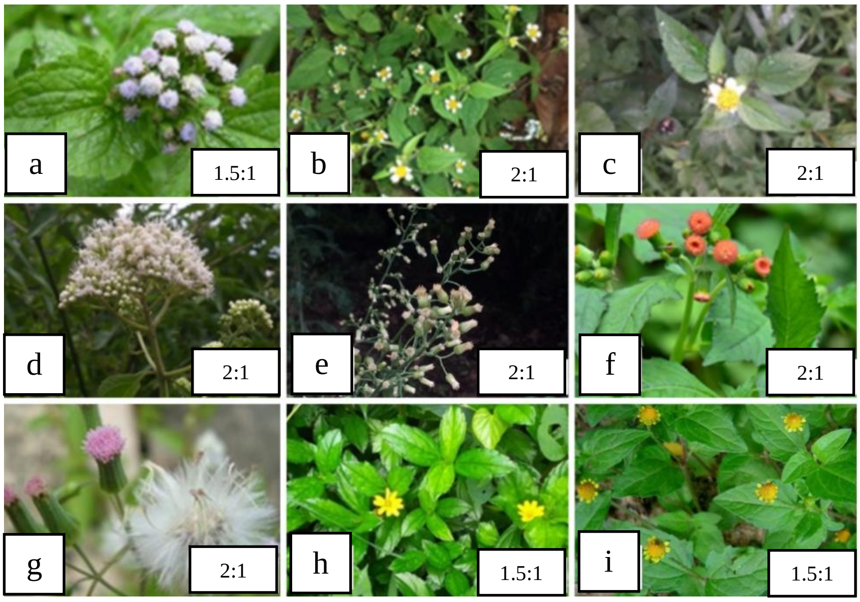

Figure 3. Invasive species of understory plants from the *Asteraceae* family at the research site are *Ageratum conyzoides* (a); *Bidens* sp.1 (b); *Bidens* sp.2 (c); *Chromolaena odorata* (d); *Conyza* sp. (e); *Crassophalum crepidioides* (f); *Emilia sonchifolia* (g); *Sphagneticola trilobata* (h); *Spilanthes iabadicensis* (i)

Table 2. Index of diversity (H') and evenness (E) of invasive understory plant species in Block Cisorog, Mount Tilu Nature Reserve

Transect	H'	E
1	1.05	0.65
2	2.04	0.85
3	2.96	0.85

Table 3. The distribution pattern of invasive understory plant species in Block Cisorog, Mount Tilu Nature Reserve

Species	Morisita index (Ip)	Distribution patterns
Asystasia gangetica	0.001082	Clumped
Amaranthus dubius	0.000337	Clumped
Syngonium podophyllum	0.020797	Clumped
Ophiopogon sp.	0.000374	Clumped
Ageratum conyzoides	0.001972	Clumped
Bidens sp.1	0.025169	Clumped
Bidens sp.2	0.025433	Clumped
Chromolaena odorata	0.000251	Clumped
Conyza sp.	0.002386	Clumped
Crassophalum crepidioides	0.002644	Clumped
Emilia sonchifolia	0.004595	Clumped
Sphagneticola trilobata	0.019114	Clumped
Spilanthes iabadicensis	0.023263	Clumped
Impatiens balsamina	0.009758	Clumped
Commelina benghalensis	0.033299	Clumped
Carex baccans	0.011135	Clumped
Cyperus odoratus	0.01162	Clumped
Austroeupatorium inulaefolium	0.0002	Clumped
Cyrtandra sandei	0.000496	Clumped
Cyrtandra grandis	0.006005	Clumped
Marsypianthes chamaedrys	0.01695	Clumped
Nepeta cataria	0.001433	Clumped
Sida rhombifolia	0.000504	Clumped
Clidemia hirta	0.00165	Clumped
Melastoma sp.1	0.001615	Clumped
Melastoma sp.2	0.001919	Clumped
Oxalis latifolia	0.025909	Clumped
Plantago major	0.0002	Clumped
Cynodon dactylon	0.013812	Clumped
Digitaria sp.	0.014022	Clumped
Isachne sp.	0.014033	Clumped
Panicum sp.	0.021745	Clumped
Setaria sp.	0.013695	Clumped
Polygonum nepalense	0.018001	Clumped
Borreria sp.	0.032203	Clumped
Selaginella sp.	0.001004	Clumped
Brugmansia sp.	0.009884	Clumped
Lantana camara	0.000501	Clumped
Stachytarpheta sp.	0.001346	Clumped

The Morisita index values for invasive understory plant species in Cisorog Block, Mount Tilu NR, are presented in Table 3. The environmental conditions measured at three transects in the research location, Cisorog Block, Mount Tilu NR, are presented in Table 4. The results of the Pearson correlation test to measure the relationship between environmental conditions and the distribution patterns of invasive understory plants at the research location are shown in Table 5.

Table 4. Environmental factors at the research site in Block Cisorog, Mount Tilu Nature Reserve

Transect	Canopy cover (%)	Temperature (°C)	Sunlight intensity (lux)	Air humidity (%)	Altitude (masl)
1	84.42	22	340	79	1534.28
2	54.53	22.6	412	83	1536.44
3	23.45	21.1	853	82	1593.28

Table 5. The results of correlation testing between environmental conditions and the spread of invasive understory plants at the research site

	Canopy cover	Temperature	Sunlight intensity	Air humidity	Altitude
Pearson correlation	-0.902	-0.201	0.675	0.946	0.600
Sig (2-tailed)	0.285	0.871	0.528	0.210	0.590

To strengthen the validation of identifying environmental factors related to the distribution of invasive understory plants at the research location, Principal Component Analysis (PCA) was used. PCA successfully identified five environmental factors grouped into two main components, explaining the overall variability of the measured environmental factors. The Eigenvalue for each component is presented in Table 6, while the ordination diagram of the PCA results is shown in Figure 4.

Table 6. Eigenvalue and environmental factor values associated with the spread of invasive understory plants at the research site

	Principal component I (PC I)	Principal component II (PC II)
Eigenvalue	3.76	1.24
Proportion	75.2	24.8
Cumulative	75.2	100
Variables:		
Canopy cover (canopy_C)	-0.952	-0.308
Temperature (temperature)	-0.821	0.571
Sunlight intensity (sunlight_I)	0.998	-0.070
Air humidity (air_H)	0.462	0.887
Altitude (altitude)	0.986	-0.167

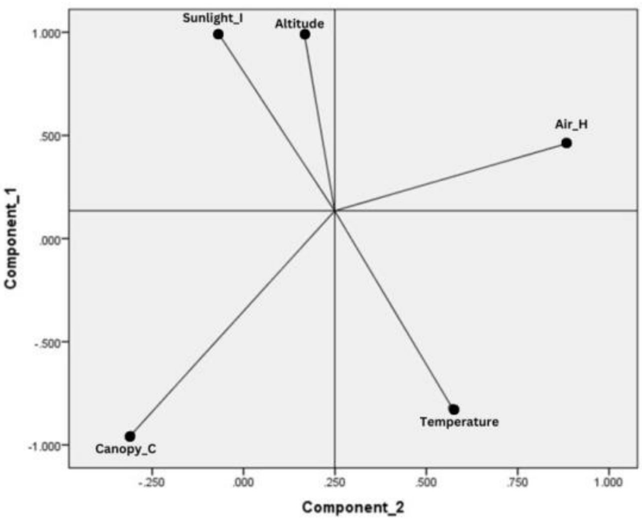

Figure 4. Principal component analysis (PCA) ordination diagram with five factors related to the spread of invasive understory plant species at the research site

DISCUSSION

Composition of Invasive Understory Plant Species

The composition of invasive understory plants varies at each transect. Transect 1, with a large canopy cover, has the lowest composition. Transect 2 has a moderate level with a medium canopy cover, while transect 3, with a small canopy cover, has the highest composition. Complex interactions with ecosystem components, including climatic, edaphic, biological, and anthropogenic factors, influence understory plant composition. These factors affect plant growth and development through light, humidity, temperature, soil texture, soil chemistry, groundwater availability, species interactions, plant dominance, and human activities (Destaranti et al., 2017).

Invasive plant species from the *Asteraceae* family are listed among the world's 100 most harmful invasive plant species (Audrya et al., 2021). The invasive capability of *Asteraceae* is due to its excellent adaptation to various environmental conditions, ranging from areas with minimal water to wet regions (Sundari et al., 2022). They thrive in tropical areas where sunlight is abundant (Paramita et al., 2019). *Asteraceae* spread through seeds equipped with a pappus, allowing the family to be dispersed by wind over long distances (Utami et al., 2020). The invasive understory plant species from the *Asteraceae* family at the research location are shown in Figure 3.

Of 39 invasive understory plant species found at the research location, 27 are herbs. Despite being smaller than surrounding plants (Dina et al., 2022), herbaceous plants have strong adaptive abilities and can compete with nearby plants, such as shrubs and bushes (Dui & Hendrik, 2019). This allows herbaceous plants to grow in vacant areas (Aisyah, 2018).

The invasive understory plants found at the research location have natural distributions from various countries. The data show that the invasive understory plant species at the research site predominantly originate from the Americas. Several reasons why invasive plants are spreading in Indonesia mainly come from the Americas. First, global trade has facilitated the introduction of American species to Indonesia (Putra, 2022). Second, Indonesia's tropical climate is similar to some regions in the Americas, allowing these species to adapt and proliferate well (Wati & Wakhidah, 2023). Third, some plant species from the Americas were intentionally introduced as ornamental plants or for other purposes, such as crops, enabling them to spread and establish in Indonesia (Irsyam et al., 2022).

Dominance of Invasive Understory Plant Species

All invasive plant species recorded in the vegetation analysis plot in Cisorog Block, Mount Tilu NR, are understory species. Thus, species that play a significant role in the community are those with a high Importance Value Index (IVI) of ≥10% (Pamoengkas & Zamzam, 2018). The higher the IVI, the more significant the contribution of the species to its community (Rawana et al., 2023).

Based on the IVI values, the invasive understory plant species with the highest IVI detected at transect 1 is *Cyrtandra grandis* (93.71%), followed by *Cyrtandra sandei* with an IVI of 36.57%. *Cyrtandra grandis* is a common plant found on the forest floor in Sumatra and Java mountainous areas (Efendi et al., 2016). *Cyrtandra grandis* can dominate its environment due to its ability to grow in various habitats, from lowlands to montane forests (Efendi et al., 2018).

The species with the highest IVI found at transect 2 is *Cyperus odoratus* (33.93%) from the *Cyperaceae* family. *Cyperus odoratus* is a rapidly and widely spreading weed. This species spreads invasively by growing aggressively and competing strongly in its environment (Candraningtyas et al., 2023). *Cyperus odoratus* in a community can negatively impact biodiversity and ecosystem balance (Taheri et al., 2021).

Commelina benghalensis from the Commelinaceae family is an invasive understory plant species with the highest IVI at transect 3, valued at 15.35%. *Commelina benghalensis* is considered one of the worst weeds globally in agricultural systems (Afiyah et al., 2023). Its invasiveness is attributed to its reproductive flexibility, producing many seeds. These characteristics, combined with its high tolerance to glyphosate, make it challenging to control once established in agricultural systems (Riar et al., 2016). Based on its invasive characteristics and detrimental impacts found at transect 3, it is essential to consider other invasive species identified at various observation transects, such as *Brugmansia* sp., which exhibits significant invasive potential and similar harmful effects.

Brugmansia sp. is an invasive understory plant species found at all three observation transects and is considered highly detrimental. According to Srivastava et al. (2014), this species competes aggressively with native plants, forms dense monospecific stands, inhibits the growth of native vegetation, and is toxic to humans and animals. All parts of this plant are toxic; consuming any part of it can cause severe anticholinergic effects and potential poisoning (Sharma et al., 2021). The plant contains tropane alkaloids such as scopolamine and hyoscyamine, the most famous and biologically active alkaloids (Cinelli & Jones, 2021).

The presence of invasive plants dominating new habitats due to the absence of natural predators and parasites results in significant financial burdens on sectors such as agriculture, forestry, fisheries, and human health due to the need to control invasive plant species (Susanti et al., 2013). This situation threatens the stability of existing ecosystems as it can lead to habitat damage and loss. It impacts the disappearance of niches for other organisms within the ecosystem (Jainuddin, 2023).

The Diversity and Evenness of Invasive Understory Plant Species

The results of Shannon-Wiener diversity index (H') calculations and species evenness index provide significant insights into the diversity and distribution of invasive understory plants in Cisorog Block, Mount Tilu NR. Based on the research findings, it is known that the diversity of invasive understory plant species in the three different transects shows moderate diversity, as indicated by the Shannon-Wiener diversity index values falling within the range of $1 \leq H' \leq 3$ (Table 2).

Community plant diversity depends on the number of species and individuals (Mokodompit et al., 2022). Environmental factors such as air humidity, soil pH, organic matter content, temperature, and light intensity also influence diversity (Wijana, 2014). In the short term, diverse plants may seem appealing, but in the long term, invasive plants can threaten ecosystem stability. Invasive plants can dominate an area and inhibit the growth of local plants through allelopathy, thereby reducing plant diversity. As a result, vegetation structure and community organisms change, disrupting energy cycles and reducing the function and quality of ecosystem services (Pambudi & Purwaka, 2019).

Table 2 shows the evenness of invasive understory plant species in three observation transects falling into the high category ($0.6 < E \leq 1$), where values approaching 1 indicate a more even distribution (Baderan et al., 2022). The diversity of invasive understory plants at the research site is moderate, but the evenness value is high. This condition indicates that the ecosystem has been disturbed. Human activities such as land degradation and deforestation have disrupted essential habitats for biodiversity, necessitating urgent action to address these issues (Rasiska et al., 2023).

Distribution Pattern of Invasive Understory Plant Species

The distribution pattern describes the qualitative characteristics of the spatial distribution of organism species, plants, and animals in a horizontal area (Nopiyanti & Riastuti, 2019). The Morisita index analysis indicates that all invasive understory plant species exhibit a clumped distribution pattern ($Ip > 0$). The Morisita index values for invasive understory plant species in Cisorog Block, Mount Tilu NR, are presented in Table 3.

Plant populations in nature tend to cluster due to environmental heterogeneity, even in narrow regions (Abywijaya et al., 2014). Clumped distribution patterns indicate nutrient concentration in specific locations from a socio-ecological perspective and suggest social interactions or plant associations from a socio-biological perspective (Metananda et al., 2015). Interactions among species form ecological communities and influence evolution and population distribution patterns (Susilo, 2018).

Clumped distribution patterns indicate lower mortality rates in environments that do not support life than in individuals scattered randomly or uniformly (Abdillah et al., 2022). Although many previous studies state that natural plant distribution patterns are generally clumped, research by Nopiyanti and Riastuti (2019) and Audrya et al. (2021) found that invasive plants can exhibit uniform distribution patterns. Additionally, research by Anjani et al. (2023) at the *Gymnospermae* collection of Bogor Botanical Gardens revealed that invasive weed plants have a random distribution pattern.

Analysis of Environmental Factors Most Related to the Distribution of Invasive Understory Plant Species

Distribution patterns are closely related to environmental conditions (Haruna et al., 2022). The environmental conditions observed included temperature, light, humidity, altitude, and canopy cover, which are categorized as climatic factors (Manuaba et al., 2018). The environmental conditions measured at three transects in the research location, Cisorog Block, Gunung Tilu NR, are presented in Table 5. Based on Table 4, the environmental factors at the research location vary among the three transects. According to Abywijaya et al. (2014), the presence of invasive plants is significantly influenced by temperature, air humidity, sunlight intensity, altitude, geographic location, and the degree of vegetation openness.

The non-overlapping environmental factor lines (Figure 4) indicate that these environmental factors are not strongly correlated with each other. Table 6 shows that sunlight intensity has the highest absolute value in the first component (PC I), while air humidity has the highest value in the second component (PC II). This indicates that sunlight intensity is the most influential variable in PC I, while air humidity is the most influential in PC II. These two factors influence the distribution of invasive understory plants in Cisorog Block, Mount Tilu NR.

Sunlight intensity and air humidity significantly influence the spread of invasive plants (Abywijaya et al., 2014). Invasive plants grow optimally with high light intensity, optimal temperature, and humidity (Ihsan et al., 2021). High sunlight intensity increases carbon absorption in leaf tissues, supporting the growth of invasive plants (Utami & Murningsih, 2018). Cisorog Block in Mount Tilu NR is conducive to the growth of invasive understory plants due to the high sunlight and open areas around the highway. This is consistent with Ihsan et al. (2022), who stated that highways facilitate the entry of plants that adapt to high light intensity.

Invasive plants can grow in average to dry air humidity (40–85%) (Sulistiyowati et al., 2021). Air humidity within this range is essential for optimal growth (Kartikasari et al., 2023). The research location in Cisorog Block, Mount Tilu NR, has ideal humidity (79–83%) for invasive species. Although high humidity usually affects evaporation and plant growth, invasive plants are not impacted due to their high adaptability to the environment (Priyatmoko, 2019).

Canopy cover strongly correlates negatively with the spread of invasive understory plants at the research location. Areas with low canopy cover allow more sunlight to reach the ground, enhancing the growth of invasive plants (Purnomo et al., 2018). Conversely, areas with high canopy cover inhibit the growth and spread of invasive plants (Zulharman, 2017).

CONCLUSION

Based on the research, 39 species of invasive understory plants from 21 families were found at the study site. The species with the highest Important Value Index (IVI) were *Cyrtandra grandis* (93.71%) at transect 1, *Cyperus odoratus* (33.927%) at transect 2, and *Commelina benghalensis* (15.353%) at transect 3. The evenness index of invasive understory plants ranged from 0.65 to 0.85 (high category), and the diversity index ranged from 1.05 to 2.96 (medium category). All invasive understory plant species in Cisorog Block, Mount Tilu NR, exhibited a clustered distribution pattern with a Morisita Index (Ip) >0. Correlation tests and PCA analysis showed that sunlight intensity and air humidity were the main factors most closely related to the distribution of invasive understory plants at the site. Given these findings, controlling invasive plants through regular monitoring, selective removal, and habitat restoration is essential. Regulating human disturbances, enhancing native plant diversity, and maintaining soil moisture can further support conservation efforts. Additionally, engaging local communities and conducting further research on species ecology and adaptive management are crucial to sustaining ecosystem balance.

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