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Sustainability of Coffee based Agroforestry Systems and Opportunities for Conservation in the Central Western Ghats, India

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ABSTRACT

The purpose of this study is to quantify the floristic diversity in forests and coffee agroforests and to know the effects of different landholding sizes in Kodagu district of India's the Western Ghats. We collected the data on trees, shrubs and herbs from 50 sample plots of 0.16 ha. each and analyzed for various diversity parameters. Results revealed Shannon's (*H'*) was highest in coffee agroforests (3.60) compared to that of natural forest (3.32). Conversely, Simpson's (D) values did not differ between the land-use types. This study revealed that the considerable number of tree species are being managed and conserved in coffee agroforests, similar to that of adjoining natural forests. IVI revealed that *Artocarpus integrifolia* was found to be dominant in coffee agroforests while in natural forests, *Elaeocarpus tuberculatus* species was dominant. Considerable variation in various diversity parameters among different landholding sizes with higher diversity in small holding compared to medium and large size coffee farms. Contrary, higher basal area ($m^2\ ha^{-1}$) was recorded in large farms compared to small and medium-size farms. We found that coffee agroforests resembled natural forest suggesting that traditional coffee farms are being sustainably managed and can help to conserve the biodiversity of this region.

Introduction

Rapid loss of global biodiversity and ecosystem services has drawn greater attention of scientists and policy makers to prevent species extinction and ecosystem degradation while allowing for sustainable resources use (Adams and Hulme, 2001). Although the extinction of species is a natural process, current rates of extinction caused by human activities in the tropical rain forest are estimated at 1000 to 10,000 times higher than the natural rate (Berkes, 2009). Western Ghats landscapes in peninsular India are the unique mosaics of natural forests interspersed with agricultural lands, coffee agroforests, tea plantations and various other tree-based production systems which are known to be the most species-diverse terrestrial ecosystems (Baghwat *et al.*, 2008). The majority of the 34 global biodiversity hotspots identified worldwide occur within tropical regions and the Western Ghats in South India is one among them (Myers *et al.,* 2000). Forests of Western Ghats contain the most diverse plant communities, with up to 350-400 tree and liana species coexisting in a single hectare (Devagiri *et al.,* 2016 and Murthy *et al.,* 2016). In addition to the rich biodiversity, these forests are also acting as natural sinks of carbon, with a sequestration potential of 80-150 Mg C ha^{-1} (Devagiri *et al.,* 2013) and thus playing a fundamental role in the global carbon cycle. Among different land use systems, agroforestry is one of the important land use systems which are most prevalent in the Western Ghats region. In addition to enhancing the productivity of agricultural land, agroforestry systems have contributed to the conservation of biological diversity. Studies show that in humid tropical landscapes, coffee agroforestry system has a comparable conservation value to natural forests (Baghwat *et al.*, 2008).

Kodagu is one of the greenest landscapes in India and is part of the Western Ghats, with 81% of the geographical area under tree cover. The district harbors diverse ecosystems such as natural forests, sacred groves, coffee agroforests and forest plantations that contribute to the diversity of species representing 8% of India's plant wealth (Pascal and Pelissier, 1996 and Baghwat *et al.*, 2005a and 2005b). This diverse landscape is undergoing transformations concerning biodiversity and canopy density due to the changed production system under the current liberalized market situation (Devagiri *et al.,* 2012). There is a gradual increase in area under coffee agroforests, rubber and other tree species plantations (CAFNET, 2011). An assessment of change in forest cover of Kodagu district during the last 20 years between 1977 and 1997 indicated the decline in forest cover from an area of 2566 km^2 to 1841 km^2 representing a reduction of 18% of the total geographical area. A large part of it has been converted into coffee; teak and teak mixed with other tree species plantations (Elourd, 2000). To realize the opportunities for conservation outside the natural forests area and to device conservation strategies, deeper knowledge on the level of diversity that exists in production landscapes such as coffee agroforests and other tree-based systems is very fundamental. Therefore, this study was conducted to know the species composition and floristic diversity and to explore the opportunity for conservation in the production landscape in Central Western Ghats of India.

Materials and Methods

Study area

The study was conducted in forest-coffee agroforests landscape mosaics of Kodagu district (2017-18), which lies in the Central Western Ghats region (70° 25' - 76° 14' E and 12° 15' - 12° 45' N) covering an area of 4106 km^2. The district shares a common border with Kerala in the south and is surrounded by three other districts of Karnataka *viz*., Dakshina Kannada, Hassan, and Mysore. The eastern border of Kodagu district extends over the Mysore plateau. It has a steep West to East climatic gradients especially, for temperature and rainfall from the edge of the Ghats (Elourd, 2000). The study area, with an altitudinal range of 300-1300 m.a.s.l., receives average annual rainfall ranging from 1500 to 3500 mm with maximum rainfall during monsoon season (June to September). April and May record the highest mean maximum temperature (32°C), while December and January will have the lowest mean minimum temperature (15°C). Soils are lateritic to red loamy, which have a mature profile and main rock formation belongs to the most ancient Archaean system with rock composed of peninsular gneiss, gneissic granites and gneiss (Pascal, 1986).

Land-use pattern

Kodagu district is the largest coffee growing region in India producing about 38% of India's coffee and is also known as the land of river Cauvery, which is a lifeline for several million farmers in the states of Karnataka and Tamil Nadu as well a source of drinking water to many towns and cities. Realizing the significance of the river Cauvery, the pioneering farmers of Kodagu have adopted a shade grown agroforestry system for cultivation of coffee, cardamom, and other plantation crops as well paddy cultivation in low lying areas. Over some time, coffee intercropped with black pepper and orange has been established as a major cropping pattern in the district. Currently, the coffee plantations of Kodagu are recognized as one of the most diverse coffee production systems in the World. The shade-grown coffee plantations cover 33% of the landscape of the district complimenting the other forested landscapes like reserve forests and protected areas, sacred forests and other wooded areas. In addition to hosting spectacular biodiversity, the landscape provides a range of ecosystem services which sustains the livelihood of the local communities (Devagiri *et al.*, 2012).

Site selection and sampling design

The entire district was divided into three bio-climatic zones mainly based on the vegetation types *viz.*, evergreen, moist deciduous and dry deciduous types. In the evergreen vegetation type coffee agroforests were identified and stratified in such way that the farms are geographically interspersed with natural forests and based on the size of land-holdings *viz.* large (>10 ha), medium (2.5 ha ≤10 ha) and (small (<2.5 ha) while selecting the coffee agroforest sample plots (Fig. 1). In the above selected land-use type 50 sample plots of 40 m x 40 m (0.16 ha.) were laid to conduct the inventory. Nested sampling approach was adopted for the collection of data on trees, shrubs and herbs as depicted in Figure 2.

Total of 50 sample plots of which five from evergreen natural forests and 45 in coffee agroforests were laid for data collection. In each of 0.16 ha. plots, all the woody plants were counted and identified as far as possible *in-situ* at species level using field keys of Pascal and Ramesh (1987), Flora of Coorg (Keshavamoorthy and Yoganarasimhan (1989) and Flora of Karnataka. Voucher specimens of species, which could not be identified in the field, was collected for identification at the College of Forestry, Ponnampet, with the help of taxonomist. Height and girth at breast height (gbh) of all the trees with ≥30 cm gbh in each sample plots were measured by using Blume Leiss Hypsometer (which is based on the trigonometric principles) and measuring tape, respectively.

Data analysis

The stand structures of trees in coffee agroforestry were analyzed based on tree density, basal area and Importance Value Index (IVI). The IVI was calculated as the sum of average relative frequency (RF), relative density (Rd) and relative dominance (RD) of tree species using the following formula.

IVI (%) = (RF+Rd+RD)/3

For the quantitative analysis of tree species in the coffee agroforests and adjoining natural forests, diversity indices employed. Species diversity indices were commonly applied for species distribution analysis which includes *viz.*, Shannon–Wiener diversity index (*H'*), Simpson's (D), species richness and Jacquard's index of similarity. Shannon diversity (using natural logarithms) and Simpson index (the reciprocal form) were computed using Bio-Diversity Pro 2.0 software.

Results and Discussion

Vegetation structure: species diversity, sand density and basal area

Species richness and diversity varied in forests and coffee agroforests (Table 1). Total of 102 tree species in coffee agroforests and 50 tree species in adjoining forests were recorded. Shannon–Wiener diversity index (*H′*) was highest in coffee agroforests (3.60) compared to the natural forest (3.32). Conversely, Simpson’s dominance index (D) values did not differ between the land-use types. Results revealed that a considerable number of tree species are being managed and conserved in coffee agroforests. However, as compared to coffee agroforests in other regions, the number of tree species observed in the study area appears to be higher. Notably, in this study, the number of tree species in coffee agroforests was higher than that of adjoining natural forests. A study conducted by Lopez-Gomez *et al.,* (2008) found similar results where they recorded 107 tree species in coffee farms as against 62 tree species in natural forests.

On the other hand tree species diversity was found to be higher in a forest than in coffee farms as reported in other studies (Correia *et al.,* 2010 and Lopez-Gomez *et al.,* 2008). Variation in species diversity and composition between the land-use types may be attributed to management regime. In coffee agroforests, the management is protection oriented where as in natural forest through protection oriented which subjected to disturbances due to grazing, illegal felling and collection of non-timber forest produce. Chima and Uwaegbulem (2012) evaluated tree species populations under different land use systems in Port Harcourt region of Nigeria and reported that tree species richness was higher in biodiversity conservation area than the unprotected secondary regrowth and arable farmland. Murthy *et al.,* (2016) reported on Western Ghats of India where the more disturbed evergreen and moist deciduous forest had low species diversity compared to less disturbed forests. In another study conducted by Devagiri *et al.,* (2019) in coffee agroforests of Central Western Ghats region showed that coffee agroforests resembled natural forests in terms of species richness and diversity. This study suggests that traditional coffee agroforests in Western Ghats region contain higher floristic diversity and these offers greater opportunities for biodiversity conservation in this region.

Across the coffee farms and adjoining natural forest in evergreen vegetation type, tree density and basal area cover varied considerably (Table 1). Tree density of 287 ± 13.53 (stems ha^{-1}) was recorded in coffee agroforests, while in adjoining natural forests slightly higher tree density of 351 ± 19.35 (stems ha^{-1}) was recorded. Conversely, the basal area was found to be lower in coffee agroforests (29.54 ± 1.34 m^2 ha^{-1}) compared to natural forests (39.53 ± 0.38 m^2 ha^{-1}). These values compare with tree density (1087 stems ha^{-1}) and basal area (52.60 m^2 ha^{-1}) values recorded by Swamy *et al.,* (2000) for a humid evergreen forest in Tamil Nadu.

However, the density was within the range of 257 - 664 stems ha^{-1} and the basal area within the range 29-42 m^2 ha^{-1} for agroforests, but it was on the lower side of the values recorded in natural forests as reported by Devagiri *et al.,* (2016) and Swamy *et al.,* (2010) for tropical evergreen forests of Western Ghats region in Karnataka. The density of trees in coffee plantations is an important factor since the shade provided by the trees affects the yield of coffee. Tree density recorded in the current study is within the limits of Coffee Board recommendations of 250 trees per hectare for variety robusta.

Importance Value Index

Importance value index (IVI) indicates the dominant species in a community (Curtis and McIntosh, 1950). The most dominant species in coffee agroforests of the study area was *Artocarpus integrifolia* with an IVI value of 23.11% followed by *Grevillea robusta* and *Lagerstroemia lanceolata* (Table 2).

About, 62.13% of IVI of tree species recorded in coffee agroforests was contributed by three species out of a total of 102 tree species. Whereas, in the natural forest the dominant species recorded were *Elaeocarpus tuberculatus* with IVI value of 28.25% followed by *Dimocarpus longan* and *Mangifera indica* (Table 2).

About, 70.6% of IVI of tree species recorded in natural forest contributed by three species out of a total of 50 tree species. The higher IVI value of these tree species is probably due to the farmer's conscious retention of trees for various benefits. An earlier study by Negawo and Beyene (2017) has also indicated similar results.

Effect of landholding sizes on floristic diversity and vegetation structure

Results obtained on diversity and vegetation structure parameters are presented in Table 3. Species richness and diversity was found to be higher in small coffee farmers containing 74 tree species and diversity value of 3.60.

Both medium and large coffee plantations recorded a relatively lesser number of species and diversity value compared to that of small-sized holdings. However, Simpson's dominance was found to be higher in both large and medium-size farms as compared to small holdings. Higher species richness and diversity in small size coffee plantation could be attributed to being management regimes as well probably due to land tenure system. Farmers having small holdings tend to manage their plantations intensively by retaining diverse shade trees to sustain and improve productivity.

On the contrary tree diversity and basal areas was found to be less in small holdings compared to medium and large holdings. It is mainly because framers owning relatively larger farm areas can afford to retain the number of large sized trees.

Similarly, beta diversity values also indicate that large and medium-size farms share common species with a similarity value of 77.08. The replacement of native trees by common native and exotic fast-growing trees is one of the major reasons for higher similarity (Elouard *et al.,* 2000).

Among the coffee farms of different landholding sizes in evergreen vegetation type, tree density and basal area were recorded and presented in Table 3. Tree density of 280 ± 26.14, 277 ± 28.28 and 305 ± 28.38 (stems ha^{-1}) was recorded in small, medium and large, respectively. Similarly, basal area was recorded to be higher in large holdings (35.86 ± 2.12 m^2 ha^{-1}). The results of the present study are comparable with the study conducted by Muthappa (2000).

Girth class distribution of tree species in forests and coffee agroforest

The girth class distribution of tree species in natural forests and coffee agroforests in different land holding sizes was positively skewed, and a higher percentage of trees was present in the size class between 60-120 cm.

The distribution of tree species in different girth classes of coffee agroforests and natural forests are presented in Figure 3. The girth class distribution pattern of tree species in forests and agroforests was positively skewed and shows the normal distribution pattern except in girth class below 60 cm.

The absence of trees in the lower girth class indicates that tree seedlings are cleared during cultural operations. Similar results were also reported by Sathish (2005) and Basavarajappa (2017) in coffee plantations of Kodagu. Pommery and Elouard (1997) reported that the future population (young trees) was represented by 13%, present population (mature trees) 82% and past population (old trees) 5%. Kumar *et al.*, (1994) in their studies in home gardens of Kerala have also reported similar results.

Table.1 Vegetation structure, diversity and composition in coffee base agroforestry and adjoining natural forest (Mean ± SE)

Parameters	Coffee agroforestry	Natural forests
Species richness	102	50
Shannon–Wiener diversity index (*H*′)	3.60	3.32
Simpson index (D)	0.05	0.05
Jacquard's index of similarity	22.15	
Tree density (stems ha^{-1})	287 ± 13.53	351 ± 19.35
Basal area (m^2 ha^{-1})	29.54 ± 1.34	39.53 ± 0.38

Table.2 Importance value index in coffee agroforests and natural forests

Species	Importance Value Index	
	Coffee agroforests	Natural forests
Acrocarpus fraxinifolius	12.07 (7)	-
Aporosa lindleyana	10.48 (9)	9.84 (10)
Artocarpus hirsuta	12.76 (4)	9.91 (9)
Artocarpus integrifolia	23.11 (1)	-
Bischofia javanica	-	16.97 (6)
Caryota urens	12.19 (6)	13.50 (8)
Dimocarpus longan	-	22.24 (2)
Elaeocarpus serratus	-	14.52 (7)
Elaeocarpus tuberculatus	-	28.25 (1)
Grevillea robusta	22.32 (2)	-
Lagerstroemia lanceolata	16.70 (3)	-
Mangifera indica	12.73 (5)	20.11 (3)
Olea dioica	-	18.08 (5)
Syzygium cumini	10.90 (8)	19.46 (4)
Terminalia bellirica	9.32 (10)	-
The value in the brackets indicated ranking based on IVI in the coffee agroforests and natural forests		

Table.3 Effect of landholdings on tree diversity and structure (Mean ± SE)

	Land holdings		
Parameters	Large	Medium	Small
Species richness	73	72	74
Shannon–Wiener diversity index (*H'*)	3.43	3.50	3.60
Simpson index (D)	0.06	0.06	0.04
Jacquard's similarity index			
Large	-	77.08	72.33
Medium	-	-	69.76
Small	-	-	-
Tree density (stems ha^{-1})	305 ± 28.38	277 ± 28.28	280 ± 26.14
Basal area (m^2 ha^{-1})	35.86 ± 2.12	30.42± 2.27	22.33 ± 1.56

Fig.1 Distribution sample plots of landholding sizes in coffee agroforests and natural forest

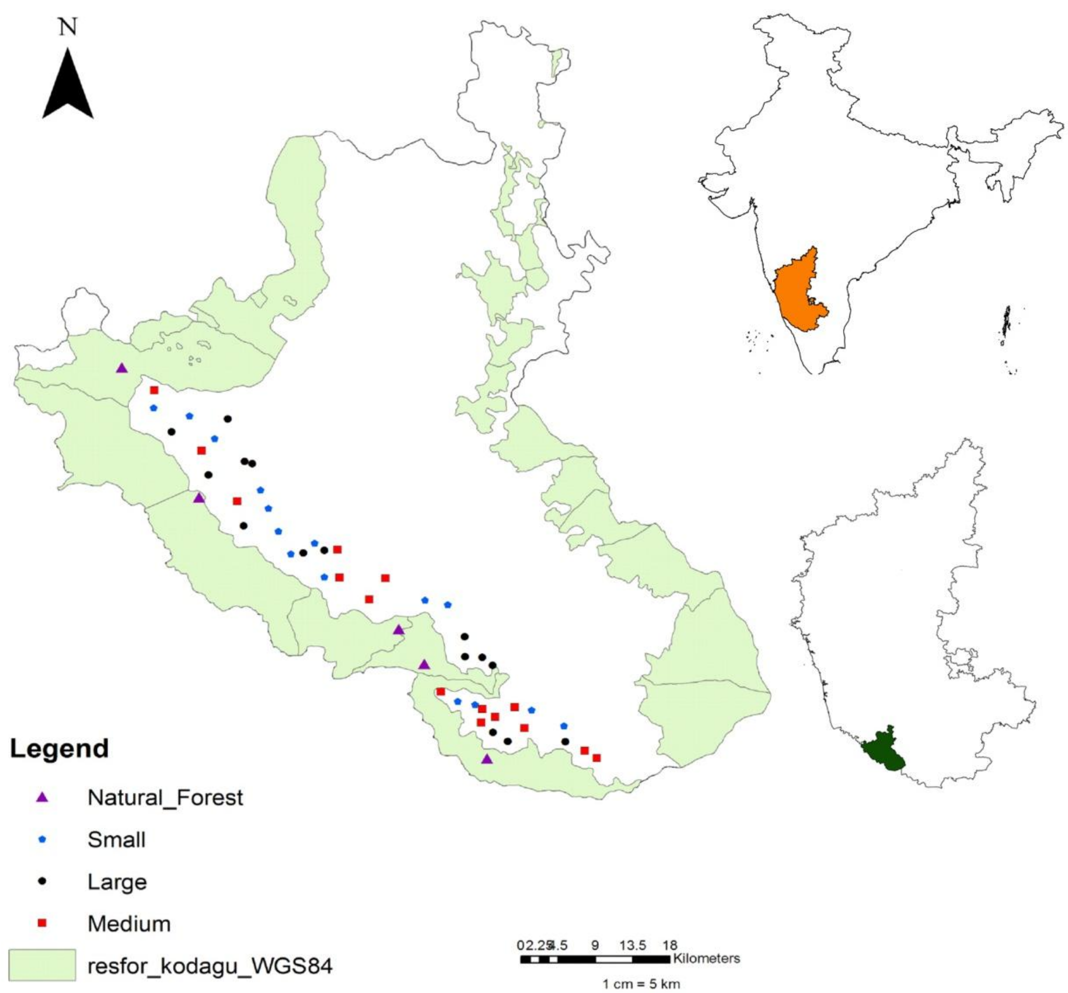


Fig.2 Diagram showing nested phase sampling for one site

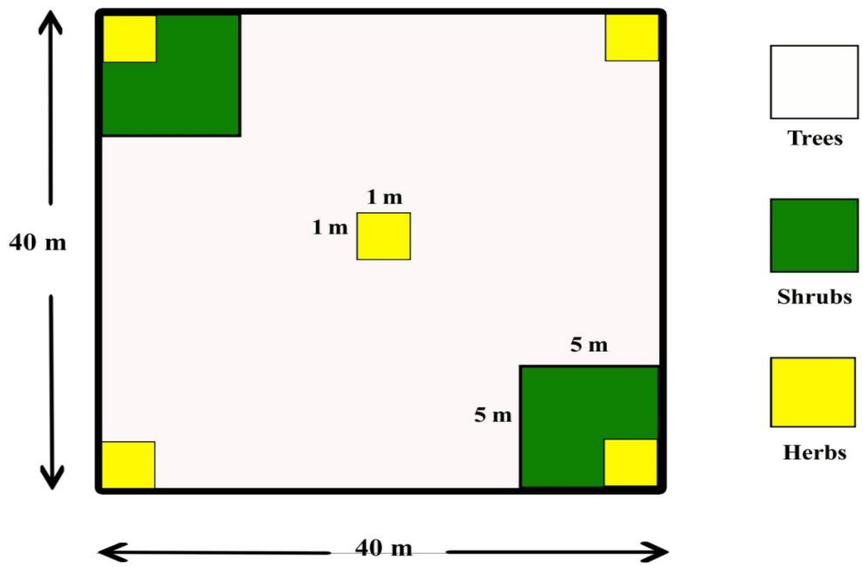
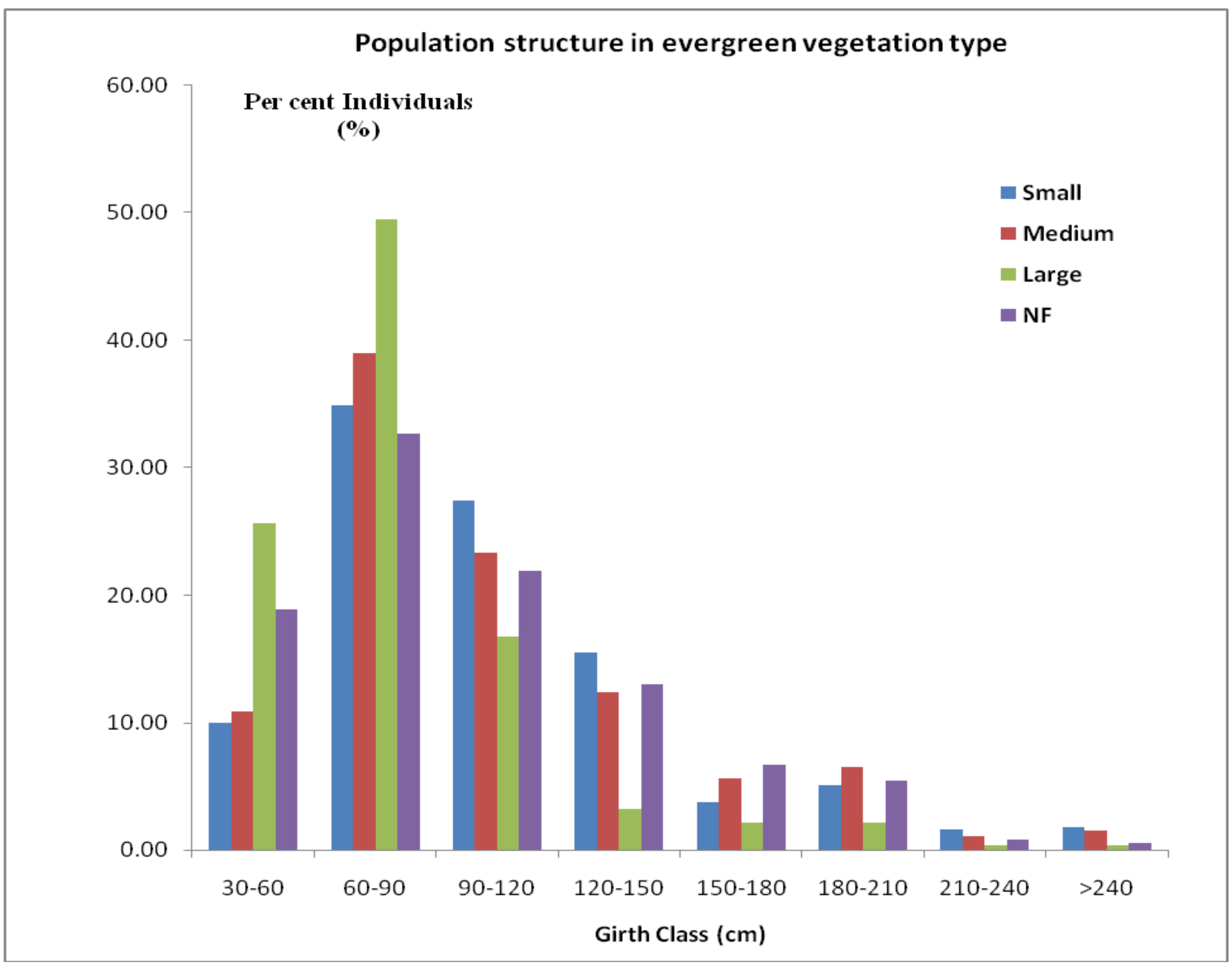


Fig.3 Effect of land holdings on girth class distribution in coffee agroforests and natural forests



In conclusion, the diversity and species richness in coffee agroforests were reasonably higher than that of natural forests. However, Shannon's and Sampson's diversity indices showed that species diversity of the natural forests was lower than that of coffee agroforests. The similarity between forests and coffee agroforests in terms of species sharing was found to be 22.15%. The most dominant species in coffee agroforests of the study area was *Artocarpus integrifolia* with an IVI of 23.11% and in natural forests, *Elaeocarpus tuberculatus* was dominant with IVI value of 28.25%. Effect of landholdings on tree density, species richness, Shannon–Wiener diversity index (*H′*) and Simpson's diversity indices revealed that small size coffee farms are more diverse than large and medium-sized coffee farms. However, basal area was found to be highest in case of large landholding. This study suggests that traditional coffee agroforests in Western Ghats region contain higher floristic diversity and these land-use systems offer greater opportunities for biodiversity conservation in this region.

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