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Diversity and composition of invasive understory plants in Kapalo Banda Taram Ecotourism Area, West Sumatra, Indonesia

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Abstract. *Nurhasanah D, Solfiyeni, Mufti HM, Maideliza T. 2025. Diversity and composition of invasive understory plants in Kapalo Banda Taram Ecotourism Area, West Sumatra, Indonesia. Biodiversitas 26: 4500-4510.* Invasive plants are species that establish and spread rapidly outside their natural habitats, often dominating new environments. This study aims to analyze the composition, structure, and diversity of invasive understory plants (seedlings and ground vegetation) in the Kapalo Banda Taram Ecotourism Area, Lima Puluh Kota District, West Sumatra Province, Indonesia. This study used a survey method using two transects with purposive sampling. Location 1 (transect 1) in the eastern part and Location 2 (transect 2) in the southern part of the area. The length of each transect was 50 meters, and along the transect, 25 plots measuring 2×2 meters were systematically placed on each transect. In each plot, observations were made regarding the presence of species, the number of individuals, and environmental factors. Results showed that in Location 1, there were 18 families, 26 genera, 26 species, and 1,213 individuals of understory plants, including 9 invasive families, 14 genera, 14 species, and 1,168 individuals. In Location 2, there were 9 families, 16 genera, 17 species, and 734 individuals, with 5 invasive families, 10 genera, 10 species, and 614 individuals. The dominant families in Location 1 were Melastomataceae (31.16%), Cyperaceae (28.85%), and Poaceae (28.28%), with *Cyperus rotundus* as the most dominant species (IVI: 43.92%). In Location 2, Asteraceae dominated (50.14%), with *Chromolaena odorata* as the most dominant species (IVI: 57.52%). The Shannon-Wiener diversity index (H') indicated moderate diversity, with values of 2.34 and 2.26. Canonical Correspondence Analysis (CCA) revealed that environmental factors such as light intensity, humidity, temperature, and soil pH significantly influence the distribution and dominance of invasive understory species. This study provides valuable insights into the management of invasive plants in the Kapalo Banda Taram Ecotourism Area, aiding conservation and sustainable tourism efforts.

Keywords: Biodiversity, composition, ecotourism, Kapalo Banda Taram, structure

INTRODUCTION

In recent years, the rate of deforestation has increased markedly, driven primarily by land conversion and illegal logging (Setyawati 2015). This environmental degradation has reduced native vegetation cover and deteriorated ecosystem services including triggering floods and landslides, caused biodiversity loss while simultaneously created conditions that facilitate the spread of invasive alien plant species. Invasive alien species are a growing global challenge, attracting international concern because of their escalating spread and the profound negative impacts they impose on biodiversity, ecosystem services, and human well-being (IPBES 2023). Invasive alien plants are particularly concerning, as they can grow rapidly, outcompete native flora, and dominate entire ecosystems, often resulting in the extinction of native species or altering habitats to the point where native organisms can no longer survive (Tjitrosoedirdjo et al. 2016a, b; Solfiyeni and Nurmalasari 2025).

Indonesia, as a megadiverse archipelago, is especially vulnerable to biological invasions due to its rapid land-use change and frequent ecosystem disturbances. Among its islands, Sumatra is particularly at risk. This island, home to extensive lowland and montane rainforests, contains globally significant biodiversity. However, these forests are increasingly degraded by logging activities and fragmented by large-scale oil palm plantations, infrastructure development, and settlement expansion (Solfiyeni et al. 2022a, b). Such transformations not only reduce habitat continuity but also create ecological gaps that favor the establishment and spread of invasive plant species. In Sumatra, invasive species increasingly threaten both primary forests and regenerating secondary forests. They often colonize disturbed areas where native vegetation has been degraded, enabling them to dominate the resources for growth like light, water, and nutrients. The invasion of alien species results in shifts in species interactions, alterations in nutrient cycling, and reduced ecological resilience. There are several dangerous invasive species in Indonesia including *Chromolaena odorata*, *Mikania micrantha*, and *Bellucia pentamera*. These plants share traits such as rapid growth, prolific seed production, long-distance dispersal mechanisms, and a high degree of environmental adaptability-characteristics common to successful invaders (Huda et al. 2022; Solfiyeni et al. 2024a).

There are several introduction pathways of invasive alien species. Some species were brought intentionally to be propagated for ornamental, agricultural and forestry purposes, while others arrived unintentionally via human activities such as tourism, trade, and logging. For instance, *B. pentamera* was initially introduced through botanical collections but has since escaped cultivation and proliferated in natural areas. In West Sumatra, its spread along riverbanks is believed to be facilitated by ecotourism activity and minimal post-introduction management (Solfiyeni et al. 2024a). Once established, species like *B. pentamera* are difficult to control, as they regenerate rapidly and inhibit the regeneration of native flora.

Several studies in West Sumatra have documented the impacts of invasive plants on local ecosystems. In protected and managed landscapes such as Silokek Geopark, Bukit Langkisau, and areas surrounding industrial plantations, invasive species have been shown to reduce native plant diversity and alter microclimatic conditions-such as lowering soil moisture and increasing surface temperatures-further stressing native vegetation (Solfiyeni et al. 2022a). Despite these impacts, detailed ecological assessments-particularly of understory vegetation in ecotourism areas-remain limited. This lack of data hinders the development of targeted and effective management strategies. One area of growing concern with the presence of invasive plants is the Kapalo Banda Taram Ecotourism Area, located in Lima Puluh Kota District, West Sumatra Province. The site encompasses diverse ecosystems, including forested hills, riverine zones, and lowland vegetation. It harbors a rich array of plant life, particularly in the understory layer, which includes herbs, grasses, shrubs, and seedlings. These plants contribute significantly to forest functions such as nutrient cycling, erosion control, and microclimate regulation (Rasiska et al. 2023). They are also highly sensitive to changes in light, humidity, temperature, and soil pH, making them reliable indicators of ecological disturbance (Mestre et al. 2017). Moreover, many understory species in this area hold ethnobotanical importance for local communities, with uses in traditional medicine, food, and household materials. However, initial field observations and interviews suggested that several of these plants may be invasive or non-native, exhibiting aggressive growth patterns, high reproductive rates, and the ability to suppress surrounding vegetation. Unfortunately, scientific documentation on the composition and ecological roles of these invasive understory species is still lacking.

To address this critical knowledge gap, the present study examines the composition, structure, and diversity of invasive understory plants across the eastern and western slopes of the Kapalo Banda Taram area. Using systematic field methods and ecological analyses, the study aims to identify dominant invasive species, evaluate the environmental variables influencing their distribution, and provide evidence to inform site-specific conservation strategies. This research is particularly timely given the increasing intersection between conservation and tourism in the region. In parallel, efforts to manage invasive plants must also prioritize the conservation of vulnerable native and endemic species. In Sumatra, several bamboo taxa, integral to ecological and cultural landscapes, are listed in the IUCN Red List and face heightened risk due to competition with invasive plants (Ritonga et al. 2023). Protecting these species requires a comprehensive approach that includes habitat restoration, ecological monitoring, public education, and sustainable tourism planning. Ultimately, mitigating the spread of invasive plants in ecologically sensitive areas such as Kapalo Banda Taram is essential not only for preserving biodiversity but also for maintaining the ecological integrity of landscapes that sustain local livelihoods, cultural heritage, and nature-based tourism.

MATERIALS AND METHODS

Study area and period

This research was conducted in the Kapalo Banda ecotourism area located in Kenagarian Taram, Harau District, Lima Puluh Kota District, West Sumatra Province, Indonesia. The collection of research data was carried out in November 2024 to February 2025 at the Kapalo Banda Taram ecotourism area. This area is on the edge of the forest and crossed by a river, which is then dammed into an irrigation lake, useful for irrigating rice fields and plantations owned by the surrounding community, which provides natural beauty that is still maintained. Kapalo Banda tourist attraction has an area of 10.5 km^2 with an average altitude of 250 meters above sea level. This tourist attraction is 134 km from Padang (the provincial capital of West Sumatra), 8 km from the Sarilamak district capital, and 5 km from Kenagarian Harau. Two locations were selected to observe the spread of invasive plants in this area: the eastern side of the hills near the river (Location 1) and the southern side, far from the river (Location 2). The distance between locations 1 and 2 is approximately 360 m. Geographically, this area is located at 0°11'29.4' S 100°43'10.3' E (Figure 1).

Data collection

This study used transect method by establishing two transects, i.e., namely Location 1 on the east side and Location 2 on the south side, each with a length of 50 m (Figure 2). Along the transect, 25 plots measuring 2×2m were made with the placement of plots systematically alternating right and left (Figure 2). In each plot, observations were made to document understory species and the number of individuals of each species. Environmental factors measured in all plots, such as light intensity using a lux meter, air temperature using a thermometer, soil pH using a soil tester, and air humidity using a thermo-hygrometer were measured. The invasive plants documented within the sampling plots were collected for identification at Herbarium Andalas (ANDA), West Sumatra, by comparing them with existing specimens and matching them with official websites such as Global Biodiversity Information Facility (GBIF) and Plant of the World Online (POWO). Invasive plant species were identified using plant identification reference books, namely “75 Important Invasive Plant Species in Indonesia” (Tjitrosoedirdjo et al. 2016b) and “A Guide Book to Invasive Alien Plant Species in Indonesia” (Setyawati 2015), and other publications related to invasive plants.

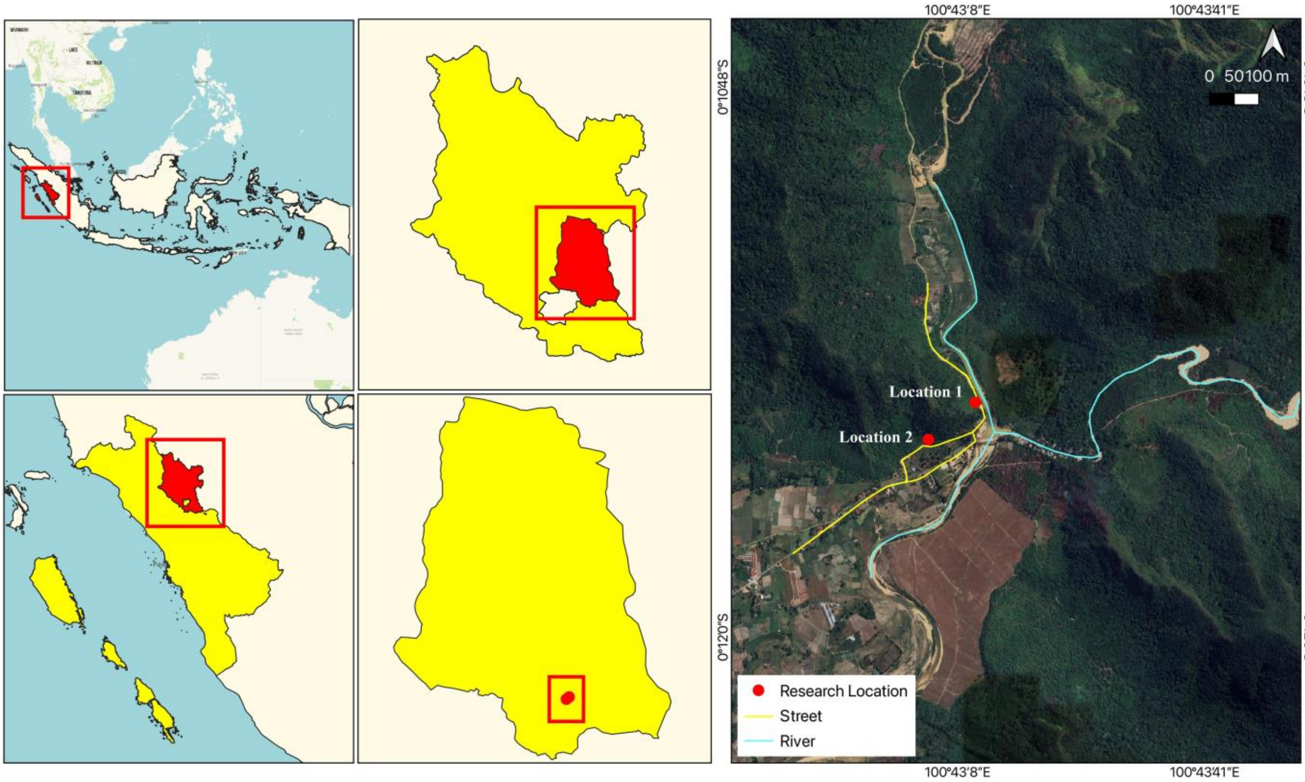

Figure 1. Research location map of the Kapalo Banda Taram Ecotourism Area in West Sumatra, Indonesia

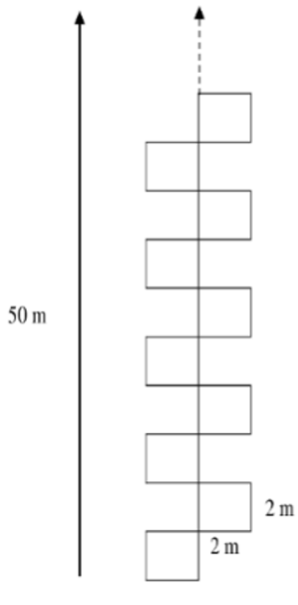

Figure 2. Layout of 25 systematically placed 2×2 m plots along two 50-meter transects for understory vegetation sampling

Data analysis

Vegetation composition

Composition is the arrangement of species based on the number of individuals of each species which can inform the dominant and co-dominant families. A list of families, genera, species, and number of individuals in the area will be presented in table form. The dominant and co-dominant families were analyzed as follows:

$$\text{Dominant family and co} - \text{dominant family} = \frac{\text{Number of individuals in a family}}{\text{Number of individuals in all families}}\, x\ 100\%$$

Dominant family if it has a percentage value of > 20% while co-dominant family if it has a percentage value of 10-20% (Johnston and Gillman 1995).

Invasive plant structure

Importance Value Index (IVI). Importance Value Index (IVI) indicates the ecological position of a species within vegetation community. IVI is the sum of Relative Density and Relative Frequency of a species and calculated as follow Mueller-Dombois and Ellenberg (1974):

$$\text{Density of a species} = \frac{\text{Total number of individuals}}{\text{Sample plot size}}$$

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

$$\text{Frequency of a species} = \frac{\sum subplots\ found\ a\ species}{\sum all\ sample\ subplots}$$

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

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

Species Diversity Index. Species diversity was calculated using the Shannon-Weiner Diversity Index (Odum 1998) as follows:

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

$$pi = ni / N$$

Where, H: Shannon-Weiner diversity Index, pi: Index of each species (ni/N), ni: Importance Value, N: Total number of importance values of all individuals, ∑: Number of individual species.

The diversity and abundance of a species are influenced by environmental components, both biotic and abiotic. According to Mueller-Dombois and Ellenberg (1974), the greater H 'indicates the higher the species diversity. The value of species diversity based on Shannon-Weiner is categorized as follows: H'>3 indicates high diversity, 1≤H'≤3 indicates moderate diversity, and H'<1 indicates low diversity.

Sorensen Similarity Index

$$IS = \frac{2C}{(A+B)} X\ 100\%$$

Where, IS: Sorensen Species Similarity Index, A: Number of plant species in area 1, B: number of plant species in area 2, C: number of plant species that are the same in both areas.

IS value <50% indicates a low level of similarity, IS value >50% indicates a high level of similarity.

Canonical Correlation Analysis (CCA) was analyzed using Paleontological Statistics (PAST) software version 3:04 (Hammer 2014).

Explanation: The correlation value between variables in CCA analysis: 0 means there is no correlation, CCA: 0-0.25 means the correlation is very weak, CCA: 0.25-0.5 means the correlation is moderate, CCA: 0.5-0.75 indicates a strong correlation, CCA: 0.75-0.99 indicates a very strong correlation, and CCA: 1 indicates a perfect correlation (Clarke and Gorley 2005).

RESULTS AND DISCUSSION

Vegetation composition

At Location 1, a total of 1,213 individuals of understory plant were recorded, representing 18 families, 26 genera, and 26 species. Among these, 1,168 individuals from 14 species were invasive. In Location 2,734 individuals were documented, consisting of 9 families, 16 genera, and 17 species, including 614 individuals from 10 invasive species. In Location 1, dominant families included Melastomataceae (31.16%), Cyperaceae (28.85%), and Poaceae (28.28%). In Location 2, Asteraceae dominated (50.14%), with co-dominance by Poaceae (12.40%) and Polypodiaceae (11.72%) (Table 1). Melastomataceae dominance in Location 1 was primarily driven by three invasive species: *Melastoma malabathricum*, *B. pentamera*, and *Clidemia hirta*. Similarly, the Cyperaceae family was represented mainly by *Cyperus rotundus*, while *Megathyrsus maximus* dominated Poaceae. In Location 2, *C. odorata* (Asteraceae) was the most dominant invasive species.

At Location 1, Melastomataceae family had the highest number of individuals, totaling 378 across three species. This family is characterized by its small, numerous fruits and seeds, which facilitate rapid and widespread dispersal. All species of Melastomataceae identified in the research area are invasive plants, specifically *M. malabathricum, B. pentamera,* and *C. hirta* (Setyawati 2015; Tjitrosoedirdjo et al. 2016a, b). The Melastomataceae family comprises a group of pioneer plants commonly found in disturbed tropical rainforests. This family exhibits a diverse range of growth forms, including trees, shrubs, woody vines, and herbs, and thrives in various habitats, from lowland tropical forests to mountainous regions, savannas, and disturbed secondary vegetation (Veranso-Libalah et al. 2017). Notable species within the Melastomataceae family include *M. malabathricum* and *C. hirta*, both of which are prevalent as weeds and recognized as pioneer species due to their seeds' rapid germination. In contrast, *B. pentamera* is a tree that produces fruit year-round, characterized by its abundant fruits and seeds (Solfiyeni et al. 2022b).

The Cyperaceae family is also the dominant plant family in Location 1. This dominance may be attributed to the large number of species within the Cyperaceae family. Govaerts et al. (2020) noted that the Cyperaceae family is highly diverse, comprising 100 genera and approximately 2,000 species distributed across various climates worldwide. Additionally, factors contributing to the population growth of the Cyperaceae family include inherent characteristics such as high reproductive rates, rapid growth, and natural processes that facilitate their expansion (Reznicek 2022). This family can thrive in nearly all open and sheltered areas, both in tropical and subtropical regions. In contrast, the Poaceae family is more prevalent in temperate regions. This observation is supported by research conducted by Večeřa et al. (2021), which indicates that the Poaceae family is commonly found in forests, shrubs, and grasslands, but is less abundant in wetland areas.

At Location 2, the Asteraceae family dominated 50.15% of the total plant population. This family is characterized by the highest number of individuals, totaling 368 across 5 species. The Asteraceae family is one of the largest groups of flowering plants, encompassing more than 1,600 genera and 25,000 species distributed worldwide. Notable species within this family include kirinyuh, chicory, sunflower, lettuce, coreopsis, dahlia, and daisy, as well as several important medicinal plants such as wormwood, chamomile, and dandelion (Nikolić and Stevović 2015). The Asteraceae family is also recognized as a cosmopolitan group of plants due to its extensive distribution across various regions, including temperate, cold, and subtropical areas (Medeiros-Neves et al. 2018).

Members of this family exhibit high adaptability, allowing them to thrive in a variety of environmental conditions, including disturbed areas. Some Asteraceae species act as pioneer plants that appear on disturbed lands, such as post-coal mine lands. This is supported by research conducted by Hapsari et al. (2020), which also found that the invasive species *C. odorata* from the Asteraceae family, characterized by rapid growth and development, has seeds with long-term viability. Additionally, some Asteraceae species are recognized as invasive plants that can disrupt natural ecosystems. For instance, *C. odorata* and *M. micrantha* are two invasive species that rapidly proliferate in open land, along forest edges, and in agricultural regions. These species possess a remarkable ability to regenerate, produce large quantities of seeds. They can inhibit the growth of native species through allelopathy, the release of chemical compounds that suppress the germination and growth of other plants (Yu et al. 2016).

Importance Value Index (IVI)

Based on the analysis of understory vegetation structure in both locations, distinct species were identified. The dominant species, as indicated by the highest Importance Value Index (IVI), also varied between the two sites. The relative frequency, relative density, and index of importance for each species in both locations are presented in Table 2.

Based on the results of Table 2, the top ten species according to the Importance Value Index (IVI) at both study locations were dominated by invasive species, with eight of the ten species being invasive. At Location 1, 26 understory plant species were found, of which 14 were invasive (>50%), while at Location 2, there were 17 species, of which ten were invasive (58%). This means that more than half of the understory plant diversity at both sites consisted of invasive species. The most dominant species were *C. rotundus* with an IVI of 43.92% at Location 1 and *C. odorata* with an IVI of 57.52% at Location 2. Meanwhile, the lowest IVI values were found in non-invasive species such as *Grona heterocarpos* and *Hippobroma longiflora* (0.77%) at Location 1, and *Mallotus apelta* (1.01%) at Location 2. Whereas, *G. heterocarpos* and *H. longiflora* at Location 1 are native plants in the area, *M. apelta* at Location 2 is not a native plant. IVI is an important parameter that indicates the distribution and dominance of a species in a vegetation community (Huda et al. 2022; Solfiyeni et al. 2024b). High IVI values of invasive species indicate a potential ecological threat from them, which often inhibit the growth of native plants through intense competition for light, water, and nutrients, as well as through allelopathic mechanisms, namely the release of chemical compounds that are detrimental to other plants (Zhang et al. 2021).

Table 1. Composition of understory plants in the Kapalo Banda Taram Ecotourism Area in West Sumatra, Indonesia

Family	Genus	Species	Number of individuals	Percentage (%)
Location 1				
Melastomataceae**	3	3	378	31.16
Cyperaceae**	1	1	350	28.85
Poaceae**	1	1	343	28.28
Location 2				
Asteraceae**	5	5	368	50.14
Poaceae*	3	3	91	12.40
Polypodiaceae*	1	1	86	11.72

Notes: **: Dominant family *: Co-dominant family

Table 2. Ten dominant species of understory plants with the highest Relative Density (RDi), Relative Frequency (RFi), and Importance Value Index (IVI) in the Kapalo Banda Taram Ecotourism Area in West Sumatra, Indonesia

Species	Family	RDi(%)	RFi(%)	IVI (%)	Information
Location 1					
Cyperus rotundus	Cyperaceae	28.85	15.07	43.92	Invasive
Megathyrsus maximus	Poaceae	28.28	15.07	43.34	Invasive
Clidemia hirta	Melastomataceae	19.13	14.38	33.51	Invasive
Bellucia pentamera	Melastomataceae	8.41	10.27	18.68	Invasive
Melastoma malabathricum	Melastomataceae	3.63	8.22	11.85	Invasive
Clibadium surinamense	Asteraceae	3.96	5.48	9.44	Invasive
Acacia mangium	Fabaceae	1.07	6.16	7.23	Invasive
Clitoria laurifolia	Fabaceae	0.99	4.79	5.78	Non-invasive
Trema tomentosa	Cannabaceae	0.99	3.42	4.41	Non-invasive
Spermacoce alata	Rubiaceae	0.82	2.74	3.56	Invasive
Location 2					
Chromolaena odorata	Asteraceae	36.65	20.87	57.52	Invasive
Mikania micrantha	Asteraceae	9.54	15.65	25.19	Invasive
Nephrolepis biserrata	Polypodiaceae	11.72	9.57	21.28	Non-invasive
Megathyrsus maximus	Poaceae	10.90	9.57	20.46	Invasive
Asystasia gangetica	Achantaceae	6.95	11.30	18.25	Invasive
Cyperus rotundus	Cyperaceae	6.81	9.57	16.38	Invasive
Clidemia hirta	Melastomataceae	6.54	5.22	11.76	Invasive
Clibadium surinamense	Asteraceae	3.41	5.22	8.62	Invasive
Bellucia pentamera	Melastomataceae	2.32	3.48	5.79	Invasive
Trema cannabina	Cannabaceae	1.50	1.74	3.24	Non-invasive

Note: Classification of invasive plants based on invasive plants (Setyawati 2015; Tjitrosoedirdjo et al. 2016a, b)

Chromolaena odorata species at Location 2 exhibits remarkable reproductive capacity, with a single plant producing approximately 80,000-90,000 seeds, reaching thousands to tens of thousands of seeds per square meter. It spreads by wind, animals, or mechanical means, and forms dense thickets that restrict the growth of other species. Furthermore, phenolic compounds and alkaloids in *C. odorata* leaves exert strong allelopathic effects on seed germination and the growth of other plants, exacerbating local biodiversity declines. Open microhabitats and low vegetation densities often accelerate the invasion of this species (Padmanaba et al. 2017).

Cyperus rotundus, known as the "world's worst weed" is extremely difficult to eradicate due to its highly resistant rhizome reproduction and allelopathic mechanisms. Its tuber exudates can slow germination and reduce the growth of soybean seedlings and other plants including inhibiting the growth tolerance index and germination rate (Darmanti et al. 2015; Kusuma et al. 2017). Mechanical control processes such as uprooting or plowing often exacerbate the spread by damaging tubers, which then continue to develop.

The differences between the two locations also indicate different stages of invasion. Location 2 appears to have entered an advanced invasion phase, with the sole dominance of *C. odorata* driving vegetation homogenization and reducing the total species count. On the other hand, Location 1, despite being dominated by invasive species such as *C. rotundus*, maintains a more diverse community structure, possibly due to less aggressive nature of the invasive species than *C. odorata*, allowing space for other species. Ecologically, the dominance of *C. odorata* and *C. rotundus* indicates the potential for significant declines in local ecosystem function through competition for light, space, and water, as well as through allelopathic effects. Therefore, regular monitoring of IVI is a crucial mitigation measure for detecting early stages of invasion and prioritizing conservation actions.

For management, the best approach is the application of integrated management methods: mechanical (uprooting, cutting, mulching), chemical (e.g., glyphosate, specifically against *C. rotundus*), and biological (e.g., using *Pareuchaetes pseudoinsulata* against *C. odorata*) control (Padmanaba et al. 2017). Planting native species after invasive clearance and habitat restoration are also important to prevent reinvasion and support natural regeneration. By combining the findings of IVI as an indicator of invasive dominance and the biological mechanisms underlying that dominance, this analysis confirms that adaptive and site-specific strategies, particularly regarding community structure and invasive morphological traits, are key to effective understory ecosystem management.

Reproductive organs

The successful spread of invasive plants is influenced by various factors, including fruit production, dispersal methods (both generative and vegetative), competition with native plants, and several other characteristics such as height, developmental model, and invasion timing (Moravcova et al. 2015). Species that reproduce both vegetatively and generatively, particularly those that produce a large quantity of fruit per stem and a high number of seeds per fruit, have a greater potential to dominate, especially under favorable habitat conditions. Table 3 presents the reproductive methods of invasive species in both research locations.

Various invasive plant species exhibit effective reproductive and dispersal strategies, encompassing both vegetative and sexual methods, enabling them to persist, grow rapidly, and dominate new habitats (Table 3). *Cyperus rotundus* reproduces vegetatively through rhizomes and tubers, which persist in the soil and regrow when conditions are favorable (Lim 2016). This strategy allows for rapid growth in disturbed areas. *Clidemia hirta* excels in nitrogen and water uptake, growing year-round and producing large numbers of fruits over 100 seeds per fruit and hundreds per large individual each year. Its high shade tolerance and non-flammable nature further enhance its spread (Tanasale et al. 2023). *Bellucia pentamera* produces spherical fruits containing thousands of tiny seeds that are dispersed by a variety of vertebrates, including monkeys, birds, mammals, and humans. Furthermore, this plant produces allelopathic compounds such as tannins and flavonoids that suppress the growth of other plants (Dillis et al. 2018). *Melastoma malabathricum* grows best in open, dry soil. Its seeds are dispersed by animals such as birds and civets, while its allelopathic compounds inhibit the germination and growth of surrounding vegetation (Sarma et al. 2019; Master et al. 2020).

Several other species, such as *Clibadium surinamense, Acacia mangium, Pueraria montana, Muntingia calabura, M. micrantha, Asystasia gangetica, Passiflora foetida, Ruellia tuberosa, Spermacoce alata* and *Crassocephalum crepidioide*s, rely on reproduction through flowers and seeds. *Acacia mangium* grows quickly, reaching up to 20 m tall, bears cream-colored flowers, and produces shiny black seeds. *Pueraria montana* has hairy pods containing several seeds. *Muntingia calabura* has one-day flowers and red fruits filled with small yellow seeds. *Mikania micrantha* can reproduce both sexually and asexually, with lightweight seeds that are easily blown away by the wind. *Asystasia gangetica* combines self- and cross-pollination, with hermaphroditic flowers that attract pollinators. *Passiflora foetida, R. tuberosa, S. alata*, and *C. crepidioides* produce numerous seeds that are dispersed by wind or animals (Koodkaew and Rottasa 2017; Poudel et al. 2019; Mocharla and Aluri 2021; Liang et al. 2023; Lorence and Faccenda 2024).

Chromolaena odorata exhibits adaptive reproductive strategies that enhance its proliferation in non-native environments. The plant generates a large number of small flowers clustered in structures known as capitula, which promotes efficient pollination and results in the production of a high quantity of seeds. This is especially evident in introduced populations in Asia, which produce a higher number of seeds per capita than native populations in Central and South America. The seeds produced by the introduced populations are often lighter and equipped with a pappus to facilitate wind dispersal, thereby increasing dispersal effectiveness, even though there is a corresponding decline in germination rates and seedling performance. This variation in reproductive traits is significantly influenced by environmental conditions and the ecological context of the plant's origin, enabling *C. odorata* to optimize its reproductive strategies in response to new environmental challenges. Consequently, this adaptability contributes to its widespread and notable success as an invasive species (Li et al. 2024).

Crassocephalum crepidioides, a member of the Asteraceae family, has reproductive mechanisms that facilitate its dispersal and survival across diverse environments. The dispersal of its seeds is predominantly facilitated by wind or animal activity. The reproductive strategies that most contribute to the invasiveness of understory species in the Kapalo Banda Taram Ecotourism Area are those that enable rapid propagation, wide dispersal, and high reproductive output. Species such as *C. odorata*, *C. hirta*, and *M. micrantha* exhibit prolific seed production, with some individuals capable of generating hundreds of thousands of seeds annually. These seeds are often small, lightweight, and adapted for wind or animal dispersal, increasing their colonization potential across diverse microhabitats. Additionally, vegetative reproduction via rhizomes and stolon's, as seen in *C. rotundus* and *M. maximus*, allows for rapid clonal expansion, enabling these species to dominate disturbed or open sites quickly. Allelopathic traits further enhance competitiveness by suppressing native species germination and growth. These characteristics, combined with tolerance to a wide range of environmental conditions and the ability to thrive under anthropogenic disturbance, make these reproductive traits especially effective in driving invasion success in this ecotourism area contributing to the species' successful propagation and subsequent dissemination into novel environments, thus classifying it as an adaptive and invasive plant (Dossou et al. 2019).

Table 3. Reproductive organs of invasive plants in the Kapalo Banda Taram Ecotourism Area in West Sumatra, Indonesia

Species	Reproductive organs
Cyperus rotundus	Rhizome
Megathyrsus maximus	Seeds and vegetatively through rhizomes and stolon's
Clidemia hirta	Flowering throughout the year, each fruit contains more than 100 small seeds. Large plants can produce more than 500 fruits in one year
Bellucia pentamera	Fruit throughout the year with small seeds
Melastoma malabathricum	Many seeds are located in the fruit flesh
Clibadium surinamense	Seeds
Acacia mangium	Seeds
Pueraria montana	Seeds
Muntingia calabura	Seeds
Mikania micrantha	Flowers, seeds
Asystasia gangetica	Fruit in capsules containing four seeds
Passiflora foetida	Seeds
Ruellia tuberosa	Flowers, ripe fruit in pods, 7-8 seeds/each
Spermacoce alata	Seeds ellipsoid
Chromolaena odorata	Seeds
Crassocephalum crepidioides	Seeds (4,379 seeds per plant)
Emilia sonchifolia	Flower, corolla, stigma, pollen, fruit, seeds, shoots

Sources: Setyawati (2015), Ho et al. (2016), Tjitrosoedirdjo et al. (2016a, b), Wang and Wang (2018), Kato-Noguchi (2023), Li et al. (2024), and Cui et al. (2025)

Table 4. Diversity index at two research sites in Kapalo Banda Taram Ecotourism Area in West Sumatra, Indonesia

Location	Number of species	Number of invasive species	Number of all Individuals	Shannon-Wiener Index (H')
Location 1	26	14	1.213	2.34
Location 2	17	10	734	2.26

Understory plant diversity index

The diversity index of understory plants at locations 1 and 2 were 2.34 and 2.26, respectively (Table 4). These results indicate that the level of species diversity of understory in this ecotourism area is moderate. The diversity of understory species in a given area is influenced by various factors, including tree stand density and soil properties such as soil pH and nutrient content (Zhang et al. 2021). In addition to environmental factors, species diversity within a community is also influenced by disturbances, both natural and anthropogenic. Based on the results of the study, the understory diversity index at the research site is categorized as moderate ($1 \leq H' \leq 3$), indicating that the understory vegetation is in a relatively stable ecological condition (Hadi et al. 2016). However, the presence of invasive plants can disrupt this stability. According to Ormsby and Brenton-Rule (2017), invasive plants, which can be either native or non-native species, have the potential to disturb the balance of the ecosystem through aggressive dominance. This disruption can lead to a decline in environmental quality and significantly impact biodiversity in both the short and long term.

Location 2 was dominated by *C. odorata* and contained 17 species, including 10 invasive species. On the other hand, Location 1, where *C. odorata* was absent, harbored higher number of species with 26 of which 14 species are classified as invasive. This difference in species richness suggests that the invasion of *C. odorata* may suppress the growth of surrounding species, as explained by Thiébaut et al. (2019). Invasive species are known to release allelochemicals that can inhibit the growth of native plant species. These chemicals can disrupt the physiological processes of neighboring plants, leading to reduced rates of germination and growth. Interestingly, the high number of invasive species (14 out of 26 species) in Location 1, which was not invaded by *C. odorata*, indicates that other environmental factors, such as anthropogenic disturbances or resource availability, also contribute to invasive plant colonization (Pyšek et al. 2020). The two sites shared only 8 species in common, most of which were classified as invasive. This observation suggests that invasive plants tend to exhibit a broad ecological tolerance, enabling them to thrive in a variety of habitat conditions. However, the low native species similarity index between the two plots (37.21%) implies that *C. odorata* selectively inhibits the growth of certain species, particularly those that are less adaptable to shaded environments.

Sorensen Similarity Index

The two locations had Sørensen Similarity Index (SSI) of 37.21%, indicating that the level of plant community similarity between the two locations is low to moderate. SSI values below 50% indicate significant differences in species composition between the south side transect (Location 2) and the east side transect (Location 1). The east side transect (Location 1) was dominated by *C. rotundus*, while *C. odorata* dominated the west side transect (Location 2). Thapa et al. (2016) stated that the invasion of non-native plants, such as *C. odorata*, can drastically alter the structure of vegetation communities by competing for resources (light, nutrients, and space), thereby reducing the diversity of native species and leading to the formation of homogeneous communities.

Canonical Correlation Analysis (CCA) of abiotic factors and five dominant species

The correlations between abiotic factors, such as light intensity, humidity, temperature, pH, and altitude and the presence of invasive species were analyzed using Canonical Correlations Analysis. The results of this analysis are presented in Figures 3 and 4. Canonical Correspondence Analysis (CCA) is a multivariate method that explains the relationship between biological components, such as understory vegetation types, and environmental factors such as soil pH, relative light intensity, soil temperature, humidity, air temperature, and altitude. The results of CCA are presented as a two-dimensional biplot with Axis 1 and Axis 2 representing the main environmental gradients that influence species distribution. In the graph, the direction and length of the arrows indicate how much influence an environmental factor has on the presence of a particular plant species. The longer the arrow, the greater the influence.

Based on the CCA results in Figure 3, at Location 1, *C. rotundus* is close and in the same direction as the moisture vector, soil temperature, and air temperature, indicating that this species grows optimally in areas with high humidity and temperature levels. This is in line with research by Mandal et al. (2022) which showed that the growth of *C. rotundus* significantly increased at higher temperatures and sufficient soil moisture. Meanwhile, *M. malabathricum* is located quite far towards the top (positive Axis 2), indicating that this species tends to be influenced by other factors that are not dominantly indicated by the environmental vectors used in this analysis, or has tolerance to different conditions than other species. *B. pentamera* is located far to the left (negative Axis 1), close to the direction of soil pH and relative light intensity. This indicates that this species tends to favor soils that have low pH and high light levels, which are generally found in open habitats. This is in accordance with the research of Solfiyeni et al. (2022a) that the habitat of *B. pentamera* is usually at the edge of the forest or in the forest gap with high light intensity and temperature. In contrast, *C. hirta* is in the quadrant opposite to the altitude and air temperature, indicating that the presence of this species is more dominant in areas with lower altitude and warmer temperatures. In general, the position of species close to the center of the graph (zero point), such as *M. maximus*, indicates that certain environmental factors do not strongly influence the species. These plants can grow in various types of environmental conditions. However, it tends to grow more optimally on land with high light intensity and neutral soil pH.

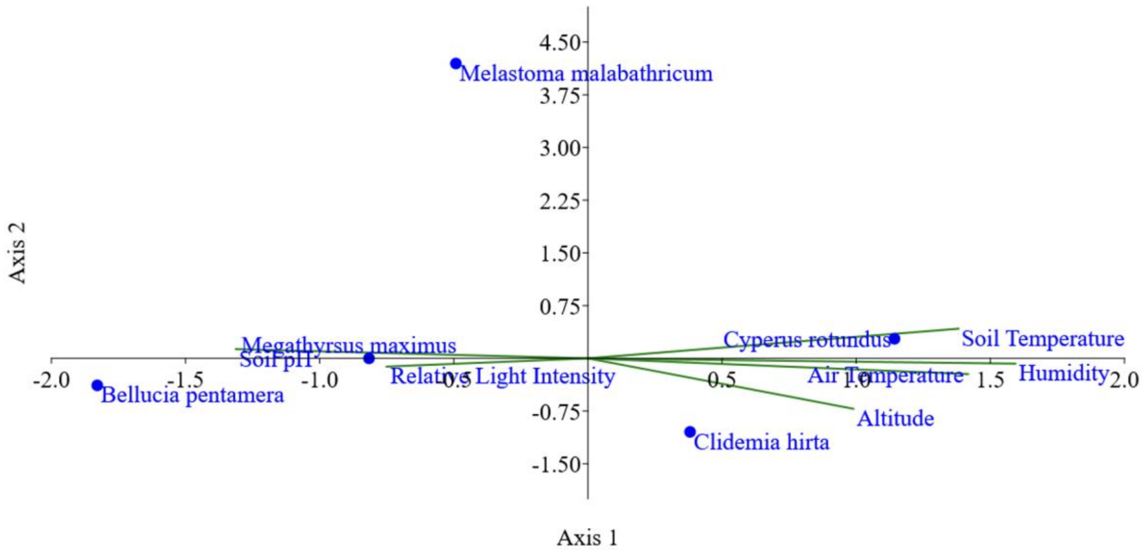

Figure 3. Canonical Correspondence Analysis (CCA) for Location 1 showing the relationship between five dominant understory species and environmental variables

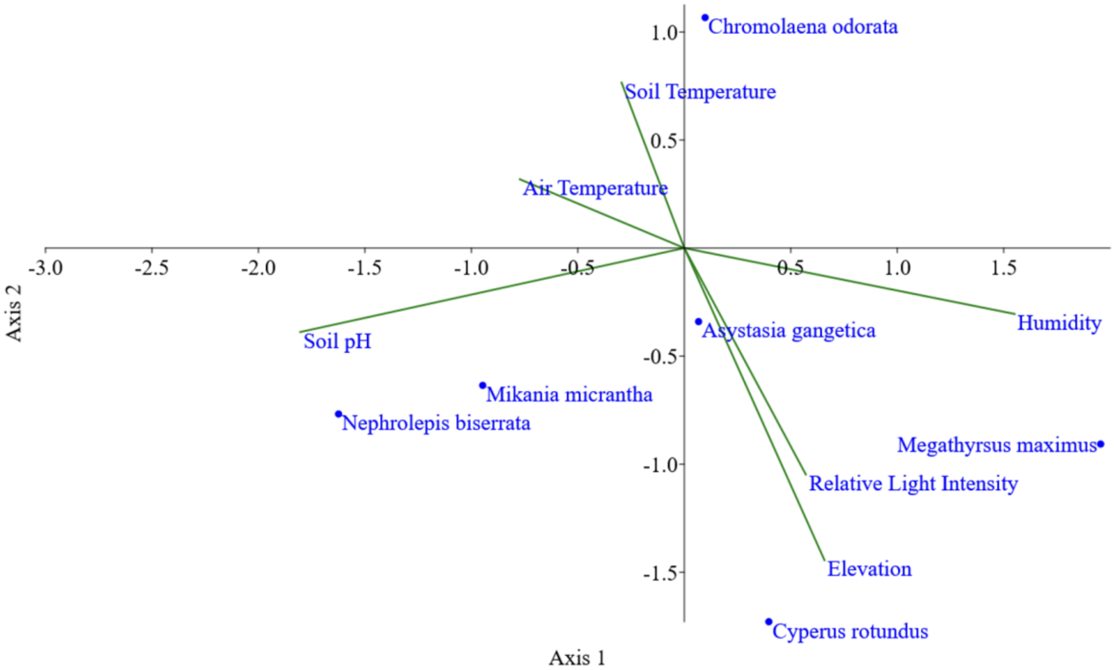

Figure 4. Canonical Correspondence Analysis (CCA) for Location 2 showing the relationship between five dominant understory species and environmental variables

Based on Figure 4, at Location 2, the results of the CCA analysis provide a visual depiction of the relationship between plant species and environmental factors at the research site. The two main axes (Axis 1 and Axis 2) illustrate the main variations in species distribution and show how each abiotic factor contributes to shaping the distribution pattern of understory vegetation. The second axis (Axis 2) specifically highlights the influence of temperature, especially soil temperature and air temperature. In this context, *C. odorata* emerges as a species that is strongly influenced by temperature factors. This species is at the top of the graph, adjacent to the direction of the soil and air temperature vectors, indicating its preference for environmental conditions with relatively high temperatures. This finding is corroborated by Wanyama et al. (2023), who showed that *C. odorata* is highly adaptable to warm and open environments and exhibits optimal growth under these conditions. This preference explains why this species often dominates open land after disturbance, such as fire scars or land clearing, where microhabitat temperatures tend to increase. Meanwhile, the first axis (Axis 1) shows that the variables of air humidity, relative light intensity, and altitude are the most influential factors on species distribution in general. The direction of the arrows of the three variables pointing to the right side of the graph shows a strong positive correlation with Axis 1. Identifying key abiotic drivers through CCA not only deepens our understanding of species-environment interactions but also supports more effective and targeted conservation efforts. Factors such as soil pH, canopy cover, and elevation may be vital for sustaining the distribution and persistence of priority *Melastoma* species. Therefore, incorporating abiotic variables into habitat management planning is critical to ensuring long-term biodiversity resilience. This finding is in line with research by Liu (2025), which states that humidity and light are the two main factors that shape the presence of species in forest ecosystems.

This condition is shown by the position of *A. gangetica* and *C. rotundus,* which are close to the moisture and light vectors, indicating the preference of the two species for bright and humid habitats. The position of *C. rotundus* at the bottom right of the graph also indicates that this species tends to be found in locations with higher altitudes and cooler microclimates. This is consistent with the results of Pu et al. (2025), who stated that variations in soil temperature and altitude could significantly affect the distribution of vegetation species. *Asystasia gangetica*, located closer to the center of the graph, showed a balanced response to various environmental factors. Although affected by moisture and light, this species appears more tolerant to fluctuations in temperature, both soil and air. This finding corroborates Yang et al. (2016), who emphasized the importance of species tolerance to microclimate in plant community dynamics. In contrast, *M. micrantha* and *Nephrolepis biserrata* are found on the left side of the graph, closer to the soil pH vector and away from the moisture and light arrows. This position suggests that these two species prefer habitats with shady, flat conditions and more acidic soils. Research by Yousaf et al. (2016) supports these findings, stating that the interaction between soil pH and moisture can affect species distribution, especially in plants sensitive to soil acidity.

In this context, *M. maximus* also showed strong relationships with several key abiotic factors. The position of this species on the CCA graph is parallel and quite close to the direction of the air humidity vector, relative light intensity, and altitude. This suggests that *M. maximus* has a preference for environmental conditions that are humid, bright, and at a certain altitude. This finding is in line with Habermann et al. (2022), who stated that tropical grass species such as *M. maximus* are highly dependent on light and high humidity for optimal growth, especially in open habitats. The altitude vector, which is also in the same direction as the position of *M. maximus*, indicates that this species tends to develop better at certain altitudes, which may provide better drainage conditions and sufficient light intensity. This finding is corroborated by Zheng et al. (2019), who mentioned that variations in altitude can create environmental conditions that favor the colonization of invasive species. In addition, the position of *M. maximus* away from the soil pH and temperature vectors suggests that this species has a relatively wide tolerance to variations in these two variables. This indicates that as long as sufficient moisture and light are available, *M. maximus* is able to adapt well. The study by Irakiza et al. (2022) supports this by stating that *M. maximus* is a tropical grass species that is adaptive and tolerant to a variety of soil conditions and microclimates.

Based on the research results, it can be concluded that more than half of the understory species in Kapalo Banda Taram Ecotourism Area are invasive. High IVI values indicate that without mitigation efforts, invasive species will continue to dominate and weaken local vegetation communities. The use of integrated control strategies and habitat restoration are essential steps implicitly needed to maintain the ecological diversity and stability of understory communities in the future. Invasive species such as *C. odorata*, *C. hirta*, and *M. micrantha* are highly adaptive. They combine mass seed production, efficient dispersal methods, vegetative reproduction (when applicable), and broad environmental tolerance while some also release compounds that suppress competitors. This combination of traits makes them dominant forces in areas like Kapalo Banda Taram and similar ecotourism sites, and difficult to control without appropriate intervention.

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