

Tree Species Diversity, Vegetation Structure, and Importance Value Indices of Shola Forests in the Central Western Ghats, Chikkamagaluru, Karnataka, India

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Abstract

Shola forests, relict montane rainforests endemic to the Western Ghats–Nilgiris Hills complex, represent one of South Asia's most threatened yet species-rich ecosystems. Quantitative assessments of tree diversity, vegetation structure, and Importance Value Index (IVI) along elevational gradients in the Central Western Ghats remain underrepresented in the literature. This study addresses this gap through systematic vegetation sampling across 23 belt transect plots (20 × 20 m; total 0.92 ha) in Shola forests of the Bhadra Tiger Reserve (BTR; 17 plots, 0.68 ha) and the Chikkamagaluru Territorial Forest Division (CTF; 6 plots, 0.24 ha), spanning an elevational range of 1,300–1,930 m. All trees with a diameter at breast height (DBH) ≥ 10 cm were enumerated, and vegetation structure was analysed using basal area, relative density (RD), relative frequency (RF), relative dominance, IVI, Shannon-Wiener Diversity Index (H'), Simpson's Diversity Index (D), and Pielou's Evenness Index (J'). Floristic data were cross-referenced with IUCN Red List of Threatened Species (Version 2023-1).

A total of 727 trees were documented across 68 species, 33 genera, and 29 families. BTR Sholas exhibited higher species richness (59 species, 25 families; H' = 3.3, D = 0.1, J' = 0.80), indicative of a mature climax community, while CTF Sholas recorded 31 species and 21 families (H' = 2.9, D = 0.07, J' = 0.85). Lauraceae dominated both zones; in BTR, *Litsea floribunda* (IVI = 30.26) and *Cryptocarya stocksii* (IVI = 26.48) were the most prominent species, with *Syzygium cumini* contributing the highest basal area per species (5.78 m²). Twelve IUCN-threatened taxa were identified, underscoring the conservation urgency. Girth class distributions peaked at mid-elevations (1,500–1,700 m) and declined above 1,700 m.

The Chikkamagaluru Shola forests harbour exceptional diversity, including a high proportion of endemic and threatened taxa, and provide critical ecosystem services including carbon storage, watershed regulation, and climate buffering. Lauraceae dominance and elevated late-successional IVI values confirm the climax status of these communities. Urgent conservation interventions, including invasive species removal, habitat restoration, and adaptive management, are needed. The findings provide a robust baseline dataset for SDG Target 15.4, the Kunming-Montreal Global Biodiversity Framework, and state-level conservation policy.

Introduction

Mountain forests cover approximately 12.3% of the Earth's terrestrial surface and are widely recognised as the planet's most biologically diverse and ecologically sensitive ecosystems (Price et al., 2013). They harbour an estimated 80% of global terrestrial biodiversity, serve as

critical headwaters for major river systems, and sequester disproportionately large quantities of atmospheric carbon relative to their areal extent (Körner et al., 2017). Yet montane forests globally are among the most threatened biomes, subject to the compounding pressures of land-use change, plantation expansion, and accelerating climate change threats that are particularly acute in tropical biodiversity hotspots (Myers et al., 2000; Chandrashekar et al., 2006; Brondizio et al., 2019).

The Western Ghats–Sri Lanka biodiversity hotspot, a UNESCO World Heritage Site, is the epicentre of this crisis in South Asia. Among the most remarkable ecological formations within this hotspot are the Shola forests, a distinctive mosaic of stunted, dense, evergreen montane rainforest patches interspersed with rolling montane grasslands above 1,200 m elevation contour (Asuramani et al., 2019). These relict forest fragments, shaped by millennia of orographic precipitation and cloud immersion, represent ecological islands harbouring unique concentrations of endemic and narrowly distributed plant species. The Shola–Forest grassland landscape complex is not only an irreplaceable repository of biodiversity but also functions as a critical hydrological buffer, regulating streamflow for densely populated lowland regions across Karnataka, Tamil Nadu, and Kerala (Robin & Nandini, 2012; Bunya et al., 2012).

Chikkamagaluru district in the Central Western Ghats presents a particularly compelling study system. The district encompasses Mullayanagiri (1,930 m above MSL), the highest peak in Karnataka, and hosts the ecologically significant Bhadra Tiger Reserve (BTR), a landscape that evolved from the Jagara Valley Wildlife Sanctuary (1951) through successive expansions, culminating in its designation under Project Tiger in 1998. Despite this administrative recognition, rigorous quantitative assessments of tree diversity, vegetation structure, and functional composition of the Shola forests within BTR and the adjacent Chikkamagaluru Territorial Forest Division (CTF) remain conspicuously absent from the peer-reviewed literature.

The Shola Forest is being rapidly degraded by exotic plantation expansion, particularly agricultural encroachment, and altered fire regimes (Jose et al., 2021; Mohandass & Davidar, 2009). Climate change exerts additional pressure through upslope migration of vegetation zones, altered precipitation patterns, and increased drought frequency, threatening to decouple the fine-tuned ecological relationships that sustain Shola biodiversity (Krishnaswamy et al., 2014; Bawa et al., 2020). Against this backdrop, baseline floristic inventories and structural assessments are not merely academic exercises; they are foundational prerequisites for evidence-based conservation planning, ecological monitoring under the Convention on Biological Diversity (CBD), and compliance with SDG Target 15.4 on mountain ecosystem conservation.

The present study addresses this gap through a systematic phytosociological assessment of Shola Forest tree communities in Chikkamagaluru district across an elevational gradient from 1,300 m to 1,930 m. The specific objectives are: (i) to document and characterize tree species composition and taxonomic diversity; (ii) to quantify structural attributes including basal area, species density, and IVI; (iii) to evaluate species diversity, evenness, and dominance using established ecological indices; (iv) to examine the pattern of girth class distribution along the elevational gradient and (v) to identify IUCN-threatened species and assess the conservation significance of the study sites. The findings are expected to provide a robust baseline dataset for long-term ecological monitoring and landscape-level conservation planning.

Materials and Methods

Study Area

The study was conducted in the Shola Forests of Chikkamagaluru district, situated in the Central Western Ghats of Karnataka, India (approximately 13°00'–13°35' N, 75°30'–76°05' E). The district spans an area of approximately 7,201 km² and is characterised by a rugged

topography encompassing the Baba Budangiri range and the Kudremukh–Mullayanagiri ridge. Mullayanagiri (1,930 m) constitutes the highest peak in Karnataka. The climate is humid subtropical to montane, with mean annual rainfall ranging from 1,925 to 3,038 mm, predominantly delivered by the South-West Monsoon (June–September), and mean annual temperatures ranging from 19°C to 30°C at lower elevations, decreasing significantly above 1,500 m. Soils are predominantly lateritic at lower elevations, transitioning to humus-rich montane soils with elevated organic matter content at higher altitudes (Ravishankar and Nagaraja, 2021).

The study specifically targeted forest patches above 1,200 m elevation, encompassing two major administrative jurisdictions: (1) the Bhadra Tiger Reserve (BTR), originally designated as Jagara Valley Wildlife Sanctuary in 1951, expanded in 1972, and brought under Project Tiger in 1998; and (2) the Chikkamagaluru Territorial Forest Division (CTF), with study sites in the Baba Budangiri and Mullayanagiri regions. Shola forest patches within this landscape occur as discrete islands of closed-canopy forest within a broader matrix of montane grassland, the defining feature of the Shola Forest grassland mosaic (Nagaraja et al., 2014).

The study area is rich in the diversity of flora and fauna. It is surrounded by lunar grain hills and dense forests, a favourable climate for coffee plantations, and the temperature varies from 19° to 30°C. The average rainfall is 1925-3038 mm. Mullayanagiri is the highest peak with an elevation of 1930 m above MSL in Karnataka, India. The research investigation consists of an area that is above 1200 m in elevation. This elevated terrain encompasses key reserves and forested areas, notably Bhadra Tiger Reserve, and Chikkamagaluru Territorial Forest.

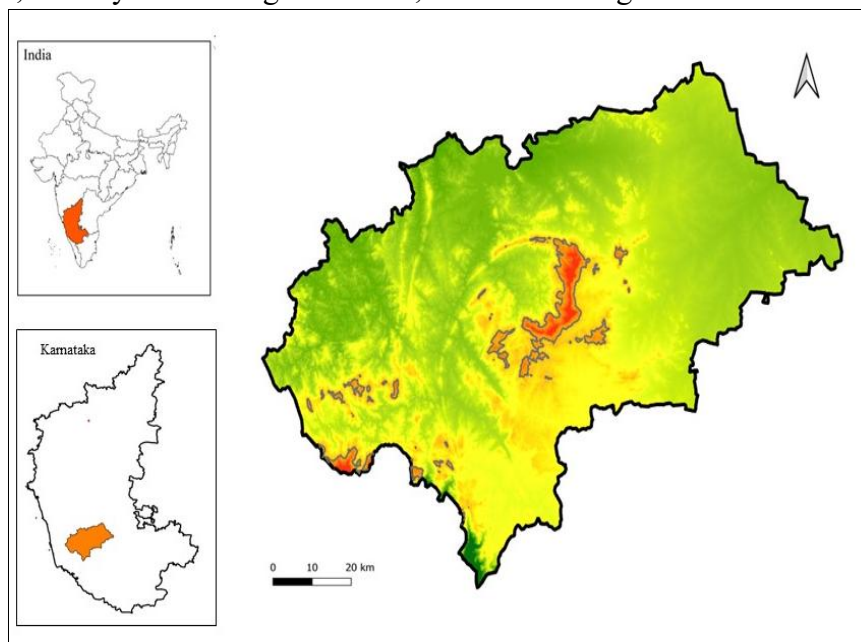


Figure 1. Shola Forest-Grassland in Chikkamagaluru district

Methods

Vegetation Sampling design

Vegetation composition was assessed using the belt transect method following the approach of Misra (1968). Study sites above 1,200 m elevation were selected to capture the full elevational range of Shola Forest occurrence. Belt transects of 100 m length and 50 m width were established in each Shola forest patch. Each transect consisted of three 20 × 20 m nested plots separated by a 10 m buffer interval. The number of transects in each Shola forest patch varied based on the extent of the forest fragment. Tree species identity was established using authoritative regional floras (Gamble, 1935; Yoganarasimhan, 1981; Saldanha, 1985; Keshava

Murthy, 1990). The number of plots sampled across each protected area is summarised in Table 1.

Table 1. Sampling design summary showing the distribution of transects and plots across study zones and elevation ranges.

Study Area	Elevation Zone (m)	No. of Plots	Plot Size (m)	Area Sampled (ha)
Bhadra Tiger Reserve (BTR)	1300–1800	17	20 × 20	0.68
Chikkamagaluru TFD – Baba Budangiri	1700–1930	4	20 × 20	0.16
Chikkamagaluru TFD – Mullayanagiri	1500–1930	2	20 × 20	0.08
Total	1300–1930	23	20 × 20	0.92

Note: BTR = Bhadra Tiger Reserve; CTF = Chikkamagaluru Territorial Forest Division; TFD = Territorial Forest Division.

Data collection

Within each 20 × 20 m plot, all trees with a diameter at breast height (DBH) ≥ 10 cm measured at 1.37 m above ground were enumerated (Misra 1968). For each tree, the following data were recorded: (i) DBH (cm), measured using a diameter tape; (ii) species identity (scientific name and local/vernacular name); (iii) GPS coordinates of each plot centre; and (iv) elevation (m) recorded using a calibrated Garmin GPS device. Girth at breast height (GBH) was also measured for girth class analysis. Plant specimens with uncertain identity were collected as herbarium vouchers and subsequently identified using authoritative regional floras (Gamble, 1935; Yoganarasimhan, 1981; Saldanha, 1985; Keshava Murthy, 1990) and cross-validated with the digital database.

Phytosociological and Biodiversity Analysis

Species composition analysis was performed by consolidating all species records into a comprehensive inventory. The following phytosociological parameters were computed for each species following Curtis and McIntosh (1950).

Absolute Density (AD) = Number of individuals of a species / Total area sampled (ha)

Relative Density (RD) = (Number of individuals of a species / Total number of all individuals) × 100

Absolute Frequency (AF) = Number of plots in which a species occurs / Total number of plots sampled

Relative Frequency (RF) = (AF of a species / Sum of AF of all species) × 100

Basal Area (BA) = $(\pi/4) \times \text{DBH}^2$ (expressed in m²)

Relative Dominance (R.Dom) = (Basal area of a species / Total basal area of all species) × 100

Importance Value Index (IVI) = RD + RF + R.Dom (maximum value = 300)

Biodiversity Indices

Species diversity was assessed using three complementary indices. The Shannon–Wiener Diversity Index (H') was employed to assess species evenness and proportional representation, with typical values ranging from 1.5 to 3.5, and occasionally reaching up to 4.5 in highly diverse communities (Magurran, 2004). Simpson's Diversity Index (D) was used to quantify species dominance and overall diversity, with values ranging from 0 (infinite diversity) to 1 (no diversity), emphasising the influence of the most abundant species ID within each plot. Evenness index species evenness refers to how evenly distributed each species is in an

environment. The evenness of a community can be represented by Pielou's evenness index (Pielou, 1966).

Shannon-Wiener Diversity Index (H')

It was calculated using the formula by Shannon (1948)

$$H' = -\sum(P_i)[\log(P_i)]$$

$$\text{where, } P_i = \frac{n_i}{N}$$

(n_i = number of individuals of a species, N = total number of individuals of all species)

Simpson Index of Diversity (D)

It was calculated as per Simpson (1949).

$$D = 1 - \sum P_i^2$$

$$\text{where, } P_i = \frac{n_i}{N}$$

(n_i = number of individuals of a species, N = total number of individuals of all species)

Pielou's Evenness Index (E)

The evenness was calculated according to Pielou (1975).

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

where, H' = Shannon wiener index, S = No of species present

Results and Discussion

Structural attributes

A total of 727 individual trees representing 68 species, 33 genera, and 29 families were recorded across all 23 plots (0.92 ha). In the Bhadra Tiger Reserve, 17 vegetation plots (0.68 ha) across three elevation zones recorded 519 individual trees belonging to 59 species and 25 families. This high taxonomic diversity reflects a wide range of evolutionary lineages and ecological niches, characteristic of Shola forests known for their endemism and microclimatic specialisation. Of the 59 species recorded in BTR, nine were classified as IUCN-threatened taxa. In the Chikkamagaluru Territorial Forest Division, six plots (0.24 ha) in the Baba Budangiri and Mullayanagiri regions recorded 208 individual trees belonging to 31 species and 21 families, of which three species were IUCN-threatened.

Diversity Attributes

In the Bhadra Tiger Reserve, the Simpson's Diversity Index ($D = 0.1$) and Shannon-Wiener Index ($H' = 3.3$), a low Simpson's Index and high Shannon Index together reflect a stable, mature ecosystem with high resilience and ecological function (Diane, 2020). The Shannon Index suggests a complex assemblage with numerous species occurring at varying abundances. These values are typical of climax or near-climax communities, often seen in relatively undisturbed Shola forests (Revathy et al., 2023). The Evenness Index (0.8) further complements the diversity indices by indicating a relatively uniform distribution of individuals among species, implying reduced dominance by any single taxon and a balanced ecological structure (Table 1).

In Chikkamagaluru territorial Forest, the Simpson's Diversity Index (0.07) indicates, and the Shannon-Wiener Index (1.26) both indicate a moderate to high level of species diversity, suggesting that the community includes a mix of common and less frequent species. The Evenness Index (0.85) implies a relatively uniform distribution of individuals among the species present, indicating low dominance and balanced species representation (Table 2).

Table 1. Results of the structure and diversity of the Shola Forest montane forest in Bhadra Tiger Reserve and Chikkmagaluru Territorial Forest, Chikkmagaluru

Sl. No.	Parameters	Bhadra Tiger Reserve	Chikkmagaluru Territorial Forest
1	Number of Plots	17	6
2	Number Species	59	31s
3	Total Basal Area (m2)	40.2	13.74
4	Number of Families	25	20
5	Numbers of Genera	41	28
6	Number of Individual Species	519	208
7	Simpons's Index	0.1	0.07
8	Shannon Wiener-Index	3.3	1.26
9	Evenness similarity index	0.8	0.85
10	IUCN (threatened Species)	9	3

Girth Class Distribution Pattern Across Elevation Gradients:

Analysis of girth class distribution across elevation zones revealed a distinct concentration of individual trees within the mid-elevation ranges, particularly between 1,500–1,600 m and 1,600–1,700 m (Figure 2). These zones exhibited the highest tree density across all girth classes, with a sharp rise in density in the 30–60 cm and 60–90 cm girth categories. The 1,600–1,700 m elevation band supported the greatest overall abundance, suggesting that this range may represent optimal environmental conditions for tree growth and regeneration. In contrast, the higher elevation zone (1,700–1,800 m) supported significantly lower tree densities across all girth classes, reflecting ecological constraints associated with increasing altitude. The lowest elevation bands (1,300–1,400 m and 1,400–1,500 m) displayed moderate densities without the concentration observed in the mid-elevation zones. Large-diameter trees (GBH > 150 cm) were consistently rare across all elevation zones, indicating their relative scarcity and possibly reflecting the low abundance of mature or old-growth individuals resulting from natural senescence or historical anthropogenic disturbance (Figure 3).



Figure 2. Girth class distribution of tree across the elevation in the Shola Forest of Bhadra Tiger Reserve, Chikkamagalur

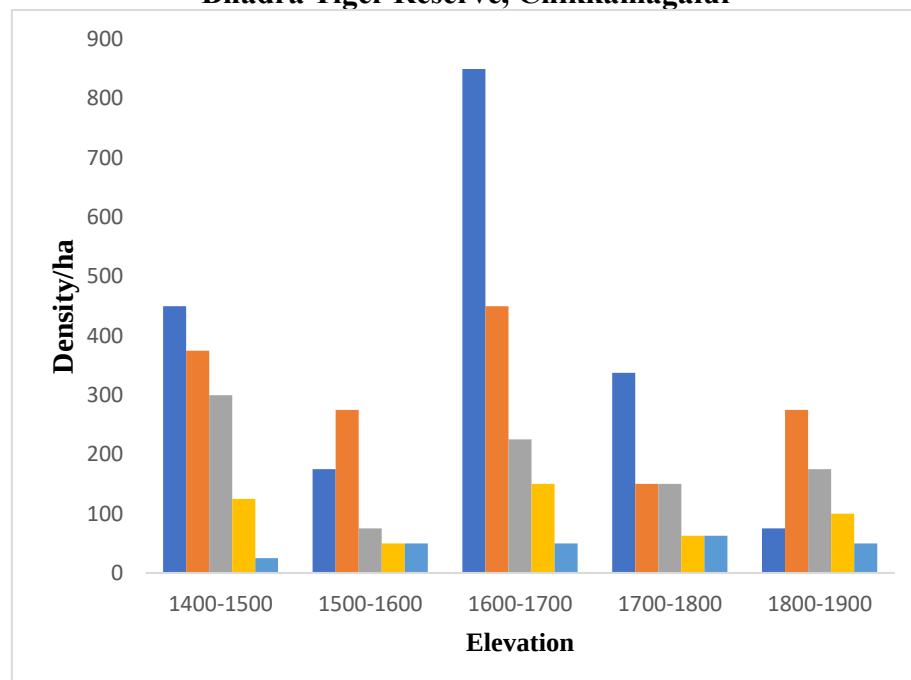


Figure 3 Girth class distribution of trees across the elevation in the Shola Forest of Chikkamagaluru Territorial Forest, Chikkamagalur

Species Importance Value Index (IVI), Bhadra Tiger Reserve

The IVI analysis for BTR (Table 4) reveals a floristic structure characteristic of mature closed-canopy forests. *Litsea floribunda* (Lauraceae) attained the highest IVI (30.26), followed by *Cryptocarya stocksii* (IVI = 26.48) and *Syzygium cumini* (IVI = 24.70). *Neolitsea zeylanica* (IVI = 23.39) and *Meliosma simplicifolia* (IVI = 15.46) also ranked among the top co-dominant species. The strong dominance of Lauraceae (represented by *Litsea*, *Cryptocarya*, *Cinnamomum*, *Neolitsea*, *Actinodaphne*, and *Persea*) in the upper IVI tiers aligns with the well-documented biogeographic pattern of Lauraceae dominance in tropical montane Shola Forest. The presence of *Eucalyptus robusta* (IVI = 5.65) in BTR plots at lower elevations is noteworthy, indicating past plantation expansion into natural forest areas, a phenomenon that poses

significant biodiversity risks through competitive exclusion of native flora and alteration of soil microbial communities (Krishnaswamy et al., 2014).

Table 2. Count, frequency, basal area, Relative Density, Relative Frequency, Relative Dominance and Importance Values (IIV) of the vegetation in Bhadra Tiger Reserve

Sl. No.	Species name	Family	Count	Frequency	Basal area	Relative Density	Relative Frequency	Relative Dominance	IVI
1	Actinodaphne bourdillonii Gamble	Lauraceae	19	29.41	0.58	3.66	3.36	1.44	8.46
2	Actinodaphne tadulingamii Gamble	Lauraceae	7	23.53	0.26	1.35	2.68	0.64	4.67
3	Antidesma acidum Retz.	Phyllanthaceae	2	5.88	0.34	0.39	0.67	0.84	1.90
4	Artocarpus heterophyllus Lam.	Moraceae	1	5.88	0.50	0.19	0.67	1.23	2.10
5	Bridelia species	Phyllanthaceae	5	11.76	0.13	0.96	1.34	0.32	2.63
6	Canthium dicoccum (Gaertn.) Merr.	Rubiaceae	1	5.88	0.03	0.19	0.67	0.07	0.93
7	Celtis timorensis Span.	Cannabaceae	2	5.88	0.28	0.39	0.67	0.69	1.74
8	Chionanthus malaelengi subsp. linocieroides (Wight) P.S.Green	Oleaceae	1	5.88	0.24	0.19	0.67	0.60	1.46
9	Cinnamomum cassia (L.) J.Presl	Lauraceae	13	29.41	0.81	2.50	3.36	2.00	7.86
10	Cinnamomum malabattrum (Burm.f.) Bl.	Lauraceae	1	5.88	0.11	0.19	0.67	0.28	1.14
11	Cinnamomum perrottetii Meissn.	Lauraceae	4	17.65	0.03	0.77	2.01	0.08	2.86
12	Cinnamomum Species	Lauraceae	1	5.88	0.09	0.19	0.67	0.23	1.09
13	Cinnamomum sulphuratum Nees	Lauraceae	19	11.76	1.59	3.66	1.34	3.93	8.94
14	Cinnamomum travancoricum Gamble	Lauraceae	5	5.88	0.41	0.96	0.67	1.01	2.65
15	Cinnamomum verum Presl	Lauraceae	8	23.53	0.34	1.54	2.68	0.83	5.06
16	Cinnamomum wightii Meissn.	Lauraceae	3	5.88	0.03	0.58	0.67	0.07	1.32
17	Croton laccifer L.	Euphorbiaceae	1	5.88	0.05	0.19	0.67	0.12	0.98
18	Cryptocarya stocksii Meissn.	Lauraceae	64	41.18	3.81	12.33	4.70	9.45	26.48
19	Cryptocarya wightiana Thw.	Lauraceae	1	5.88	0.09	0.19	0.67	0.22	1.08

20	Dimocarpus longan Lour.	Sapindac eae	11	23. 53	0.12	2. 12	2.68	0.30	5.1 1
21	Diospyros montana Roxb.	Ebenacea e	2	5.8 8	0.23	0. 39	0.67	0.56	1.6 2
22	Elaeocarpus tuberculatus Roxb.	Elaeocarp aceae	7	5.8 8	0.27	1. 35	0.67	0.66	2.6 8
23	Eucalyptus robusta Sm.	Myrtacea e	14	5.8 8	0.92	2. 70	0.67	2.28	5.6 5
24	Fagraea ceilanica Thunb.	Gentianac eae	1	5.8 8	0.04	0. 19	0.67	0.11	0.9 7
25	Ficus amplocarpa E. Govindarajalu & P. Masilamoney	Moraceae	1	5.8 8	0.00	0. 19	0.67	0.01	0.8 7
26	Ficus species	Moraceae	1	5.8 8	1.61	0. 19	0.67	3.99	4.8 6
27	Flacourtia montana Graham	Flacourtia ceae	6	11. 76	0.58	1. 16	1.34	1.43	3.9 3
28	Glochidion species	Eubhorbi aceae	2	5.8 8	0.22	0. 39	0.67	0.56	1.6 1
29	Gordonia obtusa Wall. ex Wt. & Arn.	Theaceae	4	5.8 8	0.31	0. 77	0.67	0.76	2.2 0
30	Grewia tiliifolia Vahl	Malvacea e	1	5.8 8	0.09	0. 19	0.67	0.22	1.0 9
31	Ixora notoniana Wall. ex G. Don	Rubiacea e	1	5.8 8	0.01	0. 19	0.67	0.01	0.8 8
32	Knema attenuata (Hook. fil. & Thoms.) Warb.	Myristica ceae	12	29. 41	1.35	2. 31	3.36	3.34	9.0 0
33	Litsea bourdillonii Gamble	Lauarace ae	28	35. 29	1.97	5. 39	4.03	4.87	14. 30
34	Litsea deccanensis Gamble	Lauarace ae	7	23. 53	0.36	1. 35	2.68	0.90	4.9 3
35	Litsea floribunda (Bl.) Gamble	Lauarace ae	65	58. 82	4.45	12. 5 2	6.71	11.03	30. 26
36	Litsea stocksii Hook.f.	Lauarace ae	10	5.8 8	0.12	1. 93	0.67	0.30	2.9 0
37	Litsea wightiana (Nees) Benth. & Hook. fil.	Lauarace ae	3	11. 76	0.19	0. 58	1.34	0.47	2.3 9
38	Litsea wightiana (Nees) Benth. & Hook. fil.	Lauarace ae	2	5.8 8	0.19	0. 39	0.67	0.47	1.5 2
39	Macaranga peltata (Roxb.) Müll.Arg.	Eubhorbi aceae	1	5.8 8	0.04	0. 19	0.67	0.09	0.9 5
40	Maesa indica (Roxb.) A. DC.	Primulace ae	1	5.8 8	0.00	0. 19	0.67	0.01	0.8 7
41	Meliosma simplicifolia (Roxb.) Walp.	Sabiaceae	21	35. 29	2.98	4. 05	4.03	7.38	15. 46
42	Memecylon species	Melastom ataceae	8	23. 53	0.21	1. 54	2.68	0.51	4.7 4

43	Memecylon umbellatum Burm. f.	Melastom ataceae	38	29. 41	0.38	7. 32	3.36	0.95	11. 63
44	Myristica malabarica Lamark.	Myristica ceae	1	5.8 8	0.02	0. 19	0.67	0.04	0.9 0
45	Neolitsea cassia (L). Kosterm	Lauarace ae	2	11. 76	0.08	0. 39	1.34	0.21	1.9 3
46	Neolitsea zeylanica (Nees & T. Nees) Merr.	Lauarace ae	38	58. 82	3.78	7. 32	6.71	9.36	23. 39
47	Nothapodytes nimmoniana (J.Graham) Mabb.	Icacinace ae	1	5.8 8	0.09	0. 19	0.67	0.23	1.0 9
48	Olea dioica Roxb.	Oleaceae	10	41. 18	1.25	1. 93	4.70	3.09	9.7 2
49	Palaquium species	Sapotacea e	14	11. 76	0.78	2. 70	1.34	1.93	5.9 7
50	Pavetta indica L.	Rubiacea e	1	5.8 8	0.04	0. 19	0.67	0.10	0.9 7
51	Persea macrantha (Nees) Kosterm.	Lauarace ae	9	23. 53	0.20	1. 73	2.68	0.49	4.9 1
52	Prunus ceylanica (Wight) Miq.	Rosaceae	1	5.8 8	0.03	0. 19	0.67	0.07	0.9 3
53	Pterocarpus marsupium Roxb.	Fabaceae	4	11. 76	0.66	0. 77	1.34	1.64	3.7 5
54	Rapanea capitellata (Wall.) Mez	Primulace ae	1	5.8 8	0.06	0. 19	0.67	0.14	1.0 0
55	Schefflera capitata (Wt. & Arn.) Harms	Araliaceae	3	5.8 8	0.55	0. 58	0.67	1.36	2.6 1
56	Symplocos macrophylla Wall. ex A. DC.	Symploca ceae	1	5.8 8	0.22	0. 19	0.67	0.54	1.4 0
57	Symplocos species	Myrtacea e	1	5.8 8	0.02	0. 19	0.67	0.06	0.9 3
58	Syzygium cumini (L.) Skeels	Myrtacea e	26	47. 06	5.78	5. 01	5.37	14.32	24. 70
59	Xantolis tomentosa (Roxb.) Raf.	Sapotacea e	1	5.8 8	0.48	0. 19	0.67	1.18	2.0 4
	Grand Total		51 9	87 6.4 7	40.36	10 0. 00	100. 00	100.00	300 .00

Note: RD = Relative Density; RF = Relative Frequency; R.Dom = Relative Dominance; IVI = Importance Value Index (max. 300).

In CTF (Table 5), Litsea floribunda attained the highest IVI (31.36), followed by Ligustrum perrottetii (IVI = 32.70) and Cryptocarya wightiana (IVI = 32.32). Syzygium cumini (IVI = 29.06) was again among the dominant species. Lauraceae continued to dominate the upper IVI tiers, consistent with the pattern observed in BTR. The density of the ten most abundant species across the CTF is illustrated in Figure 3.

Table 3. Count, frequency, basal area, Relative Density, Relative Frequency, Relative Dominance and Importance Values (IIV) of the vegetation of Chikmagalur Territorial Forest

Sl. No.	Species name	Family	Count	Frequency	Basal area	R D	R F	R. Dominance	IV I
1	<i>Callicarpa tomentosa</i> (L.) L.	Lamiaceae	3	16.67	0.13	1.44	1.25	0.94	3.63
2	<i>Canthium dicoccum</i> (Gaertn.) Merr.	Rubiaceae	1	16.67	0.12	0.48	1.25	0.88	2.61
3	<i>Celtis timorensis</i> Span.	Cannabaceae	1	16.67	0.04	0.48	1.25	0.28	2.01
4	<i>Cinnamomum sulphuratum</i> Nees	Lauraceae	14	66.67	0.72	6.73	5	5.22	16.95
5	<i>Cinnamomum verum</i> J.Presl	Lauraceae	6	66.67	0.24	2.88	5	1.77	9.66
6	<i>Cryptocarya wightiana</i> Thwaites	Lauraceae	24	83.33	2	11.54	6.25	14.53	32.32
7	<i>Daphniphyllum neilgherrense</i> (Wight) K.Rosenthal	Daphniphyllaceae	4	66.67	0.08	1.92	5	0.57	7.5
8	<i>Elaeagnus latifolia</i> L.	Elaeagnaceae	7	50	0.5	3.37	3.75	3.66	10.78
9	<i>Euodia lunulakenda</i> (Gaertn.) Merr.	Rutaceae	4	33.33	0.31	1.92	2.5	2.24	6.66
10	<i>Euonymus indicus</i> B.Heyne ex Wall.	Celastraceae	7	66.67	0.36	3.37	5	2.61	10.98
11	<i>Eurya nitida</i> Korth.	Pentaphyllacaceae	1	16.67	0.01	0.48	1.25	0.08	1.81
12	<i>Flacourtia montana</i> J. Graham	Salicaceae	1	16.67	0.11	0.48	1.25	0.77	2.5
13	<i>Glochidion zeylanicum</i> (Gaertn.) A.Juss.	Phyllanthaceae	3	33.33	0.14	1.44	2.5	1.02	4.96
14	<i>Ixora notoniana</i> Wall. ex G.Don	Rubiaceae	2	16.67	0.07	0.96	1.25	0.5	2.71
15	<i>Ligustrum perrottetii</i> A.DC.	Oleaceae	11	83.33	2.91	5.29	6.25	21.16	32.7
16	<i>Litsea glabrata</i> (Wall. ex Nees) Hook.f.	Lauraceae	2	33.33	0.24	0.96	2.5	1.75	5.21
17	<i>Litsea stocksii</i> Hook. fil.	Lauraceae	1	16.67	0.02	0.48	1.25	0.12	1.85
18	<i>Litsea floribunda</i> Gamble	Lauraceae	31	100	1.23	14.9	7.5	8.95	31.36
19	<i>Macaranga peltata</i> (Roxb.) Mull.Arg.	Euphorbiaceae	2	33.33	0.12	0.96	2.5	0.84	4.3

20	Memecylon talbotianum Brandis	Melastomataceae	6	33.33	0.21	2.8 8	2. 5	1.5	6.8 8
21	Microtropis latifolia Wight ex M.A.Lawson	Celastraceae	4	66.67	0.09	1.9 2	5	0.68	7.6
22	Neolitsea zeylanica (Nees & T.Nees) Merr.	Lauraceae	15	66.67	0.6	7.2 1	5	4.37	16. 58
23	Nothapodytes nimmoniana (J.Graham) Mabb.	Icacinaceae	2	33.33	0.04	0.9 6	2. 5	0.28	3.7 4
24	Nothopodia beddomei Gamble	Anacardiaceae	1	16.67	0.01	0.4 8	1. 25	0.06	1.7 9
25	Olea dioica Roxb.	Oleaceae	1	16.67	0.03	0.4 8	1. 25	0.2	1.9 3
26	Persea macrantha (Nees) Kosterm.	Lauraceae	1	16.67	0.04	0.4 8	1. 25	0.32	2.0 5
27	Rapanea striata Mez	Primulaceae	2	33.33	0.04	0.9 6	2. 5	0.3	3.7 6
28	Scolopia crenata (Wight & Arn.) Clos	Salicaceae	17	33.33	0.92	8.1 7	2. 5	6.7	17. 37
29	Symplocos cochinchinensis subsp. laurina (Retz.) Nooteb.	Symplocaceae	8	83.33	0.5	3.8 5	6. 25	3.63	13. 73
30	Syzygium cumini (L.) Skeels	Myrtaceae	23	66.67	1.79	11. 06	5	13	29. 06
31	Vernonia arborea Buch.-Ham.	Asteraceae	3	33.33	0.15	1.4 4	2. 5	1.07	5.0 2
Grand Total			208	1333. 33	13.74	10 0	10 0	100	30 0

Note: RD = Relative Density; RF = Relative Frequency; R.Dom = Relative Dominance; IVI = Importance Value Index (max. 300).

Comparative Diversity Assessment

The Bhadra Tiger Reserve (BTR) Shola demonstrated comparatively high floristic diversity among the montane ecosystems of the Western Ghats (Table 5). The Shannon–Wiener diversity index recorded for BTR ($H' = 3.3$) was marginally higher than that reported from the Brahmagiri Wildlife Sanctuary Shola forests of Karnataka ($H' = 3.1$; Revathy et al., 2023), indicating greater species heterogeneity and ecological complexity within the BTR landscape. Likewise, BTR exhibited higher species richness (59 species) and family representation (25 families) relative to Brahmagiri WLS (47 species and 22 families), reflecting a more diverse floristic assemblage. The low Simpson’s dominance index values observed for both BTR ($D = 0.10$) and Brahmagiri ($D = 0.08$) suggest minimal dominance by individual taxa and indicate structurally stable forest communities. Furthermore, the comparable Pielou’s evenness values for BTR ($J' = 0.80$) and Brahmagiri ($J' = 0.79$) imply a relatively balanced distribution of individuals among species. In contrast, the Chikkamagaluru Territorial Forest Division (CTF)

Shola exhibited comparatively lower diversity ($H' = 1.26$) and reduced species richness (31 species), indicating lower floristic heterogeneity and comparatively simplified community composition.

Study Location	No. of Species	No. of Families	H'	D	J'	IUCN Spp.	Reference
Bhadra Tiger Reserve, Shola	59	25	3.3	0.1	0.80	9	Present study
Chikkamagaluru TFD, Shola	31	21	1.26	0.07	0.85	3	Present study
Brahmagiri WLS, Shola, Karnataka	47	22	3.1	0.08	0.79	7	Revathy et al., 2023

Note: H' = Shannon-Wiener Index; D = Simpson's Index; J' = Pielou's Evenness Index. Values from published literature unless marked 'This study'. WLS = Wildlife Sanctuary;

Discussion

Ecological Significance of High Floristic Diversity

The documentation of 68 tree species belonging to 29 families within a sampling area of less than one hectare highlights the exceptionally high floristic richness characteristic of montane Shola forests of the Western Ghats. Among the study sites, the Bhadra Tiger Reserve (BTR) Shola exhibited comparatively high diversity ($H' = 3.3$) with 59 species representing 25 families. This diversity value is comparable to that reported from Brahmagiri Wildlife Sanctuary Shola forests ($H' = 3.1$; Revathy et al., 2023), indicating similar levels of ecological complexity and floristic heterogeneity in these montane ecosystems. In contrast, the Chikkamagaluru Territorial Forest Division (CTF) Shola recorded lower diversity ($H' = 1.26$) with 31 species belonging to 21 families, suggesting comparatively reduced species heterogeneity and simplified community composition.

The Simpson's Dominance Index further supports these observations. The relatively low dominance value recorded in BTR ($D = 0.10$) indicates that no single species overwhelmingly dominates the community, reflecting a structurally complex and ecologically stable forest system. Similarly, the low dominance value observed in Brahmagiri Shola forests ($D = 0.08$; Revathy et al., 2023) suggests comparable patterns of species distribution and community stability. The Pielou's Evenness Index values for BTR ($J' = 0.80$) and Brahmagiri ($J' = 0.79$) further indicate a relatively equitable distribution of individuals among species, supporting balanced niche sharing and resource utilisation within these Shola ecosystems.

Additionally, the occurrence of a higher number of IUCN-listed species in BTR (9 species) compared to CTF (3 species) emphasises the ecological and conservation significance of BTR Shola forests. Collectively, these findings demonstrate that BTR Sholas maintain high species richness, balanced community structure, and substantial conservation value, reinforcing their importance as critical montane biodiversity reservoirs within the Western Ghats landscape.

IUCN- Threatened Species and Conservation Priority

The presence of 12 IUCN-threatened species, nine in BTR and three in CTF, across a combined sampling area of 0.92 ha is a compelling indicator of the high conservation value of these forests. Species such as *Nothapodytes nimmoniana* (Icacinaceae), listed as Vulnerable, and *Pterocarpus marsupium* (Fabaceae), as threatened species in the Shola forests of Chikkamagaluru

The detection of nine threatened species within the relatively small BTR sampling area implies that the broader Bhadra landscape likely harbours substantially higher threatened species richness than currently documented, a conclusion with immediate implications for protected

area management priorities. This finding is consistent with the IPBES (2019) assessment that approximately 25% of species in the Western Ghats hotspot face some level of threat, with forest fragmentation being the primary driver.

Elevation Patterns and Implications for Climate Change Vulnerability

The unimodal pattern of tree density along the elevational gradient with peak density at 1,500–1,700 m is consistent with the mid-domain effect and the prevailing moisture and temperature optima for Shola Forest tree communities (Krishnaswamy et al., 2014). The decline in density above 1,700 m reflects ecotonal dynamics at the Shola–grassland interface, where soil conditions, increased wind exposure, and lower mean temperatures constrain tree establishment.

This elevational pattern has profound implications for climate change vulnerability. Projected mean temperature increases of 1.5–3.0°C across the Western Ghats by 2070 (Bawa et al., 2020) are expected to shift the lower boundary of optimal Shola conditions upslope, effectively compressing the available habitat for Shola Forest communities between rising lower boundaries and fixed summit elevations. This 'summit trap' scenario, analogous to patterns observed in Himalayan montane forests (Körner et al., 2021) and the Andean páramo (Brondizio et al., 2019) represents perhaps the most critical long-term threat to Shola biodiversity conservation.

The scarcity of large-diameter trees (GBH > 150 cm) across all elevation zones warrants particular attention. In old-growth tropical forests, large-diameter trees (which typically represent a minor fraction of stems but a major fraction of basal area and biomass) are disproportionately important for carbon storage, microhabitat provision, and ecosystem resilience (Lutz et al., 2018). Their rarity in the present study may reflect past selective logging, natural senescence processes, or both, an aspect requiring further investigation through tree ring analysis and historical land-use reconstructions.

Conclusion

This study provides a comprehensive quantitative assessment of tree species diversity, vegetation structure, Importance Value Index, and elevational distribution patterns for the Shola forests of Chikkamagaluru district in the Central Western Ghats. The findings reveal that these forests harbour exceptional biodiversity, 59 tree species from 25 families, including 9 IUCN-threatened taxa, within a sampling area of less than one hectare, underscoring their status as a global biodiversity priority. The dominance of Lauraceae, high Shannon-Wiener Index values ($H' = 3.3$ and 1.26 for BTR and CTF, respectively), low Simpson's Dominance Index, and equitable species evenness collectively confirm the mature, climax-community status of these forests. The mid-elevation concentration of tree density (1,500–1,700 m) identifies an ecological optimum zone that is simultaneously the area most vulnerable to upslope compression under projected climate change scenarios.

These findings carry actionable conservation and policy implications: (i) immediate designation of the most species-rich and threatened-species-dense Shola patches within BTR as ecologically sensitive zones requiring zero-disturbance management; (ii) prioritization of active restoration particularly removal of Eucalyptus plantations and replanting of native Lauraceae species in degraded forest margins; (iii) establishment of long-term permanent vegetation monitoring plots along the documented elevational gradient to track climate-driven compositional shifts; and (iv) integration of the documented IUCN-threatened species data into state-level Species Recovery Plans and Karnataka's Biodiversity Management Committee action plans.

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