



RESEARCH ARTICLE

Taxonomic and ecological assessment of invasive plant diversity along an altitudinal gradient on Mount Gamalama, Ternate Island, Indonesia

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Abstract

This study provides the first comprehensive assessment of invasive flora along the Mount Gamalama hiking trail, Ternate Island, Indonesia, a volcanically active ecosystem of high conservation value. Through exploratory surveys and taxonomic verification, this study documented 31 invasive species from 16 families and 29 genera across an elevational gradient of 369–940 m. Asteraceae was the dominant family (32.3 %), reflecting its global role in invasion dynamics. Most species originated from the Americas (41.9 %), introduced mainly through horticultural and agricultural pathways. The community structure was predominantly herbaceous (74 %), with shrubs (13 %) and lianas (13 %), consistent with global invasion trends. Nineteen species exhibited reported allelopathic activity, suggesting that chemical interference drives colonisation and competitive dominance. Taxonomic ratio analysis (Family/species (F/S) = 0.516; genus/species (G/S) = 0.935) indicated a balanced yet evolutionarily diverse assemblage, with no species of conservation concern under IUCN criteria. The results indicate that invasive plants are widely distributed across the surveyed altitudinal gradient and several species have documented allelopathic properties in previous studies. Together, these findings provide essential baseline data for monitoring and managing invasive species while supporting conservation planning in volcanic island ecosystems under increasing anthropogenic pressure.

Keywords: allelopathy; altitudinal gradient; tropical island ecosystem; volcanic island; Wallacea

Introduction

Indonesia is recognised as one of the world's mega biodiverse countries, characterised by high biodiversity and abundant natural resources (1). In recent decades, however, this rich biodiversity has faced increasing threats from the spread of invasive plant species, particularly in open areas where they can pose significant risks to the survival of native flora (2, 3). Ternate Island, situated in North Maluku Province within Indonesia's archipelagic region, is renowned for its rich biodiversity, although not all plant species currently present are native. The island lies within Wallacea (4), a transitional biogeographic zone between the Wallace Line and the Weber Line, where Asian and Australasian species converge. Its prolonged isolation from continental shelves during Pleistocene sea-level fluctuations fostered high endemism and unique evolutionary trajectories. Unlike neighbouring regions, Wallacea—including Ternate—was never connected via land bridges, allowing distinct species to evolve independently (5). Consequently, Ternate serves as a key area for studying speciation, faunal mixing and biodiversity conservation in Southeast Asia (6). Moreover, biodiversity on every island contributes substantially to economic, social, cultural and ecological aspects of local communities (7).

Despite these attributes, the local ecosystem faces increasing pressure from invasive species. Both native and non-native invasives can disrupt ecological balance through aggressive dominance, leading to environmental degradation and declines in biodiversity over both short and long terms (8). One particularly affected area is the hiking trail of Mount Gamalama, which, in addition to its cultural and geographical significance, hosts a unique ecosystem with extensive open habitats. Human activities, such as trekking, may facilitate the spread of invasive species along trails through propagule dispersal and habitat disturbance, potentially affecting native plant communities and ecosystem functioning.

Although invasive species are recognised as a major driver of biodiversity decline (9), studies examining their presence and ecological impacts along Mount Gamalama remain limited. Therefore, a focused investigation of invasive species in this area is essential as an initial step toward informed ecosystem conservation.

This study aims to identify the invasive plant species and their respective families along the Mount Gamalama hiking trail. Such identification is critical for understanding the diversity of invasive plants and their potential impacts on the local ecosystem. The results are expected to provide long-term baseline data to support future management and control strategies for invasive species in the region.

Materials and Methods

This study was conducted on Ternate Island, North Maluku, along the Mount Gamalama hiking trail from the Moya trailhead to Post 2 (Fig. 1). Field surveys were carried out between March and May 2025 using an exploratory survey approach. The surveyed area covered an elevational gradient ranging from 369 to 940 m above sea level. Invasive plant species encountered along the trail and in adjacent disturbed habitats were recorded through direct field observations, georeferenced using a global positioning system (GPS) and photographed for documentation. The survey focused on documenting species occurrence, taxonomic identity, growth form and distribution across the surveyed elevational gradient. Because the primary objective of the study was to compile a baseline inventory of invasive flora, all invasive species encountered during field observations were documented and included in the analysis.

Representative plant specimens collected during the survey were retained as reference materials and are currently stored in the Plant Biology Laboratory, Department of Biology Education, Universitas Khairun, Indonesia. Plant specimens encountered during the survey were documented and identified based on their morphological characteristics. Taxonomic verification was conducted by comparing field observations with reference images provided in A Guide Book to Invasive Alien Plant Species in Indonesia (10). To further confirm the invasive status of each species, multiple authoritative online databases were consulted, including the Invasive Species Specialist Group (ISSG; www.issg.org), the Global Invasive Species Database (GISD; iucngisd.org), the Invasive Species Compendium (CABI; www.cabi.org) and the United States National Invasive Species Information Center (www.invasive.org). This multi-source approach ensured accurate identification and classification of invasive plant taxa present at the study site.

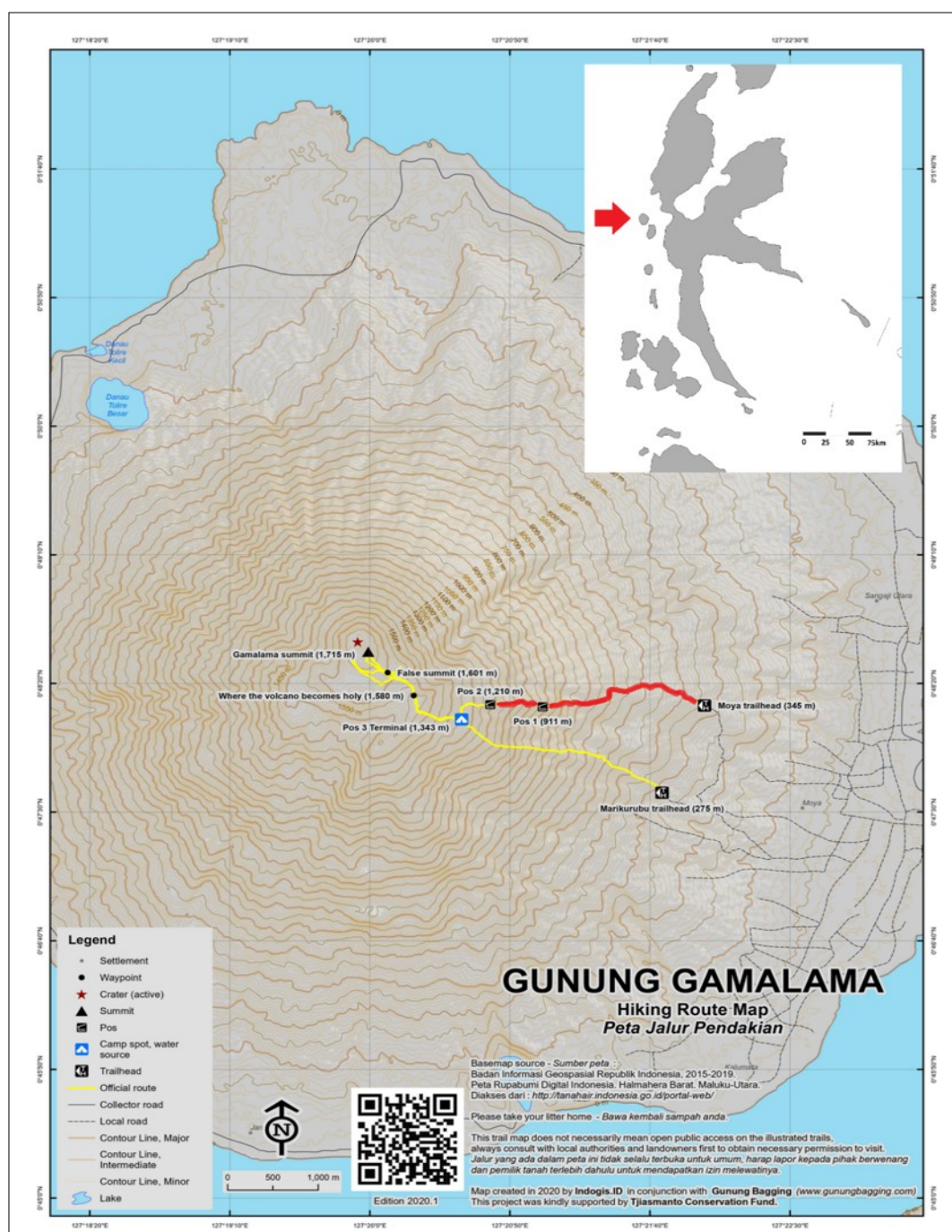


Fig. 1. Map of the study area. The inset shows the map of North Maluku Province (Indonesia). The red line indicates the data collection route.

Source: Figure was modified from gunungbagging.com (<https://www.gunungbagging.com>).

The collected data were analysed and subsequently categorised based on family, scientific name, local name and location coordinates. This study also provides a descriptive overview of each invasive species identified. To verify the species name and ensure that the accepted name and its synonyms are used, the main online plant service provider websites, namely World Flora Online (WFO) Plant List (<https://wfoplantlist.org/>) and International Plant Names Index/IPNI (<https://www.ipni.org/>) are used.

Further analyses were conducted to assess various aspects of the invasive plant species. Family dominance was evaluated to determine which plant families were most prevalent. Taxonomic structure was analysed using taxonomic richness, expressed as the ratio of families to species (F/S) and genera to species (G/S). The origin and natural distribution of each species were determined based on the Plants of the World Online (POWO) (<https://powo.science.kew.org/>). Invasive plants were classified by growth form into trees, shrubs/subshrubs, or herbs. Vertical distribution was analysed based on the elevation of each species above sea level (meters above sea level)

Additionally, information on the allelopathic potential of each invasive species was compiled from previously published experimental studies. The allelopathic status assigned in this study refers exclusively to evidence reported in the literature and should not be interpreted as direct evidence of allelopathic activity under field conditions on Mount Gamalama. A subsequent conservation assessment classified each species according to the IUCN Red List (<https://www.iucnredlist.org/>). This classification provides insight into the rarity or abundance of each species.

Results

Taxonomic composition of invasive flora, conservation status and geographic origins

The survey of invasive plants along the Mount Gamalama hiking trail revealed a diverse assemblage of species distributed across the surveyed elevational gradient. Table 1 summarises the recorded species, including their family affiliations, local names and geographic coordinates. A total of 31 invasive species representing 16 families and 29 genera were documented along the surveyed section of the trail, spanning an elevational range of 369–940 m above sea level. The recorded flora exhibited considerable taxonomic diversity, with species occurring across a broad range of habitats and elevations within the study area. The composition of invasive plant families recorded along the Mount Gamalama hiking trail is illustrated in Fig. 2. A total of 16 families were identified, with Asteraceae being the most represented (10 species, 32.3 %), followed by Acanthaceae (3 species, 9.7 %) and several families, including Commelinaceae, Fabaceae, Malvaceae and Verbenaceae were each represented by two species (6.5 % of the total invasive flora). The remaining families, such as Campanulaceae, Convolvulaceae, Cucurbitaceae, Dioscoreaceae, Lamiaceae, Melastomataceae, Nephrolepidaceae, Poaceae, Pteridaceae and Rubiaceae, each accounted for 3.2 % of the total species.

Taxonomic analysis of the flora in the study area revealed 16 families and 29 genera, encompassing 31 species, yielding a family-to-species ratio of 0.516 and a genus-to-species ratio of 0.935. This indicates moderate taxonomic representation across families and genera. Among the 31 invasive plant species identified in the study

area, none are endemic and most have received limited IUCN assessments. None of the species is considered rare or near-threatened. Notably, three species, *Commelina diffusa* Burm. f., *Urena lobata* L. and *Stachytarpheta jamaicensis* (L.) Vahl. are classified as least concern (LC), while *Ipomoea indica* (Burm.) Merr. is listed as data deficient (DD). The remaining species have not been evaluated (Not evaluated (NE)). These findings highlight that the invasive flora in the region consists largely of widespread species with low conservation priority, emphasising their potential ecological dominance in local habitats.

The invasive species on Mount Gamalama exhibit diverse geographic origins. Of the 31 species, 41.9 % are native to regions spanning North to South America, 16.1 % from Africa to Asia, 12.9 % from Asia to Australia and smaller proportions from North America, South America, Africa alone, or combined regions (3–9.7 % each). The full distribution is illustrated in the accompanying bar chart (Fig. 3).

Altitudinal distribution, ecological niches and allelopathic potential

The altitudinal distribution of invasive species on Mount Gamalama was recorded to assess their occurrence across different elevation zones. The surveyed species were found at elevations ranging from 369 m above sea level (*Elephantopus mollis* Kunth) to 940 m (*Emilia sonchifolia* (L.) DC.), with several species occurring at intermediate elevations, such as *Asystasia gangetica* (L.) T. Anderson at 520 m, *Strobilanthes reptans* (G.Forst.) Moylan ex Y.F.Deng & J.R.I.Wood at 618 m and *Dioscorea bulbifera* L. at 794 m. These data provide insights into the elevational preferences and ecological niches of invasive plants on the mountain, which may inform management and conservation strategies. The vertical distribution of these species is illustrated in Fig. 4.

The invasive species on Mount Gamalama were categorised based on their growth habit. Of the 31 species recorded, 4 species (13 %) were classified as lianas (*Centrosema pubescens* Benth., *Coccinia grandis* (L.) Voigt, *D. bulbifera* and *Mikania micrantha* Kunth), 4 species (13 %) as shrubs (*Melastoma malabathricum* L., *Sida rhombifolia* L., *Stachytarpheta cayennensis* (Rich.) Vahl. and *U. lobata*) and the remaining 23 species (74 %) as herbs. The herbaceous species were further subdivided into annual, grassy, terrestrial, erect and creeping types, with each category representing a proportion of the total herbaceous species. This classification highlights the diversity of growth forms among the herbaceous invasive flora and the grouping of these herb types is illustrated in a pie chart shown in Fig. 5.

Among the 31 invasive plant species recorded along the Mount Gamalama hiking trail, 19 species have been reported to exhibit allelopathic activity in previous studies. These species, along with their corresponding references, include *A. gangetica* (11), *Ageratum conyzoides* L. (12), *Ageratum houstonianum* Mill. (13), *Bidens pilosa* L. (14), *Crassocephalum crepidioides* (Benth.) S.Moore (15), *E. sonchifolia* (16), *Erigeron sumatrensis* Retz. (17), *M. micrantha* (18), *Synedrella nodiflora* (L.) Gaertn. (19), *C. diffusa* (20), *Tradescantia fluminensis* (21), *Ipomoea indica* (22), *Coccinia grandis* (23), *Dioscorea bulbifera* (24), *Centrosema pubescens* (25), *Hyptis capitata* (16), *Melastoma malabathricum* (26), *Pityrogramma calomelanos* (27) and *Stachytarpheta cayennensis* (28).

Table 1. Invasive plant species observed along the Mount Gamalama hiking trail

Sl. No.	Species (Family)	Local name	GPS point
1	<i>Asystasia gangetica</i> (L.) T. Anderson (Acanthaceae)	Rumput Palestina	0°48'17.826" N 127°21'46.668" E
2	<i>Ruellia brevifolia</i> (Pohl) C. Ezcurra (Acanthaceae)	Kencana	0°48'15.384" N 127°21'25.283" E
3	<i>Strobilanthes reptans</i> (G.Forst.) Moylan ex Y.F.Deng & J.R.I.Wood (Acanthaceae)	-	0°48'17.700" N 127°21'32.826" E
4	<i>Ageratum conyzoides</i> L. (Asteraceae)	Bandotan	0°48'14.225" N 127°21'24.348" E
5	<i>Ageratum houstonianum</i> Mill. (Asteraceae)	Bandotan liar	0°48'11.046" N 127°21'04.218" E
6	<i>Bidens pilosa</i> L. (Asteraceae)	Ketul	0°48'13.106" N 127°21'52.115" E
7	<i>Crassocephalum crepidioides</i> (Benth.) S.Moore (Asteraceae)	Sintrong	0°48'19.547" N 127°21'39.210" E
8	<i>Elephantopus mollis</i> Kunth (Asteraceae)	Sawi hutan	0°48'13.367" N 127°21'52.907" E
9	<i>Erechtites valerianifolius</i> (Link ex Spreng.) DC. (Asteraceae)	Sintrong	0°48'10.728" N 127°21'08.399" E
10	<i>Emilia sonchifolia</i> (L.) DC. (Asteraceae)	Gafu saru	0°48'11.847" N 127°21'04.044" E
11	<i>Erigeron sumatrensis</i> Retz. (Asteraceae)	Jelantir	0°48'19.541" N 127°21'41.819" E
12	<i>Mikania micrantha</i> Kunth (Asteraceae)	Sembung rambat	0°48'17.946" N 127°21'27.708" E
13	<i>Synedrella nodiflora</i> (L.) Gaertn. (Asteraceae)	Legetan	0°48'14.364" N 127°21'24.497" E
14	<i>Hippobroma longiflora</i> (L.) G. Don (Campanulaceae)	Kitolod	0°48'17.244" N 127°21'30.695" E
15	<i>Commelina diffusa</i> Burm. F (Commelinaceae)	Aur-aur	0°48'19.499" N 127°21'41.933" E
16	<i>Tradescantia fluminensis</i> Vell. (Commelinaceae)	Kuping Monyet	0°48'19.578" N 127°21'37.985" E
17	<i>Ipomoea indica</i> (Burm.) Merr. (Convolvulaceae)	Koali awa	0°48'14.376" N 127°21'24.371" E
18	<i>Coccinia grandis</i> (L.) Voigt (Cucurbitaceae)	Timun mungil	0°48'10.686" N 127°21'08.112" E
19	<i>Dioscorea bulbifera</i> L. (Dioscoreaceae)	Kapupu (Halmahera)	0°48'12.498" N 127°21'15.336" E
20	<i>Centrosema pubescens</i> Benth. (Fabaceae)	Sentro	0°48'17.063" N 127°21'47.706" E
21	<i>Desmodium scorpiurus</i> (Sw.) Desv. ex DC. (Fabaceae)	Semanggi	0°48'19.170" N 127°21'35.009" E
22	<i>Hyptis capitata</i> Jacq. (Lamiaceae)	Rumput Kenop	0°48'14.135" N 127°21'52.037" E
23	<i>Sida rhombifolia</i> L. (Malvaceae)	Sidaguri	0°48'10.961" N 127°21'03.594" E
24	<i>Urena lobata</i> L. (Malvaceae)	Congo jute	0°48'13.403" N 127°21'52.817" E
25	<i>Melastoma malabathricum</i> L. (Melastomataceae)	Harendong	0°48'18.347" N 127°21'45.755" E
26	<i>Nephrolepis brownii</i> (Desv.) Hovenkamp & Miyam. (Nephrolepidaceae)	Paku pedang	0°48'10.746" N 127°21'08.957" E
27	<i>Centotheca lappacea</i> (L.) Desv. (Poaceae)	Rumput Lilit Kain	0°48'12.240" N 127°21'10.997" E
28	<i>Pityrogramma calomelanos</i> (L.) Link (Pteridaceae)	Paku	0°48'14.478" N 127°21'51.227" E
29	<i>Mitracarpus hirtus</i> (L.) DC. (Rubiaceae)	Daun samak	0°48'11.112" N 127°21'10.619" E
30	<i>Stachytarpheta cayennensis</i> (Rich.) Vahl. (Verbenaceae)	Pecut kuda	0°48'14.879" N 127°21'50.790" E
31	<i>Stachytarpheta jamaicensis</i> (L.) Vahl. (Verbenaceae)	Pecut kuda	0°48'14.544" N 127°21'25.656" E

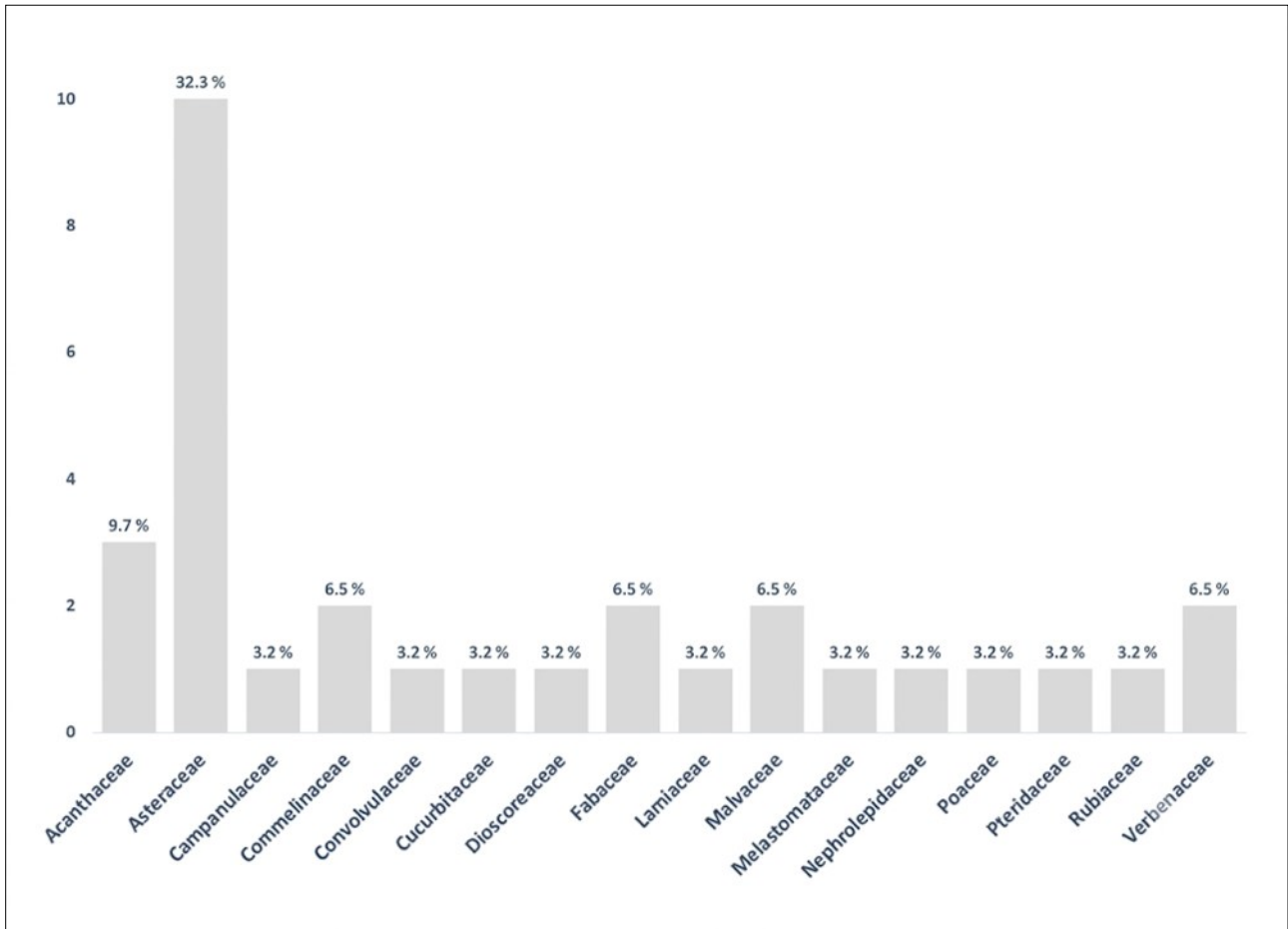


Fig. 2. Number and percentage of invasive species per family. A total of 31 species from 16 families were identified.

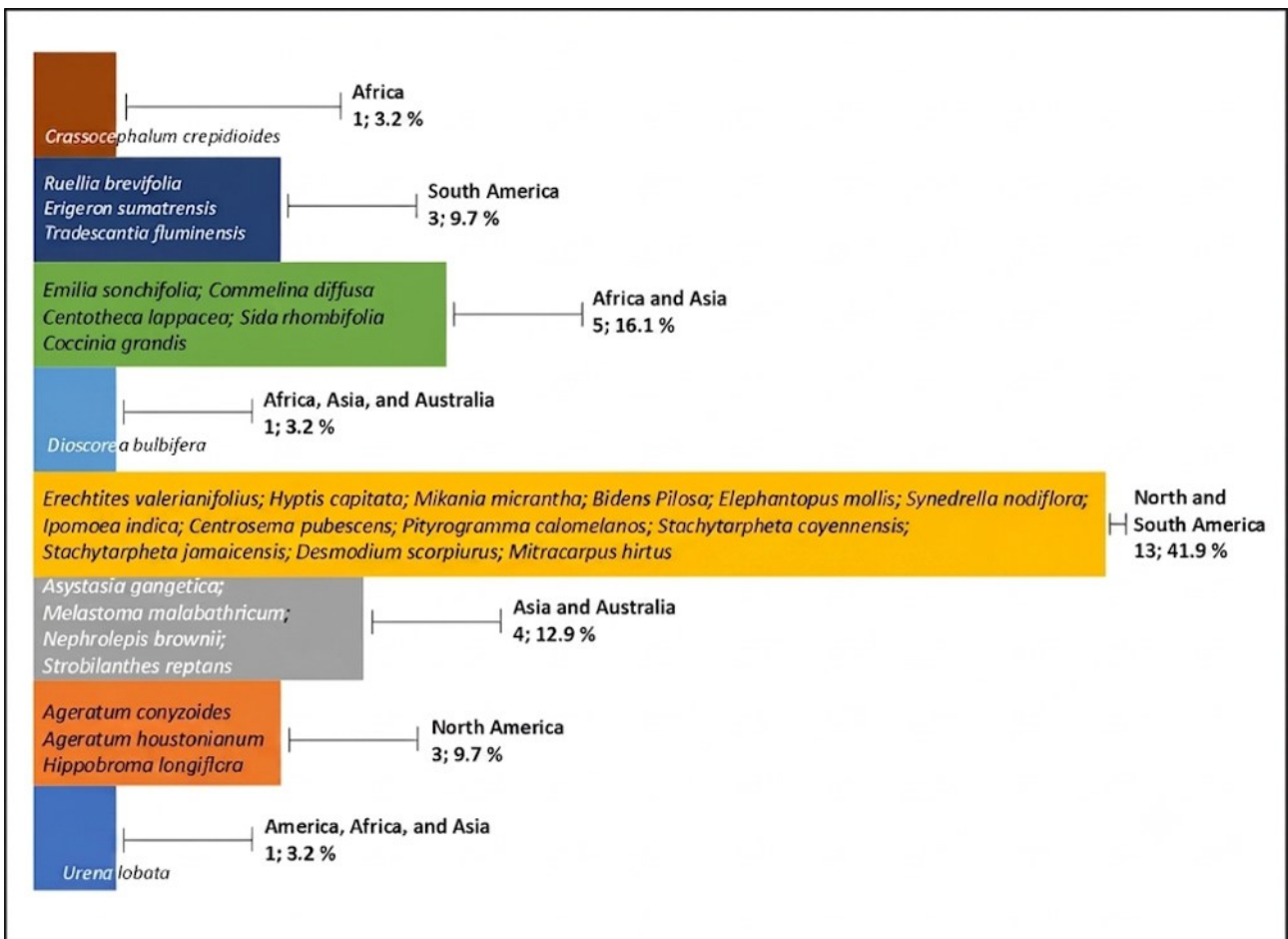


Fig. 3. Geographic origins of invasive species occurring on Mount Gamalama. The numbers represent the total species count and the corresponding percentage from each geographic region.

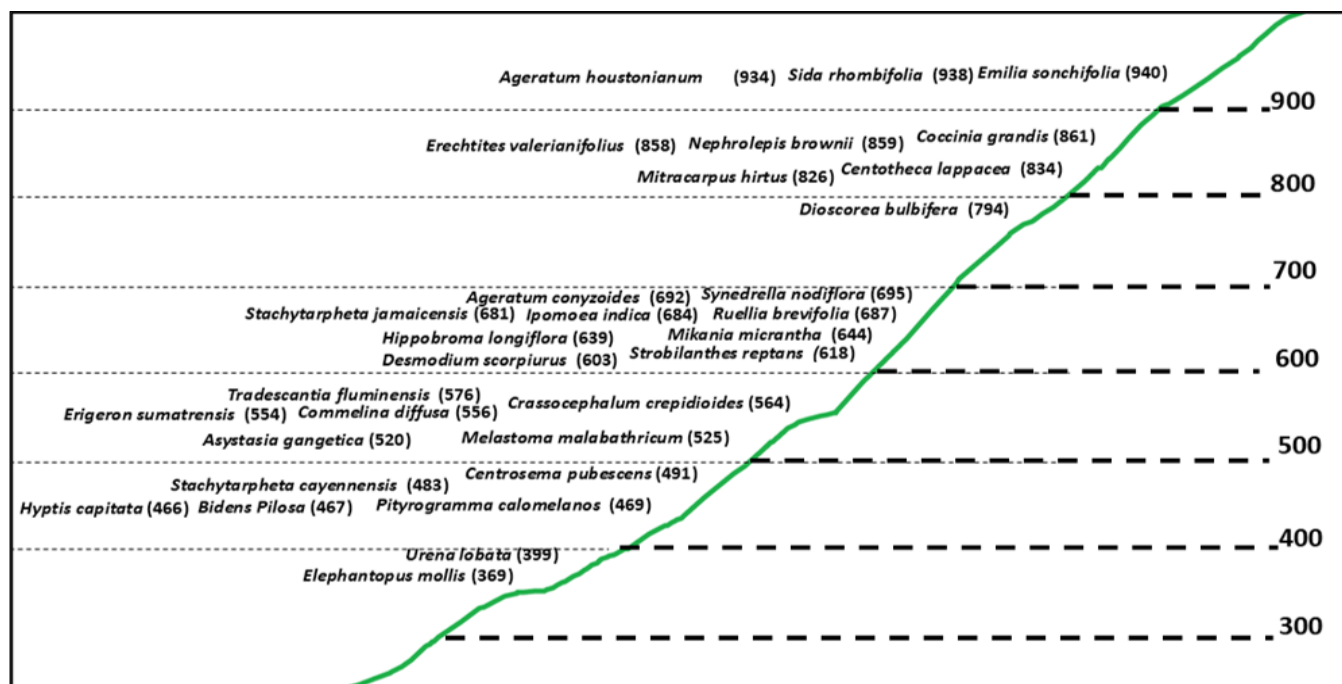


Fig. 4. Altitudinal distribution of invasive plants on Mount Gamalama.

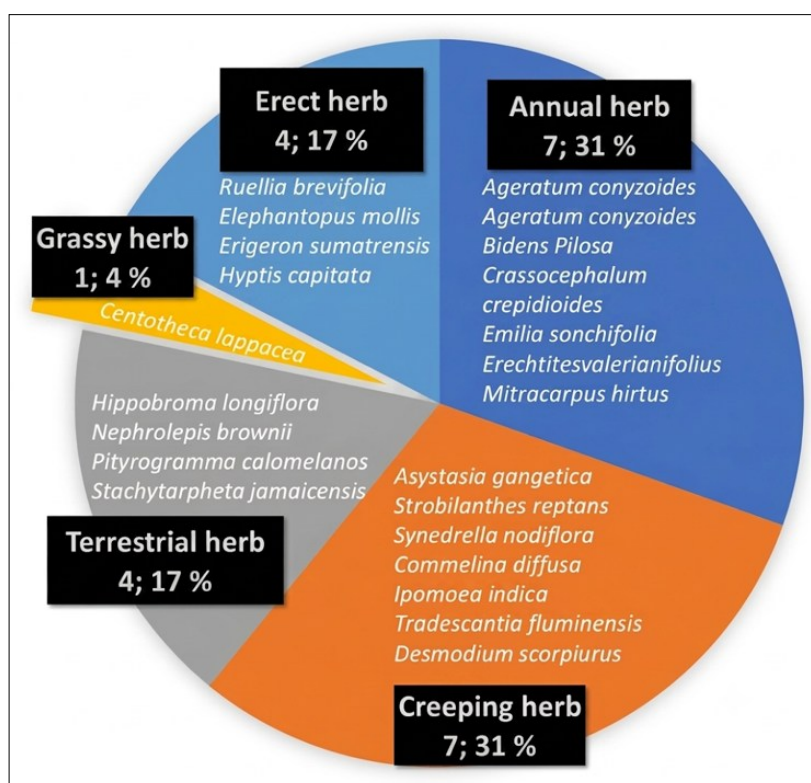


Fig. 5. Categorisation of herbaceous invasive species on Mount Gamalama according to growth form.

Discussion

Taxonomic composition of invasive flora and conservation status

The survey of invasive plant species along the Mount Gamalama hiking trail revealed a taxonomically diverse community, comprising 31 species from 16 families and 29 genera. Dominance by Asteraceae, followed by Acanthaceae, reflects typical patterns in tropical ecosystems where certain families exhibit high dispersal capacity and ecological plasticity. Asteraceae is widely recognised as a family that includes many globally invasive species. According to

previous researchers, invasive species from the Asteraceae family are listed among the 100 worst invasive alien plant species in the world (29). These findings corroborate numerous studies reporting that invasive plants from the family Asteraceae consistently dominate within plant communities (30). Members of this family achieve ecological dominance through a suite of functional traits such as high specific leaf area, rapid growth rates, efficient resource allocation and elevated reproductive output combined with broad ecological plasticity. Collectively, these attributes enable Asteraceae species to outcompete both native and naturalised taxa across diverse and competitive environments (31).

The taxonomic structure of invasive plants on Mount Gamalama is characterised by a F/S of 0.516 and a G/S of 0.935, suggesting a relatively even distribution of species among taxonomic groups and moderate taxonomic diversity within the recorded invasive flora. The family-to-species ratio, approximately 0.5 : 1, indicates that each family comprises an average of two species; however, certain dominant families such as the Asteraceae contribute up to 10 species, highlighting uneven species distribution across families. Meanwhile, the high genus-to-species ratio implies that most species belong to distinct genera, with only a few shared among genera, reflecting a broad evolutionary and ecological breadth. High genus-to-species ratios have been shown to indicate taxonomically widespread community structures, often associated with greater ecological diversity and can serve as effective indicators of biodiversity patterns at higher taxonomic levels (32).

In ecological theory, taxonomic ratios such as species-to-genus (or species-to-family) are traditionally employed as indicators of taxonomic diversity and potential competitive dynamics within communities. Although recognised as biased due to their dependency on sampling area, recent advances propose unbiased estimators that adjust for species–area relationship, offering more accurate characterisation of floral diversity across regions (33). Such taxonomic spread aligns with the concept that higher taxonomic distinctiveness often correlates with varied ecological niches and robust evolutionary divergence.

Regarding conservation status, none of 31 invasive plants recorded in the study area are endemic and most have received limited assessment by the IUCN. Invasive plants tend to exhibit wide ecological tolerance, broad dispersal mechanisms and adaptability to disturbed environments (34). Similarly, invasive species are rarely considered rare or threatened, as their success depends on robust reproductive capacity, competitive advantage and the ability to establish self-sustaining populations across diverse habitats (35). This aligns with the broader understanding that invasive plants are not conservation priorities from a rarity perspective but pose significant ecological risks by displacing native biodiversity and altering ecosystem processes.

Geographic origins, growth forms and functional traits of invasive species

The invasive species recorded originates from diverse geographic regions, with the largest proportion (41.9 %) native to the Americas. Other species originate from Africa to Asia (16.1 %) and Asia to Australia (12.9 %), while a few species are from single or combined regions. This distribution reflects historical introduction pathways, including horticulture, agriculture and accidental dispersal. The dominance of American species aligns with global patterns, as many neotropical plants have proven highly invasive in Southeast Asia due to their rapid growth, competitive strategies and ecological plasticity (36).

A global analysis of alien flora underscores the prominent role of North America and the Neotropics as key donor regions to other parts of the world, reflecting the intensive historical exchange of ornamental and agricultural plants into tropical Asia (37).

The invasive plant community along the Mount Gamalama hiking trail is predominantly composed of herbaceous species (74 %), with shrubs and lianas playing a secondary role. This pattern echoes findings from other tropical and temperate ecosystems,

where invasive flora is largely dominated by herbaceous growth forms (38). Herbaceous invaders at the site demonstrate a variety of growth habits including erect, creeping, annual and grassy forms and often display enhanced root adaptability, which augments their capacity to establish and persist in new environments. This aligns with global evidence that invasive species tend to exhibit distinct root traits such as high specific root length that enable them to effectively colonise and modify ecosystems (39).

Altitudinal distribution and ecological niches

Invasive species on Mount Gamalama occur across a wide elevational gradient (369–940 m), with some taxa showing distinct preferences for instance, *E. mollis* at lower sites and *E. sonchifolia* at higher ones. Such variation indicates differing ecological tolerances and overlapping niches at mid-elevations, creating zones of potential competition. Similar patterns have been observed in the Himalayas, where the altitudinal distribution of *Ageratina adenophora* (Spreng.) R.M.King & H.Rob. was linked to germination and survival constraints rather than local adaptation (40). More broadly, invasion dynamics in mountain systems are shaped by propagule pressure, abiotic barriers and ecological plasticity, with globalisation and climate change expected to intensify risks even in alpine habitats (41).

Allelopathic potential

The presence of 19 allelopathic invasive species out of 31 recorded invasive plants on the slopes of Mount Gamalama underscores the critical role of chemical interference in plant colonisation. *Ageratum conyzoides* releases phenols, tannins, precocene I and II, coumarins and flavonoids, which inhibit seed germination, root growth and shoot development in both crops and native species (42). *Ageratum houstonianum* exhibits similar effects, as its aqueous extracts suppress germination and root elongation, demonstrating a chemical strategy that enhances invasiveness (13). The liana *M. micrantha* also exerts strong allelopathic effects on *C. diffusa*, reducing leaf number and causing plant mortality within 10–15 days at certain concentrations, highlighting its potential as a natural bioherbicide (43).

Other key Asteraceae species, such as *B. pilosa*, *C. crepidioides* and *E. sonchifolia*, produce phenolic acids, flavonoids, sesquiterpenes and pyrrolizidine alkaloids that inhibit germination and impair seedling growth of neighbouring plants (44). Through litter, root exudates and leaf leachates, these compounds create chemically inhospitable soil conditions for native regeneration. Combined with rapid reproduction and aggressive vegetative growth, these allelopathic traits enable Asteraceae species to act as keystone invasives, maintaining long-term establishment in disturbed volcanic habitats on Mount Gamalama.

Conservation implications and restoration opportunities

The presence of 31 invasive plant species along the Mount Gamalama hiking trail highlights the need for proactive management to prevent further spread into surrounding native vegetation. Hiking trails are recognised as important pathways for the introduction and dispersal of invasive plants through increased human movement and habitat disturbance. Consequently, regular monitoring programs should be established along the trail to facilitate the early detection of newly established invasive species and to assess changes in species distribution over time.

Management efforts should prioritise invasive species that are widespread, occur across broad elevational ranges, or have documented ecological impacts in other regions. Mechanical removal and habitat maintenance may help reduce the establishment and expansion of invasive populations in heavily disturbed areas. In addition, restoration activities using native plant species could be implemented in degraded sites to enhance ecosystem recovery and increase resistance to future biological invasions. These measures would contribute to the long-term conservation of the Mount Gamalama ecosystem and support the sustainable management of biodiversity within this volcanic island landscape.

Conclusion

This study provides the first comprehensive documentation of invasive plant species along the Mount Gamalama hiking trail, revealing a taxonomically diverse assemblage dominated by herbaceous species and Asteraceae. The recorded species span a wide elevational range and originate from multiple biogeographic regions, particularly the Americas, reflecting well-known introduction pathways into island ecosystems.

Although traits such as phenotypic plasticity, allelopathy and competitive ability were not experimentally tested in this study, the literature indicates that these functional attributes may contribute to the ecological success of several species in the area. The identification of 31 invasive species, including 19 species previously reported to exhibit allelopathic activity, suggests that multiple ecological mechanisms may contribute to invasion success along the Mount Gamalama hiking trail. The findings presented here therefore serve as essential baseline data for understanding invasive plant diversity on Mount Gamalama. Future research should incorporate experimental or field-based ecological assessments to directly evaluate the functional traits and ecological impacts of key invaders. Such evidence will be crucial for developing targeted management and conservation strategies aimed at protecting the unique volcanic ecosystems of Temate Island.

Authors' contributions

SS conceived the study, led the research, drafted and finalised the manuscript. HDS and AT conducted the field data collection, with AT also verifying the plant identification. ADK proofread the manuscript and carried out the English language editing. SK performed the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflicts of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT to check the type and review the idea. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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