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Diversity and Distribution of Herbaceous Plant Community in the Grassland across an Elevational gradient in the Brahmagiri Wildlife Sanctuary, Western Ghats

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ABSTRACT

Tropical montane grasslands, particularly those in the Western Ghats of India, harbor a rich diversity of herbaceous and graminoid species that play crucial ecological roles but remain largely underrepresented in conservation and ecological studies. This study investigates the diversity, distribution, and spatial patterns of herbaceous plant species across an elevational gradient (1200–1500 m) in the montane grasslands of Brahmagiri Wildlife Sanctuary, a critical ecological corridor within the Western Ghats biodiversity hotspot. Using a nested sampling design, we documented 959 individuals belong to 33 species with Poaceae, Leguminosae, and Compositae emerging as dominant families. Diversity indices including species richness, Shannon-Wiener index, Simpson's index of dominance, and Pielou's evenness were calculated, and Principal Component Analysis were used to explore relationships among biodiversity metrics and environmental variables. The results reveal distinct elevational patterns in species composition and life forms, with grasses peaking at mid-elevations and forbs increasing towards higher elevations. Dispersion analysis indicated predominantly clumped distributions at most elevations, reflecting environmental heterogeneity and species-specific ecological strategies. Principal Component Analysis highlighted strong associations between diversity indices and topographic factors such as slope and aspect, suggesting that microhabitat heterogeneity and abiotic factors significantly influence community assembly. These findings underscore the ecological significance and vulnerability of herbaceous communities in high-altitude grasslands and advocate for their explicit inclusion in biodiversity conservation planning. Present study contributes critical baseline data for understanding how elevation-driven environmental gradients shape plant diversity in tropical montane ecosystems facing accelerating anthropogenic and climatic pressures.

1. Introduction

Grasslands, defined as ecosystems dominated by graminoid vegetation with sparse tree and shrub cover (FGTC, 1992), represent one of the most extensive terrestrial biomes, covering approximately 52.54 million km² or 40.5% of the global land surface excluding polar regions (White et al., 2000). These ecosystems not only provide vital ecosystem services such as water and climate regulation in support of agriculture, biogeochemical cycle, carbon storage, cultural, recreational services, and biodiversity support livelihood for all the pastoral communities (White et al., 2000; Suttie et al., 2005; Rawat & Adhikari, 2015). Despite their ecological and socioeconomic value, grasslands are among the most threatened ecosystems, with an estimated 50% of temperate and 16% of tropical grasslands already converted to agricultural land (World Conservation Monitoring Centre, 1992). This conversion has drastically reduced suitable habitats for grassland-dependent flora and fauna, accelerating biodiversity loss (Clark, 1989; Zavaleta & Hulvey, 2004; Ceballos et al., 2010).

In India, grasslands span nearly 24% of the land area and encompass a diverse array of types, ranging from alpine meadows to dry tropical savannas (Dabadghao & Shankarnarayan, 1973; Singh & Joshi, 1979; Kumar & Raman, 2012).

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While many of these systems are anthropogenically influenced and cereal in nature, high-altitude grasslands of the Western Ghats remain ecologically distinct. These montane grasslands interspersed with Shola forests above 1800m harbor unique assemblages of graminoid and herbaceous species, including a high proportion of endemics (Pascal, 1988; Ramesh et al., 2010). However, these systems face increasing threats from land-use change, invasion of exotic species, afforestation, and climate variability (Joshi et al., 2023).

Despite being often neglected, these herbaceous layers play a critical ecological role within these ecosystems. Although it contributes minimally to overall biomass, it plays a disproportionate role in ecosystem functioning, biodiversity maintenance, and ecological resilience (Gilliam, 2007). In ecosystems such as scrub and deciduous forests, this layer often supports greater species richness than the tree and shrub strata (Sarmiento, 1992). Moreover, herbaceous species are particularly vulnerable, exhibiting extinction rates more than three times higher than those of woody plants (Pimm & Raven, 2000; Wilcove et al., 1998). Their functional traits such as leaf morphology, stature, and resource-use efficiency offer important insights into how plant communities respond to biotic and abiotic stressors (Díaz et al., 2007).

This study aims to assess the diversity and distribution patterns of herbaceous species along an elevational gradient in the montane grasslands of the Western Ghats. By focusing on this underrepresented stratum, the research seeks to uncover how species richness and composition shift with elevation and to highlight the role of herbaceous diversity in shaping the structure, function, and conservation value of grassland ecosystems.

2. Material and methodology

2.1 Study area

Brahmagiri Wildlife Sanctuary, situated between 11°55' to 12°19' N latitude and 75°44' to 76°04' E longitude in Kodagu district, Karnataka, spans 181.29 km² and is part of the Western Ghats UNESCO World Heritage Site and global biodiversity hotspot (Rawat & Adhikari, 2015). Declared a protected area in 1974, it features elevations from 65 m to 1600 m, supporting tropical wet evergreen, semi-evergreen, moist deciduous, and Shola forests interspersed with montane grasslands (Ramesh et al., 2010; Thomas & Palmer, 2007). These Shola-grassland mosaics harbor endemic herbaceous and graminoid species like *Eulalia phaeothrix*, *Dichanthium polytychum*, and *Chrysopogon hackelli* (Pascal, 1988). The sanctuary forms a crucial ecological corridor linking Nagarhole, Bandipur, Pushpagiri, Wayanad, and Aralam (Karanth & Sunkist, 2000), and supports endangered species such as the Lion-tailed macaque and Nilgiri marten (Kumara & Singh, 2004; Singh et al., 2000). It is also hydrologically important as the origin of the Lakshmanthirtha River. The area experiences annual rainfall between 2500 mm and 6000 mm, depending on altitude and slope, with distinct hot, wet, and cold seasons. Despite their ecological value in water regulation and biodiversity conservation, the montane grasslands remain vulnerable to invasions and climate change (Thomas & Palmer, 2007; Rawat & Adhika).

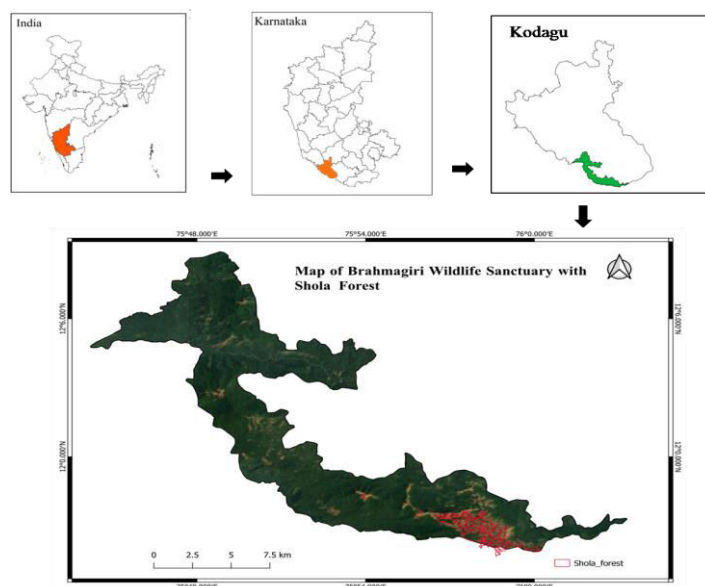


Fig 1 Study area map of Brahmagiri Wildlife Sanctuary, Kodagu

2.2 Methodology

To assess herbaceous and shrub diversity along the elevational gradient, sampling plots measuring 25m × 25m were randomly established at elevations ranging from 1200 m to 1500 m. Within each main plot, a 5 × 5 m subplot was nested to record data on shrubs and under-shrubs. Further, five 1 × 1 m quadrats were systematically placed within each 5 × 5 m subplot—one at each corner and one at the center to quantify herbaceous and graminoid species composition following nested sampling protocols (Ellenberg, & Mueller, 1974; Kent, 2012). Species was identified using regional floras, standard field guides, and monographs (e.g., Gamble, 1928; Keshava murthy, 1990), and further verified at the herbarium of the Indian Institute of Science (IISc), Bangalore. Fieldwork was conducted with minimal disturbance to native flora and fauna in compliance with standard ecological survey ethics (Sutherland et al., 2004). Diversity metrics such as species richness, Shannon-Wiener diversity index, Simpson's index of dominance, and Pielou's evenness index were calculated (Kindt & Coe,

2005). In addition, the relationship between species richness and abundance of herbaceous families was analysed, and a Principal Component Analysis (PCA) biplot was generated using R Studio (version 4.4.1) to visualize trait and compositional variation across elevations (Legendre & Legendre, 2012)

3. Results and Discussion

A total of 959 individuals belongs to 33 species were documented from sampling plots laid in the three elevations of grassland area. The species such as *Strobilanthes callosa* (20.81%) followed by *Themeda triandra* (17.10%) and *Pteridium aquilinum* (12.6%) were found to be dominant in the region (Fig.2).

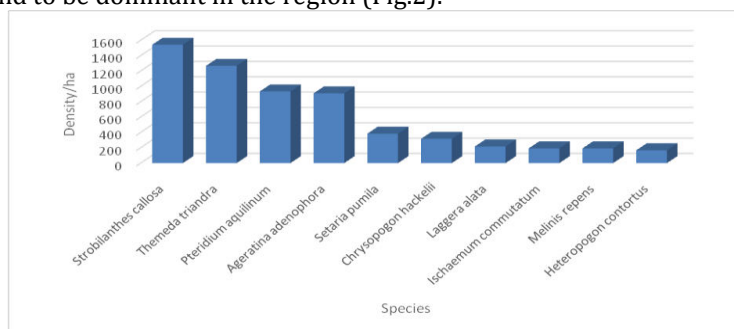


Fig 2. Top ten species in grassland of Brahmagiri Wildlife Sanctuary

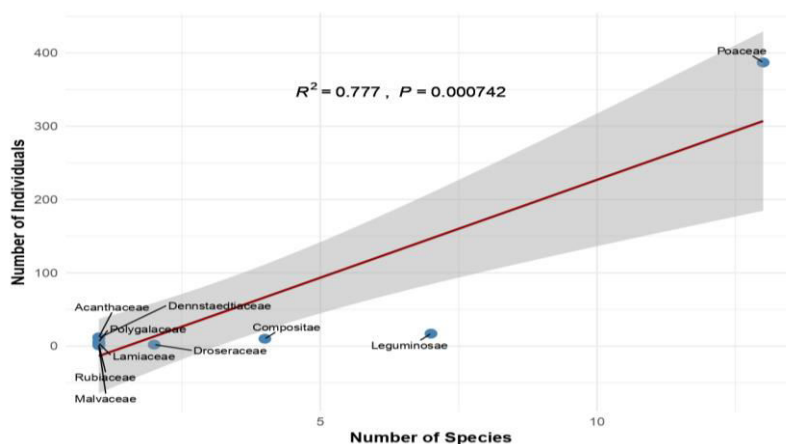


Fig 3. Relationship between species richness and abundance among herbaceous plant families

Out of the 13 plant families documented across the sampled plots, *Poaceae* emerged as the most dominant, comprising 13 species and 387 individual occurrences, highlighting its ecological prominence in the study area. This was followed by *Leguminosae*, with 7 species and 59 individuals, and *Acanthaceae*, represented by 1 species and 185 individuals. The strong positive linear relationship between species richness and individual abundance ($R^2 = 0.892$, $P < 0.001$) indicates that families with higher species diversity tend to support a greater number of individuals. This pattern is consistent with the niche complementarity and sampling effect hypotheses, where taxonomic richness enhances community productivity and resource use efficiency (Tilman et al., 1997; Loreau & Hector, 2001). The ecological dominance of *Poaceae* may be attributed to their adaptive traits such as C4 photosynthesis, efficient water use, and tolerance to grazing and fire, making them highly competitive in open grassland habitats (Linder et al., 2018). Similarly, the representation of *Leguminosae* reflects their ecological importance in nitrogen fixation and early successional roles, while *Acanthaceae* is often associated with understory and edge habitats, contributing to biomass and habitat complexity (Doell, 2007; Tsvuura et al., 2012). The observed distribution pattern highlights how functional and taxonomic traits jointly influence community assembly processes along environmental gradients.

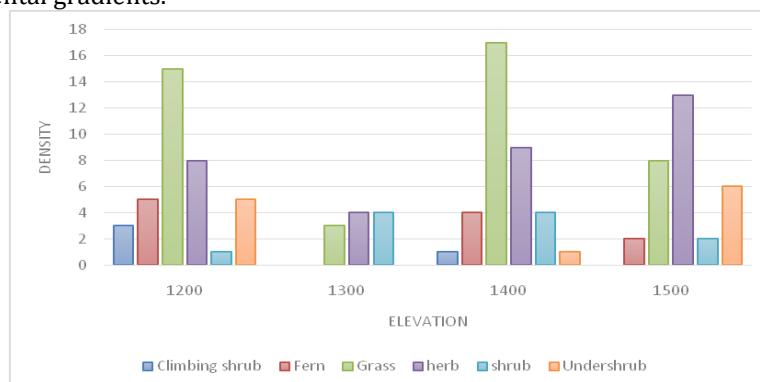


Fig 4. Distribution of various plant life forms along an elevation gradient in tropical montane grasslands

Life-form composition along the 1200–1500 m grassland gradient showed clear elevational patterns driven by environmental filtering. **Grasses (Poaceae)** were dominant at all elevations, peaking at 1400 m (17 species), reflecting their adaptability to open, resource-variable environments (Fatima et al., 2021). **Herbs** increased with elevation, reaching their highest richness at 1500 m (13 species), likely due to cooler temperatures and greater microhabitat heterogeneity favoring forbs (Ensslin et al., 2015). In contrast, **ferns** declined with elevation, consistent with their preference for lower, moister habitats (Kessler et al., 2011). **Shrubs and climbing shrubs** were limited to mid-elevations, suggesting niche specialization in transitional zones (Rahbek et al., 1995). **Undershubs** showed a bimodal distribution (1200 m and 1500 m), possibly indicating adaptation to both disturbance and climatic extremes (Krishnan & Davidar, 1996).

These patterns underscore elevation as a key driver of grassland community assembly, with implications for biodiversity management under climate change.

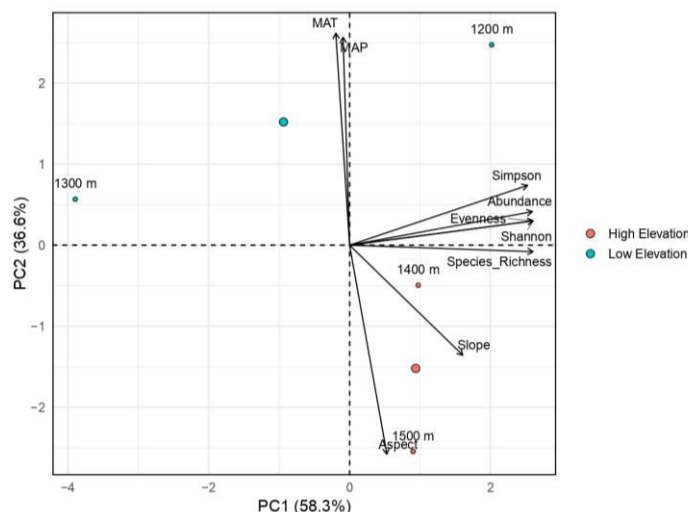


Fig 5. Principal Component Analysis (PCA) Biplot of Elevation-based Biodiversity Metrics

Principal Component Analysis (PCA) was employed to investigate multivariate relationships among biodiversity indices such as species richness, Shannon, Simpson, Evenness, and Abundance. Environmental variables such as elevation, Mean Annual Temperature [MAT], Mean Annual Precipitation [MAP], slope, and aspect across the elevation gradient in tropical montane grasslands. The first two principal components—PC1 (58.3%) and PC2 (36.6%)—together accounted for 94.9% of the total variance. PC1 was predominantly driven by positive loadings from diversity metrics and abundance, indicating that community diversity increases with elevation and topographic complexity. PC2 was influenced mainly by climatic variables such as MAT and MAP.

The strong alignment of diversity indices with slope and aspect on PC1 suggests that microhabitat heterogeneity and environmental filtering at higher elevations play a crucial role in shaping herbaceous plant assemblages in these grasslands (Joshi et al., 2023; Ensslin et al., 2015; Dainese et al., 2015). These findings reinforce the idea that elevation-driven gradients in temperature, moisture, and terrain complexity govern the distribution of biodiversity in tropical montane grassland ecosystems.

Table 1 Dispersion index and distribution pattern of herb species across elevation gradients

Elevation (m)	Mean Abundance	Variance	Dispersion Index (s^2/mean)	Chi-square (χ^2)	df	P-value	Distribution Pattern
1200	1.06	2.23	2.11	71.78	32	0.00016	Clumped
1300	0.14	0.13	0.88	30	32	0.66	Uniform
1400	1.03	2.44	2.37	80.67	32	<0.0001	Clumped
1500	0.8	1.28	1.6	54.5	32	0.014	Clumped

The spatial distribution patterns of herbaceous species varied notably along the elevation gradient (1200–1500 m), as indicated by the dispersion index (variance-to-mean ratio) and Chi-square test results. At 1200 m, 1400 m, and 1500 m, dispersion index values were greater than one (2.11, 2.37, and 1.60, respectively), with statistically significant Chi-square values ($p < 0.05$), indicating a clumped distribution pattern. Such aggregation is often linked to environmental heterogeneity, limited seed dispersal, and patchy resource availability—conditions typical of topographically complex montane grasslands (Mukherjee, & Sarma, 2014; Vidyashree et al., 2022). In contrast, the 1300 m elevation exhibited a dispersion index < 1 (0.88) and a non-significant Chi-square value ($p = 0.66$), suggesting a uniform distribution. This pattern may result from competitive exclusion or homogenous microhabitat conditions at that elevation. Collectively, these findings underscore the role of elevation-driven abiotic filtering and microhabitat variation in structuring herbaceous plant assemblages across tropical montane grasslands. The list of plant species documented with respect to their family and habit are given below.

Table 2 List of plant species documented in Grassland of Brahmagiri wildlife Sanctuary

Sl.no	Scientific Name	Habit	Family
1	<i>Ageratinaadenophora</i> (Spreng.) R.M.King&H.Rob.	Under shrub	Compositae
2	<i>Anaphalislawii</i> (Hook.f.) Gamble	Herb	Compositae
3	<i>Bothriochloapseudischaemum</i> (Nees ex Steud.) Henrard	Grass	Poaceae
4	<i>Cajanus rugosus</i> (Wight & Arn.) Maesen	Climbing Shrub	Leguminosae
5	<i>Canthiumcoromandelicum</i> (Burm.f.) Alston	Shrub	Rubiaceae
6	<i>Chamaecristamimosoides</i> (L.) Greene	Herb	Leguminosae
7	<i>Chrysopogonhackelii</i> (Hook.f.) C.E.C.Fisch.	Grass	Poaceae
8	<i>Crassocephalumcrepidioides</i> S.Moore	Herb	Compositae
9	<i>Crotalaria nana</i> Burm.f.	Herb	Leguminosae
10	<i>Desmodiastrumracemosum</i> (Benth.) A.Pramanik & Thoth.	Herb	Leguminosae
11	<i>Dichanthiumannulatum</i> (Forssk.) Stapf	Grass	Poaceae
12	<i>Droseraspatulata</i> Labill.	Herb	Droseraceae
13	<i>Emilia sonchifolia</i> (L.) DC.	Herb	Compositae
14	<i>Eragrostisunioloides</i> (Retz.) Nees ex Steud.	Grass	Poaceae
15	<i>Eriocaulon quinqueangulare</i> L.	Herb	Eriocaulaceae
16	<i>Heteropogoncontortus</i> (L.) P.Beauv. ex Roem. & Schult.	Grass	Poaceae
17	<i>Impatiens lawsonii</i> Hook.f.	Herb	Balsaminaceae
18	<i>Ischaemumcommutatum</i> Hack.	Grass	Poaceae
19	<i>Ischaemumtimoreense</i> Kunth	Grass	Poaceae
20	<i>Laggera alata</i> (DC.) Sch.Bip. ex Oliv.	Grass	Poaceae
21	<i>Leucas stelligera</i> Wall. ex Benth.	Herb	Lamiaceae
22	<i>Melinis repens</i> (Willd.) Zizka	Grass	Poaceae
23	<i>Oplismenusburmanni</i> (Retz.) P.Beauv.	Grass	Poaceae
24	<i>Osbeckia virgata</i> D.Don ex Wight & Arn.	Grass	Poaceae
25	<i>Polygala persicariifolia</i> DC.	Herb	Polygalaceae
26	<i>Pteridium aquilinum</i> (L.) Kuhn	Fern	Dennstaedtiaceae
27	<i>Setaria pumila</i> (Poir.) Roem. & Schult.	Grass	Poaceae
28	<i>Strobilanthescallosa</i> Nees	Shrub	Acanthaceae
29	<i>Tephrosia purpurea</i> (L.) Pers.	Herb	Leguminosae
30	<i>Tephrosia tinctoria</i> (L.) Pers.	Undershrub	Leguminosae
31	<i>Themeda triandra</i> Forssk.	Grass	Poaceae
32	<i>Urena lobata</i> L.	Undershrub	Malvaceae
33	<i>Utricularia</i> Spp	Herb	Lentibulariaceae

**Fig 6** Some of the important species of Grassland documented in BWS, Kodagu

4. Conclusion:

This study offers a comprehensive assessment of herbaceous plant diversity and distribution across an elevational gradient in the montane grasslands of Brahmagiri Wildlife Sanctuary one of the least explored yet ecologically vital ecosystems in the Western Ghats. The findings highlight the dominance of Poaceae, Leguminosae, and Acanthaceae families and reveal a strong positive relationship between species richness and individual abundance, supporting the niche complementarity and sampling effect hypotheses. Elevation significantly influenced growth-form composition and

spatial dispersion, with grasses and herbs responding distinctly to changing climatic and topographic conditions. Principal Component Analysis further confirmed that biodiversity metrics such as species richness, evenness, and dominance were closely aligned with slope, aspect, and elevation underscoring the role of microhabitat heterogeneity and abiotic filtering in shaping herbaceous community assembly. Importantly, the study demonstrates that herbaceous species despite often being underrepresented in conservation efforts contribute substantially to ecosystem structure, resilience, and biodiversity in tropical montane grasslands. The predominance of clumped distribution patterns, except at mid-elevations, reflects the influence of habitat complexity and patchy resource availability on species dispersion. These findings stress the ecological importance and vulnerability of herbaceous flora in high-altitude landscapes, where they face mounting pressures from exotic species invasion, and climate variability. Integrating herbaceous diversity into regional conservation frameworks is therefore essential to maintain the ecological integrity, hydrological balance, and functional resilience of the Western Ghats montane ecosystems.

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