

Diversity and composition of flowering plants in lahar-affected soils of La Salle Botanical Garden, Philippines

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Abstract. Paras AMI, Casa IBM, Luis JZSS, Bravo LIB, Co AJM, Inciong DRIB, Gumangan JCT. 2025. Diversity and composition of flowering plants in lahar-affected soils of La Salle Botanical Garden, Philippines. *Biodiversitas* 26: 6089-6098. The 1991 Mt. Pinatubo eruption and subsequent lahar flows created extensive sterile volcanic substrates that eliminated pre-existing vegetation, initiating primary succession across the landscape in Philippines. Despite extensive research on agricultural recovery efforts, natural vegetation recolonization patterns in these extreme environments remain poorly documented. This study conducted a rapid biodiversity assessment of flowering plants in lahar-affected soils at the La Salle Botanical Garden (LSBG) in Porac, Pampanga, Philippines, to characterize early successional dynamics and identify functional traits enabling establishment in volcanic substrates. Using the Line Intercept Technique across two temporal surveys (August-September 2024), eight angiosperm species from eight families were recorded, comprising three native and five naturalized taxa. The community exhibited low diversity ($H' = 0.58$) and strong dominance by two invasive species: *Passiflora foetida* and *Asystasia gangetica*, which collectively accounted for > 54.56% of relative density. While these pioneer species possess stress-tolerant traits—including drought tolerance, rapid growth, and efficient dispersal—that enable persistence in nutrient-poor, physically unstable lahar substrates, their dominance raises concerns about invasion-mediated alternative stable states that may prevent progression toward native-dominated communities. The overwhelming presence of invasive species suggests that natural succession alone is unlikely to restore native vegetation without active management intervention. Our findings provide critical baseline data for long-term monitoring and emphasize the urgent need for early invasive species control coupled with targeted enrichment planting of stress-tolerant native species to shift succession trajectories toward restoration goals. This study highlights LSBG's role as a living laboratory for understanding tropical volcanic succession and demonstrates how functional trait approaches can inform restoration practice in extreme disturbance environments.

Keywords: Functional traits, Mt. Pinatubo, primary succession, tropical restoration, volcanic substrates

Abbreviations: Asl: Above sea level, DENR: Department of Environment and Natural Resources, LIT: Line Intercept Technique, LSBG: La Salle Botanical Gardens, PAST: Paleontological Statistics

INTRODUCTION

Biodiversity underpins ecosystem resilience and human well-being, yet it continues to decline due to accelerating pressures from climate change, land conversion, and pollution (Roe 2019; Benton and Wallace 2023). In the Philippines—one of the world's most critical biodiversity hotspots—losses among flowering plants threaten ecological stability and the delivery of vital ecosystem services (Acma et al. 2021; Ada and Cruz 2021). Volcanic eruptions, in particular, produce some of the harshest disturbances to terrestrial biodiversity. Following the 1991 Mt. Pinatubo eruption, thick lahar deposits covered extensive areas of Pampanga, Zambales, and Tarlac, creating infertile, unstable substrates that continue to hinder vegetation recovery and delay succession (Abugho et al. 2020; Quimbo 2022). Understanding how plant communities re-establish under these extreme conditions is crucial not only for advancing ecological theory on succession but also for developing effective, science-based restoration strategies for ecosystems affected

by lahar, i.e. fast-moving mixtures of volcanic debris and water (Delcamp et al. 2015; Vallance and Iverson 2015).

Ecological succession on freshly deposited lahar substrates is governed by several interacting mechanisms, often described by the facilitation, inhibition, and tolerance models (Connell and Slatyer 1977). In the facilitation model, early colonizers modify microhabitats—improving soil moisture, nutrient availability, and microclimate—thereby enabling the establishment of later species. The inhibition model, in contrast, posits that dominant pioneers can suppress or delay colonization by other taxa through competition or allelopathy, resulting in persistent low diversity. The tolerance model highlights the role of abiotic filtering, where only species physiologically adapted to harsh conditions can persist regardless of interactions. Studies on the Merapi (Indonesia) and Pinatubo volcanic systems show that all three mechanisms may operate simultaneously: early legumes and stress-tolerant herbs often facilitate subsequent species establishment, while invasive taxa such as *Acacia decurrens* Willd. can monopolize space and inhibit native recruitment (García-Romero et al. 2015). Such dynamics lead to multiple

successional trajectories driven by soil texture, moisture, and colonization history rather than a single linear recovery path.

Prior to the catastrophic June 1991 eruption of Mt. Pinatubo, the surrounding lowlands supported diverse tropical vegetation communities characteristic of the Philippine lowland forest ecosystem (Jones and Newhall 1996; Singh et al. 2024). These included mixed dipterocarp forests at higher elevations and agricultural landscapes interspersed with secondary growth vegetation in the lower slopes and valleys (Abugho et al. 2020). The eruption and subsequent lahar flow fundamentally transformed this landscape. Pyroclastic flows, ashfall, and particularly the massive lahar deposits, mobilized during monsoon rains following the eruption, completely buried existing vegetation under depths ranging from several centimeters to multiple meters of volcanic debris. This catastrophic disturbance created essentially sterile substrates that eliminated pre-existing plant communities across vast areas, initiating primary succession from bare volcanic material rather than secondary succession from residual propagules (Nakao et al. 2021). Unlike secondary succession where soil seed banks, root systems, and vegetative fragments facilitate recovery, the lahar-affected areas of Mt. Pinatubo represent true primary succession scenarios where colonizing species must arrive via long-distance dispersal and establish in nutrient-poor, physically unstable volcanic substrates with extreme microclimate conditions (Guanzon et al. 2023).

The 1991 Mt. Pinatubo eruption remains one of the most dramatic volcanic disturbances of the twentieth century. The eruption deposited silica-rich tephra and coarse sand, producing soils deficient in organic matter and nutrients (Abugho et al. 2020; Nakao et al. 2021). Lahars continue to reshape these landscapes more than three decades later (Guanzon et al. 2023; Singh et al. 2024). Although certain pioneer species, such as *Passiflora foetida* L. and *Asystasia gangetica* (L.) T. Anderson, can rapidly colonize these unstable areas, lahar substrates typically exhibit sparse vegetation, low species richness, and strong dominance patterns characteristic of early succession (Ramkumar 2016). Effective restoration in such settings requires integrating geomorphic stabilization, soil amelioration, and species-site matching, ensuring that selected species tolerate nutrient-poor substrates while supporting soil development and erosion control (Ho et al. 2016; Parlucha et al. 2017; Peduto et al. 2022). Botanical gardens offer unique opportunities to study succession in such disturbed environments, which represent semi-managed but ecologically representative systems. The La Salle Botanical Garden (LSBG) in Porac, Pampanga, lies within the zone heavily impacted by Mt. Pinatubo lahars. Its mission as a “living library” for research, education, and conservation makes it an ideal site for biodiversity assessments that can guide both local restoration and broader conservation strategies (Nogales et al. 2022). However, despite extensive research on agricultural recovery and crop restoration efforts following the catastrophic 1991 Mt. Pinatubo eruption, the broader ecological impacts on natural vegetation communities, specifically the recovery patterns, species composition, and succession dynamics of native and naturalized angiosperms in lahar-affected ecosystems, remain

underexplored (Nakao et al. 2021). While agricultural rehabilitation has been well-documented, the natural recolonization processes in volcanic substrates present unique opportunities to understand primary succession in tropical disturbed landscapes. (Babaan et al. 2018).

Conceived as a “living library” for education, conservation, and research, LSBG serves as a model site for monitoring vegetation recovery in volcanic landscapes (Nogales et al. 2022). Unlike many post-eruption studies that focus on agricultural rehabilitation or forest regeneration, investigations within botanical gardens can reveal how naturalized and native species interact under controlled disturbance regimes. This setting offers both research value—by providing replicable, monitored conditions—and practical relevance for restoration, as garden-based data can inform enrichment planting and soil rehabilitation strategies for nearby degraded zones (Babaan et al. 2018).

Angiosperms, or flowering plants, represent approximately 80% of the Philippine flora, encompassing roughly 8,000 species (Keya and Rahman 2017; Ada and Cruz 2021). They are vital providers of ecosystem services, from pollinator support and carbon sequestration to soil stabilization. Their capacity to re-establish in lahar-affected soils thus serves as a key indicator of early ecosystem recovery and resilience. However, quantitative assessments of angiosperm diversity, abundance, and dominance in lahar environments remain scarce, particularly within botanical gardens where ecological monitoring could complement restoration practice.

This study addresses these knowledge gaps by conducting a rapid biodiversity assessment of flowering plants in the lahar-affected soils of the La Salle Botanical Garden. Using biodiversity indices such as Shannon, Simpson, Dominance, and Evenness, the research evaluates species richness, abundance, and community structure to determine which angiosperms persist and dominate under these conditions. The results contribute to understanding how facilitation, inhibition, and tolerance mechanisms shape early vegetation assembly and provide a theoretical basis for guiding restoration in volcanic landscapes. By establishing baseline data within a botanical garden context, this study links ecological succession theory with applied restoration science, highlighting how managed conservation spaces can function as living laboratories for resilience and biodiversity recovery in post-eruption ecosystems.

MATERIALS AND METHODS

Study area

The study was conducted in the grassland zone of the La Salle Botanical Garden (LSBG), located in Porac, Pampanga, Philippines. The area encompasses approximately 24 hectares of lahar-deposited substrate derived from the 1991 Mt. Pinatubo eruption. Two survey points within the site were assessed during August and September 2024 to capture temporal variation in vegetation structure and composition.

Point A (15°06'21"N, 120°30'24"E) lies on a slightly elevated, nearly flat terrain with an elevation of 129.44 m above sea level (m asl), while Point B (15°06'17"N,

120°30'34"E) is similarly flat at 123.39 m asl. The soil across both points is predominantly sandy, reflecting its volcanic origin. Given the site's proximity to Mt. Pinatubo (approximately 17.5 km from the crater), the substrate remains largely composed of lahar-derived materials characterized by low organic matter and poor water retention (Abugho et al. 2020; Quimbo 2022) (Figure 1). Field observations indicated minimal human disturbance, with no evidence of recent cultivation or landscaping activities. The vegetation is composed primarily of natural grasses, herbaceous plants, and scattered shrubs features typical of early successional communities developing on lahar soils (Guanzon et al. 2023). The climate of Porac follows the Type I classification of the Modified Coronas system, featuring two pronounced seasons: a dry season from November to April and a wet season from May to October. Locally, conditions are marked by cool mornings, dry midday periods, and frequent late-afternoon rainfall influenced by the southwest monsoon and convectional activity.

Survey points were selected to maximize the detection of naturally occurring flowering plants within open grassland habitats. The expansive and minimally managed landscape reduced the influence of ornamental planting, ensuring that the sampling reflected the site's native and naturalized flora. Subsequent transect-based sampling was conducted within these representative grassland patches to document species composition and diversity.

Procedures

Study design

This study employed a descriptive botanical inventory to document flowering plant diversity within the lahar-affected grassland of the La Salle Botanical Garden (LSBG), Porac, Pampanga. The objective was to generate baseline information on species composition and abundance to

support long-term ecological monitoring and guide restoration strategies in volcanic substrates.

Two survey periods were implemented during the monsoon growing season (August–September 2024) to capture both temporal and spatial variation in vegetation structure. The first survey (August 2024) used two 20-m transects bordered by 10 m × 10 m quadrats placed systematically on opposite sides of each transect line. This initial layout provided high-resolution data on micro-scale vegetation patterns within relatively homogeneous patches of lahar grassland.

Following preliminary field observations that revealed pronounced heterogeneity and patchiness in plant distribution, the second survey (September 2024) adopted an expanded configuration: a 100-m baseline subdivided into ten alternating 10 m × 10 m quadrats on both sides. This adjustment was intentional and methodological rather than procedural drift. The first survey functioned as a pilot assessment to evaluate sampling efficiency and detect the spatial extent of variation, whereas the second refined the approach to improve representativeness across the grassland mosaic. Such adaptive modification aligns with best-practice protocols for primary-succession studies in volcanic environments—such as those developed for Mt. Merapi and Mt. Pinatubo—where early assessments often require iterative sampling design to balance precision and coverage (Newhall 2021; Sambajon et al. 2024).

Surveys were conducted during the monsoon period when vegetation growth and detectability are at their peak, ensuring that phenological differences did not confound estimates of abundance or diversity. Transect and quadrat placement followed a systematic-random approach: within each sampling area, the starting point of the baseline was determined using random-number coordinate offsets, and quadrats were positioned at fixed 10-m intervals along the transect to ensure spatial consistency while minimizing observer bias. Overall, the combined sampling effort covered approximately 1,200 m², sufficient to characterize early-stage community composition within the lahar grassland.

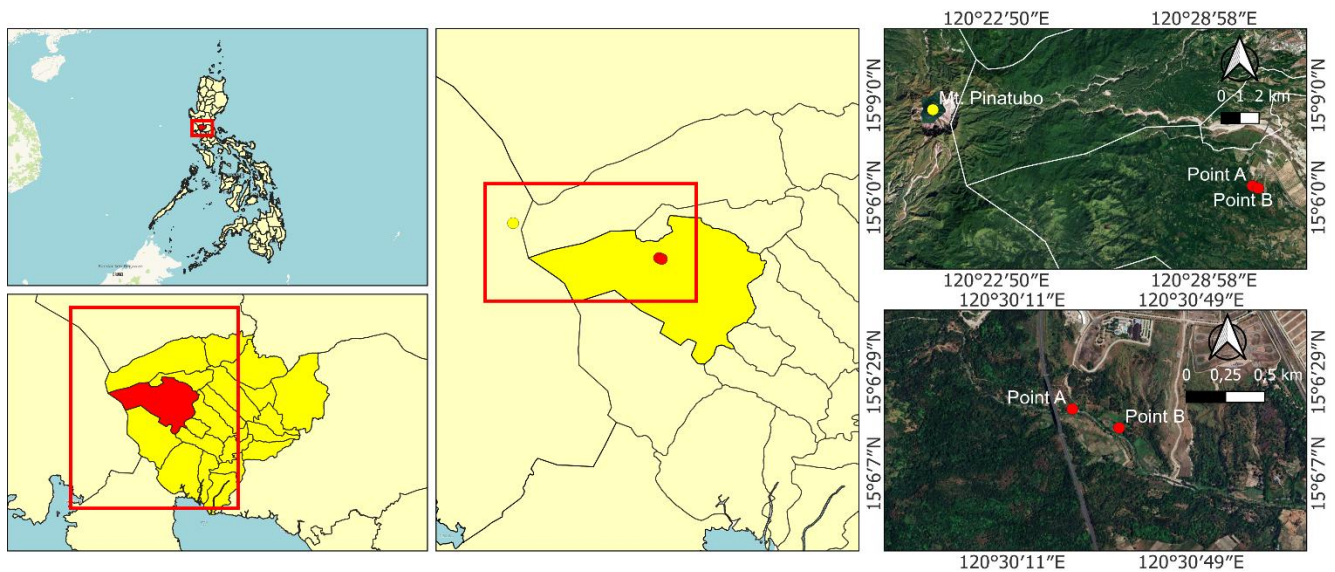


Figure 1. Study area at La Salle Botanical Garden, Porac, Pampanga, Philippines. Point A (15°06'21"N, 120°30'24"E), Point B (15°06'17"N, 120°30'34"E), Mt. Pinatubo (15°08'35.25"N, 120°20'58.25"E)

Data collection and documentation

Fieldwork was conducted from August to September 2024, coinciding with the wet-season growth period when most angiosperms are in full bloom and taxonomically identifiable. Surveys were carried out from 06:00 to 10:00 a.m. to take advantage of optimal natural light, minimal wind interference, and reduced heat stress—conditions that improve visibility and observer consistency.

Within each quadrat, all flowering angiosperms were recorded using the Line Intercept Technique (LIT) (Biodiversity Management Bureau, Deutsche GIZ GmbH 2017) to estimate ground cover and species dominance. Individual plants intersecting each transect line were counted, their intercept length measured, and representative individuals photographed for subsequent taxonomic confirmation. Only healthy and undamaged specimens—those with intact leaves and reproductive structures, no visible pest or disease damage, and upright growth—were included in the dataset to minimize misidentification due to morphological anomalies.

Each taxon was photographed using a high-resolution smartphone camera, and abundance was quantified as the total count per square meter. Vegetation data were collected during two survey periods to capture short-term temporal variation characteristic of early successional communities. Results are presented at three analytical levels: (i) Cumulative community summary (Table 1): Overall species list and importance values combining data from both survey periods, representing the total species pool and general community structure across the study period; (ii) Temporal snapshot 1 (Table 3): Species composition, density, and frequency data from the August 2024 survey, representing early monsoon season conditions; (iii) Temporal snapshot 2 (Table 4): Species composition, density, and frequency data from the September 2024 survey, representing mid-monsoon season conditions. This temporal resolution enables assessment of short-term colonization processes and seasonal shifts in species abundance within the lahar-affected grassland ecosystem.

Taxonomic identification of angiosperms

Plant species were identified using a two-tiered approach. Initial recognition was performed through an online platform supported by photographic documentation (Atara et al. 2024). Identification to applicable taxonomic level (genus, species, or variety/cultivar) was achieved using taxonomic keys available from the International Aroid Society and online databases such as Co's Digital Flora of the Philippines (<https://www.philippineplants.org/>).

Species were subsequently verified by experts at the University of the Philippines Diliman, following the protocols of the Jose Vera Santos Memorial Herbarium. Verification involved the mounting and labeling of specimens according to herbarium standards for angiosperms, supported by high-quality photographs of flowers, inflorescences, fruits, and shoot tips. Voucher specimens were collected when needed, but physical samples were submitted only upon request. The combined use of preliminary online identification and herbarium confirmation ensured taxonomic accuracy (Kanieski et al. 2018).

Ethical consideration

All research activities were carried out in accordance with Philippine laws on biodiversity research and collection. A Wildlife Gratuitous Permit was secured from the Department of Environment and Natural Resources (DENR) Regional Office in Pampanga prior to fieldwork. Collection of plant materials was kept at the minimum necessary for taxonomic identification, and voucher specimens were only prepared when required for herbarium confirmation. No endangered or threatened plant species, as listed in the DENR Administrative Order 2017-11, were harmed or removed from the study site. The study adhered to ethical standards for biodiversity research, ensuring that sampling did not cause long-term disturbance to the lahar grassland ecosystem.

Data analysis

Biodiversity indices

Quantitative analysis employed the Shannon–Wiener (H'), Simpson (D'), Pielou's Evenness (E), and Margalef Richness (R) indices. These indices were chosen for their complementary ability to describe different dimensions of community structure in disturbed ecosystems. The Shannon index integrates both richness and evenness, the Simpson index emphasizes dominance effects, Evenness reflects ecological balance, and Margalef provides a standardized richness metric sensitive to sample size. Using this suite of indices allows comprehensive interpretation of community organization and disturbance response, consistent with best practices in volcanic-succession studies (e.g., Mulya et al. 2021; Kitikidou et al. 2024). Indices were calculated for each transect and then compared across survey points to capture community-level patterns. Species abundance data were processed using PAST software to compute biodiversity indices (Biodiversity Management Bureau, Deutsche GIZ GmbH 2017).

The following formulae were used to calculate biodiversity indices:

Species richness (Margalef Index):

$$R = \frac{S - 1}{\ln N}$$

Where, S : Number of species, N : Total number of individuals

Shannon–Wiener Index (H'):

$$H' = -\sum(p_i \ln p_i)$$

Where, p_i : Proportion of individuals of species i .

Simpson Index (D):

$$D = \sum p_i^2$$

Where values closer to 1 indicate dominance by few species, and values near 0 indicate higher diversity

Pielou's Evenness (E):

$$E = \frac{H'}{\ln S}$$

Density (Dens): $Dens = \frac{n}{A}$

Where, n : Number of individuals of a species, A : Area sampled

Relative Density (RD): $RD = \frac{Dens_i}{\sum Dens} \times 100$

Frequency (F): $F = \frac{\text{number of plots where species } i \text{ occurs}}{\text{total number of plots}}$

Relative Frequency (RF): $RF = \frac{F_i}{\sum F} \times 100$

Interpretation of values

Biodiversity indices were interpreted following established ecological standards (Mulya et al. 2021) but with emphasis on contextual comparison rather than rigid numerical thresholds. Diversity values in lahar-affected ecosystems are strongly influenced by substrate age, disturbance intensity, and environmental stress, making relative patterns—such as dominance shifts or changes in evenness—more meaningful than absolute index values.

For reference and comparability, standard interpretive ranges were still adopted. Species richness (R) was considered low when < 2.5, medium between 2.5-4.0, and high when > 4.0. The Shannon–Wiener Index (H') was categorized as very low (≤ 1.9), low (2.0-2.49), moderate (2.5-2.99), high (3.0-3.49), and very high (≥ 3.5). Simpson's Dominance Index (D') ranged from 0, indicating minimal dominance, to 1, representing complete dominance by one or few species. Evenness (E) was interpreted as very low (0.05-0.14), low (0.15-0.24), moderate (0.25-0.49), high (0.50-0.74), and very high (0.75-1.00).

Indices from the two survey periods (August and September) and between the two sampling scales (short transects vs. long transect with quadrats) were compared descriptively to assess spatial heterogeneity and temporal variation in community composition. No inferential statistical tests were performed due to the limited sampling effort and exploratory nature of the study. This limitation is acknowledged and discussed in the interpretation section.

RESULTS AND DISCUSSION

Floral species composition

A total of eight angiosperm species, representing eight families, were documented across both survey periods in

the lahar-affected area of the La Salle Botanical Garden (Table 1). Of these, three were native—*Momordica charantia* L., *Ipomoea obscura* (L.) Ker Gawl., and *Spermacoce hispida* L.—while five were naturalized species including *A. gangetica*, *Tridax procumbens* L., *Calopogonium mucunoides* Desv., *P. foetida*, and *Lantana camara* L.. None of the recorded species were listed under the IUCN Red List, reflecting the prevalence of common pioneer taxa typical of disturbed lahar landscapes.

During the first survey (August 2024), *P. foetida* exhibited the highest density and relative density values, indicating strong initial dominance (Table 3). In contrast, the second survey (September 2024) showed a compositional shift toward *A. gangetica*, which replaced *P. foetida* as the most abundant taxon (Table 4). Native species persisted at low densities across both surveys, suggesting limited recruitment under high competition pressure from fast-growing naturalized taxa. Overall, the assemblage represents an early successional community dominated by stress-tolerant herbs and climbing species adapted to nutrient-poor lahar soils (Table 5).

Patterns of species dominance also highlight the early establishment of invasive taxa within the community (Barfknecht et al. 2020). The two most abundant species, *P. foetida* and *A. gangetica*, are regionally recognized as invasive throughout the Philippines and Southeast Asia. Both exhibit traits conducive to rapid colonization, including prolific seed production, wide environmental tolerance, and the ability to form dense ground cover that limits native seedling recruitment (Tilley et al. 2022; Denton and Dale 2025). Their combined relative density (> 54%) suggests successful occupation of early successional niches that may constrain subsequent colonization by native species.

Table 1. Cumulative species list and importance values for angiosperm vegetation in Mt. Pinatubo, Philippines, lahar deposits across both survey periods (August-September 2024)

Species/cultivar	Family	Common or local name	Origin/distribution status	Conservation status	Density (ind./m ²)	Relative density (%)	Relative frequency (%)
<i>Asystasia gangetica</i> (L.) T. Anderson	Acanthaceae	Asistasiya, zamboanginita (local bulak-bulak)	Naturalized	NE	2.84-7.48	≤ 27.15	42.86
<i>Momordica charantia</i> L.	Cucurbitaceae	Ampalaya (local paria, palia)	Native	NE	0.01	0.04	7.14
<i>Tridax procumbens</i> L.	Asteraceae	Coatbuttons, tridax daisy	Naturalized	NE	0.11-0.85	0.40–5.12	10-14.29
<i>Calopogonium mucunoides</i> Desv.	Fabaceae	Calopo	Naturalized	NE	0.08	0.29	7.14
<i>Ipomoea obscura</i> (L.) Ker Gawl.	Convolvulaceae	Obscure morning glory	Native	NE	0.02-0.07	0.07-0.25	21.43
<i>Passiflora foetida</i> L.	Passifloraceae	Wild passionfruit, stinking passionflower (local pasyonarya)	Naturalized	NE	3.15-4.55	18.98-27.41	40
<i>Lantana camara</i> L.	Verbenaceae	Lantana (local kantutay)	Naturalized	NE	0.05-0.90	0.64-5.42	20
<i>Spermacoce hispida</i> L.	Rubiaceae	Landrina	Native	NE	0.05-0.10	0.30-3.08	20

Note: Values represent overall community structure across the study period. Density: Individuals/m², Relative density: Percentage of total individuals, Relative frequency: Percentage occurrence across all plots

Table 2. Biodiversity indices (species richness R, Shannon index H', Simpson dominance D', and evenness E) of flowering plants across quadrats during the first and second survey periods in lahar-affected soils of La Salle Botanical Garden, Pampanga, Philippines

Survey period	Quadrat/transect	No. of species	No. of individuals	Richness (R)	Shannon (H')	Simpson (D')	Evenness (E)
First visit (Aug 2024)	T1	3	176	0.39	0.36	0.81	0.48
	T2	4	156	0.59	0.58	0.72	0.44
Second visit (Sep 2024)	Q3	1	284	0.00	0.00	1.00	1.00
	Q4	2	312	0.17	0.15	0.93	0.58
	Q5	2	757	0.15	0.59	0.98	0.53
	Q6	2	837	0.15	0.34	0.81	0.70
	Q7	1	491	0.00	0.00	1.00	1.00
	Q8	1	3	0.00	0.00	1.00	1.00
	Q9	3	72	0.47	0.51	0.73	0.56
	Q10	1	1	0.00	0.00	0.00	1.00

Table 3. Species composition and quantitative parameters for the August 2024 survey (first temporal snapshot)

Species	Density (ind./m ²)	Relative density (%)	Frequency	Relative frequency (%)
<i>Passiflora foetida</i> L.	9.90	83.87	2	40.00
<i>Tridax procumbens</i> L.	0.85	7.20	0.5	10.00
<i>Lantana camara</i> L.	0.95	8.05	1	20.00
<i>Ipomoea obscura</i> (L.) Ker Gawl.	0.20	1.69	0.5	10.00
<i>Spermacoce hispida</i> L.	0.15	1.27	1	20.00
Total	12.05	100.00	—	100.00

Note: Values represent conditions during early monsoon season. Differences from Table 1 reflect temporal variation and the exclusion of species that appeared only in September

Species diversity and dominance patterns

Biodiversity indices derived from both surveys demonstrated consistently low species richness and diversity (Table 2). During the first visit, richness values ranged from R = 0.39-0.59, with very low Shannon diversity (H' = 0.36-0.58) and high Simpson dominance (D' = 0.72-0.81), indicating community structure strongly influenced by *P. foetida*. The second visit confirmed these patterns, with several quadrats completely dominated by a single species (H' = 0; D' = 1.00), although some quadrats with mixed species displayed slightly higher evenness (E = 0.53-1.00).

Comparative analysis (Table 5) revealed a temporal shift in dominance from *P. foetida* to *A. gangetica*, coinciding with a two-fold increase in total plant density (from 12.05 to 27.56 ind./m²) but without notable improvement in diversity metrics. These results indicate that the vegetation remains in an early successional stage dominated by a few opportunistic species that contribute to soil stabilization but restrict broader species establishment.

Temporal comparison between survey periods reveals dynamic colonization patterns (Chiarucci et al. 2021). Species showing increased density from August to September suggest successful establishment and population expansion, while species showing decreased density may represent transient colonization attempts or seasonal phenology effects (Gizachew 2021; Rheault et al. 2021). The appearance of new species in September indicates ongoing colonization from surrounding seed sources, while the persistence of dominant invasive species across both periods confirms their successful establishment in these volcanic substrates.

Density, frequency, and relative abundance

Patterns of species dominance were further illustrated through density and frequency analyses (Tables 3 and 4). During the first survey (August 2024), *P. foetida* exhibited the highest density (9.9 ind./m²) and relative density (83.9%), accounting for nearly all individuals within sampled quadrats. Its high relative frequency (40%) indicates widespread distribution across transects. Other species such as *L. camara* and *S. hispida* occurred only sporadically at very low densities, confirming the strong dominance of *P. foetida* in the early survey period.

In the second survey (September 2024), community composition shifted markedly. *Asystasia gangetica* became the most abundant taxon, recording the highest density (21.4 ind./m²) and relative density (77.6%) with a relative frequency of 42.9%. This replacement of *P. foetida* as the dominant species demonstrates the rapid growth and competitive ability of *A. gangetica* in lahar soils. Although a few other species such as *I. obscura* and *S. hispida* persisted, they contributed little to total abundance.

The summary comparison (Table 5) highlights this temporal transition in dominance and shows that, despite the increase in total plant density from the first to the second survey, overall community diversity remained low. The observed dominance patterns reflect a vegetation structure driven by a few stress-tolerant, fast-growing pioneers capable of establishing under nutrient-poor lahar conditions, typical of early successional grasslands.

Table 4. Species composition and quantitative parameters for the September 2024 survey (second temporal snapshot). Values represent conditions during mid-monsoon season

Species	Density (ind./m ²)	Relative density (%)	Frequency	Relative frequency (%)
<i>Asystasia gangetica</i> (L.) T. Anderson	21.42	77.63	0.6	42.86
<i>Tridax procumbens</i> L.	0.13	0.47	0.2	14.29
<i>Calopogonium mucunoides</i> Desv.	0.08	0.29	0.1	7.14
<i>Spermacoce hispida</i> L.	0.89	3.23	0.1	7.14
<i>Ipomoea obscura</i> (L.) Ker Gawl.	5.03	18.25	0.3	21.43
<i>Momordica charantia</i> L.	0.01	0.04	0.1	7.14
Total	27.56	100.00	—	100.00

Note: Values represent conditions during mid-monsoon season. Differences from Table 1 reflect temporal variation and the exclusion of species that appeared only in August

Table 5. Summary comparison of dominant species, total abundance, and diversity indices between the first and second surveys in lahar-affected soils of La Salle Botanical Garden, Pampanga, Philippines

Survey period	Dominant species	Total density (ind./m ²)	Relative density of dominant (%)	Species richness (R)	Shannon Index (H')	Simpson dominance (D')	Evenness (E)	Community description
August 2024	<i>Passiflora foetida</i> L.	12.05	83.87	0.39-0.59	0.36-0.58	0.72-0.81	0.44-0.48	Low diversity; dominance by <i>Passiflora foetida</i> indicates early successional stage.
September 2024	<i>Asystasia</i> (L.) T. Anderson	27.56	77.63	0.00-0.47	0.00-0.59	0.70-1.00	0.53-1.00	Low to very low diversity; dominance shift to <i>A. gangetica</i> , suggesting species turnover among pioneers.

Discussion

The consistently low diversity and high dominance observed in the floral community of the La Salle Botanical Garden confirm that vegetation in the lahar-affected soils remains in the early stages of primary succession. Similar patterns have been documented in other volcanic landscapes where disturbance intensity, nutrient-poor substrates, and unstable topography constrain colonization, allowing only a few stress-tolerant species to persist (Wohlgemuth et al. 2016; Thouret et al. 2020). In post-Pinatubo lahar zones, comparable low-diversity assemblages of herbaceous and vine species have been recorded, indicating that succession proceeds slowly under these conditions (Lasco et al. 2001; Nakao et al. 2021).

The dominance of *P. foetida* and *A. gangetica* in this study highlights the adaptive strategies of opportunistic species capable of thriving in coarse, low-nutrient, and erosion-prone substrates. Their reproductive and physiological traits—such as high seed production, rapid vegetative growth, and tolerance to drought—reflect classic pioneer characteristics suited to lahar environments (Asbur et al. 2018; Sundaram and Vasanthi 2022). However, rather than interpreting the shift from *P. foetida* to *A. gangetica* as an ecological transition, these differences are best viewed as a reflection of spatial and temporal variability within a small and heterogeneous sampling area. The methodological variation between survey periods and limited temporal scope likely influenced observed abundance patterns.

In addition, the overwhelming dominance of invasive species *P. foetida* and *A. gangetica* in the Mt. Pinatubo lahar deposits raises critical questions about long-term

succession dynamics and restoration trajectories (Chiarucci et al. 2021; Fiqa et al. 2025). *Passiflora foetida*, a pantropical invasive vine, exhibits several traits that confer advantages in disturbed volcanic substrates: rapid vegetative growth enabling quick ground cover establishment, extensive seed production with animal-mediated dispersal, climbing habit that allows exploitation of any available vertical structure, and potential allelopathic effects that may inhibit competitor establishment (Rome et al. 2024). *Asystasia gangetica* similarly demonstrates high phenotypic plasticity across environmental gradients, ability to establish in nutrient-poor soils, rapid reproduction through both seeds and vegetative propagation, and formation of dense ground cover that excludes other species (Wardini et al. 2023; Chibuzo et al. 2024).

The early establishment of these invasive species may lead to alternative stable states rather than progression toward native-dominated communities. Priority effects, where early colonizers disproportionately influence community assembly, may create invasion-dominated trajectories that persist for decades or become permanent (Young et al. 2023). This invasive monopolization threatens native species recruitment, as dense invasive cover prevents native seed germination and seedling establishment (Yu et al. 2020). It greatly affects functional diversity, as invasive monocultures reduce ecosystem functional diversity compared to native-dominated communities (Csákvári et al. 2023). It also affects the ecosystem services through altered pollinator networks, reduced habitat value for native fauna, and modified nutrient cycling; and the restoration outcomes, as natural succession may not progress toward native forest

communities without intervention (Rojas-Botero et al. 2022).

From a theoretical standpoint, the dominance structure observed can be interpreted through the facilitation–inhibition–tolerance framework (Connell and Slatyer 1977; Poorter et al. 2023). Early colonizers may initially improve microhabitat conditions—reducing erosion and increasing surface organic matter—but can later suppress subsequent recruitment through shading or competition for limited nutrients. This dynamic has been reported in volcanic ecosystems such as Merapi (Indonesia) and Arenal (Costa Rica), where initial dominance by stress-tolerant vines and herbs was followed by gradual compositional turnover as soils stabilized (García-Romero et al. 2015). The observed low Shannon diversity and high dominance indices are consistent with these early successional dynamics.

In terms of restoration, the findings emphasize the importance of matching species functional traits to lahar substrate conditions rather than prescribing specific taxa for enrichment planting. Restoration strategies in volcanic soils should prioritize species that: (i) Establish rapidly to prevent erosion, (ii) Tolerate nutrient-poor and drought-prone substrates, (iii) Promote soil improvement through litter production or nitrogen fixation. The functional traits exhibited by dominant colonizing species reveal convergence on specific trait syndromes adapted to volcanic substrate stress. *Passiflora foetida* demonstrates a stress-tolerance syndrome characterized by vining habit, deep tap roots, and small dissected leaves providing high surface area for cooling. *Aasystasia gangetica* exhibits prostrate growth form, rapid root proliferation, and high phenotypic plasticity. These trait patterns align with predictions from the Fiqa et al. (2025) framework and suggest that successful restoration should focus on native species possessing similar trait syndromes, specifically drought tolerance, nutrient efficiency, and rapid growth rates, rather than attempting to establish species lacking stress-tolerance traits. Active restoration interventions should also be considered, including early invasive species control before seed banks establish, native species enrichment planting to increase propagule pressure, creating microsites favorable for native establishment through nurse plant facilitation, and monitoring to detect native colonization and adjust management accordingly. Without such interventions, these sites may remain locked in invasion-dominated states indefinitely, representing a cautionary tale for volcanic restoration in landscapes with high invasive propagule pressure. These principles have guided successful interventions in Merapi and Pinatubo restoration projects (Dolores et al. 2020; Kidane et al. 2023). Within botanical garden settings such as LSBG, these insights can inform future enrichment trials designed to test native lahar-tolerant species under controlled conditions before large-scale application.

It is also essential to acknowledge the methodological limitations of this study. The change in sampling design between surveys, small sample size, and short observation period limit the capacity to infer long-term successional trends or species turnover dynamics. Nevertheless, these data provide valuable baseline information for future

monitoring efforts. Establishing permanent plots and adopting consistent sampling protocols in subsequent assessments would enable more reliable temporal comparisons and better capture successional progression in lahar ecosystems.

Overall, this study reinforces the value of the La Salle Botanical Garden as a living laboratory for understanding early plant community assembly in disturbed volcanic environments. Continued biodiversity monitoring, integrated with soil and microclimatic measurements, will enhance the predictive capacity of restoration models for lahar-impacted areas across Central Luzon and similar tropical regions.

Conclusion, the low species diversity and high dominance observed in the lahar-affected soils of the La Salle Botanical Garden indicate that vegetation recovery remains in an early successional phase dominated by a few stress-tolerant pioneers. These findings align with ecological patterns reported in other volcanic systems, emphasizing the strong influence of substrate infertility and disturbance on community assembly. Rather than prescribing specific enrichment species, this study underscores the importance of functional trait-based selection of lahar-tolerant native plants and the need for long-term, standardized monitoring to evaluate their establishment success. Future research should focus on establishing permanent observation plots, testing candidate native species for restoration, and integrating soil and hydrological data to guide ecosystem rehabilitation. By providing the first baseline account of flowering plant diversity in the lahar substrates of LSBG, this work contributes to both ecological theory on succession and the practical goal of developing science-informed restoration frameworks for post-eruption landscapes in the Philippines.

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