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Vegetation composition, structure and association at site invaded by *Calliandra houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

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Abstract. *Solfiyeni, Winata F, Mildawati, Marisa H. 2024. Vegetation composition, structure and association at site invaded by* Calliandra houstoniana *in Bung Hatta Grand Forest Park, West Sumatra, Indonesia. Biodiversitas 25: 3608-3616.* Invasive plants are plants that can aggressively dominate an ecosystem, thereby disrupting the balance of the ecosystem. Kaliandra (*Calliandra houstoniana* (Mill.) Standl.), an invasive alien plant species, has notably invaded several conservation areas in Indonesia, including Bung Hatta Grand Forest Park, West Sumatra. This study, conducted from October 2023 to February 2024, aimed to analyze the composition, structure and association of vegetation community affected by *C. houstoniana* and investigate the association between *C. houstoniana* and other species within the park. Sampling was conducted using the quadrat method by establishing a 20 × 50 meter observation plot, subdivided into ten 10 × 10 meter subplots for tree level; 5 × 5 meter for sapling and 2 × 2 meter for understorey. We identified all plant species within the sub-plots and measured environmental factors including light intensity, temperature and soil pH. Within the sampling plots, there were 11 families, 13 genera and 14 species at tree level with *C. houstoniana* exhibited the highest Importance Value Index (IVI = 62.96%). At sapling level, there were 9 families and 12 species with the dominance of *C. houstoniana* (IVI = 168.47%). Understorey was composed by 15 families and 19 species with *Clidemia hirta* (L.) D.Don as dominant species (IVI = 29.26%). Shannon-Wienner diversity index (H') was moderate where index for tree, sapling and understory was 2.32, 1.69 and 2.7, respectively. Only a few species managed to coexist and withstand the invasion of *C. houstoniana.* Association tests, including the Chi-Square Test and Jaccard Index, indicated no significant association between *C. houstoniana* and other species. The results of Principal Component Analysis (PCA) show that environmental factors, especially light intensity and air temperature, greatly influenced the presence of the two dominant species *C. houstoniana* and *Falcataria falcata* (L.) Greuter & R.Rankin, while the presence of *Pandanus* sp. is influenced by soil pH. The study demonstrated that *C. houstoniana* negatively impacts the diversity of local species, reducing overall diversity levels in Bung Hatta Grand Forest Park.

Keywords: Association, *Calliandra houstoniana*, composition, structure, trees

Abbreviations: ANDA: Andalas Herbarium; DBH: Diameter at Breas Height; GPS: Global Positioning System; PCA: Principal Component Analysis

INTRODUCTION

Indonesia is a megabiodiversity country with most of its biodiversity stored in forest ecosystems. Data of the Ministry of Environment and Forestry (2018) stated that Indonesia has forest area of 120 million hectares. Despite the large extent of forest area, the biodiversity in Indonesia is increasingly pressured by various factors, mainly due the deforestation and forest degradation, resulting in the disruption of natural habitat of many species which ultimately accelerates the rate of extinction, especially for species that depend on forest ecosystems (Budiharta et al. 2011). For example, Sumatra harbors 73 species of bamboo, with 30 of them being endemic; however, many species remain under threat due to habitat loss and lack of proper conservation efforts (Ritonga et al. 2024a). Amid these threats, new discoveries offer hope for the sustainability of biodiversity. The recent discovery of *Dinochloa malayana* in Sumpur Kudus, West Sumatra, highlights the region's unique bamboo diversity (Ritonga et al. 2024b). Therefore, to overcome the threats to biodiversity, the government has established conservation areas, one of which is the Bung Hatta Grand Forest Park (*Taman Hutan Raya Bung Hatta*) in West Sumatra Province.

Beside habitat loss and degradation, there is emerging threat caused by invasive alien species (Solfiyeni et al. 2022a). Invasive species are species that aggressively dominate an ecosystem, thus disturbing the balance of the ecosystem. Invasive species can affect plant diversity, soil conditions, and microclimate, especially in disturbed ecosystems such as in secondary forests (Solfiyeni et al.

2022b). The spread of invasive species changes community composition, reduces species diversity, disrupts ecosystem processes, and causes massive economic and ecological imbalances in nature (Nayak et al. 2020). Recent studies have shown that the introduction and spread of invasive species are often facilitated by human activities, including land-use changes, global trade, and climate change (Early et al. 2016). Given these significant impacts, addressing invasive alien species becomes crucial for maintaining ecosystem balance.

The study of invasive species that have successfully established in an ecosystem is essential for effective decision-making regarding their management (Gallardo et al. 2019). The extent of invasion, including various measures of the presence and abundance of alien plants in a plant community, needs to be known (Guo et al. 2015). The presence of invasive alien species in a new environment may be attributed to several reasons, such as anthropogenic activities, overgrazing, high tourism and construction (Poudel et al. 2019). Therefore, policies and regulations aimed at preventing the introduction of potentially invasive species should be strengthened. Collaboration between scientists, policymakers, and local communities is essential to effectively address the challenges posed by invasive species (Taylor et al. 2020). This cooperation can support effective management strategies at various levels, especially in conservation areas.

One example of an invasive species in Indonesia is *Calliandra houstoniana* (Mill.) Standl., or locally known as Kaliandra. This plant has been identified as an invasive species in the Invasive Species Compendium (CABI 2017), A Guide Book to Invasive Plant Species in Indonesia (Setyawati et al. 2015), and is listed among 75 Important Invasive Plant Species in Indonesia (Tjitrosoedirdjo et al. 2016). Currently, several conservation areas in Indonesia have been invaded by *C. houstoniana* including Gunung Halimun Salak National Park, Gunung Gede Pangrango National Park, Mount Ciremai National Park, Bukit Barisan Selatan National Park, and Bung Hatta Grand Forest Park. One of conservation areas affected by *C. houstoniana* is Bung Hatta Grand Forest Park, which will be the focus of this study. Managing invasive species such as *C. houstoniana* requires an effective and sustainable management strategy. This involves continuous monitoring, mechanical or chemical control, and collaboration between various stakeholders. Thus, ecosystem balance can be maintained, and biodiversity in conservation areas can be protected from the threat of invasive species.

The *C. houstoniana* is a non-native plant introduced in the Bung Hatta Grand Forest Park. According to the Bung Hatta Grand Forest Park manager, this plant was first introduced in 1991 by the West Sumatra Provincial Forestry Service to be a fire prevention plant. Research by Sahira et al. (2016) in Bung Hatta Grand Forest Park showed that *C. houstoniana* was spread in all vegetation levels, including seedling, saplings, and trees, making it as the dominant species in the vegetation community. The dominance of this species raises concerns about its impact on native biodiversity in the park. Further research is needed to reveal the prevalence of *C. houstoniana* in the Bung Hatta Grand Forest Park. Therefore, this study aims to determine the composition and structure of tree-level vegetation in the area invaded by *C. houstoniana* in Bung Hatta Grand Forest Park, West Sumatra and to understand the association between *C. houstoniana* and other tree species. With this research, it is hoped that effective strategies can be formulated to control *C. houstoniana* invasion and minimize its impact on biodiversity in the conservation area. This is important to maintain ecosystem balance and the ecological function of the Bung Hatta Grand Forest Park.

MATERIALS AND METHODS

Study area and period

The research was conducted in the Bung Hatta Forest Grand Park area, Indaruang Village, Lubuak Kilangan, Padang City, West Sumatra, Indonesia (Figure 1) in October 2023 to Februari 2024. The park is geographically located at 100°17'-100°42' E and 0°32'-1°5' S. The park is positioned along the Padang-Solok main road with the other side of the park is crossed by a small river. The park has an area of 240 Ha, consisting of protected block (64.21 ha), utilization block (117.86 ha), collection block (52.50 ha), and special block (5.43 ha). The annual rainfall is 2,500-4,000 mm, humidity is 52% to 89%, and temperatures range from 19°C to 32°C. The topography is flat, hilly to steep areas with slopes ranging from 10% to 50%. The elevation ranges 460-740 m above sea level.

Data collection procedure

The method used for data collection in this research was the quadratic method. In this study, one observation plot measuring 20 meters × 50 meters was established. The plot was selected using purposive sampling in areas invaded by Kaliandra plants, divided into 10 subplots (10 × 10 meters) for tree vegetation (i.e. woody plants with DBH of ≥10 cm), 5 × 5 meters for sapling (i.e. young woody plants with diameter between 2-10 cm) and 2 × 2 meters for understory (i.e. undergrowth and seedlings with diameter of <2 cm). Plant samples were collected for identification purposes, the supporting characteristics of each species were recorded and documentation was taken to facilitate the identification process. Plant samples were then identified in the Andalas Herbarium (ANDA), Universitas Andalas, West Sumatra, Indonesia. In the field, environmental factors were also measured, including air temperature, air humidity, light intensity and soil pH, which were measured at three points in each subplot in the morning, afternoon and evening during the research.

Data analysis

Data analysis was processed using Microsoft Excel 2010, OriginPro 2024, and PCA analysis using XLSTAT.

Vegetation composition

Plant composition was determined through the following equation:

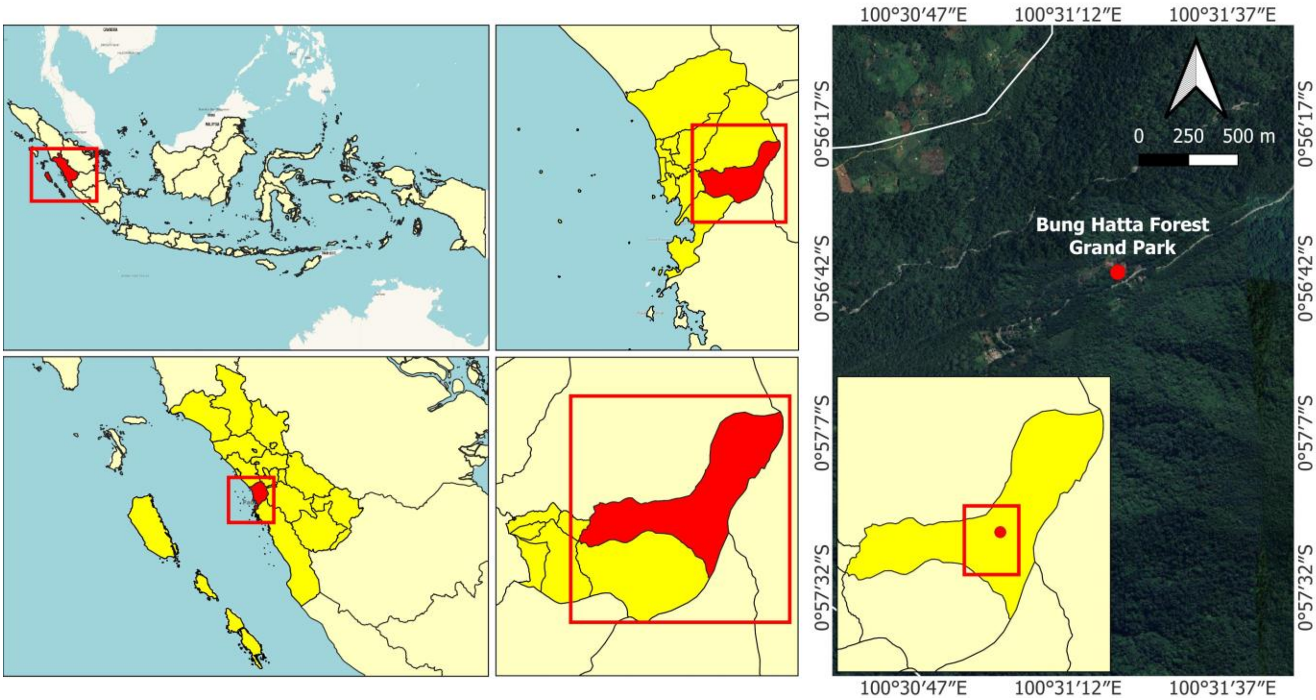

Figure 1. Map of the research location in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

$$\text{Dominant Family} = \frac{\text{Number of individuals in a family}}{\text{Number of individuals of all families}} \times 100\,\%$$

According to Johnston and Gilman (1995), a family is said to be dominant if it has a percentage value of >20%, then a family is said to be co-dominant if it has a percentage value of 10-20%.

Vegetation structure

Vegetation structure was measured as the Importance Value Index (IVI) that describes the importance of a species in its ecosystem.

According to Mueller-Dombois and Ellenberg (1974), to calculate IVI, several vegetation parameters were calculated as follow:

$$\text{Density} = \frac{\text{The number of a species}}{\text{Total area sampled}}$$

$$\text{Relative Density (RDi \%)} = \frac{\text{Density of a species}}{\text{Density of all species}} \times 100\%$$

$$\text{Frequency} = \frac{\text{Total plots of a species occurs}}{\text{Total number of plots used}}$$

$$\text{Relative Frequency (RFi \%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100\%$$

$$\text{Domination} = \frac{\text{Basal area of a species}}{\text{Total area sampled}}$$

$$\text{Relative Dominance (RDo \%)} = \frac{\text{Dominance of a species}}{\text{Dominance of all species}} \times 100\%$$

Important Value Index (IVI%) = Relative Density (RDi) + Relative Frequency (RFi) + Relative Dominance (RDo)

Diversity Index

The species diversity of an area was analyzed using the Shannon-Wienner Index (H') (Odum 1998):

$$H' = -\sum pi \ln pi$$

$$Pi = \frac{ni}{N}$$

Where:

H' : Shannon-Wienner Diversity Index

Pi : The ratio of the number of individuals of a species to the total number of all species

ni : Number of individuals of each species

N : Total number of individuals of all species

Ln : Natural logarithm (logarithm with base e)

The value of the species diversity index (H') is defined as follows:

H'>3 = High species diversity

H'1≤H'≤3 = Moderate species diversity

H'<1 = Low species diversity

Two-species association test

The calculation of the association test uses several formulas following Ludwig and Reynold (1988) including Chi-square test, association type, and association index.

Chi-Square test

The tendency of association can be determined using the Chi-Square test as follows:

$$X^2 = \frac{N\,[\,|(ad)-(bc)| - \left(\frac{N}{2}\right)]^2}{mnrs}$$

Where:

a : Number of plots with species A and B

b : Number of plots with species A only

c : Number of plots with species B only

d : Number of plots with no species A and B

N : Number of observation plots

The statistical significance of the chi-square test was determined by comparing it with the X^2 table value at the free degree = 1 and 5% level (3.84):

If the $X^2 > X^2$ table value = Associations

If the $X^2 < X^2$ table value = No association

Association type

$$E\,(a) = \frac{rm}{N}$$

If a > E (a) = Positive association
If a < E (a) = Negative association
The ratio of a to E (a) is:

$$a - E(a) = \frac{(ad - bc)}{N}$$

Association index

$$\text{Jaccard Index (JI)} = \frac{a}{a+b+c}$$

Where :
a : Number of plots with species A and B
b : Number of plots with species A only
c : Number of plots with species B only

The association index interval ranges from 0-1, where value close to 0 indicates weak association and value close to 1 shows strong association.

RESULTS AND DISCUSSION

Vegetation composition

The family-level composition of tree, sapling and uderstorey vegetation in the site invaded by *C. houstoniana* in Bung Hatta Grand Forest Park is presented in Figure 2. The research results show that the dominant family at the tree level (Figure 2.A) was Fabaceae, accounting for 35.48%, consisting of two genera and two species: *C. houstoniana* with a total of 7 individuals across all subplots and *Falcataria falcata* (L.) Greuter & R.Rankin with a total of 4 individuals. Additionally, two co-dominant families were identified: Pandanaceae and Euphorbiaceae, each with 16.13%. At the sapling level (Figure 2.B), Fabaceae also dominated with 75%
represented by a single species, *C. houstoniana*. At the understory vegetation level (Figure 2.C), the dominant family was Selaginellaceae (22%), with co-dominant families including Melastomataceae, Araceae, and Verbenaceae. The frequent occurrence of *C. houstoniana* in both tree and sapling levels led to the consistent dominance of Fabaceae. In contrast, at the ground vegetation level, *C. houstoniana* was absent, but the invasive shrub *Clidemia hirta* (L.) D.Don dominated.

The tree composition consisted of both pioneer and climax species. The pioneer species included *C. houstoniana*, *F. falcata*, *Macaranga triloba* (Thunb.) Müll.Arg., *M. tanarius* (L.) Müll.Arg., *Cratoxylum sumatranum* (Jack) Blume, *Ficus kerkhovenii* Koord. & Valeton, *Casuarina* sp., while the climax species were *Syzygium aromaticum* (L.) Merr. & L.M.Perry, *Ixonanthes petiolaris* Blume, *Polyscias diversifolia* (Blume) Lowry & G.M.Plunkett, *Symplocos fasciculata* (Roxb.) Zoll., *Oreocnide sylvatica* (Blume) Miq., and *Suregada glomerulata* (Blume) Baill (Feldhaar et al. 2016; Otunola 2022; Kawai et al. 2023). The *C. houstoniana* is classified as a pioneer species due to its ability to grow rapidly and tolerate a wide range of environmental conditions, particularly in open environments with relatively high light intensity. The *F. falcata* is known as a pioneer tree due to its ability to grow rapidly and fix nitrogen, making it highly suitable for the restoration of degraded land. Kawai et al. (2023) demonstrated changes in leaf, wood, and bark characteristics of *F. falcata* as it grows, supporting its role as an effective pioneer species across various land conditions.

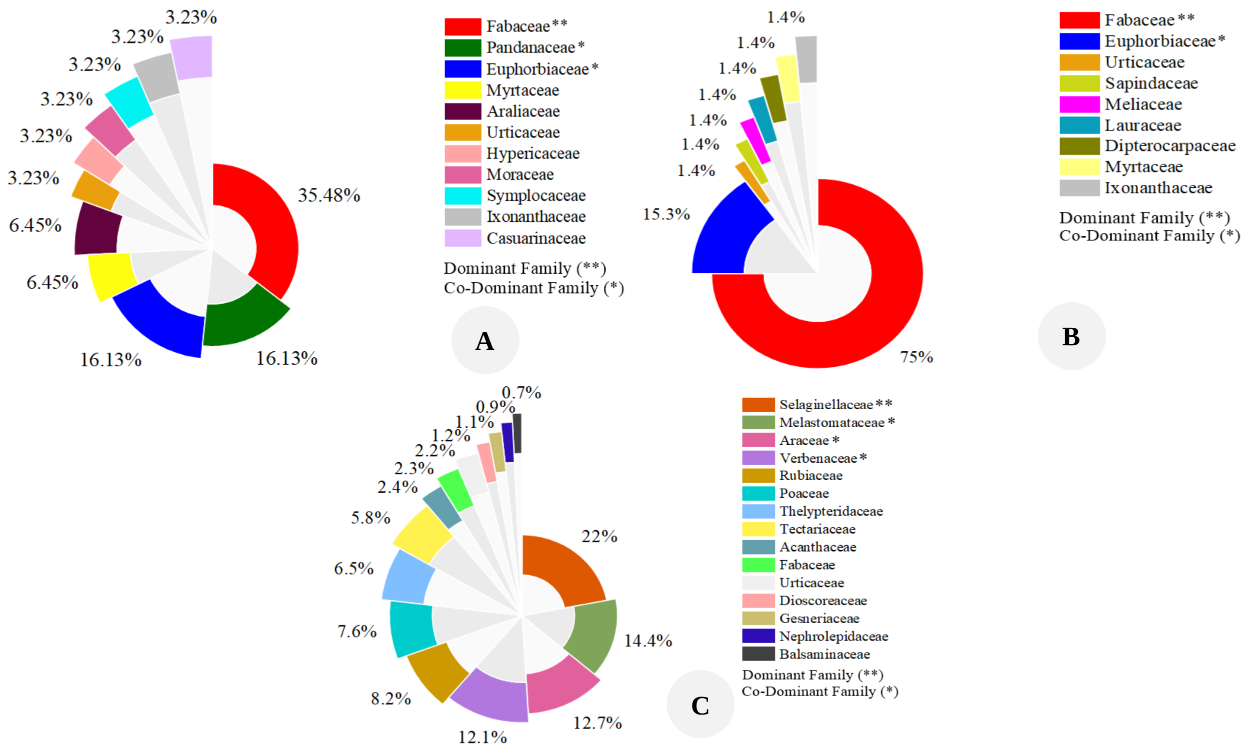

Figure 2. A. Family-level composition of tree; B. Sapling; and C. Understorey vegetation at site invaded by *Calliandra houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

Vegetation structure

The structure of vegetation was analyzed based on Relative Density (RDi), Relative Frequency (RFi), Relative Dominance (RDo) and Importance Value Index (IVI) of each species at tree, sapling, and understorey level as presented in Table 1. The most dominant species at tree level was *C. houstoniana* with an Importance Value Index (IVI) of 62.96%. The *C. houstoniana* had the highest number of individuals compared to other tree species with widespread distribution as indicated by its relative frequency of 24%. However, its basal area was smaller than *Pandanus* sp. and *F. falcata*. This indicates that *C. houstoniana* had a smaller diameter. *Pandanus* sp. and *F. falcata* ranked second and third in dominance, with IVIs of 54.06% and 51.26%, respectively. The high IVI of *C. houstoniana*, *Pandanus* sp., and *F. falcata* shows that these species have a better habitat suitability compared to others at this research site. According to Lillo et al. (2024) and Solfiyeni et al. (2024), species well-suited to their growing habitat tend to have high importance values, indicating their successful adaptation to the local environment. It would be preferable for species with high IVIs to be climax trees, as they play an important role in maintaining the structural integrity of the ecosystem.

At the sapling level, *C. houstoniana* was also highly dominant, with an IVI of 168.47%. It was followed by other pioneer species, *M. depressa* and *M. triloba*, with IVIs of 25.74% and 22.59%, respectively. Other pioneer species found at the sapling level were *M. tanarius* and *V. rubescens*. In addition to the five pioneer species, seven climax tree species were identified. The order of IVIs for saplings showed that pioneer species occupied the top five IVIs, followed by climax trees. Pioneer species are plants that grow and dominate the early stages of succession in an area (Chazdon 2013), while climax trees dominate an ecosystem during the late stages of ecological succession. Based on the species composition in this study, nearly half of the tree and sapling species are pioneers, suggesting that the forest at the study site is a young secondary forest. A young secondary forest is forest at the early stages of succession after disturbances like logging, fire, or other natural changes that disrupt the previous ecosystem. In this initial recovery phase, pioneer tree species play a crucial role (Poorter et al. 2016; Chazdon 2014). According to Gei et al. (2018) and Revilla et al. (2024), pioneer species do not always facilitate the succession process for less tolerant tree species. Some light-demanding pioneer species can inhibit the germination, establishment, and survival of other species intolerant to shade due to their dense canopy, such as pioneers from the Fabaceae family. This aligns with the findings of this study, where one of the identified pioneer species was the invasive *C. houstoniana*, from the Fabaceae family.

A total of 19 species of understrory vegetation were identified at the study site, including shrubs, herbs, small trees, and ferns. No seedlings of tree species, including *C. houstoniana*, were found. The dominant species of the ground vegetation were *C. hirta*, with an IVI of 29.26%, followed by *Selaginella plana* (Desv. ex Poir.) Hieron., with an IVI of 28.34%. Six invasive species were identified among the ground vegetation: *C. hirta*, *S. plana*, *Stachytarpheta indica* (L.) Vahl, *Asystasia gangetica* (L.) T.Anderson, *Mimosa pudica* L., and *Nephrolepis biserrata* (Sw.) Desv. The absence of *C. houstoniana* seedlings in the understory vegetation may be due to its high light requirements for germination and growth, allelopathic compounds from other invasive species, or competition with other ground vegetation species, some of which are also invasive. It is suspected that *Calliandra* seedlings can only establish in more open areas and not under dense canopy shade. Trojak et al. (2022) studied the effects of light and water availability on *Calliandra* seedling growth, emphasizing the importance of light conditions for optimal germination and growth.

As an invasive plant, *C. houstoniana* exhibits traits that allow it to germinate easily and thrive in various environments, including degraded areas. Furthermore, *C. houstoniana* produces up to 1,700 seeds each season, enabling it to rapidly invade an area. Measurements of abiotic environmental factors revealed an average air temperature of 26°C, air humidity of 87%, soil pH of 6.7, and light intensity within the plot at 11.78%. These environmental conditions are favorable for several dominant tree and sapling species in the study area, such as *C. houstoniana*, which can grow in various soil types and is tolerant of acidic soils with a pH of 4.5. It thrives in a daily temperature range of 20-30°C and naturally grows along riverbanks, but it quickly invades disturbed areas (such as roadsides) where the vegetation has been disrupted (Powell 1997). This species does not tolerate shade well and becomes less competitive with other secondary vegetation over time. These conditions match the research site, which is located near a roadside and riverbank, with its distribution decreasing or even absent in areas with dense canopy cover.

The Shannon-Wiener Diversity Index

The Shannon-Wienner index at the site invaded by *C. houstoniana* in Bung Hatta Grand Forest Parkin is presented in Figure 3. The dominance of *C. houstoniana* as an invasive species has reduced the survival of other species, leading to a decrease in species count and Shannon-Wiener diversity index values. Both pioneer and non-pioneer species diversity and richness decline as invasion intensity increases (Bempah et al. 2021). In this study, the Shannon-Wiener Diversity Index (H') for tree vegetation was 2.32, while that for saplings and understory vegetation were 1.69 and 2.7, respectively, indicating moderate diversity. Similar findings were reported in previous studies on areas invaded by *Bellucia pentamera* Naudin in PT. Kencana Sawit Indonesia (PT. KSI) conservation forest, with diversity index values for trees, saplings, and understory plants of 1.78, 2.12, and 1.8, respectively (Solfiyeni et al. 2022b; Solfiyeni et al. 2024). In the Harau Valley Nature Reserve, which is also invaded by *B. pentamera*, the diversity index values were 2.6 for trees, 1.35 for saplings, and 1.84 for understory plants, indicating moderate diversity.

In contrast, within the similar forest area but not invaded by invasive plants, it had higher diversity index values, reaching up to 4.05 (Solfiyeni et al. 2022b). The Species Diversity Index (H') is a measure used to describe the level of species diversity within a vegetation community. The higher the diversity index value, the more diverse the species within the community, which in turn indicates that the community tends to be more stable. Invasive plants pose a threat to ecosystems and environmental stability. According to Rundel et al. (2016), environmental stability and adaptation are crucial factors in increasing species richness. Species diversity in a community is determined by the number of species and individuals present. According to Rahman et al. (2023), species diversity is a measure of a species' resilience to environmental change. The high density and frequency of *C. houstoniana* have allowed this species to dominate the study site, leaving few other species present in the area. Besides the influence of invasive plant species, habitat suitability factors, such as temperature, humidity, light intensity and altitude, also affect vegetation composition in an area (Solfiyeni et al. 2024). Gojamme (2024) stated that the composition and species in a community are influenced by a combination of multiple significant environmental factors, not just one.

Table 1. Vegetation structure of trees, saplings and understorey at habitat invaded by *Calliandra houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

Species	Family	RDi (%)	RFi (%)	RDo (%)	IVI (%)
Tree					
Calliandra houstoniana (Mill.) Standl.	Fabaceae	22.58	24	16.38	62.96
Pandanus sp.	Pandanaceae	16.13	12	25.93	54.06
Falcataria falcata (L.) Greuter & R.Rankin	Fabaceae	12.90	12	26.35	51.26
Macaranga triloba (Thunb.) Müll.Arg.	Euphorbiaceae	9.68	8	2.60	20.28
Syzygium aromaticum (L.) Merr. & L.M.Perry	Myrtaceae	6.45	8	4.29	18.74
Ixonanthes petiolaris Blume	Ixonanthaceae	3.23	4	10.17	17.39
Polyscias diversifolia (Blume) Lowry & G.M.Plunkett	Araliaceae	6.45	4	2.19	12.64
Macaranga tanarius (L.) Müll.Arg.	Euphorbiaceae	3.23	4	4.17	11.40
Cratoxylum sumatranum (Jack) Blume	Hypericaceae	3.23	4	2.49	9.71
Ficus kerkhovenii Koord. & Valeton	Moraceae	3.23	4	1.76	8.99
Symplocos fasciculata (Roxb.) Zoll.	Symplocaceae	3.23	4	1.11	8.33
Oreocnide sylvatica (Blume) Miq.	Urticaceae	3.23	4	0.98	8.21
Suregada glomerulata (Blume) Baill.	Euphorbiaceae	3.23	4	0.79	8.01
Casuarina sp.	Casuarinaceae	3.23	4	0.79	8.01
Sapling					
Calliandra houstoniana (Mill.) Standl.	Fabaceae	75	37.04	56.44	168.47
Macaranga depressa (Müll.Arg.) Müll.Arg.	Euphorbiaceae	5.56	14.81	5.37	25.74
Macaranga triloba (Thunb.) Müll.Arg.	Euphorbiaceae	5.56	11.11	5.92	22.59
Swietenia macrophylla G.King	Meliaceae	1.39	3.70	6.93	12.02
Macaranga tanarius (L.) Müll.Arg.	Euphorbiaceae	2.78	7.41	1.24	11.43
Villebrunea rubescens (Blume) Blume	Urticaceae	1.39	3.70	5.22	10.32
Ixonanthes petiolaris Blume	Ixonanthaceae	1.39	3.70	5.00	10.09
Syzygium aromaticum (L.) Merr. & L.M.Perry	Myrtaceae	1.39	3.70	4.16	9.25
Nephelium lappaceum L.	Sapindaceae	1.39	3.70	4.57	9.66
Suregeda glomerulata (Blume) Baill.	Euphorbiaceae	1.39	3.70	2.96	8.05
Dipterocarpus gracilis Blume	Dipterocarpaceae	1.39	3.70	1.17	6.26
Litsea rubiginosa (Blume) Boerl.	Lauraceae	1.39	3.70	1.02	6.11
Understorey					
Clidemia hirta (L.) D.Don	Melastomataceae	14.36	14.89	-	29.26
Selaginella plana (Desv. ex Poir.) Hieron.	Selaginellaceae	21.96	6.38	-	28.34
Borreria laevis (Lam.) Griseb.	Rubiaceae	8.23	10.64	-	18.87
Homalomena rubescens (Roxb.) Kunth	Araceae	8.14	8.51	-	16.65
Stachytarpheta indica (L.) Vahl	Verbenaceae	8.60	6.38	-	14.98
Christella dentata (Forssk.) Brownsey & Jermy	Thelypteridaceae	6.13	8.51	-	14.64
Centhotheca lappacea (L.) Desv.	Poaceae	7.59	6.38	-	13.98
Heterogonium pinnatum (Copel.) Holttum	Tectariaceae	5.76	4.26	-	10.02
Asystasia gangetica (L.) T.Anderson	Acanthaceae	2.38	6.38	-	8.76
Raphidophora sp.	Araceae	2.47	4.26	-	6.73
Mimosa pudica L.	Fabaceae	2.29	4.26	-	6.54
Stachytarpheta urticifolia Sims	Verbenaceae	3.48	2.13	-	5.60
Nephrolepis biserrata (Sw.) Desv.	Nephrolepidaceae	0.91	4.26	-	5.17
Elatostema sp.	Urticaceae	2.20	2.13	-	4.32
Dioscorea alata L.	Dioscoreaceae	1.19	2.13	-	3.32
Homalomena sp.	Araceae	2.10	2.13	-	4.23
Cyrtandra pendula Blume	Gesneriaceae	1.10	2.13	-	3.23
Impatiens sp.	Balsaminaceae	0.73	2.13	-	2.86
Christella parasitica (L.) H.Lév.	Thelypteridaceae	0.37	2.13	-	2.49

Table 2. Association test between *Calliandra houstoniana* and other tree species at site invaded by *C. houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

Species	*C. houstoniana*		
	X^2 table	X^2	Jaccard Index
Macaranga triloba	3.84	1.276	0.0
Syzygium aromaticum	3.84	0.234	0.14
Pandanus sp.	3.84	0.179	0.29
Falcataria falcata	3.84	0.179	0.29
Ixonanthes petiolaris	3.84	0.046	0.17
Polyscias diversifolia	3.84	0.046	0.17
Macaranga tanarius	3.84	0.046	0.17
Symplocos fasciculata	3.84	0.046	0.17
Cratoxylum sumatranum	3.84	0.046	0.17
Oreocnide sylvatica	3.84	0.046	0.17
Suregada glomerulata	3.84	0.046	0.17
Ficus kerkhovenii	3.84	0.038	0.0
Casuarina sp.	3.84	0.038	0.0

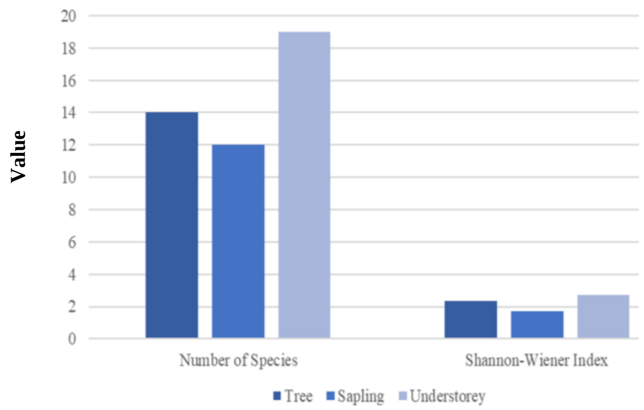

Figure 3. Number of species and the Shannon-Wiener Biodiversity Index of trees, saplings, and understorey at site invaded by *Calliandra houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

Association of *C. houstoniana* with other species

The results of the association test between *C. houstoniana* and other species are presented in Table 2, which shows that all the calculated X^2 values obtained are smaller than the X^2 table value at the free degree = 1 and 5% level (3.84). If the calculated X^2 value obtained <3.84 at the 5% probability level means that there is no association (Ludwig and Reynold 1988). The absence of association between species indicates that, directly or indirectly, the population distribution tends to show relatively independent characteristics, such as living separately and not influencing each other (Su et al. 2015). The absence of association between *C. houstoniana* and other species means that the presence of *C. houstoniana* does not depend on surrounding plant species that also dominate the location. The *C. houstoniana* can increase its potential as an invasive plant invading the area if environmental factors support its growth.

In addition to using the Chi-Square Test to assess association tendencies, the Jaccard Index was used to measure the level of association between species based on their presence or absence. According to Ludwig and Reynolds (1988), association is measured on a scale from 0 to 1, with 0 indicating no association and 1 indicating maximum association. In Table 2, the Jaccard Index values are far from 1, indicating that no clear association exists between the presence of other species and *C. houstoniana*. The Jaccard Index is based on the presence of plants within the same plot. When two species are rarely found together in the same plot, it suggests that there is no positive spatial relationship between *C. houstoniana* and other species. A positive spatial relationship occurs when species tend to grow near each other if one partner is found during sampling (Stein et al. 2014).

The analysis of association may also be due to competition among species. According to Anthelme et al. (2014), plants in lowland areas compete more intensively for light and nutrients, while in higher elevations, plants benefit from improved microclimates created by nurse plants or overall vegetation. Nurse plants provide shelter, shade, and better microclimate conditions for the growth of other plants (El Amrani 2023). This may explain why in areas invaded by *C. houstoniana*, its dominance likely makes it difficult for other species to compete. The species present in the study site may be those capable of competing with *C. houstoniana*, whose presence is not influenced by the presence of *C. houstoniana*.

Relationship between the presence of three dominant tree species and environmental factors

Environmental factors measured in the field included air temperature, air humidity, light intensity, and soil pH. The relationship between environmental factors and the presence of three dominant species, *C. houstoniana*, *Pandanus* sp., and *F. falcata*, was analyzed using PCA. The analysis revealed that the most influential environmental factors were light intensity and air temperature (Figure 4). The microclimate in a vegetation community is influenced by the canopy cover of the vegetation. The light intensity reaching below the tree and sapling canopy affects the temperature and humidity within the plot. The *C. houstoniana*, *Pandanus* sp., and *P. falcataria* are pioneer species that are thought to have grown first in the open area with high light intensity, thus dominating the study site. The *C. houstoniana* has the highest correlation with sunlight intensity and air temperature at the site. This aligns with its growth trait, as *C. houstoniana* prefers open areas and does not tolerate shade. Additionally, Solfiyeni et al. (2024) noted that invasive species can alter abiotic factors such as light intensity, air temperature, and humidity because their canopy is not as dense as that of climax trees. The competition among invasive species changes the vegetation structure, as seen with the presence of *B. pentamera* in the Harau Valley Nature Reserve and PT. KSI conservation area, leading to a reduction in the number of species and diversity indices for trees, saplings, and understory plants.

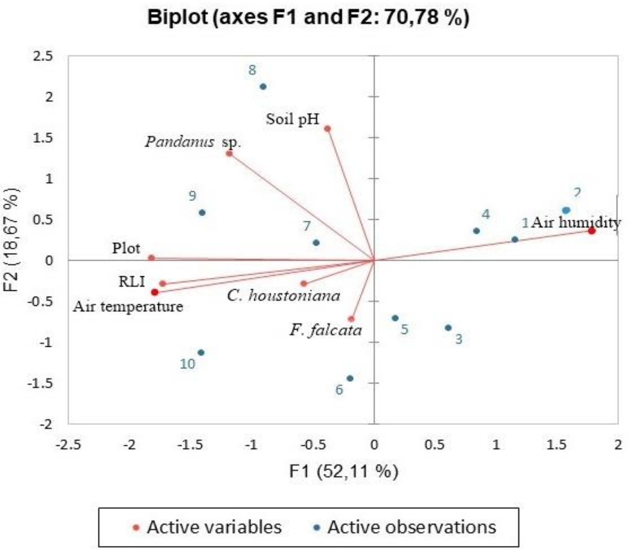

Figure 4. Relationship analysis of the presence of three dominant species with environmental factors using PCA

Invasive species pose a major threat to global biodiversity and are a primary cause of biotic homogenization in ecosystems (Olden et al. 2016). The loss of local biodiversity and biotic homogenization can reduce the long-term stability of ecosystem functions over larger spatial scales (Wang and Loreau 2016). According to Wang et al. (2021) preserving local biodiversity is essential to maintaining ecosystem stability over larger spatial scales. The *C. houstoniana* is an invasive alien species that can rapidly dominate an area. Nyiramvuyekure and Mugunga (2023) explains that *C. houstoniana* must be carefully managed, as its invasive spread can threaten biodiversity through exponential population growth.

In conclusion, the invasion of *C. houstoniana* affects plant diversity in Bung Hatta Grand Forest Park, West Sumatra. Nearly half of the tree and sapling species were pioneer species, and the dominant species in the tree, sapling, and understorey layers were invasive alien species, which can slow the successional process toward a climax community. There is no association between *C. houstoniana* and other species, and environmental factors, especially light intensity and temperature have a significant influence on the presence of *C. houstoniana*. Continuous monitoring of these factors is crucial for managing areas vulnerable to further invasion. Adaptive management practices, such as altering canopy cover, may help control the growth of *C. houstoniana*. Since no association between *C. houstoniana* and other species was found, additional studies should explore the potential long-term impacts of this invasion on ecosystem processes and species interactions, thereby helping to refine control strategies.

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