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Ruderal flora as ethnoecological capital for urban conservation policy in Kupang City, Indonesia

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Abstract. *Gaol ML, Dewi IAL, Mudita IW. 2025. Ruderal flora as ethnoecological capital for urban conservation policy in Kupang City, Indonesia. Asian J Ethnobiol 8: 390-401.* Accelerating urbanization in tropical cities like Kupang, Indonesia, disrupts green spaces and reshapes spontaneous herbaceous plant communities, which are vital for urban biodiversity. To assess these impacts, field surveys compared flora across urban and peri-urban gradients, revealing 91 species with significantly higher richness and diversity in peri-urban areas. Invasive species dominated the urban core flora, indicating biotic homogenization, while sensitive flora were found mainly in the peri-urban. Crucially, this herbaceous vegetation holds immense socio-ecological value, with 94.51% of species having medicinal uses, and peri-urban corridors supporting multifunctional species that provide material and environmental services. Policy analysis, nevertheless, indicated that current urban planning overlooked these ruderal corridors and lacks specific diversity metrics. This study establishes that peri-urban ruderal flora constitutes a significant form of ethnoecological capital, highlighting its critical importance as a reservoir of both biodiversity and ethnobotanical knowledge. By linking ecological gradients with policy analysis, this study emphasizes the urgency of safeguarding spontaneous vegetation within rapidly transforming urban landscapes. The findings provide a scientific basis for re-evaluating urban conservation strategies to incorporate these socio-ecological values into resilience planning for tropical secondary cities.

Keywords: Biotic homogenization, herbaceous species diversity, policy integration, ruderal corridors, urban-rural gradient

INTRODUCTION

Urbanization is a dominant driver of global environmental change, reconfiguring ecological communities through habitat alteration, fragmentation, and the introduction of synergistic stressors such as impervious surfaces and urban heat islands (Grimm et al. 2008; Seto et al. 2012). These anthropogenic filters act as selective agents, determining species colonization, extirpation, and the distribution of functional traits, leading to distinct urban species pools (Johnson et al. 2013; Aronson et al. 2016). The urban-rural gradient paradigm provides a foundational framework for quantifying these effects, revealing systematic shifts in biodiversity from rural peripheries to urban cores (McDonnell and Hahs 2008). This gradient encapsulates changes in human population density, land-use intensity, and impervious surface cover, allowing researchers to unravel urbanization's impact on ecological processes and biodiversity metrics, such as native species loss and biotic homogenization the increasing dominance of widespread, disturbance-tolerant species (Nagy and Lockaby 2011; Pickett et al. 2011).

The spatial heterogeneity of cities underpins characteristic vegetation patterns along these anthropogenic gradients. Urban ecological research frequently applies zonation models to demonstrate that strong contrasts in floristic composition and community structure between zones (e.g., urban core, suburban, peri-urban) are due to interacting biophysical and socio-economic drivers (Kowarik 1991; Pickett et al. 2011; Aronson et al. 2016). Such research shows that land-use types such as central business districts, residential areas, and transportation corridors contain characteristic plant assemblages directly related to their disturbance regimes and habitat connectivity (McDonnell and Hahs 2008; Rega-Brodsky et al. 2022). This kind of research is pivotal for urban biodiversity conservation, invasive species management, and the use of vegetation for climate adaptation (Elmqvist et al. 2013). Furthermore, urban flora delivers fundamental ecosystem services, from mitigating air pollution to providing cultural benefits, offering important insights for evidence-based green infrastructure design (Haase et al. 2014; Norton et al. 2015).

In tropical regions, secondary cities are experiencing rapid urban expansion, yet their unique biodiversity dynamics remain critically understudied compared to larger metropolises (Seto et al. 2011; McDonald et al. 2020). Indonesia, a tropical biodiversity hotspot, exemplifies this trend, where urban growth often outpaces the implementation of ecological safeguards in spatial planning. Within these cities, spontaneous herbaceous communities are a vital yet underappreciated component of urban biodiversity, providing essential ecosystem services but disproportionately impacted by habitat degradation (Tredici 2010; Ilie and Cosmulescu 2023). Crucially, this spontaneous vegetation often constitutes a significant form of ethnoecological capital, providing accessible medicinal, nutritional, and material resources for urban communities (Arifin and Nakagoshi 2011; Ayuningrum et al. 2024), making it a key subject for ethnobiological research that links ecological patterns directly to human wellbeing (Shackleton et al. 2017; Yuliana et al. 2025). However, within the Indonesian context, urban ecological studies have predominantly focused on floristic inventories, with a limited ethnobotanical focus on the socio-ecological value of spontaneous vegetation (Arifin and Nakagoshi 2011; Latifah et al. 2021; Hakim et al. 2024).

Urban ethnobotanical studies are crucial for exploring the dynamic relationships between urban residents and plants, providing a foundation for integrating local knowledge into urban planning. Such integration can guide the selection of plant species that offer dual ecological and socio-cultural benefits, thereby enhancing environmental quality and conserving local biodiversity amidst urban expansion. In Indonesia, a growing body of research has documented urban ethnobotanical knowledge, focusing on the potential of bamboo in city forests (Adhinata et al. 2023) and the prevalence of medicinal plants in various urban settings (Rizal et al. 2021; Nikmatullah et al. 2022; Aini et al. 2024; Safitri et al. 2024; Putri et al. 2025). However, as noted by Sujarwo (2023), the dominant focus of these studies remains on medicinal plant use and diversity inventories. Consequently, urban ethnobotanical research that explicitly links plant use to biodiversity conservation and ecological maintenance strategies remains relatively underdeveloped.

This study focuses on Kupang City, the capital of East Nusa Tenggara Province, Indonesia—an urbanizing tropical hub experiencing significant in-migration and land conversion (Seto et al. 2011; BPS Kota Kupang 2024). As with other rapidly developing tropical secondary cities, the integration of fine-scale floristic gradient analysis with ethnoecological valuation and policy gap analysis remains relatively unexplored and receives less attention. Therefore, this study aims to examine the effects of urbanization on Kupang's herbaceous communities by: (i) assessing how species richness, diversity, and composition vary along an urban-peri-urban gradient; (ii) evaluating the anthropogenic use potential (ethnoecological value) of the prevailing flora; and (iii) analyzing how existing local and national policies align with the conservation of these communities. By synthesizing ecological, ethnobotanical, and policy data, this research will provide actionable insights into the need to integrate ruderal flora and its associated socio-ecological value into urban resilience planning.

MATERIALS AND METHODS

Study area

This study was conducted in Kupang City (10°36'14"S-10°39'58"S; 123°32'23"E-123°37'01"E), the largest urban hub on Timor Island, Indonesia, located along the northwestern shore of Kupang Bay (Figure 1) (BPS Kota Kupang 2024). Having a tropical savanna climate (Köppen Aw) characterized by a pronounced dry season from April to November, with an average annual rainfall of 1,443 mm and a mean temperature of 27.6°C, the city covers 180.27 km² of mostly anthropogenic landscapes, whose land use consists of residential areas (56.2%), industrial zones (4.1%), green belts (28.2%), and scattered lots for commercial, infrastructure, and institutional purposes (Verburg et al. 2004; BPS Kota Kupang 2024). This tropical climate regime features 7-8 arid months per year, driven by continental air masses from Australia, presenting a significant constraint on urban vegetation dynamics (Byrne 2022).

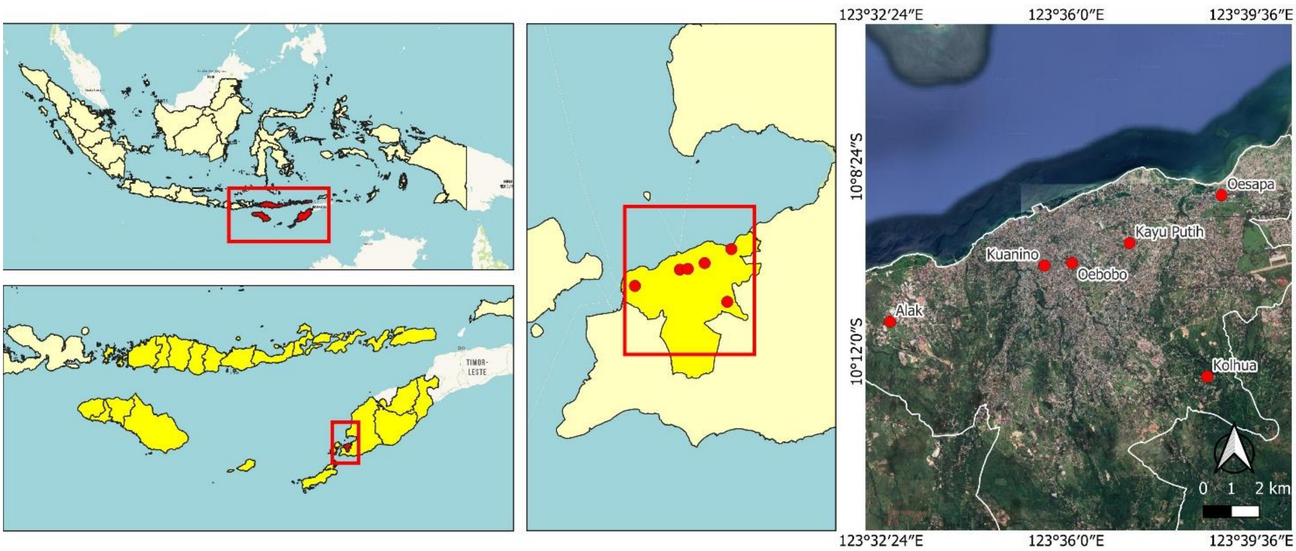

Figure 1. Study area map of Kupang City, East Nusa Tenggara, Indonesia, showing sampled urban core (Kuanino, Oebobo, Kayu Putih) and peri-urban (Kolhua, Alak, Oesapa) sites

Procedures

This study integrated field surveys with analysis of policy documents. Fieldwork employed stratified sampling along an urban gradient in Kupang City. Prior to field activities, a comprehensive review of national and regional policies, including central, provincial, and city laws and regulations (e.g., UU No. 32/2024, PP No. 21/2021, PERDA NTT No. 1/2011, PERDA Kota Kupang No. 12/2011) was conducted, along with research on Indonesian urban herbaceous dynamics (Hakim et al. 2024; Kiswantoro et al. 2024).

Based on urbanization intensity, three peri-urban (Oesapa, Alak, Kolhua) and three urban core (Kuanino, Oebobo, Kayu Putih) sites were selected for the study. Within each site, 20 randomized 1 m^2 quadrats (total n=120) were established. All herbaceous species were recorded, with density and percentage cover documented using the Braun-Blanquet scale. Species were classified as invasive/non-invasive using standardized criteria from the Guidebook of Invasive Alien Plant Species in Indonesia (Suryawati et al. 2015), cross-referenced with global databases (Weber 2003; GBIF 2023).

Voucher specimens were collected following ethical scientific collection guidelines, deposited at the Biology Laboratory of Universitas Nusa Cendana, Kupang (voucher series KPH-2024-001-120), and identified using regional floras (Soerjani et al. 1987; Tjitrosoedirdjo et al. 2016) and online platforms (Plants of the World Online (POWO) https://powo.science.kew.org/; World Flora Online (WFO) https://www.worldfloraonline.org/; iNaturalist https://www.inaturalist.org/). Given the limitation of not conducting primary ethnobotanical research, ethnoecological uses were determined through a literature synthesis of regional ethnobotanical studies (Martin 1995; Mangalik and Susandarini 2025) and databases (PROSEA https://prosea.prota4u.org/, GBIF https://www.gbif.org/). This approach was taken to establish a foundational understanding of potential use values, acknowledging that the documented uses are compiled from the broader regional literature rather than from primary data from local informants in Kupang City. The implications of this methodological choice are considered in the Discussion.

Data analysis

Standard phytosociological parameters (density, frequency, dominance, and Importance Value Index) were computed according to Mueller-Dombois and Ellenberg (2003). Species diversity was measured using the Shannon-Wiener Index (H'), with diversity class interpretations (low, moderate, high). Floristic similarity was assessed using Sørensen's coefficient. Species were categorized by urban tolerance following modified definitions from Wittig et al. (1985).

Calculation of phytosociological parameters

All phytosociological parameters were calculated according to standardized ecological methods (Mueller-Dombois and Ellenberg 2003). Density (DE) was calculated as the number of individuals per unit area, with Relative Density (RDE) expressed as RDE = (Species density/Total density) × 100. Dominance (DO) was determined as basal cover percentage per species, with Relative Dominance (RDO) calculated as RDO = (Species cover/Total cover) × 100. Frequency (FE) represented the percentage of quadrats containing the species, with Relative Frequency (RFE) expressed as RFE = (Species frequency/Total frequency) × 100. The Importance Value Index (IVI) was derived as the sum of these relative values: IVI = RDE + RDO + RFE.

Diversity and similarity indices

Species diversity was measured with the Shannon-Wiener Index (H'):

$$H' = -\Sigma[(ni/N) \times \log(ni/N)]$$

Where, ni represents the importance value of species i, and N denotes the total importance value of all species (Magurran 2004). Resulting diversity values were interpreted as: low ($H'\leq 1$), moderate ($1<H'<3$), or high ($H'\geq 3$). Floristic similarity between urban and peri-urban areas was assessed using Sørensen's coefficient (Ss): Ss = 2a/(2a + b + c), where a indicates the number of species common to both areas, b represents species unique to the first area, and c denotes species unique to the second area (Mueller-Dombois and Ellenberg 2003).

Urban tolerance classification

Species were categorized according to their distribution along the urbanization gradient using a modified classification system (Wittig et al. 1985; Knapp et al. 2010): (i) Urbanophobic: Restricted to peri-urban areas. (ii) Moderately urbanophobic: Present in both areas, but dominant in peri-urban zones. (iii) Urban-neutral: No distribution preference. (iv) Moderately urbanophilic: Present in both areas, but dominant in urban cores. (v) Urbanophilic: Restricted to urban core areas. All statistical analyses were performed using R version 4.3.1 (R Core Team 2023) with the vegan package for diversity calculations.

Thematic analysis of policy documents and peer-reviewed journal articles on the dynamics of urban herbaceous species was conducted using NVivo 14 (Luminero 2023). Initial codes were derived deductively from key concepts in the literature (e.g., "biodiversity conservation," "native species use," "ecological function"). These codes were iteratively grouped into overarching themes through comparative analysis, following the framework of Braun and Clarke (2022). The utilities of species were categorized through literature synthesis into functional categories: medicinal, food, fodder, ornamental, material resources, and environmental enhancement (Martin 1995; Mangalik and Susandarini 2025).

RESULTS AND DISCUSSION

Structure, composition, and distribution of herbaceous species

Floristic surveys along the urban gradient revealed significant ecological differentiation between zones (Figures 2 and 3). Peri-urban areas supported substantially greater species richness (62 species vs. 43 in the urban core) and consequently lower maximum Importance Value Indices (IVI) (8.40% vs. 14.95%). Shannon diversity was also higher in peri-urban areas (H′ = 2.60) compared to urban cores (H′=2.28). Compositional analysis demonstrated distinct dominant species between zones, with peri-urban communities characterized by *Synedrella nodiflora* and *Digitaria sanguinalis*. At the same time, urban cores were dominated by invasive ruderals *Paspalum conjugatum* and *Stenotaphrum secundatum* (Table 1). The Importance Value Index (IVI) stratification revealed a strong hierarchical organization, with 68.13% of species in the lowest IVI class (<1) (Table 2), conforming to Preston's law of species abundance. Urban tolerance spectra showed that 52.75% of the species were urbanophobic, concentrated mainly in peri-urban areas (Table 3, Figure 3.C). Floristic similarity between the zones was low, with a Sørensen's coefficient of 21.05%.

Table 1. Dominant herbaceous species by urban zone in Kupang City, East Nusa Tenggara, Indonesia, based on mean Importance Value Index (IVI)

Zone	Species	Mean IVI (±SE)	Functional role
Peri-urban	*Synedrella nodiflora* (Asteraceae)	8.7±0.4	Native pioneer
	Digitaria sanguinalis (Poaceae)	7.2±0.3	C_4 grass competitor
Urban Core	*Paspalum conjugatum* (Poaceae)	14.2±0.8	Invasive ruderal
	Stenotaphrum secundatum (Poaceae)	11.5±0.6	Mat-forming alien

Table 2. Distribution of herbaceous species in Kupang City, East Nusa Tenggara, Indonesia, by Importance Value Index (IVI) category

IVI category	% Species	% Total IVI	Ecological significance
Very High (>4)	5.49	27.52	Ecosystem engineers
High (3-4)	3.3	10.57	Competitive dominants
Medium (2-3)	4.4	10.32	Subordinate stabilizers
Low (1-2)	18.68	22.73	Stress-tolerant specialists
Very Low (<1)	68.13	28.87	Rare/transient specialists

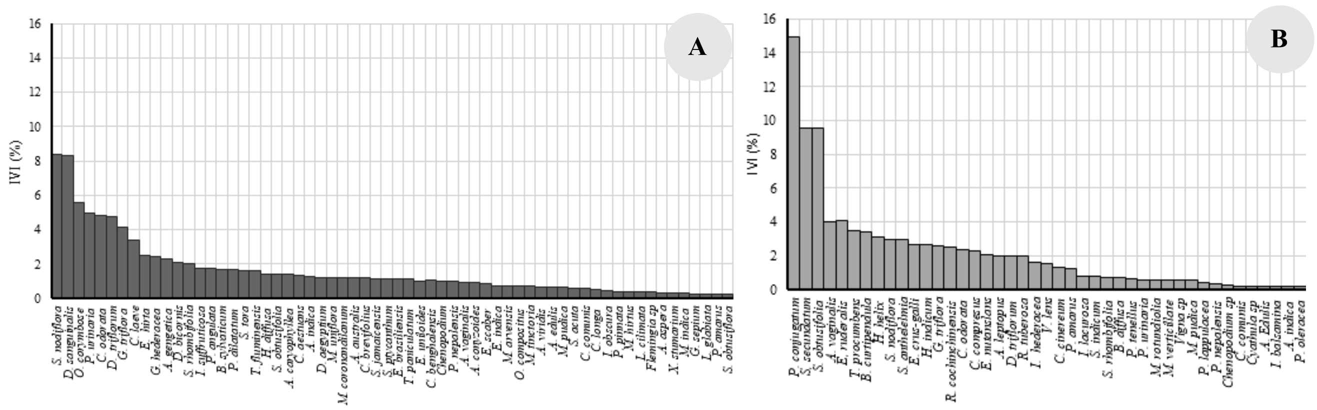

Figure 2. Floristic differentiation of herbaceous species along peri-urban-urban core gradient. A. Peri-urban and B. Urban core

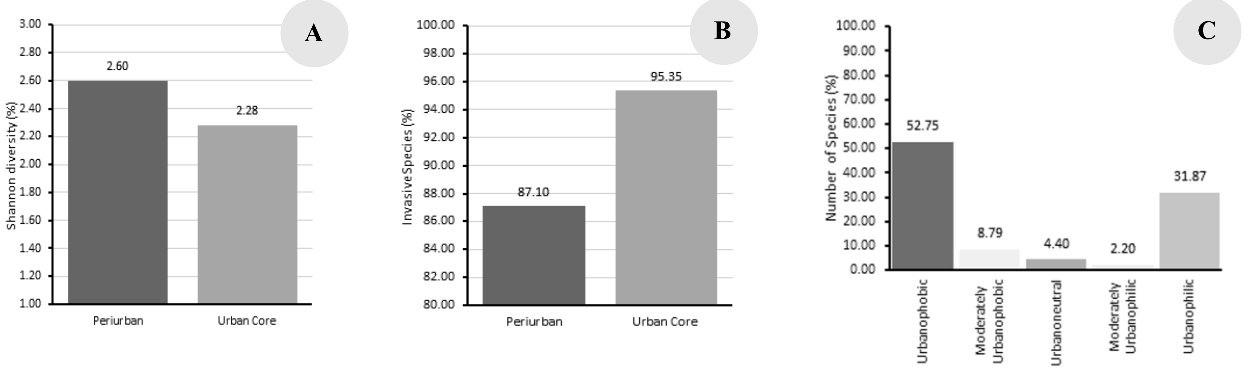

Figure 3. Hierarchical organization of herbaceous species across peri-urban-urban core gradient. A. Species diversity, B. Invasive species, and C. Species tolerance spectra

The pronounced differentiation in species composition along the peri-urban-urban core gradient demonstrates substantial biotic homogenization driven by urbanization. This pattern aligns with global studies showing urban environments filter out disturbance-sensitive specialists while favoring cosmopolitan ruderal species (Table 4) (McKinney 2006; Johnson et al. 2013). The concentration of urbanophobic species in peri-urban areas indicates these zones serve as critical refugia and a critical priority for conservation. These findings underscore the conservation value of urban peripheries in tropical secondary cities, where rapid urbanization often outpaces the development of green infrastructure. Peri-urban areas thus function as crucial reservoirs for native biodiversity, maintaining ecological functions that are lost in increasingly homogenized urban cores.

Families of herbaceous plant species

Family-level analysis revealed pronounced ecological filtering along the urbanization gradient. Poaceae and Fabaceae collectively constituted 57.02% of urban core IVI compared to 36.44% in peri-urban areas, indicating increased (↑) functional homogenization under urban pressure (Table 5). The Poaceae family showed powerful ruderal dominance in urban cores (IVI 35.36% vs. peri-urban 20.04%), while Fabaceae exhibited niche expansion in peri-urban areas (11 species vs. urban core 7). Despite 14 families being common to both zones, urban cores exhibited reduced phylogenetic diversity within dominant families, particularly a 36% reduction in Fabaceae species richness compared to peri-urban areas.

The dominance of these two families reflects not only their evolutionary adaptations to disturbed environments but also their significant, yet distinct, ethnoecological roles. The prevalence of Poaceae, with traits like rhizomatous growth and C_4 photosynthesis, aligns with their high utility as material resources, providing fodder and raw materials in heavily managed urban cores (Table 6). Conversely, the Fabaceae's success, facilitated by nitrogen-fixing symbioses, is paralleled by their high value as sources of nutrition and traditional medicine, a function particularly vital in peri-urban areas where these species are more diverse. This phylogenetic truncation in urban cores, where stress-tolerant clades outcompete complex lineages, mirrors global patterns of urban floral homogenization (He et al. 2024). The findings suggest that urban planning should prioritize native species from these families not only to enhance ecosystem resilience but also to conserve their distinct ethnoecological capital—leveraging Poaceae for material services and Fabaceae for nutritional and medicinal resources—while simultaneously conserving vulnerable families like Phyllanthaceae and Euphorbiaceae that show greater sensitivity to urbanization pressures and often possess unique ethnobotanical applications.

Table 3. Urban tolerance categories of herbaceous species documented in Kupang City, East Nusa Tenggara, Indonesia

Category	% Species	Representative taxa	Primary habitat	Conservation priority
Urbanophobic	52.75	*Grona triflora* and *G. heterophylla* (Fabaceae)	Peri-urban	Critical
Moderately urbanophobic	8.70	*Phyllanthus urinaria* (Phyllanthaceae)	Transitional	High
Urbanophilic	31.87	*Alysicarpus vaginalis* (Fabaceae)	Urban core	Low
Moderately urbanophilic	2.20	*Phyllanthus amarus* Phyllanthaceae)	Transitional	Low
Urbanoneutral	4.40	*Mimosa pudica* (Fabaceae)	Ubiquitous	Moderate

Table 4. Comparison of urban tolerance patterns in herbaceous species from Kupang City, East Nusa Tenggara, Indonesia, with global studies

Region/Study	Urbanophobic %	Urbanophilic %	Key refugia	Richness driver
Kupang, Indonesia (this study)	52.75	31.87	Peri-urban grasslands	Microhabitat preservation
Rural Poland (Galera et al. 2012)	7-31	<3	Pond margins	Hydrological features
Central European railways (Dziuba et al. 2022)	Dominant	Low	Ballast corridors	Disturbance intermediacy
Henan Province, China (Zhang et al. 2024)	–	–	Suburban greenbelts	Regional species pool

Table 5. Importance Value Index (IVI) and species richness of dominant plant families along the urban gradient in Kupang City, East Nusa Tenggara, Indonesia

Family	Urban core IVI (%)	Peri-urban IVI (%)	ΔIVI	Urban core spp.	Peri-urban spp.	Conservation priority
Poaceae	35.36	20.04	+15.32↑	6	10	Invasive control
Fabaceae	21.66	16.40	+5.26↑	7	11	Native promotion
Asteraceae	14.78	15.28	-0.50↓	5	5	Neutral
Phyllanthaceae	3.92	8.15	-4.23↓	2	3	Peri-urban refugia
Euphorbiaceae	2.87	6.33	-3.46↓	3	4	Ethnoecological focus
Total Top 2	57.02	36.44	+20.58	13	21	

Beyond their role in enhancing urban ecosystem resilience, the Fabaceae and Poaceae families hold significant ethnobotanical value as primary sources of food, medicine, and material resources. Globally, these are among the most economically and culturally important plant families (Wariss et al. 2016). The Fabaceae family is crucial for its use as food crops, green manure, and animal feed. Furthermore, species within this family are sources of a wide array of natural products, including flavors, dyes, poisons, and medicines (Patel and Shah 2014). Their socioeconomic importance extends to the provision of resources such as wood, resins, insecticides, and fibers (Isely 1982). Similarly, the Poaceae family is indispensable to humanity, serving as a primary food source, building material, medicine, fodder, fuel, and fulfilling cultural purposes (Kumari and Saggoo 2015). Specific grass species are used as dietary supplements, food flavorings, animal feed, and treatments for human ailments. Particular species also feature in cultural practices, such as being used as incense in religious ceremonies, insecticides, and for producing natural dyes (Kumari and Saggoo 2015).

Potential value of herbaceous species

The literature-documented ethnoecological uses of the recorded herbaceous species in Kupang are substantial, with 94.51% of species documented for medicinal uses and 16.48% as material sources (Table 7). Peri-urban areas showed particular preeminence in medicinal uses (96.77%), while urban cores had higher proportions of fodder resources (25.58%). Multifunctional high-value species included *Urtica dioica* (material/medicinal) and *D. sanguinalis* (material/phytoremediation) (Table 8), though their service bundles remain excluded from formal planning frameworks.

The exceptionally high medicinal prevalence indicated by the literature suggests that spontaneous urban vegetation constitutes a significant, though not yet locally verified, potential community health resource. Based on regional ethnobotanical records, these species likely represent a vital pharmacopeia, particularly for urban populations in low-income communities where access to formal healthcare may be limited (Safitri et al. 2024). Traditional knowledge associated with these plants represents significant ethnobotanical capital that enhances community resilience to health and economic stresses. However, this study's reliance on literature synthesis means these uses represent potential, rather than actively practiced, value in Kupang. This critical distinction underscores the imperative for future primary ethnobotanical research to validate which of these documented uses are actively maintained by local communities and to quantify the actual reliance on this flora for health and livelihood. The concentration of medicinal species in peri-urban areas underscores the importance of conserving these zones not merely as ecological buffers but as potential repositories of biocultural heritage that could inform community-based health initiatives.

Table 6. Functional traits and ecosystem services of the two most dominant plant families in global urban flora

Family	Key adaptive traits	Urban ecosystem service	Global species	Kupang IVI (%)	Conservation priority
Poaceae	Rhizomatous growth C_4 photosynthesis Fire/grazing tolerance	Erosion control UHI mitigation	12,000 (Christenhusz and Byng 2016)	32.05	Slope stabilization
Fabaceae	Nitrogen fixation Drought tolerance Deep rooting	Soil remediation Pollinator support	19,000 (LPWG 2023)	14.18	Degraded land rehab

Table 7. Ethnoecological uses of documented herbaceous species in urban core and peri-urban areas of Kupang City, East Nusa Tenggara, Indonesia

Use category	Urban core (n=43 spp.) (%)	Peri-urban (n=62 spp.) (%)	Overall (n=91 spp.) (%)	Policy priority
Medicinal	93.02	96.77	94.51	Critical
Material sources	18.64	12.90	16.48	High
Environmental uses	37.21	29.03	31.87	High
Food ingredients	27.91	25.81	28.57	Moderate
Fodder	25.58	14.52	17.58	Context-dependent

Table 8. High-priority multifunctional herbaceous species for conservation in Kupang City, East Nusa Tenggara, Indonesia

Species	Medicinal	Material Source	Environmental	Food/fodder	Conservation action
Urtica dioica	Yes	Textile fiber	-	-	Green industry zones
Digitaria sanguinalis	Yes	Paper fiber	Phytoremediation	Grain/flour	Brownfield remediation
Lantana camara	Yes	Handmade paper (62% cellulose)	Erosion control	-	Invasive-to-resource conversion
Vigna sp.	Yes	-	Biodiversity conservation	Edible beans	Agroecological corridors

Policy analysis and synthesis

Indonesia's regulatory framework establishes a robust legal foundation for biodiversity-sensitive urban planning, with national laws embedding conservation as a core principle and ministerial regulations requiring native vegetation in green open spaces (*Ruang Terbuka Hijau*, RTH). Kupang's local regulations further emphasize the conservation of local flora, explicitly linking the use of native species to "local ecological identity" (Table S1).

Despite this robust framework, a significant implementation gap persists, particularly concerning the conservation of spontaneous flora and its associated ethnoecological capital. Current policies overlook the specific conservation needs of ruderal corridors and the vast majority (94.51%) of documented species with medicinal value, which form a critical, informal health infrastructure for urban communities. Kupang's key local regulation predates national biodiversity amendments and lacks explicit diversity metrics or mechanisms for conserving spontaneous vegetation. This policy gap directly contradicts the empirical evidence from this study, which identifies peri-urban ruderal corridors as vital refugia for urbanophobic species and reservoirs of multifunctional flora. Current research demonstrates that these very corridors significantly enhance urban resilience through climate adaptation and socio-ecological co-benefits (Table S2), yet they remain absent from formal spatial plans. The primary barriers include competing urban land demands, limited budgetary allocation for non-ornamental greenery, and the absence of community engagement mechanisms for co-managing these ethnobotanically rich flora (Kiswantoro et al. 2024). Overcoming these challenges requires transitioning from vague mandates to specific actions: formalizing protection of ruderal corridors, creating municipal native plant nurseries, and establishing community stewardship programs for vacant lots.

Discussion

Results from Kupang City represent a prevailing trend of ecological filtering by urbanization toward biotic homogenization; remarkably, peri-urban areas show significantly higher species richness, diversity, and ethnoecological value than the urban core. The observed gradient is consistent with worldwide urbanization, in which an increase in impervious cover and anthropogenic disturbances favors the establishment of stress-tolerant alien species while reducing specialist indigenous taxa (Aronson et al. 2014; McDonald et al. 2020). The dominance of Poaceae and Fabaceae in the urban core reflects a broad response to disturbance and is likely an evolutionary predisposition for their successful establishment (He et al. 2024). Nonetheless, the context for Kupang City as a tropical secondary city reveals distinctive characteristics, particularly the extraordinary ethnoecological value of spontaneous vegetation, with 94.51% of species possessing medicinal uses that likely serve as essential healthcare resources for urban communities.

The conservation implications transcend mere preservation of biodiversity to include community health, climate resilience, and cultural preservation. The high prevalence of medicinal plants suggests that spontaneous vegetation constitutes critical informal infrastructure for public health, particularly for economically vulnerable populations in the urban core (Shackleton et al. 2017). Simultaneously, ruderal corridors and peri-urban refugia deliver low-cost climate adaptation benefits, such as urban temperature mitigation and stormwater management – benefits of immense value in secondary cities with constrained resources (Elmqvist et al. 2019). A key limitation of this study, however, is that the ethnobotanical data are derived from the literature rather than from primary fieldwork. This means the reported uses indicate significant potential ethnoecological capital, but do not confirm the extent of active local knowledge or application within Kupang's communities. This distinction is critical to avoid overclaiming and underscores the need for future in-depth ethnobotanical surveys to ground-truth these findings. The overriding challenge lies in reconciling formal planning paradigms with the informal ecological and cultural values embodied in spontaneous urban nature.

These findings compellingly make the case for reconceptualizing urban conservation policy in tropical secondary cities. Rather than imposing conventional ornamental landscaping, our evidence indicates that planning could recognize and harness the existing ethnoecological capital of spontaneous flora. The data from this study provide a scientific rationale for several strategic interventions: integrating ruderal corridors into spatial plans to protect documented refugia for urbanophobic species, prioritizing native species with high ecosystem service values in municipal planting programs, and developing frameworks that legitimize community-based management of spontaneous vegetation. Such changes will have implications that require addressing real-world barriers, including political resistance to "unmanaged" vegetation, budgetary reallocation from ornamental to functional landscaping, and the development of participatory frameworks for community engagement. The potential benefit of this approach is that Kupang City and similar cities could develop locally adapted, culturally relevant urban landscapes that enhance both biodiversity and human wellbeing, as demonstrated by the ecological and ethnoecological patterns revealed in this study.

Overall, this work demonstrates that urbanization in Kupang City catalyzes significant biotic homogenization, progressively filtering herbaceous communities toward stress-tolerant invasive species in urban cores while peri-urban areas maintain higher diversity and function as crucial refugia for specialist species. The findings reveal three fundamental patterns: a clear floristic divergence with reduced richness (43 vs. 62 species) and diversity (H' = 2.28 vs. 2.60) in urban cores; the exceptional potential ethnoecological value of spontaneous vegetation, with 94.51% of species possessing documented medicinal uses; and a pronounced policy-implementation gap where existing regulatory frameworks for biodiversity conservation lack specific mechanisms for protecting ruderal corridors and spontaneous vegetation. Collectively, the findings establish that peri-urban areas in tropical secondary cities constitute essential reservoirs of both biodiversity and documented ethnobotanical knowledge, whose conservation is imperative for maintaining urban ecological resilience and community wellbeing amid accelerating urbanization.

To address the emerging challenges, the evidence from this study points to several targeted policy and management implications. First, the documented value of peri-urban ruderal corridors provides a strong justification for their formal incorporation into Kupang's spatial plans to enhance ecological connectivity and protect urbanophobic species. Second, the prevalence of multifunctional species, particularly within the Fabaceae family, supports a strategic shift in municipal planting programs toward native species that deliver both ecological services (e.g., nitrogen fixation) and ethnoecological benefits. Third, the concentration of medicinal species in spontaneous vegetation creates a compelling rationale for developing community co-management models that can bridge the gap between formal policy and informal ethnobotanical practice. Implementation of these approaches would need to address identified barriers through budget reallocation, participatory planning, and capacity-building programs focused on the value of spontaneous urban flora.

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Table S1. Indonesian policy framework relevant to urban biodiversity conservation

Regulation	Article/ paragraph	Relevant quote (Original Bahasa Indonesia)	English translation
UU No. 32/2024 (Biodiversity Conservation)	Art. 5 Par. (1)	"Konservasi sumber daya alam hayati ... dilakukan melalui kegiatan ... pemanfaatan secara lestari"	"Conservation of biological resources ... is conducted through ... sustainable utilization activities."
PP No. 21/2021 (National Spatial Planning)	Art. 12 Par. (1)	"Penataan ruang wilayah ... harus memperhatikan ... pelestarian keanekaragaman hayati"	"Spatial planning ... must consider ... the preservation of biodiversity."
PP No. 22/2021 (Environmental Protection and Management)	Art 6 letter d	"Perlindungan ... keanekaragaman hayati ... untuk mempertahankan fungsi lingkungan hidup"	"Protection ... of biodiversity ... to maintain environmental functions."
	Art. 8 Par. (1)	"Pemanfaatan sumber daya alam ... harus menjamin kelestarian fungsi ekologis"	"Utilization of natural resources ... must guarantee the sustainability of ecological functions."
Permen ATR/BPN No. 14/2022 (Green Open Space Provision)	Art. 3 Par. (2)	"Vegetasi pada RTH ... menggunakan jenis tanaman asli (lokal) yang beraneka ragam dan memiliki nilai ekologis tinggi"	"Vegetation in Green Open Spaces ... uses diverse native (local) plant species with high ecological value."
Permen PUPR No. 5/2008 (Urban Green Space Guidelines)	Art. 4 Par. (3)	"Pemilihan jenis tanaman ... mengutamakan tanaman asli daerah ... yang memiliki nilai ekologis"	"Plant species selection ... prioritizes native regional plants ... with ecological value."
Perda NTT No. 1/2011 (Spatial Planning of ENT Province)	Art. 17 Par. (1)	"RTRW Provinsi ... mengarahkan perlindungan kawasan bernilai keanekaragaman hayati tinggi"	"The Provincial Spatial Plan ... directs the protection of areas with high biodiversity value."
Perda Kota Kupang No. 12/2011 (Spatial Planning of Kupang City)	Art. 8 Par. (4)	"Ruang Terbuka Hijau ... berfungsi ... sebagai habitat flora lokal dan penjaga keseimbangan ekosistem perkotaan"	"Green Open Spaces ... function ... as habitats for local flora and maintainers of urban ecosystem balance."
Perda Kota Kupang No. 7/2000 (Kupang City's Green Space Regulation)	Art. 5 Par. (1)	"Penanaman vegetasi di RTH kota wajib menggunakan jenis-jenis asli Nusa Tenggara Timur ... untuk menjaga identitas ekologi lokal"	"Vegetation planting in city green spaces must use native East Nusa Tenggara species ... to preserve local ecological identity."

Note: This table is based on a systematic review of Indonesia's multi-tiered regulatory framework conducted to contextualize urban herbaceous conservation within the national legal landscape. Given Indonesia's decentralized governance system, regulations at the national, provincial, and municipal levels were examined to identify policy coherence and implementation gaps related to biodiversity conservation. The selected laws and regulations were identified through a screening process using three criteria: (i) relevance to urban spatial planning and green open space (RTH) management, (ii) explicit references to biodiversity conservation, native species use, or ecological function preservation, and (iii) jurisdictional authority over urban development in Kupang City. The reviewed framework indicates that biodiversity-sensitive urban planning is mandated across governance levels, with national regulations (e.g. PP 21/2021; UU 32/2024) establishing overarching principles, ministerial regulations (e.g. Permen ATR 14/2022; Permen PUPR 5/2008) providing operational guidance for native vegetation in RTH, and regional and municipal regulations (Perda 1/2011; Perda 12/2011; Perda 7/2000) emphasizing protection of high-biodiversity areas and local ecological identity. At the same time, the framework highlights continuing implementation challenges, particularly the absence of explicit provisions for conserving spontaneous urban vegetation in older local regulations

Table S2. Summary of recent Indonesian research (2020-2024) on urban flora

Author(s) (year)	Topics covered	Relevant direct quotations
Agustiyara et al. (2025)	(3) Urban Resilience	"The analysis of Urban Green Spaces (UGS) is fundamental for sustainable urban planning and enhancing the quality of life in densely populated Indonesian cities."
Gaol and Mudita (2022)	(1) Herbaceous Flora	"The research was conducted to determine the structure and composition of herbaceous species... The results showed that the savanna was dominated by herbaceous species, especially from the Poaceae family..."
Hanum et al. (2024)	(1) Herbaceous Flora, (3) Urban Resilience	"The results of the vegetation analysis showed that the plant community in the Green Open Spaces (GOS) of Surakarta City was dominated by herbaceous plants..." / "Green Open Spaces (GOS) play a crucial role in supporting biodiversity and providing ecological services in urban areas..."
Kiswantoro et al. (2024)	(3) Urban Resilience	"Community engagement through urban gardening and tree planting programs significantly contributes to mitigating the Urban Heat Island effect..."
Latifah et al. (2021)	(1) Herbaceous Flora, (3) Urban Resilience	"The undergrowth layer in the Udayana urban forest is rich in herbaceous species..." / "Conservation of urban forests is vital for maintaining native flora and supporting ecological stability in cities."
Putri et al. (2016)	(1) Herbaceous Flora	"The study documented various herbaceous species used as herbal medicine in the Ranggawulung Urban Forest..."
Santhyami et al. (2024)	(1) Herbaceous Flora, (3) Urban Resilience	"The market survey documented a variety of herbaceous plants traded for non-edible purposes..." / "The persistence of this trade underscores the role of urban markets in sustaining ethnobotanical knowledge..."
Safitri et al. (2024)	(1) Herbaceous Flora	"The study identified several wild herbaceous plants growing spontaneously in the residential environment that are used by the community as herbal medicine."

Note**:** This table synthesizes findings from ten peer-reviewed Indonesian studies published between 2020 and 2024 that examine the ecological and social roles of urban flora. The reviewed articles were selected based on three criteria: publication in reputable national or international journals, empirical focus on Indonesian urban settings, and relevance to herbaceous flora, spontaneous vegetation, or urban resilience. The summarized literature indicates that recent research predominantly addresses herbaceous flora in green open spaces and urban forests, its contribution to ecosystem services and climate adaptation, and its role in ethnobotanical practices within residential areas and urban markets. At the same time, the review highlights a notable gap in studies explicitly examining ruderal corridors (e.g. railway margins, vacant lots, drainage channels) as distinct landscape elements for urban biodiversity or ecological connectivity, suggesting that the socio-ecological significance of spontaneous urban vegetation remains underexplored in current Indonesian urban ecology research