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Comparing tree diversity and composition in coffee farms and sacred forests in the Western Ghats of India

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Abstract Expansion of coffee cultivation is one of the causes of deforestation and biodiversity loss. However, shade grown coffee has been promoted as a means for preserving biodiversity in the tropics. In this study we compared tree diversity in two types of coffee management regimes with the sacred groves in the Western Ghats of India. We computed species accumulation curves, species diversity indices and evenness indices to compare the different management regimes. Results of diversity indices showed that shade coffee had less diversity compared to sacred groves. Exotic species dominated the tree diversity in lands where the tree harvesting rights are with the growers. Native trees dominated the tree diversity when growers had no ownership rights on trees. A species accumulation curve suggested that the sacred grove had higher species richness compared to other two habitats. Lack of incentive to preserve endemic species as shade trees is forcing growers to plant more exotic species in shade grown coffee plots. If encouraged, shade grown coffee can preserve some biodiversity, but cannot provide all ecological benefits of a natural forest.

Keywords Biodiversity · Coffee · India · Land tenure · Sacred groves · Species dominance

Introduction

Agriculture is a major livelihood for millions of people in the world. At the same time widespread agricultural development is one of the major causes of deforestation and biodiversity loss (Ehrlich 1988; Gorenflo and Brandon 2003; Chichilnisky 1994; Benhin 2006). Conservationists are concerned about the impacts of cultivation of commercial

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crops like coffee in and around biodiversity hotspots (Hardner and Rice 2002). Recently, much attention has been focused on measuring tree, ants and bird biodiversity loss due to agricultural intensification, particularly in coffee agro-ecosystems (Bhagwat 2002; Perfecto and Vandermeere 2002; Perfecto et al. 1996, 2007; Moguel and Toledo 1999; Philpott et al. 2007, 2008). Coffee can be grown under sun or under shade. Highly shaded farms provide important habitat refuges for biodiversity in some regions (Perfecto et al. 1996, 2007). Shade grown coffee may more closely resemble the natural environment (Geist and Lambin 2001; Jiménez-Avila and Martínez 1979; Perfecto et al. 2005; Moguel and Toledo 1999; Soto-Pinto et al. 2001). Furthermore, type and management of shade strongly affect species richness (Perfecto and Snelling 1995; Perfecto et al. 1996; Moguel and Toledo 1999; Blackman et al. 2005). A substantial literature on shade grown coffee in different parts of the world has shown the superior conservation value of shade-grown coffee (Perfecto et al. 1996; Moguel and Toledo 1999; Blackman et al. 2005; Jiménez-Avila and Martínez 1979; Soto-Pinto et al. 2001) compared to the sun grown coffee. However, perception of farmers that increasing shade cover in farms will diminish yields results in reducing shade density and diversity sometimes provokes losses of mammal, bird, and arthropod diversity (Philpott and Armbrecht 2006; Perfecto et al. 2007). Furthermore, researchers have also argued that species composition in shade-grown coffee farms is not identical to that of forest (Soto-Pinto et al. 2001; Rappole et al. 2003).

Shade coffee has been ambitiously promoted by conservationists and the scientific organizations as a means for preserving biodiversity in tropics (Conservation International 2001; National Audubon Society 2000; Philpott and Dietsch 2003). Coffee is a highly traded commodity in the world next only to oil in value. For some countries it is the most important source of foreign exchange (Rice and Ward 1997; Ambinakudige 2006). Today there are about 29 million coffee drinkers in the world (Ambinakudige 2006). Presence of this large number of coffee consumers encourages conservationists to promote shade coffee over sun coffee. This generates enormous pressure on growers to produce shade coffee with the goal of increased biodiversity conservation (Rappole et al. 2003).

Understanding the context of these pressures and impacts of shade coffee on biodiversity can inform policy decisions that influence the livelihoods of millions of coffee growers and workers throughout the developing world. Coffee is an international commodity, and land-use decisions by coffee growers depend on the international coffee market as well as national and local forest policies (Blackman et al. 2005; Ambinakudige 2006; Sathish 2005; Verbist et al. 2005). Livelihood advocators argue that if the international niche market for shade coffee is recognized for its role in conservation of biodiversity, millions of growers and workers will benefit by premium price aimed at conserving biodiversity (Ambinakudige 2006). To meet the goals of biodiversity conservation and improving the livelihoods of coffee growers and workers, more studies are needed to document how biodiversity patterns and shade coffee production coincide in regions where coffee is an important export.

In this study, we analyzed the impacts of different types of tree ownership rights on tree diversity and composition in shade coffee and compared it with sacred groves in the Western Ghats of India. Within shade coffee plots redeemed lands and unredeemed lands are the two tree ownership regimes analyzed in this study to document the influence of tree ownership on the decision of the coffee growers to maintain particular types of tree diversity. In redeemed land, land owner holds the tree right. In unredeemed land, government owns the tree even though the land is owned by the coffee grower (Shrinidhi and Lele 2001). We compared tree species diversity and distribution within these two types of shade grown coffee lands with adjacent sacred groves. Sacred groves are patches of forests where human impact is minimal.

These lands are set aside for village communal activities (Ambinakudige 2006; Kushalappa and Bhagwat 2001). This comparative study provides a broader picture of the human dimensions of biodiversity change due to coffee cultivation. It also informs region-specific agricultural policy as to the pros and cons utilizing shade grown coffee to ameliorate habitat decline.

Methods

This study was conducted in the Kodagu district of Karnataka state in the Western Ghats of the Southern Indian peninsula (Fig. 1). Kodagu is located on the slopes of Western Ghats Mountains. The Western Ghats region of India is one of the 34 global biodiversity hotspots in the world dedicated as such due to high levels of endemism and endangered flora and fauna (Mittermeier et al. 2005). The Western Ghats are located between 8°22′ N and 20°40′ N latitude and 73°–77° E longitude (25). Kodagu was selected because it is one of the major coffee growing regions in India. Both *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee) are grown in Kodagu. Large areas of forests have been converted to shade grown coffee cultivation in the last century in Kodagu (Ambinakudige 2006; Menon and Bawa 1998; Lele 2001). Traditionally in Kodagu, rice is grown for subsistence. Apart from coffee, black pepper, cardamom, orange and ginger are the other commercial crops of the region. Of all these crops, coffee played a major role in socio-economic development of Kodagu. The State supported and nourished the Indian coffee sector for many years by providing subsidies and extension services. When the Coffee Board of India allowed an open market for coffee in early 1990s, growers received higher prices. This encouraged coffee growers to extend the area under coffee into lands that were assigned to supplement rice cultivation and into the government-controlled forestlands. However, the recent slump in the international coffee market has weakened the local economy of Kodagu (Ambinakudige 2006).

Coffee was introduced to Kodagu on a commercial scale by British planters in 1854. Later, native farmers began coffee cultivation. This introduced more severe transformations

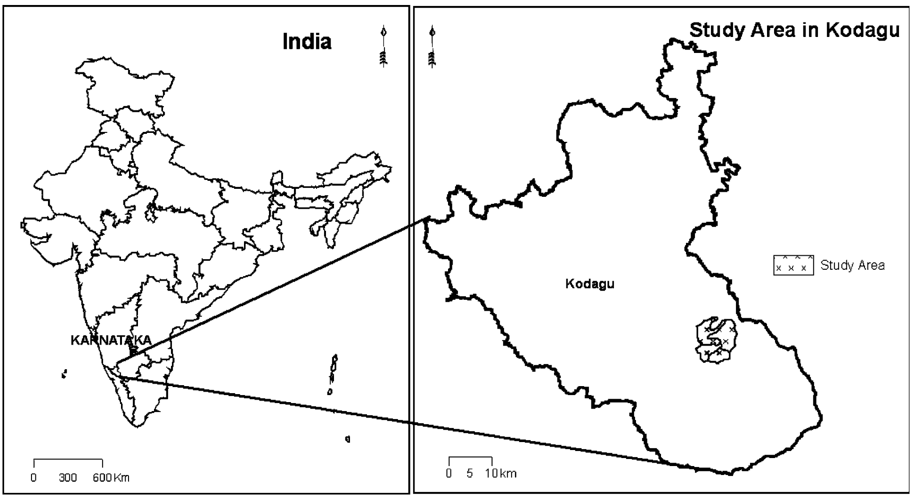


Fig. 1 Study area in Kodagu region of the Western Ghats

of the landscape (Elouard 2000; Bhagwat 2002). The French Institute of Pondicherry found that the increase in the area under coffee cultivation between 1977 and 1997 resulted in a net loss of forest habitat. Although shaded coffee plantations resemble the original forest they have a relatively high biodiversity (Moguel and Toledo 1999; Perfecto et al. 1996). Only about 36% of the land remains covered by forest in Kodagu. This is a drastic reduction from 88% observed in 1920. Around 71% of this forest loss is due to coffee cultivation (Menon and Bawa 1998). However, because of the shade trees interspersped within the coffee, there is still a substantial amount of tree cover.

To analyze the biodiversity changes due to coffee cultivation in Kodagu, one would ideally compare biodiversity found in coffee habitats to that found in habitats where the biodiversity has not been affected by human impacts. However, it is difficult to find a “pristine” landscape anywhere in the world that has no human impact. In the study area, the forestlands under state control are highly managed and planted with the commercial tree species like teak. The only landscapes with minimal impacts are the region’s sacred groves.

In many parts of Asia, Africa, Europe, America and Australia people preserve a section of natural environment as sacred groves for various social, cultural, religious and ecological purposes (Rappole et al. 2003). In India, sacred groves are located in varieties of habitats ranging from heavily forested areas of Western Ghats to the deserts of Rajasthan. Several studies (Kushalappa and Bhagwat 2001; Verbist et al. 2005; Chandran et al. 1998) have demonstrated the importance of sacred groves in biodiversity conservation.

In Kodagu, the state forest department’s estimates show that there are 1,214 sacred groves covering an area of 6,375 ha (i.e., about 1.6% of total geographical area of Kodagu). These patches are locally referred as *Devarkaadus*—which could be literally translated as God’s forests. Today many of the sacred groves have been encroached for coffee cultivation and for human settlement. Today out of 97 big sacred groves (more than 2 ha in size), 9 have been fully encroached, 30 partially encroached, 40 are intact and 9 are improved by the forest department (Kushalappa and Kushalappa 1998). To quantify the impacts of tree ownership types on tree diversity in the Kodagu region of the Western Ghats, we compared tree diversity and distribution within shade grown redeemed and shade grown unredeemed coffee lands with that contained within sacred groves.

Vegetation sampling

Sampling plots in coffee plots and the least disturbed sacred groves were selected in the southeastern part of Kodagu (Fig. 1). The average altitude is 900 m and average rainfall is about 2,000 mm. The soils in the area are classified as red loamy (FRLHT 2000). Sampling plots in coffee and sacred groves had relatively similar topography.

Based on the list of sacred groves collected from the forest department records, 15 sacred groves in the study area were initially inspected. Seven sacred groves out of 15 found were less disturbed and eight groves were completely or partially encroached for coffee cultivation or housing. Seven undisturbed sacred groves, seven redeemed coffee plots and seven unredeemed coffee plots were selected for vegetation sampling. People in and around these sacred groves were interviewed using open-ended questions. The questions included the family structure, land holdings, type of tree ownership (redeemed or unredeemed), and shade management practices.

Randomly located rectangular quadrants of 20 $\times$ 20 m were deployed in the sacred forests. Other studies in the Western Ghats and elsewhere in tropics have used sample plots ranging from 10 $\times$ 10 to 10 $\times$ 50 m (Condit 1994; Gentry 1990; Daniels et al. 1995;

Chandran 1993). Due to lower density of trees within coffee plantations, larger sample plots of 25 × 50 m size were used.

Seven plots in each of the three land tenure categories were sampled. A nylon rope of 50 m length was used to mark the central transect in coffee plots. A rope of 20 m in length was used in sacred groves. A 10 m rope (sacred groves) and 12.5 m rope (coffee plots) were used to measure the distance of each tree from the central line of transect. All trees greater than or equal to 10 cm diameter at breast height (DBH) were enumerated and identified. DBHs were measured using a measuring tape. Pascal and Ramesh's (1987) field key was used for identification of trees (Bhagwat 2002; Daniels et al. 1995; Utkarsh et al. 1998). To measure the structural complexity and heterogeneity, stem density per hectare and basal area for hectare were calculated. Forest structural heterogeneity was determined by the variability in basal area of trees in a given forest stand.

To analyze the difference in the composition of the tree species in three land habitats, species importance, species relative density and species relative dominance were calculated.

$$\text{Species relative density} = \frac{\text{Number of trees in each species}}{\text{Total number of trees}} \times 100$$

$$\text{Species relative (basal dominance) dominance} = \frac{\text{Basal area of each species}}{\text{Total BA of all species}} \times 100$$

Species importance is the average of relative density and relative dominance. Density can be very high for a species, but if the individuals are small then dominance may be low. Conversely, a species with a very high dominance may be very low in density. By taking the average of these two values we get a better idea of the size and density of vegetation (Iverson and Prasad 2002; Dallmeier and Comiskey 1998).

Tree species found only in a single land tenure type are classified as 'unique species', those shared by any two of the three tenures were classified as 'shared species' and those found in all three types are referred to as 'ubiquitous species' (Bhagwat 2002). A series of χ^2 tests were conducted to test the significance of differences in the frequencies of unique species of trees in three habitats of differing land tenure.

To compare tree richness in redeemed coffee, unredeemed coffee and sacred groves, we generated sample-based rarefaction curve (MaoTao estimates) using EstimateS (Colwell and Coddington 1994; http://www./viceroy/eed/uconn/.edu/estimates). To compare the richness between the habitats we rescaled the sample based rarefaction curves to the number of individual (Gotelli and Colwell 2001).

To compare the species diversity in terms of species richness and species evenness in shade grown coffee and the sacred groves, we used Simpson's reciprocal index (Magurran 2004; Gimaret-Carpentier et al. 1998) and the Shannon Wiener index (Magurran 2004; Gimaret-Carpentier et al. 1998).

The Shannon diversity index (H) is commonly used index to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present. The Shannon index is calculated from the equation:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

The quantity (p_i) is the proportion of individuals found in the ith species. A higher value of H indicates high species diversity in the sample (Magurran 2004).

Shannon's evenness is calculated as

$$j^i = \frac{H}{H_{\max}}$$

where H, Shannon index. Equitability assumes a value between 0 and 1 with 1 being complete evenness (Magurran 2004).

Simpson's reciprocal index is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the abundance of each species (Magurran 2004). Simpson's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species.

Simpson's index is calculated as

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N - 1)} \right)$$

where n_i is the number of individuals in ith species, and N is the total number of individuals. As D increases, diversity decreases. Simpson index is therefore usually expressed as $1 - D$ or $1/D$ (Dallmeier and Comiskey 1998). It captures the variance of the species abundance distribution. Value of the complement ($1 - D$) or reciprocal ($1/D$) of D will rise as the assemblage becomes more even (Dallmeier and Comiskey 1998). We used reciprocal of D in this study. We can measure the evenness by dividing the reciprocal form of the Simpson's index by the number of species in the sample (Magurran 2004).

$$E_{1/D} = \frac{(1/D)}{S}$$

where $E_{1/D}$ is Simpson's evenness. S, number of species in the sample and $1/D$ is the reciprocal. The Simpson's evenness measurement ranges from 0 to 1 and is not sensitive to species richness (Magurran 2004).

A randomization test as described by Solow (1993) was used to compare diversity indices (both Shannon's and Simpson's) in all the three land tenure classes. Species diversity and richness software was used to conduct randomization test. In this test, three data sets were combined into a single set. The combined data set was randomly partitioned into three subsets. Shannon and Simpson diversity indices were calculated for each subset and the differences in the indices values between land tenure classes were recorded. The procedure was repeated 10,000 times and the estimated P-value was calculated. The number of simulations producing a difference in the diversity indices greater than or equal to that observed estimates the probability that any observed difference was due to chance (Solow 1993).

Qualitative methods

To understand the human dimensions of the tree diversity change in coffee and the sacred groves a study of archival materials on the issues of coffee cultivation and the sacred groves in the region was conducted. The intent of this archival work was to reveal the history of management decisions in coffee and sacred groves. In addition, semi-structured interviews were conducted to provide detail on the role of forest policies and coffee market on people's land use decisions (Gimaret-Carpentier et al. 1998). Five knowledgable individuals in the study area were interviewed. Knowledgable individuals are those persons who have lived in the area for long time and are involved in coffee cultivation. We asked villagers to guide us to most experienced, and or older persons in the community. In particular, interviews sought to distil more information about the preferred tree species in different land tenures. State policies regulating harvests among different tenures and its influence on the decisions on retaining of any particular species were also recorded. The interviews focused solely on collecting qualitative information and not quantitative information. All the interviews were recorded and transcribed. Data were then coded and analyzed using QSR N6 qualitative data analysis software.

Results

A total of 109 different species were found in all tenures together (Fig. 2). Sacred groves had the highest number of species (62 species). Redeemed and unredeemed coffee plots had nearly the same number of species. Thirty-eight species were recorded in redeemed plots and 39 species were recorded in unredeemed coffee (Fig. 2). Basal area was highest in sacred groves. Total basal area for sacred groves was 31.54 m^2 ha^{-1}. While redeemed coffee recorded 18.91 m^2 ha^{-1}, unredeemed coffee recorded 15.59 m^2 ha^{-1} as the total basal areas (Table 1).

In the sampled plots, 4.5% of all species were ubiquitous, 18% were shared, and 76% were unique (Fig. 2). The χ^2 test revealed that observed number of unique species was higher than expected in the sacred grove but lower than expected by chance in t he redeemed coffee and unredeemed coffee (χ^2 test, $\chi^2 = 22.65$, df $= 2$, $P = 0.000$).

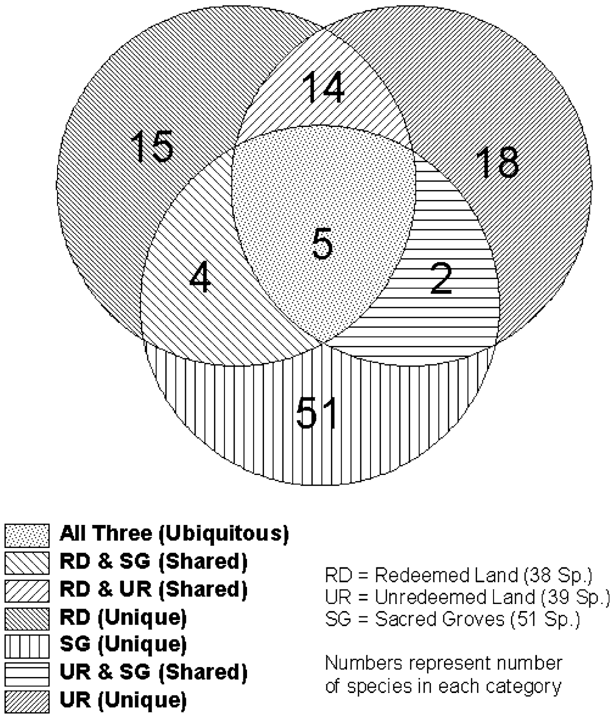
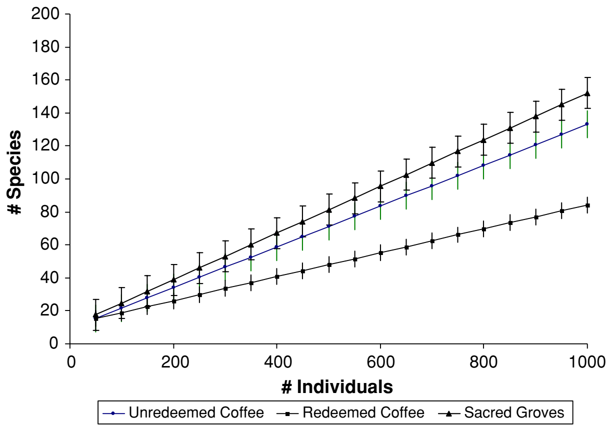


Fig. 2 Distribution of ubiquitous, shared and unique species in three habitat types differing in land tenure classes

Table 1 Species importance, relative density and dominance in three land tenure classes

Unredeemed coffee lands		Redeemed coffee lands		Sacred Groves	
Species	Species count	Species	Species count	Species	Species count
Dalbergia latifolia	73	*Grevillea robusta*	96	*Dimocarpus longan*	60
Grevillea robusta	28	*Acrocarpus fraxinifolius*	38	*Acronychia pedunculata*	40
Citrus reticulata	20	*Erythrina suberosa*	31	*Mimisilon malabarica*	37
Species	Species importance	Species	Species importance	Species	Species importance
Dalbergia latifolia	27.9%	*Grevillea robusta*	26.3%	*Dimocarpus longan*	13.4%
Grevillea robusta	9.2%	*Acrocarpus fraxinifolius*	12.8%	*Acronychia pedunculata*	8.1%
Spathodea companulata	8.3%	*Erythrina suberosa*	8.5%	*Mimisilon malabarica*	7.6%
Species	Relative density	Species	Relative density	Species	Relative density
Dalbergia latifolia	30.5%	*Grevillea robusta*	29.1%	*Dimocarpus longan*	15.7%
Grevillea robusta	11.7%	*Acrocarpus fraxinifolius*	11.5%	*Acronychia pedunculata*	10.5%
Citrus reticulata	8.4%	*Erythrina suberosa*	9.7%	*Mimisilon malabarica*	9.7%
Species	Relative dominance	Species	Relative dominance	Species	Relative dominance
Dalbergia latifolia	25.3%	*Grevillea robusta*	23.5%	*Dimocarpus longan*	13.4%
Ficus racemosa	9.9%	*Acrocarpus fraxinifolius*	14.0%	*Margaritaria Indica*	14.2%
Spathodea companulata	9.5%	*Ficus racemosa*	8.3%	*Mangifera indica*	4.0%
Total stand density per ha	273	Total stand density per ha	367	Total stand density per ha	1,361

Fig. 3 Species accumulation curves for trees in redeemed, unredeemed coffee plots and the sacred groves. Accumulation curves values were extracted in EstimateS and show Mao Tao estimates. *Error bars* show 95% interval, nonoverlapping bars show statistical differences



The χ-squared test also revealed that the difference between number of unique species in redeemed coffee and sacred groves ($\chi^2 = 0.4.27$, df $= 1$, $P = 0.039$) and between unredeemed coffee and sacred groves ($\chi^2 = 2.89$, df $= 1$, $P = 0.089$) are significant. Both redeemed and unredeemed coffee plots had nearly the same number of observed and expected unique species. There is no significant difference between the distribution of unique species between redeemed and unredeemed coffee (χ^2 test, $\chi^2 = 0.140$, df $= 1$, $P = 0.70$).

According to species accumulation curve (Fig. 3) and 95% confident intervals, there are significantly more species of trees in sacred groves compared to redeemed lands. Similarly, unredeemed coffee lands had significantly higher number of species per number of individuals compared to redeemed coffee plots. However, between sacred groves and unredeemed lands species accumulation per number of individual trees did not differ significantly (Fig. 3).

Differences in species composition in three land tenure systems

Sacred groves had the highest average tree stand density (1,361 ha^{-1} ± 599 stems ha^{-1}) compared to in redeemed (377 ha^{-1} ± 112 stems ha^{-1}) and unredeemed (273 ± 96 ha^{-1}) lands (Table 2). Different species were dominant in each of the land tenures. In redeemed coffee lands, (Table 2) *Gravellia robusta* was the important species (sp. importance = 26.3%, relative density = 29.1%, relative dominance = 23.5%). In unredeemed coffee lands, *Dalbergia latifolia* was important (sp. importance = 27.9%, relative density = 30.5%, relative dominance = 25.3%) and in sacred groves, *Dimocarpus longan* had the highest species importance and density (sp. importance = 13.4%, relative density = 15.7%, relative dominance = 13.4%). In sacred groves, *Mangifera indica* species had the highest relative dominance (14%).

Gravellia robusta is non-indigenous exotic species in the region, and was introduced mainly as a shade tree in the coffee plantations. *D. latifolia* and *D. longan* are endemic species. The dominant species in unredeemed lands, *D. latifolia*, is a deciduous species. *D. latifolia* (Rosewood) is also one of the reserved trees (can only harvested under special license) in the state and has high commercial value. *G. robusata*, the dominant species in redeemed plots is an exotic species. The dominant species in sacred groves, *D. longan* and *M. indica* are evergreen species. Thirteen percent of all species in redeemed coffee plots

Table 2 Results of randomization test using 10,000 random partitions on Shannon and Simpson indices in three land tenure classes

Simpson's index		Shannon index	
Unredeem coffee and scared grove		*Unredeemed coffee and scared grove*	
Observed, unredeemed	7.98	Observed, unredeemed	2.71
Observed, sacred grove	16.05	Observed, sacred grove	3.29
Difference (delta)	8.06	Difference (delta)	0.57
Number of simulated |delta| > observed |delta|	276	Number of simulated |delta| > observed |delta|	0
P	0.03	*P*	0.00
Redeemed coffee and scared grove		*Redeemed coffee and scared grove*	
Observed, redeemed	8.09	Observed, redeemed	2.68
Observed, sacred grove	16.05	Observed, sacred grove	3.29
Difference (delta)	7.96	Difference (delta)	0.61
Number of simulated |delta| > observed |delta|	182	Number of simulated |delta| > observed |delta|	0.00
P	0.02	*P*	0.00
Redeemed coffee and unredeem coffee		*Redeemed coffee and Unredeem coffee*	
Observed, unredeemed	7.98	Observed, unredeemed	2.71
Observed, redeemed	8.09	Observed, redeemed	2.68
Difference (delta)	0.11	Difference (delta)	0.03
Number of simulated |delta| > observed |delta|	9,462	Number of simulated |delta| > observed |delta|	8,067
P	0.94	*P*	0.81

were reserved trees. Unredeemed coffee also had 13% reserved trees, while this value increased to 16% in sacred groves. Forest department list them as reserved trees because of their rarity and thus the higher value. These reserved trees are properties of the government. Land owners need a special permission from the government to harvest these trees.

Diversity indices

The Shannon Wiener indices (H) for redeemed coffee, unredeemed coffee and sacred groves were 2.68, 2.71 and 3.29 respectively. The higher H value in sacred grove indicates higher diversity. The randomization test (Solow 1993) used to compare the H values in all three land tenures indicated that the sacred groves are more diverse than both redeemed coffee and unredeemed coffee at 95% confident interval. However, the redeemed and unredeemed coffees had 70% probability of having the same diversity at 95% confident interval. Whereas the there is only 0.46% probability that sacred groves are less diverse than the redeemed and unredeemed coffee combined. The Simpson's reciprocal index (D) also showed that the sacred groves are more diverse than both the redeemed and unredeemed coffee plots. The D value for sacred groves is 16.05, whereas for redeemed coffee D is 8.09 and for unredeemed coffee D is 7.98.

No difference in evenness was observed among the three land tenures. The Shannon's evenness measure (j') for three land use classes were 0.46, 0.49 and 0.55 for redeemed coffee, unredeemed coffee and sacred groves respectively. The evenness measure assumes a value between 0 and 1 with 1 being complete evenness (Magurran 2004). This indicates that there is not much difference in the evenness among the three land tenures. Simpson's evenness ($E_{1/D}$) also indicated that the three tenures had similar evenness. Simpson's evenness ($E_{1/D}$) for sacred grove was 0.25, for redeemed coffee was 0.21 and for unredeemed coffee was also 0.21.

The randomization test results to compare the significance of Shannon and Simpson indices in three land tenure classes are in Table 2. This test indicated that in both Shannon and Simpson indices, sacred groves are significantly more diverse than redeemed and unredeemed coffee. The test also indicated that there is no significant difference between tree diversities in redeemed and unredeemed coffee lands (Table 2).

Results of archival records and the interviews

Historical data collected from the administrative reports of various government department since British annexation of the region (Haller 1910) revealed information on the expansion pattern of coffee in the region. Records indicated that initially when the coffee was introduced, growers completely cleared the forest to plant coffee. However, coffee plants could not survive heavy monsoon rains, so shade grown coffee became the cultivation practice in this area. *Gravillea robusta* was introduced to Kodagu coffee plots around 1860s to protect coffee from the attack of leaf rust which had already devastated the coffee cultivation in Sri Lanka (Haller 1910). *Gravillea robusta* plants were also promoted by the Coffee Board of India as shade trees in the coffee growing region. Over the years *G. robusta* became a dominant shade tree in redeemed coffee. Since the tree ownership in redeemed lands rests with the land owner, once the trees are harvested, fast growing and high timber value exotic species like *G. robusta* are preferred and planted. Coffee growers in Kodagu intercrop black pepper among shade trees. *Gravillea robusta* grows tall and straight and acts as stand for pepper vines.

In unredeemed coffee lands tree ownership rests with the government, so tree harvesting is not permitted. However, farmers still plant *G. robusta* in the areas where there are fewer shade trees. As a result *G. robusta* is the second dominant species in unredeemed coffee. In sacred groves, *G. robusta* was not recorded. We also noticed some sacred groves not included in the study, that were completely or partially subsumed by coffee plantations and housing suggesting that *G. robusta* may be in these border zones.

The interviews of the knowledgeable individuals also revealed to us the possible relationship between the coffee crisis in mid 1990s and the preference for exotic species. Global coffee market witnessed lowest coffee prices in 30 years. Coffee producers though out the world, unable to make a living with coffee, are changing to other crops or abandoning their plantations (Perfecto et al. 2005). A similar trend was observed in the study area also. Some producers started growing ginger a short term commercial crops to cope with the coffee crisis. Though we need a separate study to decisively make the claim about the lower coffee price and the producer's preference for shade trees in coffee, the knowledgeable individuals are in the opinion that the people are planting more exotic trees hoping it will insurance them during the future coffee crisis. Indian coffee market once regulated by the Coffee Board of India now is an open market. Coffee producers especially the small producers who have little or no experience in the international market are looking alternative to survive during the period of lower coffee price. The one alternative seems to be planting more exotic shade tree species in coffee plots. Premium prices for these exotic timber species and the less restriction in harvesting and marketing encourages the producers to plant more exotic species like *G. robusta*.

Based on the interviews it was clear that the gradually *G. robusta* will dominate the coffee shade trees. The reason for this observation is that it is easier to acquire forest department's permission to harvest and transport exotic trees than the native trees. Also, these exotic species grow faster and straighter, so they will be more profitable.

Discussions

Sacred groves have higher tree density and diversity compared to unredeemed and redeemed coffee. Species evenness measurements indicated that all the three habitats differing in land tenures had similar evenness. Redeemed and unredeemed coffee plots were similar in species richness abundance but were different compared to sacred groves.

The interviews with the land owners of the coffee lands revealed that the government forest policies affecting tree rights have played a major role in the current documented species composition in the coffee lands. The government has a stringent law on harvesting, transporting and marketing of the wild tree species (Shrinidhi and Lele 2001). However, the law is less stringent on the harvesting exotic species like *G. robusta* (Shrinidhi and Lele 2001). In Mexico in shade grown coffee plots, *Inga edulis* higher dominance. This plant is promoted by Instituto Mexicano del Café (INMECAFE) as a better shade tree for coffee in Mexico (Ambinakudige 2006). The government policies in both cases have led to differences in tree species composition—in India because farmers can cut exotic species, and in Mexico because the government agency actively supported planting of one species. It is interesting to note that the forest department's restrictions designed to protect native trees are having the reverse effect in Kodagu. The lack of restrictions on harvesting exotic trees is leading to widespread planting of these species and further dominance of these species over native species. This illustrates how state policies have a major influence on the change and potential trends in tree diversity in the coffee growing regions.

In well-protected sacred groves, biodiversity is well preserved. At the same time, coffee, which is often considered as a threat to biodiversity, had significant tree diversity. Although diversity was less in coffee plots than sacred groves, replacing endemic species with more profitable tree species like *G. robusta* may further erode biodiversity within coffee plantations. At present, in unredeemed coffee plots, the native species *D. latifolia* has a high dominance. In the redeemed coffee lands 74% of the basal area (dominance) is generated by native species. In unredeemed lands, native species have a similar dominance (72%). This exemplifies how shade grown coffee has the propensity to conserve pockets of biodiversity even though it has less diversity than natural forests with sacred groves.

Introduction of coffee in Kodagu reorganized the patterns of tree diversity. The main way in which patterns of tree diversity and composition have changed has been due to the introduction and encouragement of non-indigenous tree species. Another disadvantage of coffee cultivation is that it discourages the regeneration of tree species because the understorey is dominated by coffee plants. In this situation, it may be wiser to encourage shade grown coffee than sun grown coffee as shade coffee retains some amount of biodiversity. However, in the regions like Western Ghats where the biodiversity is threatened by human activities, no more new coffee plantations should be encouraged. Even though coffee retains some biodiversity, it cannot substitute for natural forest. Existing coffee plantations should be encouraged to preserve endemic species. The encouragement may be in the form of niche market for the shade grown coffee where growers receive premium prices for shade grown coffee. Some conservationists such as Conservation International and National Audubon Society (Conservation International 2001; National Audubon

Society 2000; Philpott and Dietsch 2003) already advocating for premium price for shade grown coffee. Shade coffee can conserve tree biodiversity and could help improve the livelihoods of the local people if conservation practices and coffee markets are linked.

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