# Birds in shade coffee plantations: The factors structuring bird communities in a plantation landscape in the Western Ghats, India.

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By
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## Declaration

I declare that the thesis entitled "Birds in shade coffee plantations: The factors structuring bird communities in a plantation landscape in the Western Ghats, India" comprises research work done by me under the guidance of Dr. Jagdish Krishnaswamy and co-guidance of Dr. T.R. Shankar Raman and Ms. Arundhati Das. The work is original and has not been done earlier by anyone else. Part of this work, which is related to or similar to work done by other researchers, has been referred to in this thesis at appropriate places. The results presented in this thesis have not been submitted previously to this or any other University for an M.Sc. or any other degree.

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## Certificate

I declare that this thesis entitled "Birds in shade coffee plantations: The factors structuring bird communities in a plantation landscape in the Western Ghats, India" comprises research work carried out by M.O. Anand at the Centre for Wildlife Studies under my guidance and the co-guidance of Dr. T.R. Shankar Raman and Ms. Arundhati Das during the period 2005-2006 for the Degree of Master of Science in Wildlife Biology & Conservation of the Manipal Academy of Higher Education (MAHE). The results presented in this thesis have not been submitted previously to this or any other University for M.Sc. or any other degree.

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# EXECUTIVE SUMMARY

The last two decades have seen growing interest in the study and conservation of biodiversity outside protected areas. Of particular interest are tree-covered plantations in tropical regions that are often found to contain levels of biodiversity comparable to natural habitats in the area. This study was undertaken to investigate the factors responsible for structuring bird communities in shade coffee plantations in the Western Ghats hill range of southern India, a global biodiversity hotspot and an Endemic Bird Area. The study investigated responses of the overall bird community to changes in vegetation composition, habitat structure and landscape context. In addition, the responses of functional guilds within the bird community were examined independently, since different guilds are expected to show variation in their response to different habitat properties. The bird community within coffee plantations was also compared to that of contiguous tropical moist deciduous forest.

Fieldwork was carried out in twelve coffee plantations in Chikmagalur District, a major coffee-growing area in the state of Karnataka, and in the Bhadra Wildlife Sanctuary. Point counts were used to sample birds at nine to twelve points per estate over four sampling occasions. Vegetation and habitat structure were sampled using 10 m circular vegetation plots, located at the bird point count stations. Geographic Information Systems (GIS) software was used to examine features of the broader landscape in the context of sampling locations. Analysis was carried out using rarefaction, multivariate analysis, and generalized linear models within a model selection framework.

A major finding of the study was the negative impact of silver oak (*Grevilia robusta*) – an exotic shade tree in coffee plantations – on the numbers of species and individuals of almost all sections of the bird community. Proximity to contiguous forest, as well as remnant forests in the immediate surroundings was found to enhance the bird community in coffee plantations, especially of birds closely associated with moist-deciduous and semi-evergreen forests in the area. Another significant result of this study was the marked difference observed in the bird community between coffee plantations and contiguous moist-deciduous forest. Results of the study emphasize the importance of native tree species in the coffee shade layer, and presence of forest cover in the landscape for the conservation of tropical forest bird communities.

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# CONTENTS

# INTRODUCTION

The spread of human civilization has resulted in widespread to almost all natural habitats. Wildernesses and biodiversity are actively protected in less than five percent of the total land area of the globe (Pimental et al, 1992). Recent years have seen a growing interest in the potential of lands outside protected areas to conserve biodiversity. Shade coffee plantations are widely reported to have bird species assemblages similar to that of native forests in tropical landscapes (Greenberg, Bichier and Sterling, 1997b; Petit and Petit, 2003). A number of factors, acting at different scales are known to structure bird communities. These are usually a combination of those acting at the local-level, such as tree species richness, and others at the broader landscape-level; for example the amount of native tree cover in the landscape. The relative influences of these factors on bird communities in shade coffee plantations was investigated in the Chikmagalur District, in a landscape that was a mosaic of shade coffee plantations, forest fragments, contiguous forest, human settlements and agricultural fields. The study was carried out over a period of six months between December 2005 and May 2006, and 12 coffee plantations and two forest sites were sampled for birds, vegetation composition and habitat structure.

Shade coffee is grown under a shade canopy that varies from being dominated by native tree species, to one that is dominated by silver oak (*Grevilia robusta*), an exotic species that is harvested for timber. Figure 1(a) depicts a natural shade estate, while 1(b) is a monoculture stand of silver oak. Plantations of exotic tree species are expected to have less diverse bird assemblages, and this was tested in Chapter 1, where the species richness and composition of all species and functional guilds was compared across two shade types within coffee, and contrasted to the bird community of contiguous moist-deciduous forests. Rarefaction and multivariate analysis were used, and results were graphically displayed using bar graphs. This draft manuscript, titled "Bird communities in shade coffee plantations: patterns across shade types and a comparison to moist deciduous forest in the Western Ghats, India" is prepared for submission to the journal *Animal Conservation*.

Variations in shade type lead to gradients in many other habitat variables, like structural diversity and tree species richness. Patterns in the response of the bird community to these local-level gradients, as well as landscape-level gradients like the distance to contiguous forest were investigated using generalized linear models within a model selection framework. The major objective of this study was to investigate the bird community response to changes in these habitat variables, and then to identify the management practices that were influencing these variables. The study aimed to identify the management conditions under which the bird diversity of coffee plantations may be best conserved. This draft manuscript, titled "The local- and landscape-level factors structuring bird communities in a coffee plantation-tropical forest landscape in the Western Ghats, India." is prepared for submission to the journal *Ecological Applications*.

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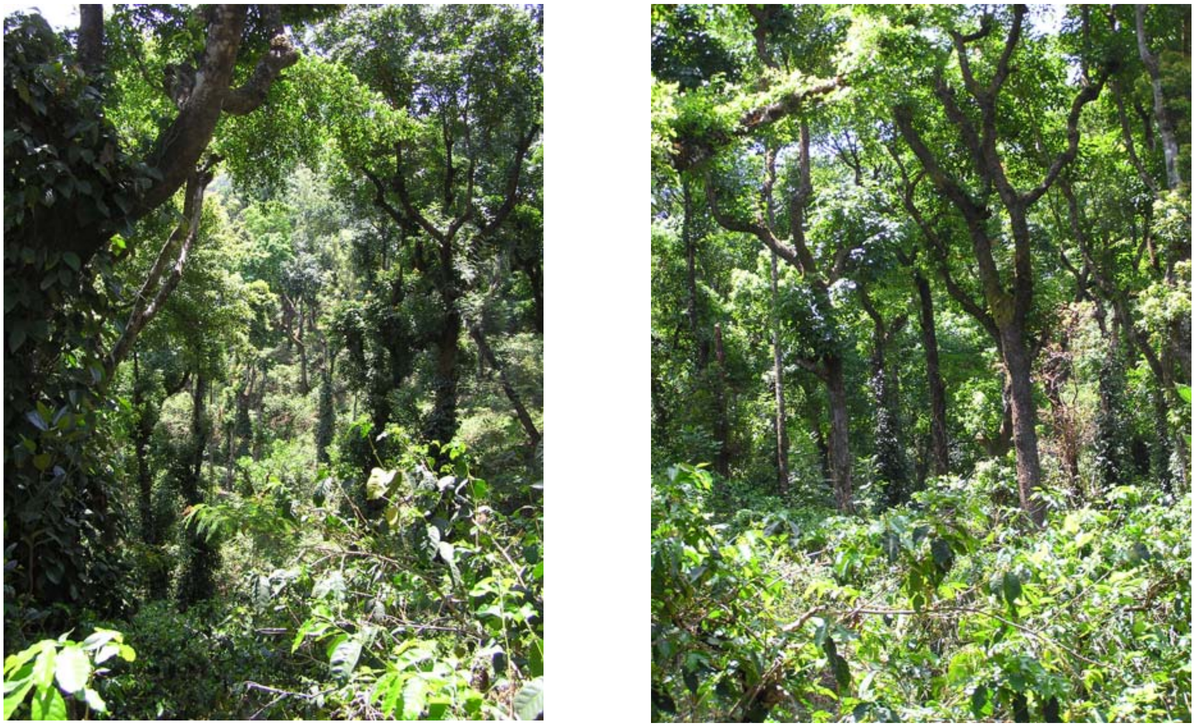


Figure 1 (a) Coffee plantation in natural shade


Figure 1(b) Coffee plantation in Silver oak shade

# CHAPTER – 1: Bird communities in shade coffee plantations: patterns across shade types and a comparison to moist deciduous forest in the Western Ghats, India.

**Abstract**

Widespread change in land cover and land use the world over is greatly altering habitat availability and suitability for wildlife. In the Western Ghats hill range, south India, coffee is grown bordering or close to forests and protected areas, under a shade dominated by natural shade of forest tree species, to monocultures of an exotic tree species, silver oak (*Grevilia robusta*), thus providing habitat of contrasting quality for a variety of taxa. Birds and vegetation were sampled using point counts between December 205 and May 2006 in four natural shade, four silver oak shade plantations and in the Bhadra Wildlife Sanctuary in the Chikmagalur District, Karnataka, India. The overall bird community was distinctly different between forest and shade coffee plantations. Rarefaction analysis consistently yielded greater numbers of bird species and individuals in forest and natural shade coffee plantations. Birds closely associated with forest were more abundant close to forest in natural rather than silver oak shade plantations. Open habitat species were found to increase at sites away from the forest. Large-bodied birds were more abundant in forest while insectivores and frugivores were most abundant in natural shade plantations. Shade coffee plantations are potentially good habitat for a wide variety of species, but plantations under a shade layer of native trees are best suited the conservation of native forest avifauna.

## Introduction

All over the world, alteration of natural landscapes and the intensification of agricultural practices have lead to major changes in land cover patterns, often resulting in a loss of biodiversity (Estrada & Coates-Estrada, 1997; Burel et al., 1998). The last two decades have seen an increasing interest in the conservation potential of human-dominated landscapes (Pimental et al., 1992; Petit & Petit, 2003). Of primary interest are agricultural areas and open habitats (Daily, Ehrlich & Sanchez-Azofeifa, 2001; Murphy, 2003; Peterjohn, B.G, 2003), and in the tropics, agroforests and plantations (see Thiollay, 1995; Greenberg, Bichier & Angón, 2000). Landscapes of tree plantations offer greater structural complexity than open habitats like pastures, and apparently facilitate wider dispersal of forest dependant species (Renjifo, 2001; Rodewald & Yahner, 2001).

Traditional coffee plantations retain to a great extent the original tree species to provide shade for the coffee bushes, resulting in a habitat that is often not unsuitable for a variety of taxa (Perfecto et al, 1996; Moguel and Toledo, 1997). Among numerous human-modified habitats in the neotropics, coffee plantations were found to be the most important for the conservation of moderately and highly vulnerable bird species (Petit & Petit, 2003). Globally, the importance of coffee plantations to biodiversity conservation is not as much the actual areal extent, as is the fact that they are located in places associated with high degrees of deforestation, habitat loss and fragmentation (Perfecto et al, 1996). This importance is further elevated by the economic importance of coffee (it is globally one of the most traded commodities) and the fact that it is grown in countries and landscapes rich in biodiversity.

Coffee plantations are a major land-cover type in the Western Ghats hill range of southern India, one of the eight 'hottest hot spots' of biodiversity (Myers et al., 2000) and an Endemic Bird Area (BirdLife international, 2006). Coffee plantations cover an area of roughly 3200sq.km in the Western Ghats (Coffee Board of India, 2005), and are typically located in the mid-elevation zone (900 msl to 1200 msl) that was originally covered by tropical moist-deciduous and tropical evergreen forests. Upto 18% of high conservation priority sites (i.e. those containing threatened and endemic animal and tree species) in the Western Ghats are located in landscapes with significant areas under coffee plantation (Das et al., *in press*). Protected areas cover roughly 10% of the Western Ghats, and coffee plantations are often located in areas surrounding, and sometimes within protected area boundaries (Kumar, 2003). They may act as buffers around protected areas, providing suitable habitat for many species, or as foraging ground and movement corridors for wide-ranging animals like elephants or hornbills (Kumar, 2003), while enhancing the biodiversity of forest fragments in a plantation landscapes (Bhagwat et al., 2005). Conversely, coffee plantations that have high connectivity with contiguous forest are found to harbour greater numbers of native and threatened bird species (Raman, 2004). In this scenario, coffee plantations may be believed to be relatively environmentally benign, compared to other plantation activities in the Western Ghats, such as tea cultivation.

Across the tropics, modernization of coffee cultivation includes more active shade-layer management, increased use of pesticides, and the development of more robust strains of coffee; an extreme case being sun coffee plantation, where the shade layer is entirely absent (Perfecto et al, 1996; Greenberg et al., 1997a; Rappole, King & Vega Rivera, 2003). Though there are no un-shaded coffee plantations in the Western Ghats, market fluctuations and restrictions on the felling and harvest of native tree species in the plantations have encouraged many coffee planters to alter the shade layer in plantations from trees native to the area to non-native shade tree species, such as silver oak (*Grevilia robusta*). Not only is the shade layer composition different in silver oak shade plantations, but these estates are subjected to the allied disturbances of repeated harvest of this fast-growing species.

Bird community dynamics in coffee plantations of central and southern America are extensively studied (reviewed by Komar, 2006). While sun coffee plantations are regularly reported to be extremely de-pauperate in bird fauna (Greenberg et al., 1997a; Greenberg, Bichier & Angón, 2000), shade coffee plantations are found to have bird species richness and diversity comparable to undisturbed forested habitats in the area, though there are marked changes in species composition such as the reduction in forest dwelling species (for example, Rappole, King & Rivera, 2003; Tejeda-Cruz & Sutherland, 2004). A number of studies look at differences between shade-types within shade coffee plantations, ranging from rustic plantations with minimal alteration to the shade layer, to shaded monocultures (Wunderle Jr., 1999; Greenberg et al., 1997a; Greenberg, Bichier & Sterling, 1997b, Calvo & Blake, 1998).

This study, conducted in the central Western Ghats, compares the bird species assemblages across three habitat-types: contiguous moist-deciduous forest, natural shade coffee plantations and Silver oak shade coffee plantations. Particularly, patterns in the following community parameters and responses are examined:

1. Overall species richness and diversity,
2. Overall bird community composition, based on species abundance,
3. Relative abundance of foraging guilds,
4. Species richness and diversity of different foraging guilds, and
5. Species richness of habitat-preference guilds and large-bodied birds.

## Methods

### Study area

The fieldwork was conducted in the Chikmagalur District (see Figure 1), which is a major coffee-growing area in the state of Karnataka, India (13°0´ N and 13°32´ N, and 75°32´ E and 75°45´ E). The study site comprised a matrix of shade-coffee plantations, tropical moist-deciduous forest, forest fragments, paddy and mustard fields, and human habitation. The crescent-shaped Bababudan hill range, which reaches up to 1900 m in elevation and comprises a habitat of montane *sholas* and grasslands is an offshoot of the central Western Ghats, and a major topographic feature of this landscape. The Bhadra Wildlife Sanctuary, a 493 sq.km stretch of contiguous tropical moist-deciduous forest characterized by tree species *Tectona grandis, Dalbergia latifolia, Terminalia allata, Pterocarpus marsupium* and *Lagerstroemia lanceolata* (Karanth, 1981), forms the northern and western boundaries of the study site, with the ridge of the Bababudan hills and the Aldur town marking the eastern and southern extremities, respectively. The study area is in the vicinity of two Important Bird Areas (Islam & Rahmani, 2004), the Bhadra Tiger Reserve, and Kemmangundi and Bababudan Hills. Twenty-five species of birds restricted to moist tropical forests of peninsular India are reported from this area, of which 13 species are endemic to the Western Ghats.

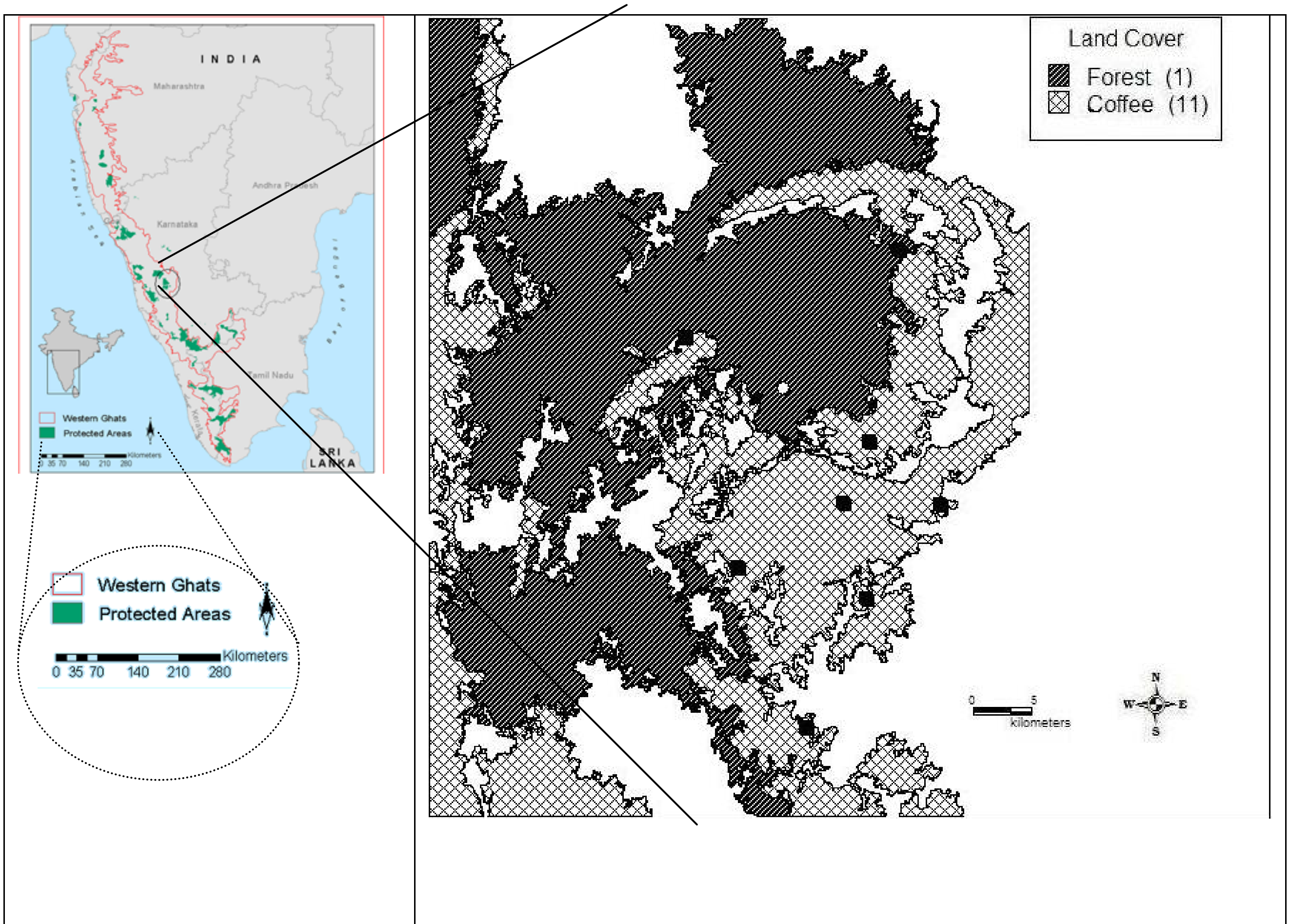



Figure 1: Map of study area showing coffee plantations as light hatching and moist deciduous forest as dark shading. Dark coloured points are the locations of the eight sampled coffee plantations and the light coloured point is the location of the site sampled in contiguous forest.

Coffee plantations in the district cover over 870 sq.km and contribute close to 25% of all coffee produced from the Western Ghats (Coffee Board of India, 2005). Shade coffee plantations of *Coffea arabica* (predominant) and *Coffea robusta* are located at elevations between 900 msl and 1400 msl, and range in area from small-scale farms of up to 10 hectares, to vast corporate plantations of several hundred hectares. All coffee in the region is grown under a shade layer, which, for the purpose of this study were classified as natural shade or silver oak shade. Natural shade coffee is grown under a planted canopy that is dominated by native trees, particularly, species of *Ficus*. The native tree composition in coffee plantations is, however, markedly different from that of adjacent moist-deciduous forests in the area. Coffee in silver oak shade plantations is grown under a canopy that, while containing a few native tree species, is dominated by silver oak.

## Bird sampling

Eight coffee plantations and two forest sites were sampled for birds, vegetation and habitat composition between December 2005 and May 2006. Estates were selected based on visual classification as of the shade layer as(1) natural shade or (2) silver oak shade plantations, based on the proportion of silver oak trees in the estate. This property was later quantified, during sampling. Estates were also classified as (1) near forest and (2) away from forest, based on proximity to contiguous forests of Bhadra Wildlife Sanctuary. This was done using 1:25000 Survey of India maps, and verified using satellite imagery (described below). Of the eight estates, two were of natural shade close to forest, and two were of natural shade away from forest. Similarly, two were of silver oak shade near and two were of silver oak shade away from the forest. Sampling units were no closer than two kilometres apart, except in the case of the two forest sites. This exception was unavoidable, due to logistical constraints such as accessibility and the availability of roads and footpaths within the forest site. Only plantations between 900 msl and 1200 msl were considered, while the forest sites were between 800 and 900msl. While attempts were made to minimize bias in site selection, one was limited by availability of permission to work on estates, along with other logistical difficulties.

Birds were sampled over two seasons, twice every season by conducting five-minute fixed-width point counts (Hutto, Pletschet & Hendrics, 1986), which are appropriate for sampling cryptic understory birds, as well as vocal canopy-dwelling species, but not highly mobile species (Raman, 2003). A minimum of nine and a maximum of 12 point counts were conducted per estate between 0630 and 0915 hrs on two successive mornings each season. All birds seen and heard within a 70 m radius of the point were recorded. Birds flying under the canopy, or within 10 m of the canopy were recorded as well. All species of swifts and swallows were excluded from sampling, as were most species of raptors; exceptions were the Oriental honey buzzard (*Pernis ptilorhyncus*), Crested serpent eagle (*Spilornis Cheela*) and three species of *Accipiter*, which were often seen perched or flying low over the canopy. The Eurasian eagle owl (*Bubo bubo*) was the only nocturnal bird recorded during sampling. When seen, species group size and canopy layer occupied were recorded, along with distance from the point center to the bird, measured using a laser range finder. Species and estimated distance class was recorded for auditory detections.

Points were located at least 150 m apart, along foot paths and trails, with an effort being made to place the points in a closed geometric shape. A Garmin GPS 12 XL was used to mark points and maintain orientation while locating points. On the ground, point count stations were marked using oil chalk. On the ground, point count stations were marked using oil chalk.

Bird observations were pooled from four sampling occasions across two seasons, and summed over all point counts within sites and shade types. Black bulbul (*Hypsipetes leucocephalus*) was excluded from analysis because although the species was encountered in a few coffee plantations, the primary habitat of the species is known to be at altitudes greater than those encountered during the study. Two other species which were detected during sampling, the

Indian pond heron (*Ardeola grayii*) and the White-throated kingfisher (*Halcyon smyrnensis*), were excluded from analysis because these are species closely associated with large ponds and water bodies, and were occasionally encountered within coffee plantations.

All detections of any species by call were assigned the mean group size derived from all occasions when the species was seen, when there were more than ten sighting detections of a species; otherwise a group size of one was assigned to the call. Bird studies in the tropics have employed similar approximation techniques (Raman & Sukumar, 2002) in order to analyze bird abundance data.

There were differences in sampling effort and the number of individuals encountered in each shade type; hence rarefaction analysis was used to estimate the expected number of species (Gotelli & Entsminger, 2000). One thousand iterations were run to estimate the number of species encountered in a sample of a specified number of individuals, and differences between habitat-type were considered significant if the 95% confidence intervals of the means did not overlap. Bar graphs were used to graphically represent the results.

Further analysis was carried out on subsets of the overall bird community, based on foraging and habitat guilds. This was done to examine the heterogeneity in the response of different guilds to different habitats, which is believed to be influenced by the natural history of the species within the guild. Guilds examined were classified based on:

1. Feeding guilds: Upper canopy insectivore, bark insectivore, middle and understory insectivore, generalist insectivore, nectarivore-insectivore, canopy frugivore, generalist insectivore, granivore, carnivore and omnivore.

2. Habitat preference: Forest typical, woodland generalist and open habitat species.
3. Life history parameters: body mass (birds weighing over 90 gms).

All guild categorizations were based on secondary information (Ali & Ripley, 1983; Raman & Sukumar, 2002), Except for body mass, all categorizations were subjective and qualitative, based on secondary information and on field observations. The guild of forest dependant birds was defined as one that comprised all species that are typical of moist deciduous and semi-evergreen forests in the area.

Relative abundances of the various foraging guilds were also used in comparing bird community composition between habitat types. Relative abundance was calculated as the number of individuals within the guild divided by the total number of individuals. These results were examined graphically. Species richness and Shannon-Weiner diversity of all species, and of species guilds based on primary diet were estimated by rarefaction analysis over 1000 randomizations. Rarefaction analysis was also used to estimate species richness of groups with different habitat preferences and large-bodied birds (birds weighing over 90 gms) in the three habitat types.

## Vegetation sampling

Tree species composition was sampled in contiguous forest and coffee plantations at all the point count stations using 10 m radius vegetation plots. All trees over 30 cm GBH were identified to species or genus, and their GBH was measured. In case the total number of trees sampled within an estate was low (less than 50), up to 12 random samples of trees were made at locations in between point count stations where the nearest four trees were identified and their girth measured. The total number of trees over 10m in height within a 30m radius of the point was counted, as was the number of silver oak trees in the same radius, in order to calculate a proportion of silver oak at each point.

## Statistical Analysis

Differences in tree and bird species richness and diversity, between habitat types and distance classes, were graphically illustrated using bar graphs. Mean estimated values of the variables were plotted as bars, with error bars representing 95% confidence interval. Non-overlapping confidence intervals were interpreted as significant results. Relative abundances of feeding guilds were graphically examined using a stacked bar graph.

Patterns in the overall bird community across different habitat types, and proximities to contiguous forest were examined using PRIMER version 5.2.2 (Primer-E, 2001). Sampling effort across sites was standardized by only using data from the first nine point count stations in each site. Bird community dissimilarity between habitat types was estimated using the Bray-Cutris index, which is:

$S_{jk} = 100(1-\{(\Sigma|y_{ij}-y_{ik}|) / (\Sigma y_{ij}+y_{ik})\})$,

where S is the Bray-Curtis measure of similarity (range=0.0 to 1.0) and j and k are the sites being compared. y represents the entry in the corresponding row and column.

Pair-wise Bray-Curtis dissimilarity values were arranged in a matrix, and dissimilarities between sites were graphically illustrated and analysed using cluster diagrams and multidimensional scaling (MDS). The MDS algorithm generates a two dimensional ‘map’ of samples, where pair-wise dissimilarities between sites are ranked, and these are plotted in two-dimensional space constrained by all the conditions imposed by the dissimilarity matrix. The relative distance between points on the map is directly proportional to the ranked dissimilarities of the points. (Clarke & Warwick, 1994).

Bray-Curtis dissimilarity was also calculated between shade types, and between different distances to contiguous forest classes. To test the significance of observed differences in overall bird community between the different groups, an analysis of simlitude (ANOSIM) was carried out, which tested the null hypothesis that similarity within groups was the same as similarity across groups. A parameter R was calculated as:

$$R=(r_B'-r_W')/(M/2),$$

where $r_B'$ is the average of rank similarities among replicates between sites, and $r_W'$ is the average of rank similarities of replicates within sites, and M is n(n-1)/2.

The R metric value has a range of –1.0 to +1.0; values close to +1.0 indicate greater degrees of similarity within a group than across groups, while values close to –1.0 indicate that there is greater similarity across groups than within (Clarke & Warwick, 1994).

## Results

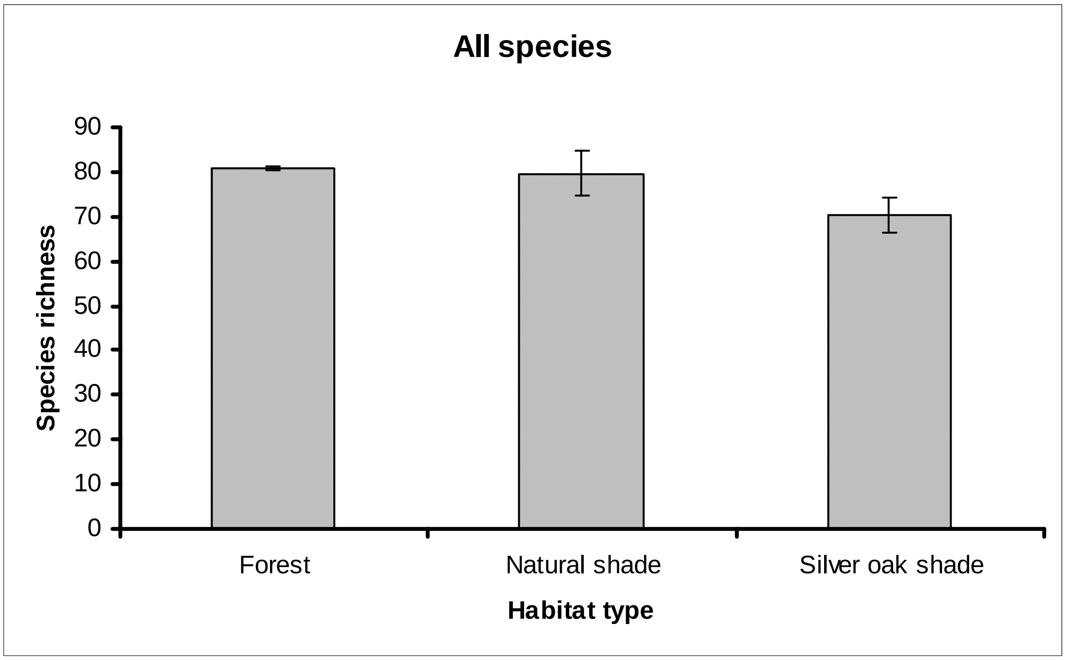
Natural shade plantations were composed of 18.99% silver oak (1 SE=0.03) and silver oak shade had 66.5% (1 SE=0.01) silver oak cover. Among habitat types, natural shade coffee plantations had the highest estimated number of tree species richness (30.56±5.01 95%CI) and Shannon-Weiner Diversity (2.72±0.15) for a sample of 175 individuals, estimated over 1000 iterations. Contiguous forest and silver oak shade coffee plantations had comparable species richness (22±0.0 and 22.5±4.63); Shannon-Weiner Diversity of forest (2.42±0.0) was significantly higher than that of silver oak shade coffee plantations (1.6±0.21).

### Overall bird community

A total of 1203, 2483 and 1949 birds of 81, 91 and 77 species were recorded in contiguous moist deciduous forest, natural shade and silver oak shade coffee plantations respectively over two sampling seasons.

Rarefaction analysis on a sample of 1200 individuals yielded the highest estimated species richness in contiguous forest (mean=80.96±0.39) and natural shade coffee plantations (79.68±5.16), which was significantly higher than that for silver oak shade plantations (70.51±3.96). Plantations near forest (72.31±4.40) and away from forest (73.16±4.07) had comparable estimated species richness per 1200 (Figure 2).

(a)

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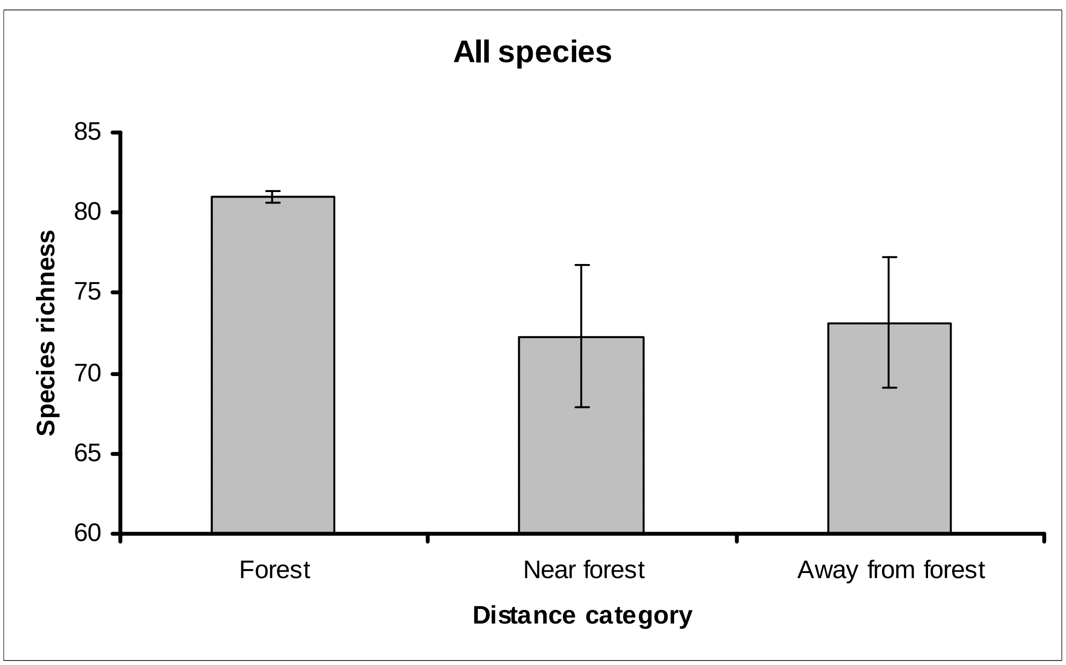


Figure 2: Estimated species richness across (a) habitat types and (b) distance categories. (Number of individuals sampled: N=175)

The overall bird community was more similar between shade types in coffee plantations (59.23% similarity), than either of the shade types were to contiguous forest (48.58% and 46.18% for natural and silver oak shade, respectively). Between groups based on distance classes, coffee plantations in near forest and away from forest distance classes were more similar to each other (57.03%), than to contiguous forest (48.58 and 45.79 for near forest and away from forest, respectively).

Significant differences were obtained in overall bird community across habitat type ($R=0.351$, $p=0.05$) and proximity to forest groups ($R=0.688$, $p=0.001$) over 999 Monte-Carlo randomizations.

For the habitat type group, positive R values were obtained for comparisons between silver oak, natural groups and forest, indicating greater similarity within the habitat types than across. Negative R values were obtained for the comparisons between shade types within coffee, indicating high variability in overall bird community within each shade type. No pair-wise comparisons yielded R values that were significant at $p \leq 0.05$ (Table 1).

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Table1(a): Pair wise R statistic value and significance level for forest, natural and silver oak shade groups.

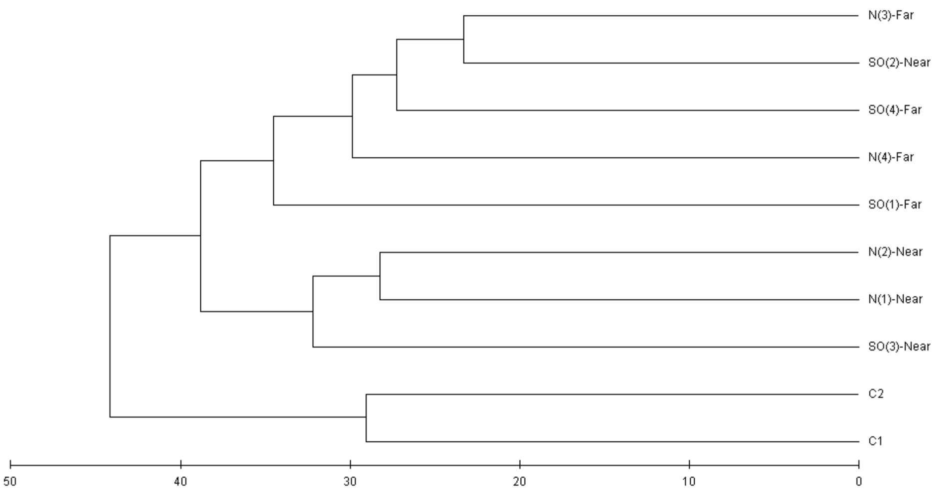
| Group1 | Group2 | No. of combinations | R Statistic | Significance level |
|---|---|---|---|---|
| Silver oak shade | Natural shade | 35 | -0.156 | 0.857 |
| Silver oak shade | Forest | 15 | 0.857 | 0.067 |
| Natural shade | Forest | 15 | 0.786 | 0.067 |

Table 1(b): Pair-wise R statistic value and significance level for forest, near-forest and away from forest groups.

| Group1 | Group2 | No. of combinations | R Statistic | Significance level |
|---|---|---|---|---|
| Away | Near | 35 | 0.365 | 0.086 |
| Away | Forest | 15 | 1.0 | 0.067 |
| Near | Forest | 15 | 1.0 | 0.067 |

The dendrogram in figure 3(a) shows that the two forest sites were most similar to each other, and that bird community similarity within the near-forest and away from forest groups was greater than across groups. The results of Multi-dimensional scaling (MDS) plot in figure 3(b) indicate that the overall bird community in near forest sites is more similar to the forest bird community than is the community in estates away from the forest. The plots also indicate that the overall bird community was more similar within the group of all coffee estates than between coffee estates and forest. The low stress value of 0.07 indicates the relative ease with which data in multiple dimensions was fitted into a two-dimensional plot.

(a)




(b)


Fig 3(a): Dendrogram and (b) MDS plot showing similarity in overall bird community between sites. Sites are labelled as shade type (number)-distance, where natural (N) and silver oak (SO) are shade types, and near (N) and far (F) are distances. C1 and C2 represent two control sites in continuous moist deciduous forest.

## Relative abundance

The bird community in contiguous forest was dominated by the guild of middle and understory insectivores (24.52%). Strata-generalist frugivores were the dominant foraging guild in natural shade (25.54%) and silver oak shade (25.45%) plantations, followed by strata-generalist insectivores (20.09% and 23.40%, respectively). The insectivore community on the whole (including nectarivore-insectivore) was dominant in contiguous forest (69.99), natural shade (56.24%) and silver oak shade (59.26%) coffee plantations. Frugivores formed a greater proportion of the overall bird community in natural (38.58%) and silver oak (36.53%) shade coffee plantations than in contiguous forest (22.28%). Carnivorous bird species comprised 2.16% of the bird community in forest, while contributing only 0.9% and 0.21% to the bird community of natural and silver oak shade coffee plantations (Table 2 and Figure 4).

Table 2: Relative (percentage) abundance of foraging guilds, represented as a percentage of the overall bird community in contiguous forest, natural shade and silver oak shade coffee plantations.

| | **Forest** | **Natural shade** | **Silver oak shade** |
|---|---|---|---|
| Upper canopy insectivore | 16.54 | 9.90 | 8.77 |
| Bark insectivore | 4.66 | 3.84 | 5.59 |
| Middle/understorey insectivore | 24.52 | 12.54 | 16.47 |
| Generalist insectivore | 11.14 | 20.09 | 23.40 |
| Nectarivore-insectivore | 13.13 | 9.86 | 5.03 |
| Canopy frugivores | 3.99 | 13.34 | 11.08 |
| Generalist frugivore | 18.29 | 25.54 | 25.45 |
| Granivore | 0.83 | 0.80 | 1.49 |
| Carnivore | 2.16 | 0.90 | 0.21 |
| Omnivore | 4.74 | 3.48 | 2.51 |

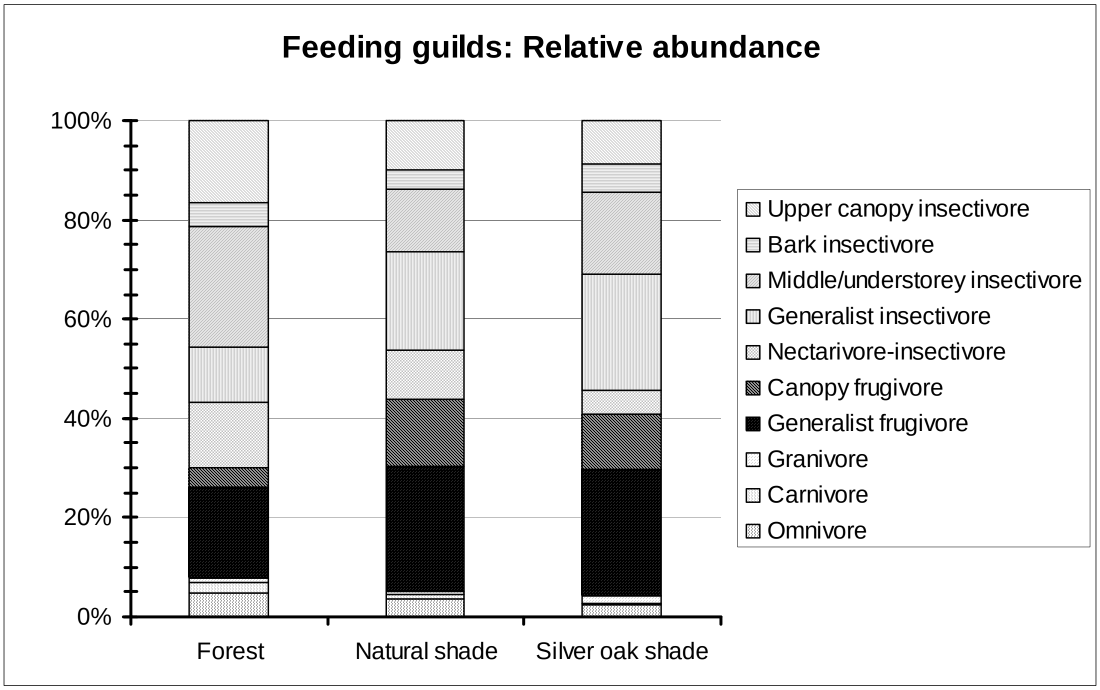



Figure 4: Relative abundances of feeding guilds across forest, natural shade and silver oak shade plantations.

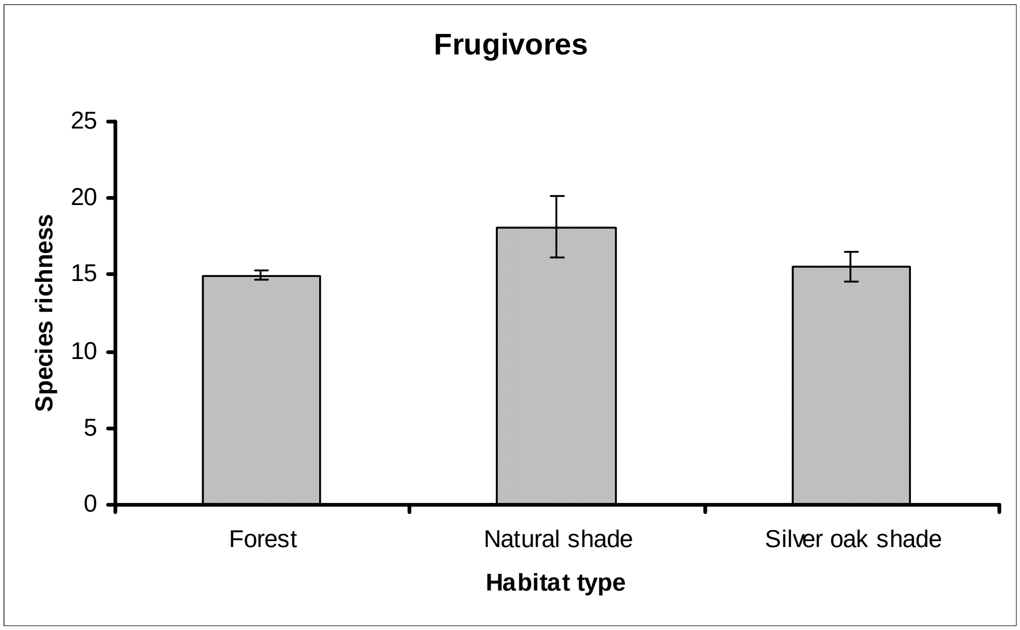
**Foraging guilds**

Estimated species richness of frugivores was highest in natural shade coffee plantations (18.14±1.98) and the Shannon-Weiner index of frugivore diversity was significantly higher in natural (2.45±0.06) and silver oak (2.40±0.05) shade coffee plantations than in contiguous moist deciduous forest (Figure 5).

Insectivore species richness was marginally higher in natural shade coffee plantations (50.08±3.51) and contiguous forest (46.88±0.66) than in silver oak shade coffee plantations (43.58±2.96). Insectivore species diversity was significantly higher in contiguous forest (3.38±0.01) than in natural and silver oak shade coffee plantations.

The guild of middle canopy and understory insectivores (Figure 6), comprising insectivore species that were rarely or never seen in the top canopy was found to have the highest estimated species richness in contiguous forest (23.89±0.67) and natural shade coffee plantations (23.38±1.37), and highest estimated Shannon-Weiner diversity in contiguous forest (2.70±0.01).

a)




(b)

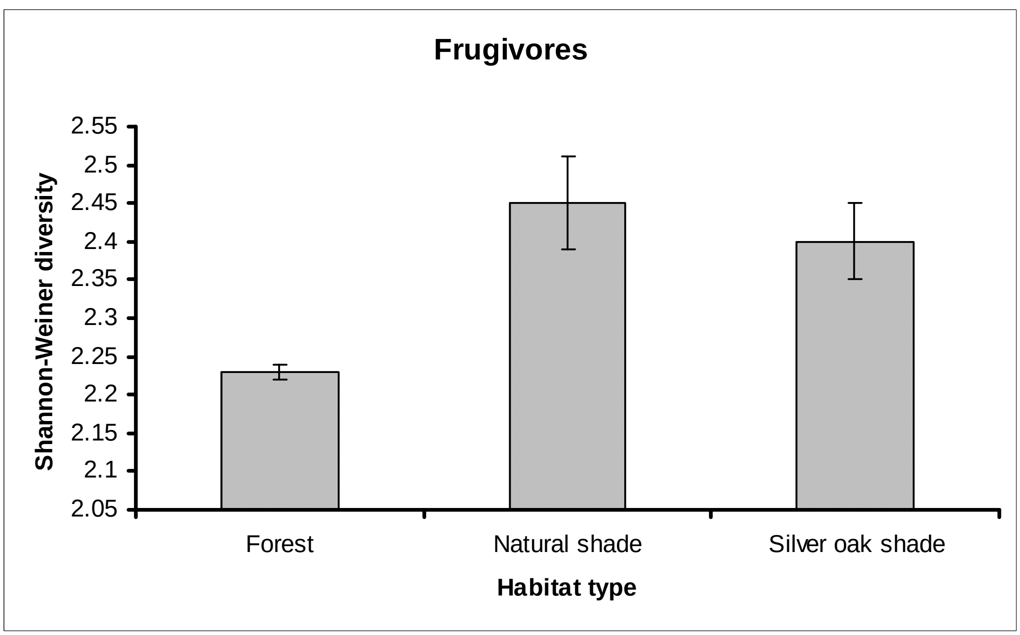
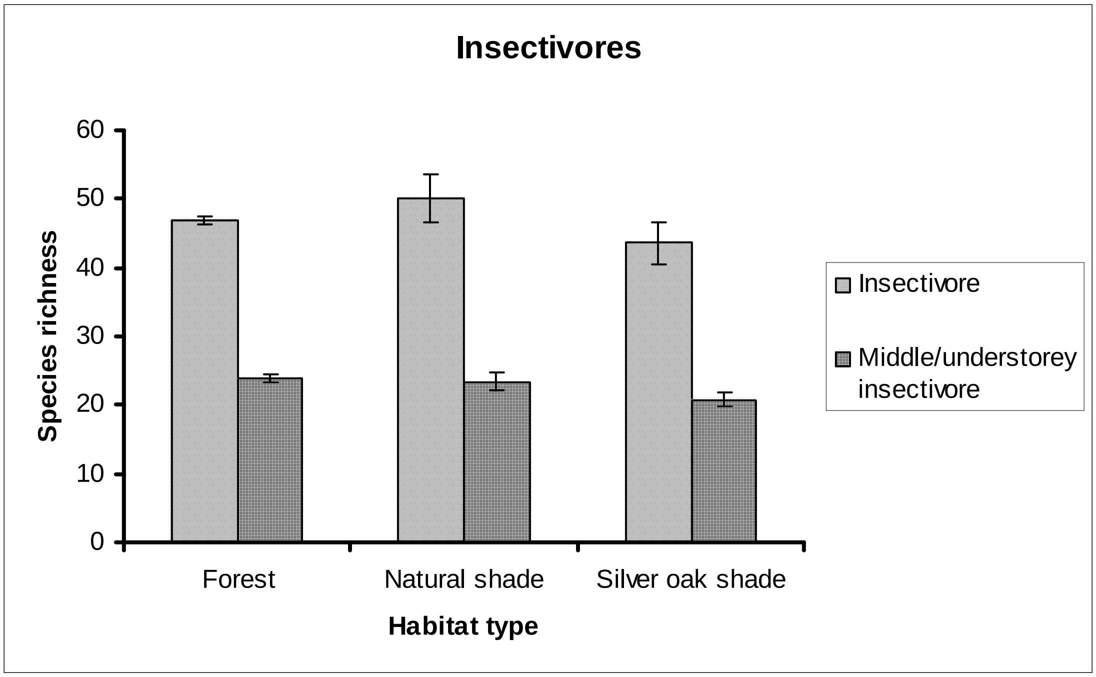



Figure 5: Estimated (a) species richness and (b) Shannon-Weiner diversity of frugivores in forest, natural shade and silver oak shade coffee plantations. N=470

(a)




(b)

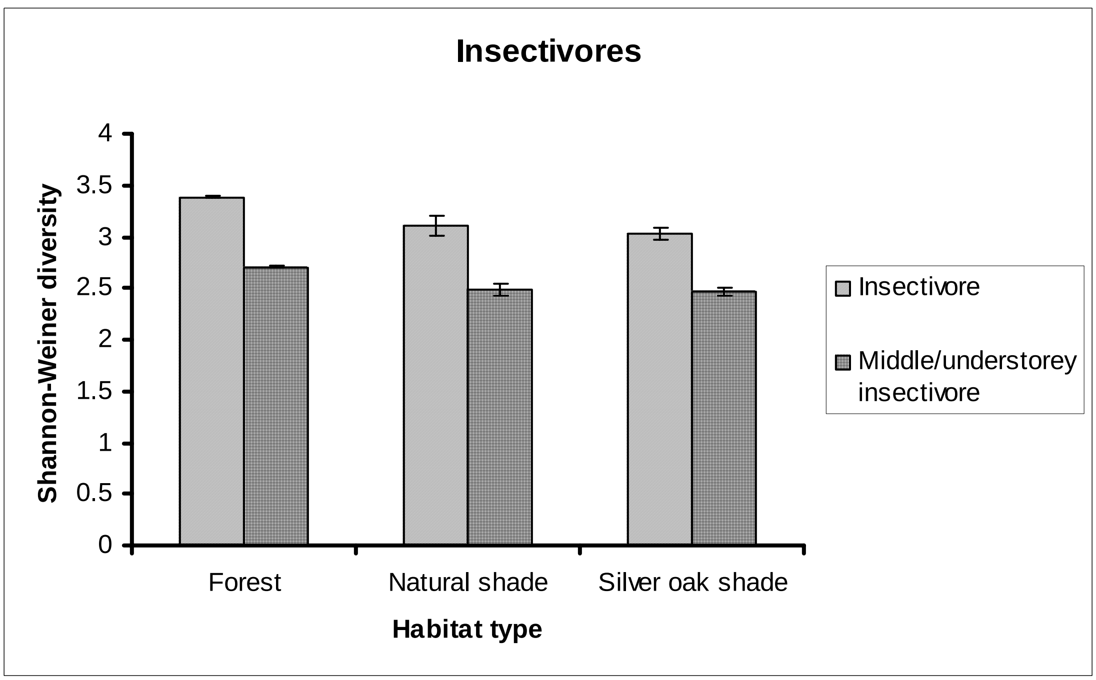



Figure 6: Estimated (a) species richness and (b) Shannon-Weiner diversity of insectivore (N=620) and middle/understorey insectivore (N=290) species in forest, natural shade and silver oak shade coffee plantations.

**Habitat-preference guilds**

Estimated species richness of forest dependant species was, as expected, highest in contiguous forest (48.05±0.79), and was significantly higher in natural shade plantations (41.57±3.10) than in silver oak shade plantations (34.38±0.55). Woodland generalist species were evenly distributed across the three habitat types, and there was greater species richness of open habitat species in silver oak and natural shade coffee plantations than in contiguous forest (Table 3 and Figure 7).

Table 3: Estimated species richness of different habitat guilds in forest, natural shade and silver oak shade coffee plantations.

| | **Forest** | | **Natural shade** | | **Silver oak shade** | |
|---|---|---|---|---|---|---|
| | Mean | 95% CI | Mean | 95% CI | Mean | 95% CI |
| Forest dependant species | 48.05 | 0.79 | 41.57 | 3.10 | 34.38 | 0.55 |
| Woodland generalist species | 21.42 | 1.40 | 20.28 | 3.40 | 19.12 | 2.81 |
| Open habitat species | 10.92 | 0.56 | 14.12 | 2.39 | 15.72 | 2.62 |

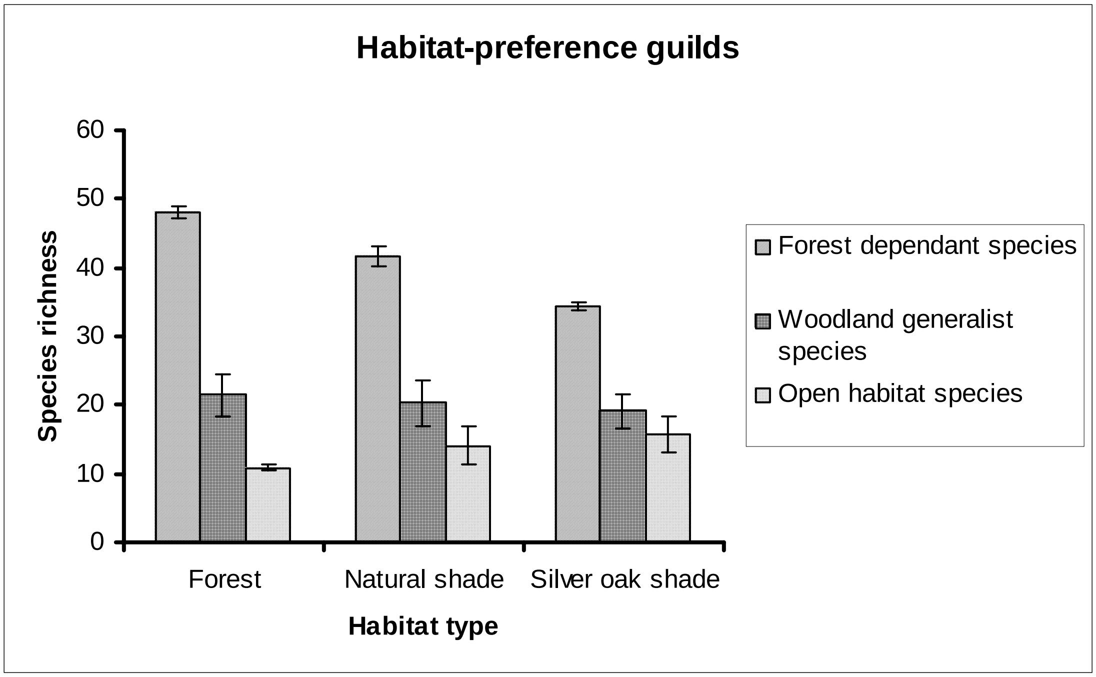



Figure 7: Estimated species richness of forest dependant (N=770), woodland generalist (N=240) and open habitat species (N=160) in forest, natural shade and silver oak shade coffee plantations.

Estimated species richness of large-bodied birds was significantly higher in contiguous forest (48.86±0.73) than natural and silver oak shade coffee plantations (Figure 7).

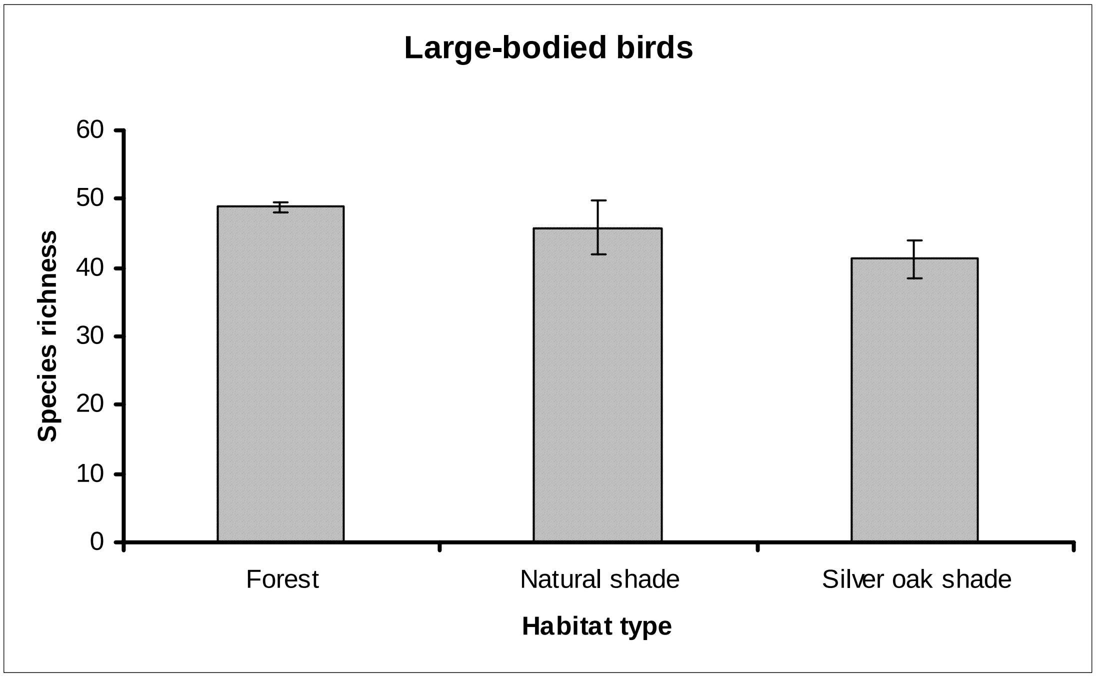



Figure 7: Estimated species richness of large-bodied bird species (N=650) in forest, natural shade and silver oak shade coffee plantations.

## Discussion

All species richness estimates were based on rarefaction analysis; hence values are valid for comparative purposes but do not necessarily represent the absolute species richness' of the habitats.

The overall bird species richness of natural shade coffee plantations was comparable to that of contiguous moist deciduous forest, and much higher than that of Silver oak dominated coffee plantations. This result is consistent with analogous studies from the neotropics (Greenberg et al., 1997b; Calvo & Blake, 1998; Tejeda-Cruz & Sutherland, 2004). There was no difference in the overall species richness between the near forest and away from forest distance classes. Other studies from tree-covered landscapes report distance to contiguous forest as only a weak predictor of species richness (Greenberg et al., 2000; Bhagwat et al., 2005). In any case, in this study, patterns across habitat types are believed to be not confounded by distance at all, since sites were selected such that plantations of both shade types were evenly placed in both distance classes.

Expectedly, species composition varied between coffee plantations and forest. Both the cluster analysis and MDS illustrate a bird community in coffee plantations that is distinctly different from that of contiguous forest. Bird community similarity was higher between natural shade and silver oak coffee plantations, than between these two types and forest. Low or negative R values for pair-wise comparisons between shade-types and distance classes within coffee indicated high variability and overlap in the bird community.

**Foraging guilds**

The bird community in contiguous forest was dominated by insectivore species. The guild of middle and understory insectivores was the most abundant and diverse in forest, and contributed more to the overall bird community in forest than in shade coffee plantations. The lowest species richness and diversity of insectivores and middle and understory insectivores was recorded in silver oak shade plantations. Coffee plantations activity involves lopping, pruning and management of all habitat strata, especially the understory which is a monoculture of coffee plants. The use of insecticides and herbicides in coffee plantations is another possible explanation for lower numbers of insectivores in coffee plantations (Perfecto et al., 1996; Greenberg et al, 1997a; Shahabuddin, 1997). The susceptibility of insectivores to such anthropogenic disturbance is well documented (for example Thiollay, 1995; Raman & Sukumar, 2002 Tejeda-Cruz & Sutherland, 2004). One species of strata-generalist insectivore – Oriental white-eye (*Zosterops palpebrosus*) – was ubiquitous in coffee plantations but rarely encountered in contiguous forest.

Frugivore species contributed a greater proportion to the overall bird community of coffee plantations than in contiguous forest. Natural shade coffee plantations exhibited similar species diversity and marginally higher species richness than Silver oak shade plantations. Thiollay (1995) reported higher abundance of small frugivores in agroforests than in forests in Sumatra; a pattern that is reversed in the case of large frugivores. During the current study, the frugivore community was dominated by small frugivores. The large frugivores, Mountain Imperial Pigeon (*Ducula badia*) and Malabar grey hornbill (*Ocyceros griseus*) were seldom encountered, even in contiguous forest. The relatively more species-rich frugivore community of coffee plantations may also be explained by the high abundance of large fruiting trees in coffee plantations, especially of the genus *Ficus* (Bhagwat, 2002). Even silver oak shade plantations had *Ficus* trees dispersed across the estate, as opposed to the forest site where no *Ficus* trees were encountered during sampling. This result is backed by the perception that many species of frugivores are not averse to crossing unsuitable habitat in search of clumped resources (Luck & Daly, 2001).

### Habitat-preference guilds and large-bodied birds

Natural shade coffee plantations which had the highest estimated tree species richness and diversity among habitat types exhibited species richness of forest-dependant birds comparable to that of contiguous forest, while being significantly higher than that of silver oak shade plantations. Similar patterns have been observed in the neotropics, where canopy tree species diversity was positively correlated with the number of forest bird species (Reitsma, Parrish & McLarney, 2001). Woodland generalist species were evenly distributed across habitats and open habitat species were more abundant in coffee plantations than in forests. This result may be influenced by not only the differences in habitat type, but also the fact that coffee plantations in the area are spatially closely associated with more open habitats like agricultural fields and fallow. Large-bodied bird species have also been shown to be negatively affected by alteration to forest habitats (Thiollay, 1995; Estades & Temple, 1999).

## Conclusions

Coffee plantations provide a unique case for conserving biodiversity while providing employment and sustenance for a large community (Sherry, 2000). In the current study, species richness across habitat types was often comparable, but turnover in the bird community was always evident, reiterating the need for caution in the promotion of shade coffee as a conservation solution. One must also be cautious when generalizing across different shade types within coffee plantations; results of this study consistently brought out differences in the bird community between natural and silver oak shade coffee plantations. Being ecologically friendly involves more than just the composition of the shade layer. Judicious use of pesticides, careful shade-lopping during the breeding season of birds, and abstinence from trapping and hunting all need to accompany the recognition of the fact that shade coffee plantations offer a novel opportunity to conserve forest birds in human-modified landscapes outside protected forests.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# CHAPTER – 2: The local- and landscape-level factors structuring bird communities in a coffee plantation-tropical forest landscape in the Western Ghats, India.

**Abstract**: Coffee plantations in the Western Ghats hill range, a Global biodiversity hotspot, cover over 15% of the land area and are located between 900 msl and 1400 msl, often spatially associated with contiguous and fragmented forests. Plantation activity and the resultant loss of forest have resulted in major changes in land use and land cover over the last century. The appropriate scale to study the impacts of habitat alteration on ecological communities is a subject of debate. In studies on landscapes that have been altered from their natural state, a major challenge is to determine the role of local-level and landscape-level properties in structuring animal communities. Four hundred and ninety six point counts were conducted over four sampling occasions and two seasons to sample the bird community along gradients of vegetation composition and habitat composition (local-level variables) and distance to contiguous forest and habitat composition within a one kilometer radius of the sampling unit (landscape-level variables) between December 2005 and May 2006. An iterative multiple regression technique was used within a model selection to investigate the patterns in the bird community across gradients in local- and landscape-level variables. Many bird community variables were found to be consistently negatively related to the proportion of silver oak at the point and the distance to contiguous forest. An increase in the number of tree species per point from three to six was predicted to result in an 80% increase in the number of forest bird species in coffee plantations away from the forest. Reduction in the proportion of an exotic tree species silver oak (*Grevilia robusta*) from 60% to 20% was predicted to increase the numbers of interior forest bird species by 20%, and of large-bodied birds by up to 35%. The findings emphasize the role of native-shade

plantations and remnant forests in a coffee-dominated landscape in conserving forest bird communities in tropical landscapes.

*Key words: Western Ghats; coffee plantations; natural shade; silver oak; interior forest species; foraging guilds; local-level variables; landscape-level variables; bird conservation.*

## INTRODUCTION

Chapter one provides a broad overview of the overall bird community in coffee plantations in a forest-coffee landscape. Of primary interest were the species composition and comparisons of species richness and diversity of estates within broad shade-type categories. Different measures of the bird community in coffee plantations were compared to those of contiguous moist-deciduous forest. Categorical measures were used to classify estates, and tree species richness was the only habitat property investigated. Whereas differences in the overall bird community were evident across the three habitat types sampled, a lot of information was lost due to the generalization of information to the shade-type level. (Refer to chapter 1 for a general introduction to bird communities in coffee plantations)

The wide array of habitat niches occupied by birds, coupled with variability in the dispersal ability of different species suggests the influence of a number of factors in structuring bird communities. These may be properties at the local-level, such as vegetation composition and structural diversity, properties at the landscape-level like the distance to contiguous forest; and usually a combination of the two (Graham and Blake, 2001; Naidoo, 2004; Cleary et al., 2005).

Tree covered landscapes, even of exotic planted species, in the vicinity of fragmented forests are believed to offer structural complexity and are often found to enhance the dispersal of forest birds (Renjifo, 2001; Rodewald and Yahner, 2001; Bhagwat, 2005). The ability of such landscapes to harbour forest bird species may be enhanced by a more species-diverse canopy layer (Reitsma, Parrish and McLarney, 2001) and by improved connectivity to natural forests (Moguel and Toledo, 1999; Raman, 2004).

In a plantation landscape, a number of local-level factors and to some extent, landscape-level factors influencing the presence and abundance of bird species are directly related to the management policies of the plantation (Reitsma, Parrish and McLarney, 2001). In shade coffee plantations in the Western Ghats, there is great variability in management policies with regard to the shade layer composition, timber harvest, shade-lopping and pruning, and leaf-litter management. The tree species composition of the shade layer is highly variable across estates, ranging from stands of planted native trees such as a variety of *Ficus*, to monocultures of silver oak (*Grevilia robusta*), an exotic tree species that is harvested on a large-scale for timber. The extraction of silver oak timber may be done annually, or less frequently, and brings out periodic changes in habitat characteristics and vegetation composition. The structure of the habitat too is related to the practice of shade-lopping, and may vary from annual intensive pruning of trees, to simply the removal of 'suckers'.

The response of different components of the overall bird community to changes in local- and landscape-level variables is expected to be guild-specific. Thiollay (1995) reported the reduction in numbers of large-bodied forest species and the proliferation of small-bodied, edge-loving generalist species as a result of conversion of rainforests to agroforests. Canopy frugivores and insectivores have been found to cross stretches of unsuitable habitat to reach resource patches (Luck and Daily, 2003), hence responding more to local-level properties, whereas species closely associated with forests may respond more strongly to a landscape variable such as proximity to contiguous forest.

The current study aims to investigate further the response of various guilds within the bird community to local- and landscape-level variables, and to associate these with management practices. Generalized Linear Models were utilized to investigate the drivers of patterns in the bird community, while testing the following hypotheses:

1. There will be more individuals and species of birds per point as the proportion of silver oak decreases.
2. Given their ability to disperse and track resources, frugivore and nectarivore and large-bodied species will respond most strongly to local-level variables. For instance, the number of frugivores per point would be negatively related to the proportion of silver oak at a point.
3. Species closely associated with forests will respond to both local- and landscape-level properties, and will be most abundant in estates of low silver oak abundance close to the forest.
4. Habitat generalist species will respond most strongly to landscape-level properties, and be most abundant at sites furthest from the forest.

# METHODS

## Study area

The fieldwork was conducted in Chikmagalur District (see Figure 1), which is a major coffee-growing area in the state of Karnataka, India (13°0´ N and 13°32´ N, and 75°32´ E and 75°45´ E). The study site comprised a matrix of shade-coffee plantations, tropical moist-deciduous forest, forest fragments, paddy and mustard fields, and human habitation. The crescent-shaped Bababudan hill range, which rises up to 1900 m in elevation and comprises a habitat of montane *sholas* and grasslands is an eastern offshoot of the central Western Ghats, and a major topographic feature of this landscape. The Bhadra Wildlife Sanctuary, a 493 sq.km stretch of contiguous tropical moist-deciduous forest characterized by tree species *Tectona grandis, Dalbergia latifolia, Terminalia allata, Pterocarpus marsupium* and *Lagerstroemia lanceolata* (Karanth, 1981), forms the northern and western boundaries of the study site, with the ridge of the Bababudan hills, and Aldur town marking the eastern and southern extremities, respectively. The study area is in the vicinity of two Important Bird Areas (Islam and Rahmani, 2004), the Bhadra Tiger Reserve, and Kemmangundi and Bababudan Hills. Twenty five species of birds restricted to moist tropical forests of peninsular India are reported from this area, of which 13 species are endemic to the Western Ghats.

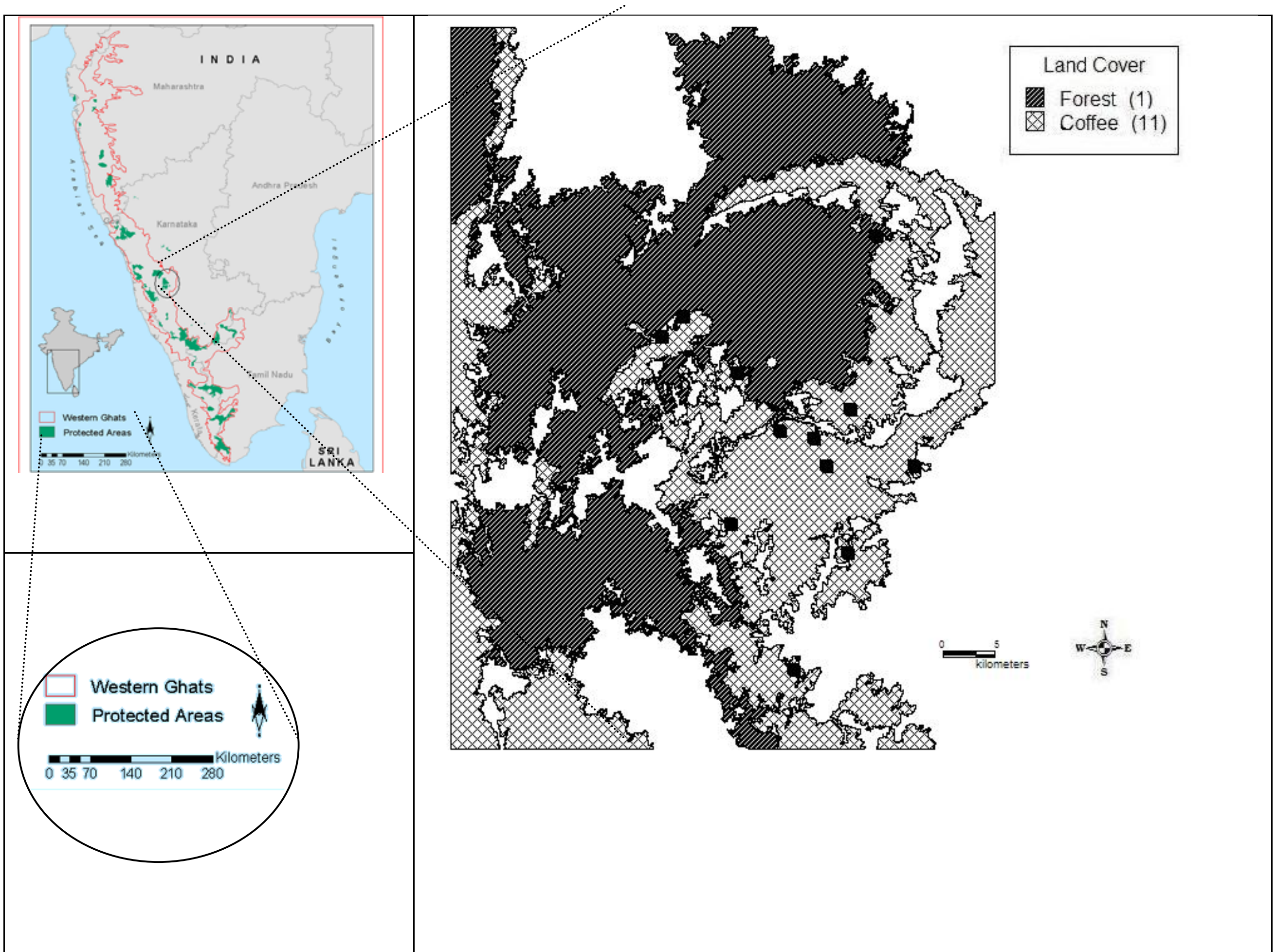


Figure 1: Map of study area showing coffee plantations as light hatching and moist deciduous forest as dark shading. Dark coloured points are the locations of the twelve sampled coffee plantations and the light coloured point is the location of the site sampled in contiguous forest.

Coffee plantations in the district cover over 870 sq.km and contribute close to 25% of all coffee produced from the Western Ghats (Coffee Board of India, 2005). Shade coffee plantations of *Coffea arabica* (predominant) and *Coffea robusta* are located at elevations between 900 msl and 1400 msl, and range in area from small-scale farms of up to 10 hectares, to vast corporately owned plantations of several hundred hectares. All coffee in the region is grown under a shade layer, which, for the purpose of this study was classified as natural shade or silver oak shade. Natural shade coffee is grown under a planted canopy that is dominated by native trees, particularly, species of *Ficus*. The native tree composition in coffee plantations is, however, markedly different from that of adjacent moist-deciduous forests in the area. Coffee in silver oak shade plantations is grown under a canopy that, while containing a few native tree species, is dominated by silver oak.

### Survey of coffee plantations

Twelve shade coffee plantations were sampled for birds, vegetation and habitat characteristics between December 2005 and May 2006. In selecting sites, an attempt was made to capture gradients in both shade-type as well as distance to contiguous forest. Topographic maps at the scale of 1:25000 from Survey of India were used to locate suitable landscapes, within which rapid ground-truthing surveys were carried out to identify estates of appropriate shade type. Only plantations falling between 900 msl and 1200 msl were considered. While an attempt was made to minimize bias in site selection, this study was limited by availability of permission to work on estates, along with other logistical difficulties.

### Bird sampling

Birds were sampled over two seasons – winter (December to February) and summer (March to May). Sampling took place twice every season by conducting five-minute fixed-width point counts (Hutto, Pletschet and Hendrics, 1986), which are appropriate for sampling cryptic understory birds, as well as vocal canopy-dwelling species, but not highly mobile species (Raman, 2003). A minimum of nine and a maximum of 12 point counts were conducted per estate between 0630 and 0915 hrs on two successive mornings each season. All birds seen and heard within a 70 m radius of the point were recorded. Birds flying under the canopy, or within 10 m of the canopy were recorded as well. All species of swifts and swallows were excluded from sampling, as were most species of raptors. Exceptions were the Oriental honey buzzard (*Pernis ptilorhyncus*), Crested serpent eagle (*Spilornis cheela*) and three species of *Accipiter*, which were often seen perched or flying low over the canopy. The Eurasian eagle owl (*Bubo bubo*) was the only nocturnal bird recorded during sampling. A total of 100 species were recorded during point counts. When seen, species group size and canopy layer occupied were recorded, along with distance from the point center to the bird, measured using a laser range finder. When heard, species and estimated distance class was recorded.

Points were located at least 150 m apart, along foot paths and trails, with an effort being made to place the points in a closed geometric shape. This was done using a Garmin GPS 12 XL to mark points and maintain orientation while locating points. On the ground, point count stations were marked using oil chalk.

Bird observations were pooled from four sampling occasions across two seasons, and the summed total was used to characterize the point. Black bulbul (*Hypsipetes leucocephalus*) was excluded from analysis because although the species was encountered in a few coffee plantations, the primary habitat of the species is known to be at altitudes greater than those encountered during the study. Two other species which were detected during sampling, the Indian pond heron (*Ardeola grayii*) and the White-throated kingfisher (*Halcyon smyrnensis*), were excluded from analysis because these are species closely associated with large ponds and water bodies, and were occasionally encountered within coffee plantations.

All detections of any species by call were assigned the mean group size derived from all occasions when the species was seen, when there were more than ten sighting detections of a species; otherwise a group size of one was assigned to the call. Bird studies in the tropics have employed similar approximation techniques (Raman and Sukumar, 2002) in order to analyze bird abundance data.

The overall bird community was divided into guilds based on foraging and habitat preferences. This was done to examine the heterogeneity in the response of different guilds to different habitats, which is believed to be influenced by the natural history of the species within the guild. Guilds examined were classified based on:

4. Feeding guilds: frugivore, insectivore, nectarivore.
5. Habitat preference: interior forest, and open habitat species.
6. Life history parameters: body mass (birds weighing over 90 gms).

All guild categorizations were based on secondary information (Ali and Ripley, 1983; Raman and Sukumar, 2002), Except for body mass, all categorizations were subjective and qualitative, based on secondary information and on field observations. The guild of interior forest birds was defined as one that comprised all species that are typical of moist deciduous and semi-evergreen forests in the area.

**Habitat variables**

Vegetation was sampled at all point count stations, using 10 m radius circular plots. All trees over 30 cm GBH within the plots were identified to genus, and whenever possible to species. In addition to vegetation plots, the following variables were measured/estimated at each point count station.

1. Canopy cover was measured using a canopy densiometer. One reading was taken at the point centre, and four others were taken at locations roughly thn metres away in four different directions. Densiometer readings were corrected to percentages
2. At each of the abovementioned locations, a measure of habitat complexity was estimated by ascertaining the presence or absence of foliage within a 0.5m radius imaginary cylinder above the observer, in the height classes: 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-16, 16-32, >32m. The average number of height classes per point that contained leafy vegetation was used as a measure of vertical stratification.
3. Canopy height was estimated in five metre classes at each of the abovementioned points.
4. The total number of trees over 10m height, within a 30m radius of the point centre was counted.
5. The total number of silver oak trees over 10 m height, within a 30 m radius of the point centre was counted. This count was divided by the count generated in (4) to obtain a value of proportion of silver oak at a point.
6. Tree species composition was obtained using 10m radius vegetation plots at each point count location for all trees greater than 30cm DBH. Local and/or scientific names were recorded and DBH measured or estimated. All trees were identified to genus, and species

whenever possible. The count of the number of species was considered as tree species per point.

7. Within each 10 m vegetation plot, the number of trees and saplings less than 10 m in height were counted. This count was used in analysis as the number of trees forming the middle canopy.

**Landscape-level variables**

Distance to contiguous forest, proportion of natural cover within a one kilometer radius of the estate, and proportion of open habitat within one kilometer of the estate were the landscape-level variables investigated. These were extracted using remotely-sensed data. Satellite IRS-1D LISS III sensor image (path-row 98-64) of the area from February 1998 was obtained and geocoded using an already geocoded November 2000 LANDSAT TM image of the same area.

Using IDRISI Kilimanjaro (Clark Labs, 2003), a Normalized Difference Vegetation Index layer was created using the near infrared and red bands, such that:

NDVI = (NIR-R)/(NIR+R)

NDVI was used to differentiate between moist deciduous forest, coffee plantations, and other open habitats. This was possible because NDVI was known to be highly correlated with various vegetation parameters such as crown closure and canopy biomass and was expected to separate moist deciduous forest vegetation from the evergreen shade layer of coffee plantations (Krishnaswamy et al., 2004).

Known locations from 120 points in coffee plantations and 24 points within moist-deciduous forest were used, along with detailed exploration of the NDVI image to reclassify it into four land-cover types: forest, coffee plantation, open habitat, and other. NDVI value of 0.45 was used as the cut-off to distinguish forest and coffee plantations, and 0.1 as the forest-open habitat cutoff. The accuracy of reclassification was visually estimated using already existing vector layers of forest boundaries and coffee plantation digitized from vegetation maps of the area, as well as the vector layer containing the locations of point count stations. The forest layer was superimposed on an image displaying political forest boundaries, and the areas of remaining forest within these were extracted. This image was used to define the proportion of forest cover within a one kilometer radius of the point. A similar technique was used to obtain the proportion of open habitat within the one kilometer radius.

All bird and habitat variables were expressed as value per point. Only data from the first nine point counts of each estate was analysed. Data were transformed in order to normalize the distribution. Count variables were (n+0.5) square-root transformed (Zar,1999; Renjifo, 2001), distances and basal areas were log transformed (Zar, 1999), and proportions were logit transformed (Johnson and Wichern, 2002).

**Analysis**

The variables were examined for spatial autocorrelation, visually by plotting correlograms and estimating spatial correlation by calculating *Moran's I* (S-PLUS, 2002). Many of the dependant and independent variables were found to be highly spatially auto-correlated.

The factors structuring bird communities in coffee plantations were examined in the framework of generalized linear modeling (GLM) and model selection. In an approach similar to Naidoo (2004), a model selection technique (Burnham and Anderson, 1998) was used to choose the most appropriate from among three competing models to explain variations in the bird community. The three models were:

1. Habitat-level variables alone,
2. Landscape-level variables alone, and
3. Habitat- and landscape-level variables.

Within the group of local- and landscape-level variables pair-wise comparisons were made, and when variables were highly correlated ($r \geq 0.7$), one of them was dropped from the analysis. One variable each was dropped from the habitat- and landscape-level groups; the number of trees within a 30 m radius of the point was highly correlated with the proportion of silver oak; hence it was dropped, as was the proportion of area under natural forest cover within a one kilometer radius of the sampled estate, since it was highly correlated with the distance to contiguous forest. The small sample size-corrected Akaike's Information Criterion ($AIC_c$) was used as the basis for model selection (Burnham and Anderson, 1994; Johnson and Omland, 2004).

One way to account for spatial autocorrelation is to not use all points from the sample by choosing a subset of points at random (Legendre, 1993). This was done in an iterative process that was used to fit a multiple linear regression model to a dataset of one dependant variable (bird community variable, Y1) against two independent variables (habitat/landscape, X1 and X2) variables. Five-hundred iterations of a multiple linear regression were run, and in each iteration three points each from Y1, X1 and X2 were chosen with replacement from each estate. Means of the three points within each variable were used to generate a total of 12 data points in each iteration, and these were fed into the regression model. Values of intercept, slopes, R-squared and $AIC_c$ were recorded for each run. The median values of $AIC_c$, intercept, slopes and R-squared were reported. A program was written to carry out the iterative regression procedure and this was run in S-Plus (S-PLUS, 2002).

Diagnostic plots of the regression and residuals were output for ten out of the 500 randomizations, and these were examined to verify whether the models met the assumptions of GLM. This was done only for the best models (selected using $AIC_c$).

The randomization model was run up to ten times for each dependant variable, in order to test the appropriateness of local-level variables alone, landscape-level variables alone, and a combination of the two. Only the best predictors in each of these categories were reported, along with the difference between that $AIC_c$ and the minimum $AIC_c$ for a given model ($\Delta_i$), and Akaike Weights ($w_i$), a measure of which model is the most appropriate for the data (Burnham and Anderson, 1994).

## RESULTS

In all, 16 response variables of the overall bird community were examined in the GLM framework, using the model-selection approach to choose the best model. Of these, seven responded most strongly to local-level variables alone, two responded strongest to properties of the landscape alone, and seven others were best explained by a combination of local- and landscape-level variables (Table 1).

Table 1: Bird community regression model selected based on $AIC_c$ and Akaike weights ($w_i$). Median regression parameters intercept, slope 1(S1), slope 2 (S2) and $R^2$ are reported.

| Bird community component | Model selected | X1 | X2 | AICc | $w_i$ | Inter-cept | S1 | S2 | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| All individuals | Local | Proportion Silver oak | Number tree species | -4.02 | 0.479 | 5.79 | -0.59 | 0.64 | 0.29 |
| All species | Local | Proportion Silver oak | Number middle-storey trees | -24.4 | 0.483 | 4.13 | -0.18 | 0.12 | 0.24 |
| Interior forest individuals | Local+landscape | Proportion Silver oak | Distance contiguous forest | -1.31 | 0.456 | 5.93 | -0.52 | -0.4 | 0.38 |
| Interior forest species | Local+landscape | Number tree species | Distance contiguous forest | -20.48 | 0.297 | 2.75 | 0.45 | -0.19 | 0.32 |
| Frugivore individuals | Local+landscape | Proportion Silver oak | Distance contiguous forest | 3.41 | 0.459 | 5.95 | -0.52 | -0.4 | 0.38 |
| Frugivore species | Local | Proportion Silver oak | Tree density | -18.65 | 0.424 | 3.09 | -0.12 | -0.12 | 0.24 |
| Insectivore individuals | Local | Proportion Silver oak | Basal area | -7.83 | 0.390 | 4.39 | -0.05 | 0.33 | 0.12 |
| Insectivore species | Local+landscape | Number tree species | Distance contiguous forest | -25.93 | 0.328 | 2.62 | 0.15 | 0.1 | 0.28 |
| Large-bodied individuals | Local+landscape | Proportion Silver oak | Distance contiguous forest | -2.66 | 0.413 | 2.27 | -0.43 | 0.05 | 0.24 |
| Large-bodied species | Local | Proportion Silver oak | Tree density | -25.34 | 0.659 | 1.03 | -0.11 | 0.35 | 0.24 |
| Middle/understory insectivore individuals | Local | Canopy cover | Number middle-storey trees | -12.58 | 0.317 | 2.55 | 0.43 | 0.13 | 0.28 |
| middle/understory insectivore species | Local+landscape | Canopy cover | Distance contiguous forest | -25.33 | 0.366 | 1.85 | 0.21 | 0.09 | 0.31 |
| Nectarivore individuals | Local | Proportion Silver oak | Number tree species | 0.459 | 0.460 | -1.75 | -0.09 | 0.51 | 0.28 |
| Nectarivore species | Landscape | Distance contiguous forest | Proportion open cover | -21.9 | 0.356 | 1.83 | -0.13 | 0.09 | 0.2 |
| Open habitat individuals | Local+landscape | Proportion Silver oak | Distance contiguous forest | -7.11 | 0.541 | 1.88 | -0.35 | 0.51 | 0.43 |
| Open habitat species | Landscape | Distance contiguous forest | Proportion open cover | -20.63 | 0.452 | 1.37 | 0.26 | 0.02 | 0.5 |

For the 16 response variables, the proportion of silver oak was selected ten times as one of the two variables of the most appropriate model, based on $AIC_c$ and $w_i$ values. Another measure of vegetation composition, the number of tree species within a 10 m radius of the point count station was another often selected (four times) variable. Patterns along gradients of the proportion of silver oak were evident across almost all the guilds examined, and were particularly significant for frugivorous and nectarivorous birds.

Distance to contiguous forest and the proportion of open habitat in a one kilometer buffer of the estate were the only two landscape-level variables examined. Proportion of open habitat was an always positive, but weak predictor of any measure of the bird community (median $R^2$=0.1, across all comparisons). Distance to contiguous forest was the most often selected landscape-level variable (nine times), and had both positive and negative relationships with different components of the bird community. Interior forest birds and open habitat birds responded strongly to distance from contiguous forest. The respective changes were in opposite directions. Interior forest birds declined and open habitat birds increased with distance to contiguous forest.

The guild of middle and understory insectivores was positively influenced more by structural complexity of the habitat: the number of middle canopy trees and the amount of canopy cover. Other local-level variables selected by the model that were related to habitat structure were basal area (once) and tree density (twice).

Predictions of the regression model indicate that a reduction in proportion of silver oak from 60% to 20% would bring about an 18% increase in the numbers of interior forest birds in estates within four kilometers of contiguous forest, as opposed to 20% in estates further than that from the forest. A similar reduction in silver oak proportion would result in as much as a 33% increase in numbers large-bodied birds close to the forest and 34% in estates far from forest. An increase in the number of tree species encountered within a 10 radius circle from three to six would be expected to result to in an 80% increase in the number of species of interior forest birds in sites away from the forest. Close to forest, the corresponding increase is only 18%.

## DISCUSSION

The results highlight the strong combined influence of shade-type and distance to contiguous forest on the bird community within coffee plantations. The proportion of silver oak at a point was found to be consistently negatively related to all the defined components of the bird community. Points with lower proportions of silver oak generally recorded greater numbers of birds and bird species. Greater magnitude of change with respect to local-level variables at the away from forest sites in the numbers of interior forest species suggests the increased role of natural shade coffee plantations in conserving the forest bird community.

Forest-dependant bird species in fragmented forest landscapes are often reported to respond to patch-level properties, such as patch area (Graham and Blake, 2001). This may, however simply be a factor of the spatial scale of analysis, as suggested by Boulinier et al. (2001) who found higher species richness of forest birds in landscapes that had larger proportions of natural cover. Naidoo (2004) reported a positive, non-linear relationship between forest dependant species richness and a model comprising both local- and landscape-level variables. In the current study, the numbers of individuals and species of interior forest birds were found to be strongly influenced by a combination of both local-level and landscape-level variables. Species richness and abundance of interior forest birds were negatively related to the proportion of silver oak, and positively to the number of tree species within a 10 m radius of the point count station. This is in agreement with Reitsma et al. (2001) who document an increase in forest dependant bird species with increasing species diversity of the canopy layer. At the landscape-level, the abundance of interior forest bird species was negatively related to distance to contiguous forest. This indicates a positive relationship between interior forest bird species and the proportion of forest cover within one kilometer of the estate (a variable that was not used in the multiple regression as it was highly negatively correlated with distance to forest). This is in agreement with other studies in tree covered landscapes (Renjifo, 2001; Rodewald and Yahner, 2001).

Open habitat species, typically habitat generalists, displayed a strong response to landscape-level variables, and were more abundant and speciose in sites at greater distances from contiguous moist deciduous forest. Another factor that may influence their numbers in sites away from forests is the fact that these sites are often closer to open, dry habitats which flank the study site to the east.

All three foraging guilds examined: frugivores, insectivores and nectarivores, were more abundant at points with lower proportions of silver oak. Such a pattern of greater abundance of these foraging guilds in more traditional plantations, as opposed to shaded monocultures has also been observed elsewhere (Calvo and Blake, 1998). Frugivores and nectarivores responded strongly to floristic properties: negatively to the proportion of silver oak and positively to tree species richness; possibly a consequence of lower abundance of resources in monoculture shade plantations (Raman, 2004). Nectarivore species richness was found to decrease with distance to contiguous forest. Two small nectarivore species, Crimson-backed sunbird (*Nectarina minima*) and Little spiderhunter (*Arachnothera longirostra*) seemed to be the most sensitive to distance from forest, and were seldom encountered very far from the forest edge. The strong response of frugivore species to local-level variables alone re-iterates the ability of many species within this group to cross unsuitable habitat to track patchy resources (Luck and Daily, 2003). The frugivores community encountered during this study comprised many canopy and strata-generalist frugivores, species which are known to proliferate in plantation landscapes (Thiollay, 1995). Large-bodied bird species, a category that includes many frugivores are capable of wide dispersal in tree-covered landscapes, and were found to be most strongly responding to habitat properties at the local level, especially to the proportion of silver oak at any point.

The guild of middle and understory insectivores, widely believed to be sensitive to disturbances in the landscape (Thiollay, 1995; Stouffer and Bierregaard, 1995) was found to respond more to local-level properties of habitat structure. The abundance of individuals and species within the guild were, however, significantly lower in coffee plantations than in adjoining forests (see Chapter 1). This would be expected, given the high degrees of habitat management in almost all coffee plantations, especially of the coffee layer and middle storey.

Shade coffee plantations are widely believed to be refuges of biodiversity in tropical landscapes (Perfecto et al., 1996; Greenberg et al., 1997b; Petit and Petit, 2003). While this may be largely valid, it must be viewed with caution for two reasons. First, numerous studies report species composition in shade coffee plantations to be markedly different from that of natural habitats in the area (Greenberg et al., 1997a); with highly sensitivity species being the being the most affected (Rappole et al., 2003; Tejeda-Cruz and Sutherland, 2004). Second, variation in bird community among shade types within coffee plantations is often evident, with shaded monocultures being relatively de-pauperate when compared to traditional coffee plantations. In the current study, the numbers of species and individuals per point was found to vary deterministically along a gradient of the proportion of silver oak. Silver oak trees have become an integral part of the economy of the region, resulting in large areas of the landscape being converted to habitat unsuitable for bird conservation. The study also identifies the importance of forest cover in the landscape in determining the numbers of interior forest birds in coffee plantations. Patches of forest in this landscape often are located on private lands that are parts of coffee estates. There is a perception among planters in the area that birds are beneficial to coffee plantations, especially in pest control. In order that this continue to be so, it is important that management practices in coffee plantation give importance to the retention native tree species in the shade layer and native forests in the landscape.

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# CONCLUSION

A hundred bird species were recorded in coffee plantations, many of which were species typical of forested and woodland habitats; an indication that coffee plantations do have potential for the conservation of native forest avifauna. There were, however, marked differences between coffee plantations and moist deciduous forest in terms of the overall bird community. Between shade types, silver oak estates consistently had fewer species and fewer individuals of most components of the bird community; an indication that not all forms of shade coffee production are suitable for bird conservation.

Low proportion of silver oak and high tree species richness of estates were found to be the local-level factors most strongly related to the abundance of birds in coffee plantations, especially the guild of interior forest birds. The proximity to contiguous forest and the proportion of natural cover in the surroundings also had a strong positive influence on interior forest bird species.

The shade layer in coffee estates, whether native or exotic, is often planted. The composition of the canopy and the proportion of silver oak are therefore variables that are strongly influenced by management practices. Fragmented forests in the study area were often located on privately owned coffee plantations, therefore their persistence and integrity are again related to management decisions. If the conservation of bird diversity is of importance it is essential that awareness be spread among management decision-makers in coffee plantations, and changes in habitat be viewed in term of the sensitivity of bird species.

# APPENDIX – 1

Table 1: Foraging, habitat, and body-size guilds, defined based on Ali and Ripley, 1983; and Raman and Sukumar, 2002.

| Guild | Abbreviation. | No. spp. |
|---|---|---|
| Bark insectivore | BI | 12 |
| Canopy frugivore | CF | 7 |
| Forest dependant | For | 57 |
| Generalist insectivore | GI | 8 |
| Large-bodied birds (over 90g) | LB | 60 |
| Middle/under storey insectivore | MI | 29 |
| Omnivore | O | 6 |
| Open habitat dependant | Open | 24 |
| Upper canopy insectivore | UI | 14 |
| Woodland dependant | Wood | 29 |
| Nectarivore | N | 4 |
| Nectarivore/Insectivore | NI | 7 |
| Carnivore | C | 7 |
| Granivore | G | 7 |
| Generalist frugivore | GF | 9 |

Table 2: Bird species checklist from coffee plantations in Chikmagalur and contiguous moist deciduous forest of the Bhadra Wildlife Sanctuary.

| Sl. No | Species | | Diet | | Habitat | Feeding and canopy guild | Size |
|---|---|---|---|---|---|---|---|
| | Common name | Scientific name | Primary | Secondary | | | |
| 1 | Ashy drongo | Dicrurus macrocercus | I | N | Wood | UI | |
| 2 | Ashy prinia | Prinal socialis | I | | Open | MI | |
| 3 | Asian brown flycathcher | Muscicapa dauurica | I | | Open | GI | |
| 4 | Asian Fairybluebird | Irena puella | N | F | For | N | LB |
| 5 | Asian paradise flycatcher | Terpsiphone paradisi | I | | Wood | MI | |
| 7 | Brown shrike | Lanius cristatus | I | C | Open | MI | |
| 8 | Bay-banded cuckoo | Cacomantis sonneratii | I | | Wood | UI | LB |
| 9 | Black-crested bulbul | Pycnonotus melanicterus | F | I | For | UI | |
| 10 | Brown-cheeked fulvetta | Alcippe poioicephala | I | | For | MI | |
| 11 | Brown-capped pygmy woodpecker | Dendrocopus nanus | I | | Wood | BI | |
| 12 | Blue-capped rock thrush | Monticola cinclorhynchus | I | | For | MI | LB |
| 13 | Black-hooded oriole | Oriolus xanthornus | F | N | For | UI | LB |
| 14 | Besra | Accipiter virgatus | C | | For | C | LB |
| 15 | Black-lored tit | Parus xanthogenys | I | | For | GI | |
| 16 | Black-naped monarch | Hypothymis azurea | I | | For | MI | |
| 17 | Bronzed drongo | Dicrurus aeneus | I | N | For | UI | LB |
| 18 | Black-rumped flameback | Dinopium benghalense | I | N | Wood | BI | LB |
| 19 | Blyth's reed warbler | Acrocephalus dumetorum | I | | Open | MI | |
| 20 | Black-throated munia | Lonchura kelaarti | G | | For | G | |
| 21 | Bar-winged flycatcher-shrike | Hemipus picatus | I | | For | UI | |
| 22 | Blue-winged leafbird | Chloripsis cochinchinensis | I | N | Open | NI | |
| 23 | Crested goshawk | Accipiter trivirgatus | C | | For | C | LB |
| 24 | Common flameback | Dinopium javanense | I | | For | BI | LB |

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|---|---|---|---|---|---|---|---|
| 25 | Common hoopoe | Upupa epops | I | | Open | GI | LB |
| 26 | Common iora | Aegithina tiphia | I | | Open | GI | |
| 27 | Common rosefinch | Carpodacus erythrinus | G | N | Open | G | |
| 28 | Common tailorbird | Orthotomus sutorius | I | | Open | MI | |
| 29 | Chestnut-bellied nuthatch | Sitta castanea | I | | Wood | BI | |
| 30 | Crimson-backed sunbird | Nectarina minima | N | I | For | NI | |
| | | | | | | | |
| | Species | | Diet | | Habitat | Feeding and canopy guild | Size |
| | Common name | Scientific name | Primary | Secondary | | | |
| 31 | Crimson-fronted barbet | Megalaima rubricapilla | F | | For | CF | |
| 32 | Chestnut-headed bee-eater | Merops leschenaulti | I | | Open | UI | LB |
| 33 | Common hawk cuckoo | Hierococcyx varius | I | C | Wood | MI | LB |
| 34 | Crested serpant eagle | Spilornis cheela | C | | For | C | LB |
| 35 | Chestnut-shouldered petronia | Petronia Xanthocollis | G | | Open | G | |
| 36 | Chestnut-tailed starling | Sturnus malabaricus | F | N | Wood | NI | LB |
| 37 | Drongo cuckoo | Surniculus lugubris | I | | For | UI | LB |
| 38 | Dark-fronted babbler | Rhopocichla atriceps | I | | For | MI | |
| 39 | Eurasian blackbird | Turdus merula | I | F | Wood | GI | LB |
| 40 | Emerald dove | Chalcophaps indica | G | F | For | G | LB |
| 41 | Eurasian eagle owl | Bubo bubo | C | | For | C | LB |
| 42 | Eurasian golden oriole | Oriolus oriolus | F | N | Wood | CF | LB |
| 43 | Forest Wagtail | Dendronanthus indicus | I | | For | MI | |
| 44 | Greater coucal | Centropus sinensis | C | I | Wood | C | LB |
| 45 | Greater flameback | Chrysocolaptes lucidius | I | N | For | BI | LB |
| 46 | Grey wagtail | Motacilla cinerea | I | | Open | MI | |
| 47 | Gold-fronted leafbird | Chloropsis aurifrons | I | N | For | NI | |
| 48 | Grey-headed canary flycatcher | Culicicapa ceylonensis | I | | For | MI | |
| 49 | Grey junglefowl | Gallus sonneratii | O | | For | O | LB |
| 50 | Greenish warbler | Phylloscopus | I | | Open | GI | |

| | Species | | Diet | | Habitat | Feeding and canopy guild | Size |
|---|---|---|---|---|---|---|---|
| | Common name | Scientific name | Primary | Secondary | | | |
| | | trochiloides | | | | | |
| 51 | Greater racket-tailed drongo | Dicrurus paradiseus | I | N | For | UI | LB |
| 52 | Hill myna | Gracula religiosa | F | N | For | N | LB |
| 53 | Heart-spotted woodpecker | Hemicircus canente | I | | For | BI | LB |
| 54 | Indian peafowl | Pavo cristatus | O | | Wood | O | LB |
| 55 | Indian blue robin | Luscinia brunnea | I | | For | MI | |
| 56 | Indian scimitar babbler | Pomatorhinus horsfieldii | I | N | For | MI | LB |
| 57 | Jungle babbler | Turdoides striatus | I | | Wood | MI | LB |
| 58 | Jungle myna | Acridotheres fuscus | F | | Open | GF | LB |
| 59 | Large cuckooshrike | Coracina macei | I | | Wood | UI | LB |
| 60 | Little spiderhunter | Arachnothera longirostra | N | I | For | NI | |
| 61 | Loten's sunbird | Nectarina lotenia | N | I | Open | NI | |
| 62 | Large woodshrike | Tephrodornis gularis | I | | For | MI | LB |
| 63 | Lesser yellownape | Picus chlorolophus | I | | Wood | BI | LB |
| 64 | Large-billed crow | Corvus macrorhynchos | O | | Open | O | LB |
| 65 | Large-billed leaf warbler | Phylloscopus tytleri | I | | For | UI | |
| 66 | Malabar parakeet | Psittacula columboides | F | N | Wood | GF | LB |
| 67 | Malabar trogon | Harpactes fasciatus | I | | For | MI | LB |
| 68 | Malabar grey hornbill | Ocyceros griseus | F | I | For | CF | LB |
| 69 | Mountain imperial pigeon | Ducula badia | F | | For | CF | LB |
| 70 | Malabar whistling thrush | Myophonus horsfieldii | I | F | For | MI | LB |
| 71 | Oriental white-eye | Zosterops palpebrosus | I | | Wood | GI | |
| 72 | Oriental honey-buzzard | Pernis ptilorhyncus | N | C | Open | C | LB |
| 73 | Orange-headed thrush | Zoothera citrina | I | | For | MI | LB |

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|---|---|---|---|---|---|---|---|
| 74 | Oriental magpie robin | Copsychus saularis | I | | Wood | MI | LB |
| 75 | Oriental turtle dove | Streptopelia orientalis | G | | For | G | LB |
| 76 | Plain flowerpecker | Diaceum concolor | F | N | Wood | GF | |
| 77 | Purple sunbird | Nectarina asiatica | N | I | Open | NI | |
| 78 | Pale-billed flowerpecker | Diaceum erythrorynchos | F | N | Open | GF | |
| 79 | Plum-headed parakeet | Psittacula cyanocephala | F | N | Wood | CF | LB |
| 80 | Pompadour | Treron pompadora | F | | For | CF | LB |
| 81 | Puff-throated babbler | Pellorneum ruficeps | I | | For | MI | |
| 82 | Rufous babbler | Turdoides subrufus | I | | For | MI | LB |
| 83 | Red spurfowl | Galloperdix spadicea | O | | For | O | LB |
| 84 | Rufous treepie | Dendrocitta vagabunda | O | | Wood | O | LB |
| 85 | Rufous woodpecker | Celeus brachyurus | I | | For | BI | LB |
| 86 | Rose-ringed parakeet | Psittacula krameri | F | N | Open | CF | LB |
| 87 | Red-vented bulbul | Pycnonotus cafer | F | I | Open | GF | LB |
| 88 | Red-whiskered bulbul | Pycnonotus jucosus | F | I | Open | GF | |
| | Species | | Diet | | Habitat | Feeding and canopy guild | Size |
| | Common name | Scientific name | Primary | Secondary | | | |
| 89 | Spotted dove | Streptopelia chinensis | G | | Open | G | LB |
| 90 | Speckled piculet | Picumnus innominatus | I | | For | BI | |
| 91 | Spangled drongo | Dicrurus hottentottus | N | I | Wood | N | LB |
| 92 | Scarlet minivet | Pericrocotus flammeus | I | | For | UI | |
| 93 | Shikra | Accipiter badius | C | | Open | C | LB |
| 94 | Small minivet | Pericrocotus cinnamomeus | I | | Wood | UI | |
| 95 | Tickell's leaf warbler | Pycnonotus affinis | I | | Wood | MI | |
| 96 | Tawny-bellied babbler | Dumetia hyperythra | I | | Wood | MI | |
| 97 | Thick-billed flowerpecker | Diaceum agile | F | N | Wood | GF | |
| 98 | Tickell's blue flycatcher | Cyornis tickelliae | I | | For | MI | |
| 99 | Verditer flycatcher | Eumyias thalassina | I | | Wood | UI | |
| 100 | Velvet-fronted nuthatch | Sitta frontalis | I | | For | BI | |

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|---|---|---|---|---|---|---|---|
| 101 | Vernal hanging parrot | Loriculus vernalis | F | | Wood | GF | LB |
| 102 | White-bellied treepie | Dendrocitta leucogastra | O | | For | O | LB |
| 103 | White-bellied woodpecker | Dryocopus javensis | I | | For | BI | LB |
| 104 | White-bellied blue flycatcher | Cyornis pallipes | I | | For | MI | |
| 105 | White-cheeked barbet | Megalaima viridis | F | | For | GF | LB |
| 106 | Western-crowned warbler | Phylloscopus occipitalis | I | | For | MI | |
| 107 | White-rumped munia | Lonchura striata | G | | For | G | |
| 108 | White-rumped shama | Copsychus malabaricus | I | | For | MI | LB |
| 109 | Yellow-browed bulbul | Iole indica | F | I | For | GI | LB |
| 110 | Yellow-crowned woodpecker | Dendrocopus mahrattensis | I | | Wood | BI | LB |