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Assessment of Species Diversity in Coffee-Based Agroforests and Natural Forests in Kodagu, Central Western Ghats

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***Abstract*:** Kodagu district in Central Western Ghats, recognized for its rich biodiversity, includes diverse land-use systems such as natural forests, coffee agroforests, and plantations. This study assessed species diversity in *Coffea arabica* and *Coffea canephora*-based agroforestry across moist deciduous and evergreen vegetation types in Kodagu. Using diversity indices and Bray-Curtis cluster analysis, the study compared tree density, species richness, and ecological dominance between coffee plantations and natural forests. The results revealed that coffee plantations and Shannon–Wiener index of 3.38 to 3.96 and species richness of 59 to 90. The importance value index (IVI) indicated that exotic species, such as *Grevillea robusta*, dominate coffee agroforests in moist deciduous vegetation type, while native species dominate evergreen forests, moist deciduous forests and coffee agroforests of evergreen vegetation type. In cluster analysis evergreen forest forms a distant cluster with similarity value of 0.9, suggesting higher diversity in this land use system. The findings highlight the ecological significance of natural forests and the role of coffee agroforests in biodiversity conservation. The study emphasizes the need for conservation strategies to balance agroforestry expansion and biodiversity preservation in Kodagu.

Keywords: Kodagu, Coffee based- agroforestry, Forests, Diversity, Conservation

The Western Ghats landscape in peninsular India stands out as a distinctive mosaic that intertwines natural forests with human-modified production landscapes, creating a unique blend of biodiversity and anthropogenic interventions. This complex tapestry includes diverse elements such as coffee agroforests, tea plantations, as well as monoculture and mixed-species forest plantations (Devagiri et al., 2019). Kodagu in Central Western Ghats stands as one of the lushest and most verdant landscapes in India, forming an integral part of the Western Ghats. The 81 % of the district's geographical area is adorned with tree cover, creating a green expanse that contributes significantly to the ecological richness of region. This district is a repository of diverse ecosystems, including natural forests, sacred groves, coffee agroforests, and forest plantations. These varied landscapes play a pivotal role in sustaining the diversity of species, encompassing approximately 8 % of India's extensive plant wealth (Bhagwat et al., 2008). Coffee is an important example of a crop traditionally cultivated under native shade trees, with strong benefit for biodiversity conservation and carbon storage.

Kodagu district, renowned for its rich biodiversity and dense woodlands, hosts coffee plantations that account for approximately 33% of its landscape. The region's coffee agroforests have been found to harbor significant species diversity. Pioneering studies by Elouard et al. (2000), Bhagwat (2002) and Sathish (2005) compared coffee agroforests with adjoining natural forests, revealing that species richness within coffee-based agroforestry systems can be comparable to, or even exceed, that of natural forests. However, Kodagu's landscape has undergone substantial changes over the past few decades, with considerable forest degradation and deforestation driven by the expansion of coffee estates. The introduction of the fast-growing *Grevillea robusta*, an exotic species commonly found in coffee plantations, has led to further modifications of tree cover of the region. These changes, driven by the desire for higher coffee yields and the economic benefits of harvesting *G. robusta*, have raised concerns about the impact on native biodiversity. This diverse set of environmental conditions provides an opportunity to explore how agroforestry systems (AFS) respond to variations in precipitation, taking into account both plant functioning and farmers' management practices across different environmental scenarios. Considering the dynamic nature of land-use change and varying climatic conditions in Kodagu, the present study was conducted to assess the species diversity in coffee based agroforests of Kodagu.

MATERIAL AND METHODS

Study site: The study was carried out in the tree-dominated landscapes of Kodagu, situated in the Central Western Ghats spread between 11°56ˈand 12°56ˈ N latitude and 75°22ˈ and 76°12ˈ E longitude. During the study period, annual rainfall in the evergreen vegetation ranged from 2,167.8 mm in 2023 to 5,110.0 mm in 2022. In contrast, the moist deciduous

vegetation experienced annual rainfall between 859.7 mm in 2023 and 1,826.6 mm in 2022.

Experimental details and sampling design: Kodagu district was divided into two bioclimatic zones based on vegetation type and average annual rainfall: the evergreen zone (regions receiving more than 2,500 mm of annual rainfall) and the moist deciduous zone (regions receiving 1,500-2,500 mm of annual rainfall). Within each vegetation type, three different land use systems were randomly selected: *C. arabica* plantations, *C. canephora* plantations and natural forests adjoining these coffee plantations, which served as controls. Coffee plantations that fall under 25-70 yr age group were selected. Nested sampling approach was adopted for the collection of data on trees (Pascal and Pelissier 1996). In each land use systems, 15 quadrats of size 40 m × 40 m were laid out randomly to carry out the tree enumeration. In each sample plots, all the woody plants were counted and identified by using field key (Pascal and Ramesh 1987). Total tree height and girth at breast height of all the trees with GBH ≥ 30 cm in each sample plots were measured by using laser hypsometer and measuring tape, respectively. Diversity parameters such as Shannon Weiner diversity index, evenness index, index of dominance and vegetation structural parameters such as tree density and importance value index (IVI) were estimated (Curtis and McIntosh 1950). Species richness is the number of different species represented in an ecological community, landscape or region. The diversity indices were calculated using PAST ver. 4.03 software and IVI was analysed in MS- excel using aggregated data of different land use systems and vegetation types. Bray- Curtis cluster analysis was also performed in PAST software.

IVI (%) = Relative frequency (Rf) + Relative density (RD) + Relative dominance (Rd)/3

RESULTS AND DISCUSSION

The vegetation types, tree-based land use systems in evergreen vegetation type recorded higher H' value and lower dominance indicating comparatively higher diversity than moist deciduous vegetation type. The evergreen vegetation type forests exhibited higher species richness and diversity with H' of 3.96, species richness of 90, followed by *C. arabica* plantations, indicating that natural forests support more diverse species. *C arabica* and *C. canephora* have higher evenness values of 0.54 and 0.49 compared to forests (0.23), suggesting that the species in coffee agroforests are more evenly distributed. Natural forests have lower dominance (0.03), meaning no single species dominates. In contrast, *C. robusta* (0.05) shows slightly higher dominance (Table 1). In moist deciduous vegetation type, *C. canephora* based agroforestry exhibited higher H' of 3.01 and species richness of 39 species. Forests and *C. canephora* plantations showed the same dominance value (0.08), while *C. arabica* has a slightly higher dominance (0.10), meaning certain species are more dominant in *C. arabica* plantations (Table 2).

The favourable environmental conditions in evergreen forests- such as consistent rainfall, moderate temperatures, nutrient-rich soils, and diverse topography- create stable habitats that support a wide range of plant species. These conditions promote higher species richness and functional diversity by allowing a variety of species to thrive in different ecological niches. Additionally, the protection-oriented management in evergreen forests limits human disturbances like grazing, logging, and non-timber forest product

Table 1. Vegetation structure and diversity attributes in natural forest and coffee plantations of evergreen vegetation type

Parameters	Forest (N=15)	*Coffea arabica* (N=15)	*Coffea canephora* (N=15)
Shannon's - Wiener diversity index (H')	3.96	3.49	3.38
Species evenness (H/S)	0.23	0.54	0.49
Dominance (D)	0.03	0.04	0.05
Species richness	90	59	60
No. of stems ha^{-1}	380 ± 14.22	352 ± 22.2	278 ± 19.21

Table 2. Vegetation structure and diversity attributes in natural forest and coffee plantations of moist deciduous vegetation type (Mean ± Standard error)

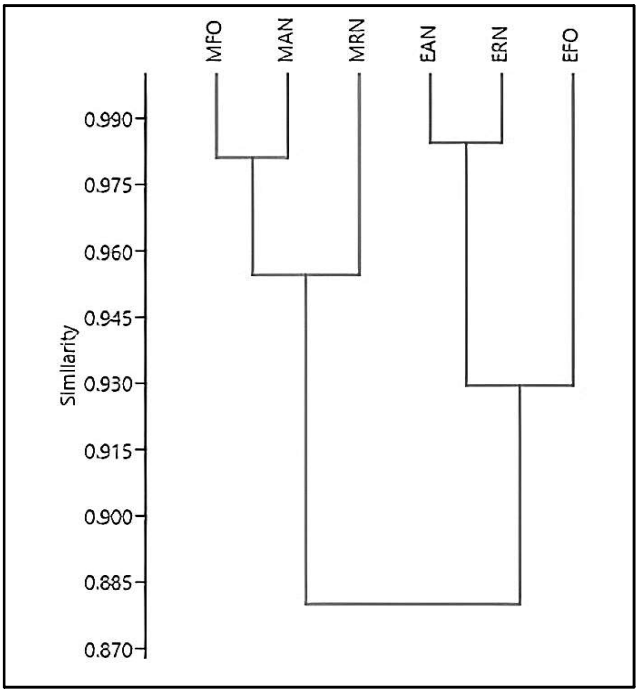
Parameters	Forest (N=15)	*Coffea arabica* (N=15)	*Coffea canephora* (N=15)
Shannon's - Wiener diversity index (H')	2.81	2.69	3.01
Species evenness (H/S)	0.55	0.45	0.40
Dominance (D)	0.08	0.10	0.08
Species richness	30	33	39
No. of stems ha^{-1}	318 ± 10.22	355 ± 28.77	292 ± 9.69

collection, which helps preserve biodiversity by maintaining natural regeneration cycles and preventing habitat degradation (Devagiri et al., 2019). In contrast, the disturbances in moist deciduous forests disrupt the ecological balance, reducing habitat quality and hindering species richness. The combination of optimal abiotic factors and reduced human impact in evergreen forests fosters a more diverse and resilient ecosystem, contributing to the higher diversity observed in these regions. Similar to the present study Devagiri et al. (2019) reported higher H' of 2.90 and 49 species in the evergreen forests of Kodagu.

In evergreen vegetation type, forests exhibited the highest stem density (380), followed by *C. arabica* (352). In moist deciduous vegetation, *C. arabica* recorded higher tree density (355). Tree density and basal area in plantations and natural forests of the tropics are influenced by precipitation. Climatic variables *viz.,* mean annual rainfall and rainfall seasonality may be key factors that directly or indirectly affect the density of tropical species (Mensah et al., 2023). Apart from precipitation interplay of various climatic factors *viz*., temperature, altitude and soil properties operating in evergreen vegetation might influence density. Management interventions like selective felling, weeding might have contributed to lower number of trees in coffee compared to natural forests. The higher stand density in *C. arabica* may be attributed to the fact that few *C. arabica* cultivars exhibit a general positive trend in yield with increasing shade, as highlighted by Koutouleas et al. (2022). Thus, to achieve this positive trend more shade trees are maintained. Whereas *C. canephora* has higher ability to sustain productivity even under high temperature and high-water vapour deficit than *C. arabica* plants (DaMatta and Ramalho 2006). Thus, lower tree density is observed in *C. canephora*.

Guillemot et al. (2018) reported that tree density was more in higher precipitation zone compared to moderate precipitation zone in the Cauvery watershed areas of Kodagu. Current study confirms this trend of higher stem density in evergreen vegetation with higher precipitation. Stem density per hectare (trees with dbh 10cm) in tropical landscapes varies from 245 stems ha^{-1} (low) to intermediate (420-617 stems ha^{-1}) and high value of > 639 stems ha^{-1} (Suratman 2012). Based on this classification, basal area of the plots of the present study can be categorized as low to intermediate. Swamy et al. (2010) reported stand density of 257 to 644 stems ha^{-1} in evergreen forests of Western Ghats. The mean tree density recorded in evergreen forests of the present study are within this range. Similar to the current study observations, Sundarapandian and Swamy (1999) also observed higher stem density in evergreen forests (748 stems ha^{-1}) than moist deciduous forests (332 to 450 stems ha^{-1}).

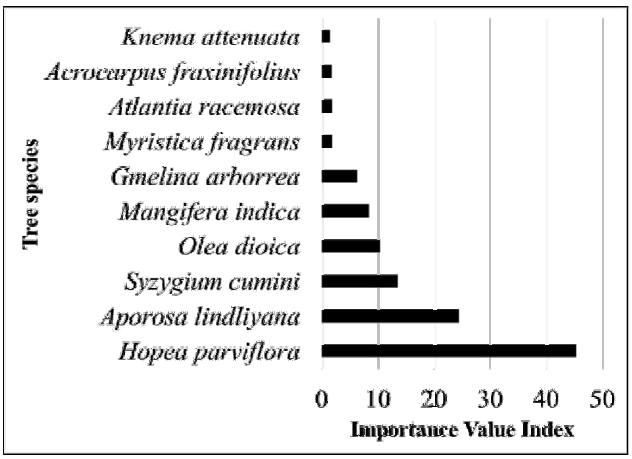
The importance value index (IVI) aids in understanding species distribution and community structure, particularly in varying environmental conditions. In evergreen vegetation type, forests recorded IVI values ranging from 1.45 to 45.21, with *Hopea parviflora* recording the higher IVI value, followed by *Aporosa lindliyana* (24.30) and *Syzygium cumini* (13.46) and *Knema attenuata* recorded the lower value of 1.45. In *C. arabica* based agroforestry *Artocarpus heterophyllus* reported higher IVI of 21.25, followed by *Grevillea robusta* and *Mangifera indica* and *Gmelina arborrea* recorded the lowest of 3.19. In *C. canephora* plantations. *Lagerstroemia microcarpa* exhibited higher IVI of 20.11, followed by *Grevillea robusta*. *Cinnamomum malbathrum* recorded lower IVI of 3.01. In moist deciduous vegetation type IVI ranged from 3.26 in *C. canephora* plantations to 18.04 in *C. arabica* plantations. In moist deciduous forests *Terminalia tomentosa* recorded the higher IVI of 14.52 and *Dalbergia latifolia* lower of 3.38. In *C. arabica* plantations *G. robusta* exhibited higher IVI value of 18.04, followed by *S. cumini* and *Pterocarpus marsupium* exhibited lower IVI value of 3.73. In *C. canephora* plantations also *G.robusta* exhibited higher value of 16.16 and *Leucaena leucocephala* lower of 3.26. The higher IVI in evergreen vegetation type may be attributed to higher basal area contributing to higher relative dominance (Fig. 1). Maheswarappa and Vasudeva (2018) recorded IVI in the



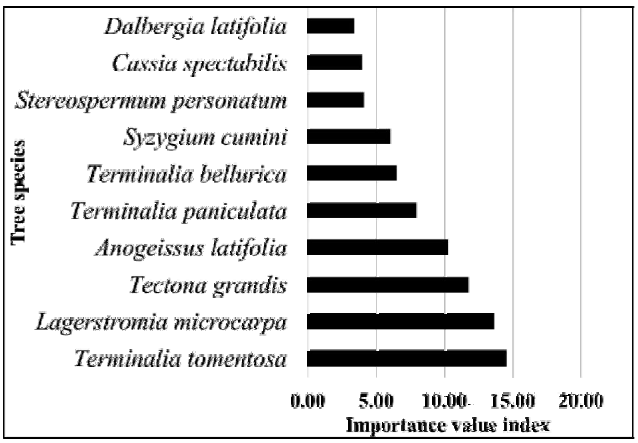
EFO- Evergreen forests, EAN- Evergreen *C. arabica* based agroforestry, ERN- Evergreen *C. canephora* based agroforestry, MFO- Moist deciduous forests, MAN- Moist deciduous *C. arabica* based agroforestry, MRN- Moist deciduous *C. canephora* based agroforestry

Fig. 2. Dendrogram showing similarity between land uses based on species diversity

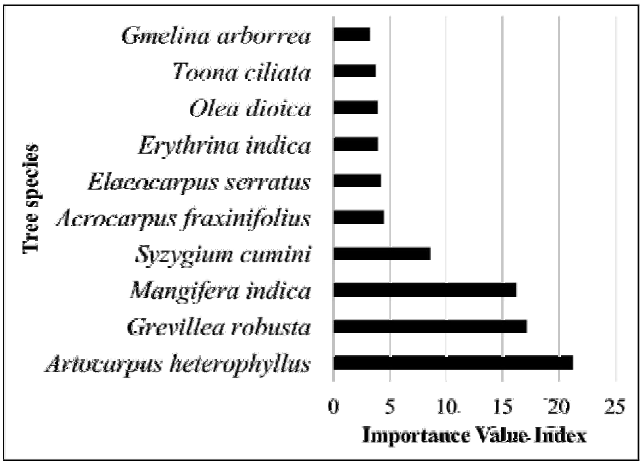
range of 8.07 to 17.87 in evergreen forests which is similar to present study findings. In coffee agroforests *G. robusta* was the dominant tree species. Similar observations were recorded by Devagiri et al. (2019) and Sathish et al. (2022), highlighting that coffee agroforests with large native trees is replaced with silver oak. The primary reason for this shift may be the existing harvest regulations and tenure systems, which restrict the harvest and sale of native trees while



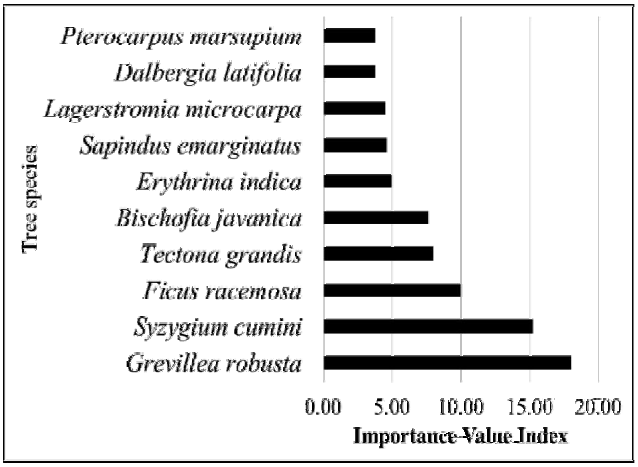
Evergreen forests



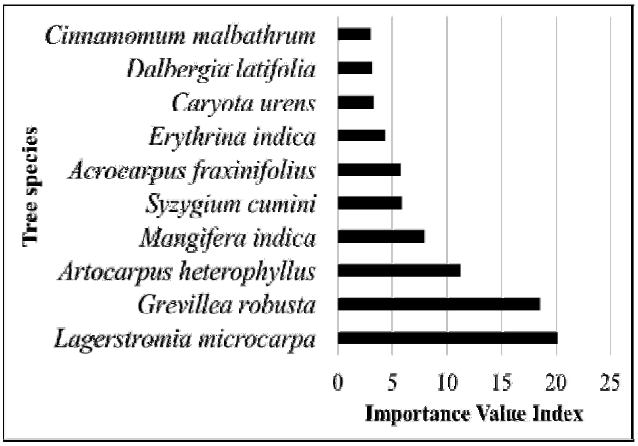
Moist deciduous forests



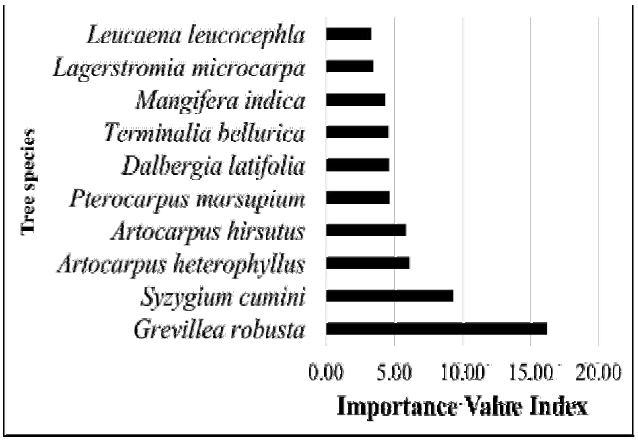
Evergreen *Coffea arabica* plantation



Moist deciduous *Coffea arabica* plantation



Evergreen *Coffea canephora* plantation



Moist deciduous Coffea canephora plantation

Fig. 1. Importance value index of tree-based land use systems of Kodagu

encouraging the cultivation of fast-growing exotic species like silver oak. Although *G. robusta* dominates the landscape in many coffee agroforests, particularly in moist deciduous regions, it ranks only as the second most dominant species in agroforests situated within evergreen vegetation zones. This reduced dominance in evergreen regions can be attributed to the more favourable environmental conditions, which support a wider variety of species. Additionally, many of these coffee agroforests in evergreen zones originated from remnant evergreen forests, which has contributed to maintaining a higher level of species diversity. This contrast highlights the ecological variability between different vegetation zones, where the dominance of *G. robusta* is moderated by local environmental factors, such as climate and soil conditions, as well as the presence of remnant native species.

Cluster analysis: The Bray- Curtis cluster analysis was performed for different tree-based land use systems based on similarity values of diversity indices (Fig. 2). There were two clusters, among them moist deciduous forests and *C. arabica* plantation in moist deciduous vegetation exhibited highest similarity, clustering at around 0.99, indicating that these two land uses share the most similar characteristics. *C. canephora* in moist deciduous vegetation type is closely linked to this group, clustering at 0.97. The next cluster involves *C. arabica* and *C. canephora* plantations in evergreen vegetation type with similarity value of 0.95. Evergreen forest forms the distant cluster, joining EAN- ERN at below 0.9. This suggests evergreen forests is distinct due to higher diversity. The cluster analysis suggests that while coffee plantations and forests within the same vegetation type share ecological similarities, evergreen forests stand out as distinct due to their greater biodiversity. Zamora et al. (2016) also highlighted that coffee plantations can serve as biodiversity refuges, natural forests, particularly undisturbed ones, consistently show higher species richness and distinct compositions which aligns with the present study findings.

CONCLUSION

This study provides a comprehensive analysis of species diversity in coffee-based agroforests and natural forests within the Kodagu region of the Western Ghats. The findings illustrate important ecological patterns and relationships between natural ecosystems and agroforestry landscapes, shedding light on the impact of human interventions such as coffee cultivation on biodiversity. The comparison between moist deciduous and evergreen zones further highlights the importance of vegetation type in determining species diversity. The study confirmed that evergreen zones, which experience higher rainfall, support more diverse and complex ecosystems than the moist deciduous zones. The findings highlight the ecological significance of natural forests and the role of coffee agroforests in biodiversity conservation. The study emphasizes the need for conservation strategies to balance agroforestry expansion and biodiversity preservation in Kodagu.

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