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# The mammalian communities in coffee plantations around a protected area in the Western Ghats, India

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ABSTRACT

Forest reserves are increasingly becoming isolated, embedded in a matrix of various kinds of human land-use. Coffee plantations form the dominant matrix around many forest reserves in the tropics. In such a situation, the species richness and abundance of animals in coffee plantations can be expected to be determined by their proximity to the forest reserve and characteristics of the local vegetation. We tested this hypothesis with data on mammals (excluding bats, murids and insectivores) collected from 15 coffee plantations around the Bhadra Wildlife Sanctuary in the Western Ghats mountain ranges in India, between December 2005 and May 2006. We estimated mammal species richness and abundance from indirect evidence in belt transects and track plots, and from sightings during night surveys. We sampled the vegetation of the plantations from 36 plots of 5 m × 5 m, in each estate. Twenty-eight species of mammals were recorded from 15 plantations. The number of species recorded in individual estates ranged from 5 to 19, with an average of 11.8. Distance from the Sanctuary was the most important factor that negatively influenced species richness, and the abundance of many species. Local vegetation characteristics influenced only the abundance of some small species. Coffee plantations can be a buffer around forest reserves and improve connectivity between them. However, increasing conversion of native shade into silver oak and hunting are two issues that must be addressed if coffee plantations are to form high-quality matrix around forest reserves in the Western Ghats.

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## 1. Introduction

Forest reserves are increasingly becoming patches embedded in a matrix of human altered habitats of various kinds, such as plantations, agricultural fields and pastures. The ability of organisms to use this matrix is important for the persistence of their populations (Saunders et al., 1991; Fahrig, 2001; Ricketts, 2001). Matrices can be corridors between patches of remnant forests, have resident populations of several species, and are used by several species as feeding or breeding grounds. Hence, such matrices can be as important as the forest fragments themselves (Numa et al., 2005; Estrada et al., 2006). However, the values of a matrix depend on its biophysical characteristics and type of land use (Simberloff et al., 1992; Dunford and Freemark, 2004). The Western Ghats mountain ranges in India, a biodiversity hotspot covering nearly 160,000 $km^2$, have undergone extensive habitat fragmentation due to conversion of

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natural forests to plantations of tea, coffee, cardamom and teak (Menon and Bawa, 1997). Several protected areas established in the remaining forest are embedded in a matrix of these plantations. Coffee plantations is such a matrix covering nearly 3300 km$^2$, which equals approximately 25% of the total protected area network in the Western Ghats (World Conservation Monitoring Centre, 2005).

Coffee cultivation was introduced in India in the 1740s and soon it replaced the best stretches of mid-elevation moist deciduous and evergreen forests. Indian coffee is grown traditionally under shade comprising native forest tree species (Elliot, 1898; Coffee Board of India, 2006). It has been argued that in the tropics, such traditional agricultural practices that incorporate trees are compatible with conservation of native biodiversity (Moguel and Toledo, 1999; Rice and Greenberg, 2000; Siebert, 2002; Daily et al., 2003; McNeely and Schroth, 2006). However, in the last few decades, coffee planters in India have started shading coffee with silver oak (*Grevillea robusta*), an exotic timber-producing tree from Australia. It is a fast growing, sparse shade species, fetching about $700 per m$^3$, and provides an additional source of income against the fluctuations of coffee prices (Damodaran, 2002). The conversion of diverse natural shade to monocultures in coffee plantations elsewhere has led to the loss of biodiversity (Perfecto and Vandermeer, 1994; Perfecto and Snelling, 1995; Greenberg et al., 1997), and conversion to silver oak shade in the Western Ghats probably has similar effects.

Given the suggested merits of shade grown coffee and strategic location around remnant forests in the biodiversity rich Western Ghats (Das et al., 2006), coffee plantations may provide good opportunities for the conservation of wildlife outside protected areas. It also provides an ideal opportunity to examine the factors that influence the use of such a matrix by species that occur in adjoining natural forests. In this paper, we examine the species richness and abundance of mammals (excluding bats, murid rodents and insectivores) in coffee plantations around a protected area in the Western Ghats. We hypothesized the mammalian communities in coffee plantations to be a function of their proximity to the protected area and vegetation characteristics, particularly the extent of silver oak.

## 2. Methods

### 2.1. *Study area*

This study was carried out from December 2005 to May 2006 in the coffee landscape around the moist deciduous forests of Bhadra Wildlife Sanctuary (492 km$^2$) in the Chikmagalur district, Karnataka (Fig. 1). Chikmagalur is the largest coffee producing area in India. Both varieties of coffee, *Coffea arabica* and *C. robusta*, are grown here over about 87,000 ha, constituting approximately 24% of total land under coffee production in the country. Arabica is grown from 800 m to 1500 m elevation and robusta is restricted to lower elevations. This region contributes approximately 25% of total coffee production and 42% of total production of arabica (Coffee Board of India, 2006). Arabica requires more shade (~70%) than robusta (~40%), therefore this region accounts for a high proportion of coffee production under natural shade (Damodaran, 2002). These plantations follow a three-tier shade system. The lower shade consists of nitrogen fixing species such as *Erythrina lithosperma* and *Gliricidia maculata*, which are planted for this purpose. The mid-layer consists of trees, like several *Ficus* spp., that shed their leaves in the monsoon and maintain a dense canopy during the summer. The top layer consists of hardwood species, which may attract rain-bearing clouds. Although this layer has a tree composition similar to the original forest, they differ in the proportion of silver oak. These plantations practice mixed cropping of pepper (*Piper* sp.), areca nut (*Areca catechu*), orange (*Citrus* sp.), ginger (*Zingiber officinale*), vanilla (*Vanilla planifolia*) and other spices, along with coffee.

The altitude of Chikmagalur ranges from 700 m to 1500 m. The mean temperature varies from 15 °C to 30 °C and the mean annual rainfall is approximately 1800 mm, most of it between June and September. The period from December to March is normally dry. The predominant vegetation types in the region includes moist deciduous and semi-evergreen forests, with montane forest and grasslands at >1400 m altitude. The major land use types other than coffee plantation were state owned reserve forests and revenue lands, consisting of deciduous forests and high altitude grasslands. Coffee plantations were interspersed among these different land use types (Fig. 1).

### 2.2. *Field methods and data analysis*

We sampled 15 coffee estates for non-volant mammals. We excluded murids and shrews because they could not be sampled with the methods that we used. The estates were selected based on their distance from the Bhadra Wildlife Sanctuary (Bhadra WLS) and the extent of silver oak. The estates ranged in area from 44 ha to 160 ha (Table 1), and were at least two kilometres away from each other. Three estates shared boundary with the Bhadra WLS, while one was about 18 km from the Sanctuary.

#### 2.2.1. *Sampling mammals*

During four days of sampling in each estate, mammal species richness and relative abundance were estimated using the following methods:

(a) In each estate, we randomly placed 12 belt-transects (250 m × 2 m), along existing trails, at least 200 m apart from each other. These transects were thoroughly searched for tracks, scats and other signs of mammals (Wemmer et al., 1996). The total number of individual signs across all transects for each species is used as an index of relative abundance in each estate. Estate number 15, where leaf litter had been removed just prior to sampling, was excluded from belt transects. A total of 168 transects was sampled once.

(b) Twelve track plots (Wemmer et al., 1996) were set up in each estate to sample small terrestrial mammals. Each track plot was 1 m in diameter and baited with chicken entrails and rotten fruits. The track-plots were at least

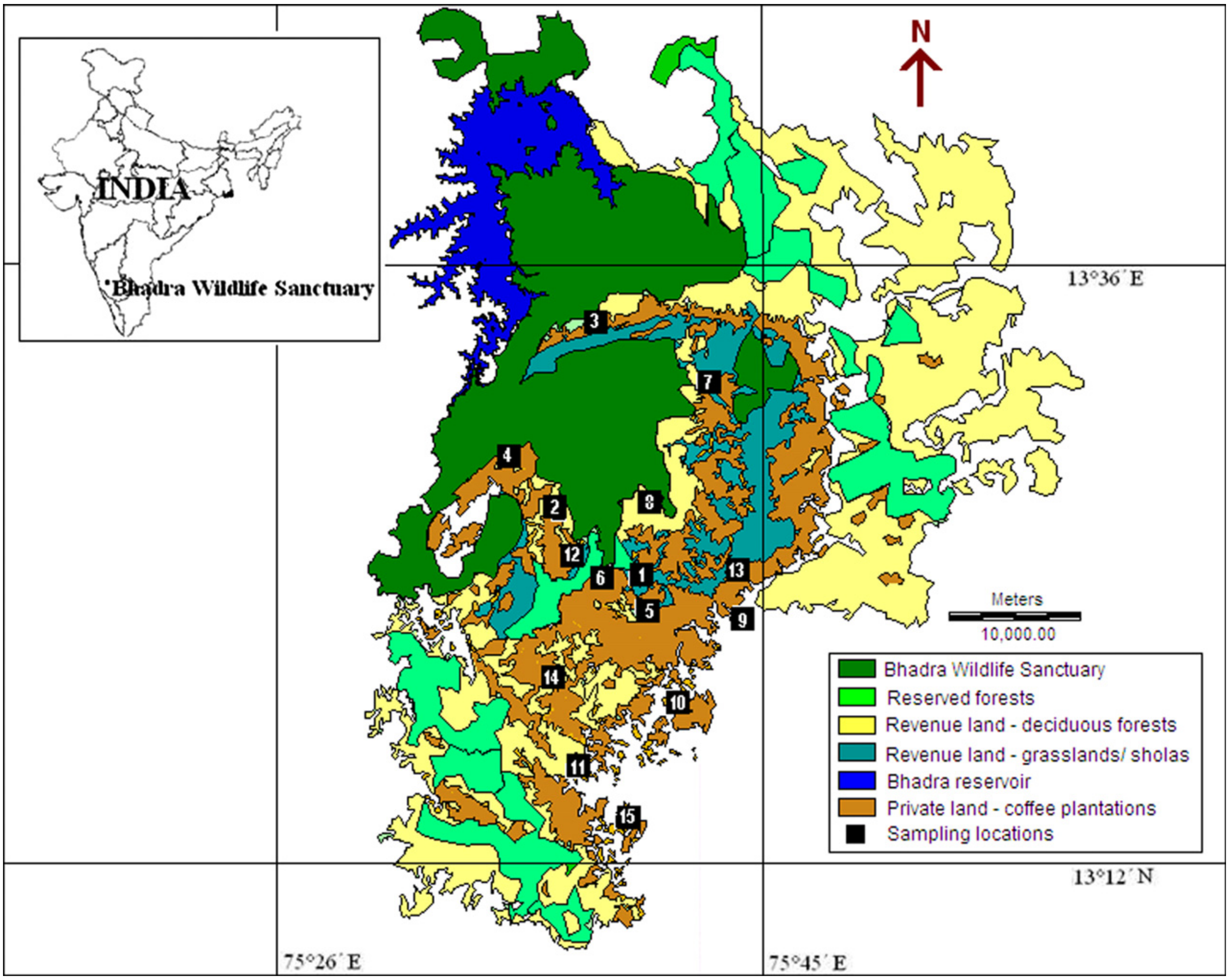


**Fig. 1 – Map of Bhadra WLS with sampling locations, marked 1–14 (see Table 1).**

**Table 1 – General description of the 15 estates**

| Estate no. | Area (ha) | Distance from Bhadra WLS (m) | Altitude range (m) | Tree species (36 plots) | Silver oak (%) | Trees/plot (5 × 5 m) | Mammal species |
|---|---|---|---|---|---|---|---|
| 1 | 132 | 1881 | 1181–1374 | 31 | 31.9 | 4.7 | 12 |
| 2 | 160 | 0 | 973–1173 | 31 | 33.1 | 4.4 | 13 |
| 3 | 152 | 0 | 825–1178 | 20 | 52.6 | 4.7 | 17 |
| 4 | 140 | 206 | 941–1223 | 27 | 14.4 | 2.5 | 12 |
| 5 | 128 | 2931 | 1179–1306 | 24 | 34.5 | 3.2 | 8 |
| 6 | 84 | 185 | 1052–1304 | 36 | 11.4 | 3.2 | 10 |
| 7 | 80 | 894 | 804–1066 | 38 | 11.2 | 3.0 | 11 |
| 8 | 72 | 0 | 761–840 | 22 | 38.8 | 2.7 | 19 |
| 9 | 88 | 8376 | 1107–1238 | 31 | 30.5 | 3.6 | 8 |
| 10 | 94 | 10740 | 1120–1265 | 25 | 21.5 | 3.0 | 9 |
| 11 | 90 | 14356 | 816–928 | 24 | 25.9 | 3.0 | 11 |
| 12 | 100 | 328 | 844–999 | 36 | 20.2 | 2.8 | 16 |
| 13 | 130 | 5488 | 1187–1503 | 24 | 34.5 | 2.3 | 15 |
| 14 | 160 | 7662 | 1040–1311 | 17 | 43.7 | 3.1 | 11 |
| 15 | 44 | 18253 | 1083–1158 | – | – | – | 5 |

200 m away from each other and monitored for three consecutive days. This resulted in a total of 552 track-plot nights in 15 estates. Since tracks of small carnivores were difficult to identify to species level, these were assigned to one of three groups: small cats (jungle cat, leopard cat, rusty spotted cat and feral cat), mongooses (grey, ruddy, stripe-necked and brown mongooses), and palm civets (common and brown palm civets).

(c) We conducted night transects along existing trails, using a spotlight for detecting nocturnal mammals (Umapathy and Kumar, 2000). One transect of approximately 1 km in length was walked twice in each estate, except for estate number 15 where it was walked only once. These transects were placed in areas where we were likely to encounter the nocturnal mammals, and walked between 19:00 h and 21:00 h.

(d) All opportunistic sightings of mammals were recorded.

### 2.2.2. *Sampling vegetation*

Trees $\geqslant$10 cm girth at breast height (3.18 cm diameter) were enumerated from three plots (5 m × 5 m) along each belt transect, resulting in a total of 36 plots for each of the 14 estates. Vegetation sampling could not be carried out in Estate 15 due to lack of field time. Trees were identified to species and voucher specimens collected. From this data we estimated several vegetation characteristics such as percentage of silver oak trees, and number of trees, tree species and basal area per plot for each estate (Appendix A). Food species for mammals were identified from scats, literature and local knowledge.

### 2.2.3. *Estimating distance to Bhadra WLS*

Distance of each belt transect and track plot to Bhadra WLS was extracted from the digitized forest layer of Greater Bhadra landscape (Pascal et al., 1985) using IDRISI-Kilimanjaro (Clark Labs, 2003). The shortest distance of each estate to Bhadra WLS was used in analysis.

### 2.2.4. *Data analysis*

Mammal species richness was determined for each estate by tallying the total number of species detected using all sampling methods. We estimated relative abundance for each species from the proportion of track plots visited over three days and the encounter index estimated from belt transects. Based on descriptions of their natural history and habitat preferences (Prater, 1979; Menon, 2003, Table 2), we classified each species into one of three feeding guilds – carnivore, herbivore and omnivore. The omnivores included a wide range of items in their diet such as fruits, grains, seeds, bark, leaves, insects, small reptiles and birds. Additionally, we characterized each species as a habitat generalist (able to persist in disturbed areas) or forest specialist (confined to undisturbed forest). This categorization did not include small cats and mongooses because species in these groups could not be identified reliably from tracks and droppings.

We used scatter plots and Pearson correlation coefficient to identify variables that had significant influence on species richness and abundance. These variables were then used in a multiple regression to further select variables that best

**Table 2 – Method-wise summary of species encounters**

| Species | No. of tracks[a] | Signs in belt transects | Sightings/calls in night transects | Opportunistic sightings | Feeding guild | Habitat preference |
|---|---|---|---|---|---|---|
| Bonnet macaque *Macaca radiata* | 11 | 353 | | 91 (groups) | O | G |
| Common langur *Semnopithecus entellus hypoleucos* | | 4 | | 1 | O | S |
| Sambar *Cervus unicolor* | | 22 | | 2 | H | S |
| Mouse deer *Moschiola meminna* | 1 | 4 | | | H | S |
| Indian Muntjac *Muntiacus muntjak* | 15 | 60 | 2 | 19 | H | S |
| Spotted deer *Axis axis* | 13 | 41 | 1 | 14 | H | S |
| Gaur *Bos gaurus* | 3 | 16 | | 5 | H | S |
| Wild pig *Sus scrofa* | 2 | 82 | 3 | 14 | O | G |
| Asian elephant *Elephas maximus* | | | 1 | | H | S |
| Sloth bear *Melursus ursinus* | 1 | 7 | | | O | S |
| Jackal *Canis aureus* | 9 | 6 | 1 | | C | G |
| Dhole *Cuon alpinus* | | 9 | | | C | S |
| Tiger *Panthera tigris* | | 6 | | | C | S |
| Common leopard *P. pardus* | 1 | 13 | | 1 | C | S |
| Small cats[b] | 68 | 48 | | 1 | C | – |
| Small Indian civet *Viverricula indica* | 76 | 126 | 1 | | O | G |
| Palm civets[c] | 53 | 163 | 4 | | O | G |
| Mongoose[d] | 32 | 9 | | 6 | C | – |
| Blacknaped hare *Lepus nigricollis* | 9 | 259 | 2 | 12 | – | G |
| Indian porcupine *Hystrix indica* | 4 | 57 | | | – | G |
| Indian giant squirrel *Ratufa indica* | | | | 19 | O | G |
| Jungle striped squirrel *Funambulus tristriatus* | | | | 28 | O | G |
| Dusky striped squirrel *F. sublineatus* | | | | 5 | O | S |
| Large brown flying squirrel *Petaurista philippensis* | | | 10 | | O | S |
| Total records | 298 | 1285 | 25 | 218 | | |

Feeding guilds: omnivores (O), herbivores (H) and carnivores (C). Habitat preferences: habitat generalists (G) and forest specialists (S).

a Total number of tracks pooled over all track plot nights.

b Small cats grouped together. Possible species are jungle cat *Felis chaus*, leopard cat *Prionailurus bengalensis*, rusty spotted cat *P. rubiginosus* and feral cat.

c Palm civets grouped together. Possible species are common palm civet *Paradoxurus hermophroditus* and brown palm civet *P. jerdoni*.

d Mongooses grouped together. Four species of mongoose recorded in direct sightings: grey mongoose *Herpestes edwardsii*, ruddy mongoose *H. smithii*, stripe-necked mongoose *H. vitticollis* and brown mongoose *H. fuscus*.

accounted for the variability in species richness and abundance (Sokal and Rohlf, 1981).

## 3. Results

### 3.1. Vegetation characteristics

A total of 93 tree species were recorded from all the plots in 14 estates (Appendix B). The tree species richness in 36 vegetation plots ranged from 17 to 38 per estate with a mean of 27.57 ( 4.38 ± SD, $n$= 14, Table 1). The number of trees ranged from 1 to 9 per plot (mean = 3.35 ± 0.22, $n$ = 14) and the number of species per plot from 2 to 6 (mean 2.59 ± 0.49, $n$ = 14). Silver oak formed 11.21–52.66% of the trees (mean 29.89% ± 12.24, $n$ = 14) and was negatively correlated with tree species richness in 36 plots ($r = -0.76$, $p = 0.002$, $n$ = 14) and number of fruit trees per plot ($r = -0.60$, $p = 0.02$, $n$ = 14). There was no correlation between any vegetation characteristic and distance to the Sanctuary (Pearson's correlation coefficient $r$ = 0.05–0.36, $p > 0.05$ for all, $n$ = 14).

After silver oak, *Erythrina lithosperma* was the most abundant species, grown to enhance shade. *Ficus glomerata*, *Artocarpus integrifolia* (jackfruit), *Sapindus laurifolius* (soapnut), *Syzigium cuminii* and *Toona ciliata* occurred in all estates in good abundance. Out of all trees recorded, 33% were food sources for frugivorous and some herbivorous mammals, with *F. glomerata* being the most abundant. *Ficus* spp. formed 36.64% (±11.04) of all fruit trees in an estate. In estates with high silver oak abundance, the *Ficus* species were essentially retained for permanent shade and mulch.

### 3.2. Mammal species richness

At least 28 species of mammals were detected in 15 coffee estates (Table 2). Twenty-two species were recorded from belt transects, out of which 15 were also recorded from track plots. In night transects 25 mammals belonging to nine species were recorded, out of which only the flying squirrel and elephant were not recorded using any other method. Opportunistic sightings added three species to the total richness, namely the Indian giant squirrel, jungle striped squirrel and dusky striped squirrel. Number of species recorded an estate ranged from 5 to 19 with a mean of 11.80 (±3.63, Table 1).

Estates close to the Bhadra WLS had many more species than the estates far away. Tiger scats and tracks were detected only in three estates (Estates 2, 3 and 8), all on the periphery of Bhadra WLS. The farthest record was at 1.02 km from the forest boundary. In contrast, signs of leopard were recorded as far as 8.7 km from Bhadra WLS. Of the six estates where leopards were detected, three were adjacent to Bhadra WLS. Apparently, leopards are frequently able to move through coffee plantations, as attacks on domestic animals by leopard were reported from 13 of 15 estates. The presence of dhole and sloth bear, two other large carnivores in the area, was detected in only one plantation each, 100 m and 912 m from the Sanctuary, respectively.

Among the large herbivores, the Asian elephant, gaur and sambar records were limited to the estates close to the Sanctuary (<1 km). In contrast, chital and muntjac were more widespread. Chital was recorded from seven estates and found as far as 14 km from Bhadra WLS. Muntjac was recorded from 11 estates and was the most widespread herbivore. Common langur found in this region, a forest dependent subspecies, was recorded from only one estate that was adjacent to Bhadra WLS (Estate 8). Civets, mongoose, hare, bonnet macaque and jungle striped squirrel were recorded from most of the estates.

Overall mammal species richness in an estate was negatively correlated with its distance from Bhadra WLS ($r = -0.71$, $p = 0.003$, Fig. 2). Species richness in carnivores and herbivores showed a strong negative relationship with distance from Bhadra WLS ($r = -0.75$, $p = 0.001$ and $r = -0.66$, $p = 0.008$, respectively, Fig. 3a) while the number of omnivore species was less affected by distance ($r = -0.45$, $p = 0.09$). The richness in obligate forest species showed a sharp decline as distance from Bhadra WLS increased ($r = -0.83$, $p = 0.00$, Fig. 3b), while the species richness in generalist mammals did not show any relationship with distance ($r = -0.19$, $p = 0.50$, Fig. 3b).

Only three of the six vegetation characteristics that we estimated showed a significant correlation with mammal species richness (Table 3). We included these and distance to Bhadra WLS as covariates in a linear multiple-regression for mammal species richness (Table 4). While distance remained the major determinant of species richness overall and in different guilds (except habitat generalists and omnivores), number of fruit trees per plot was the other determinant, negatively influencing species richness (Table 4). Carnivores were positively correlated with percentage of silver oak.

### 3.3. Abundance

The most abundant species in track plots were the small Indian civet, palm civets, small cats, and mongooses (Table 2). The most abundant species in belt transects were the bonnet macaque, blacknaped hare, palm civets and small Indian

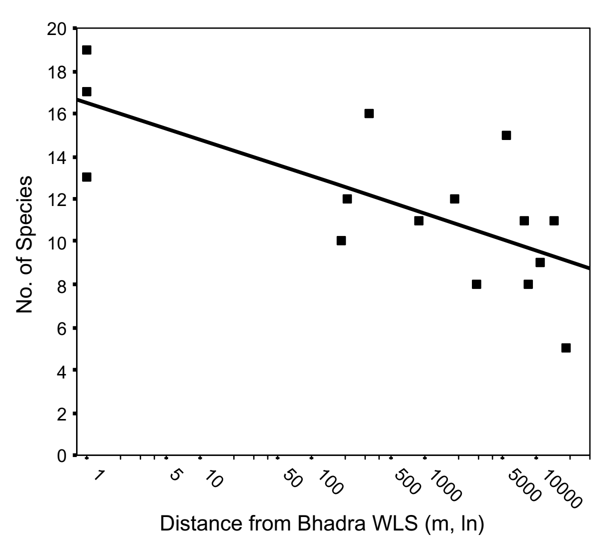


**Fig. 2 – Variation in mammal species richness with distance from Bhadra WLS ($R^2$ = 0.50, $p$ = 0.003).**

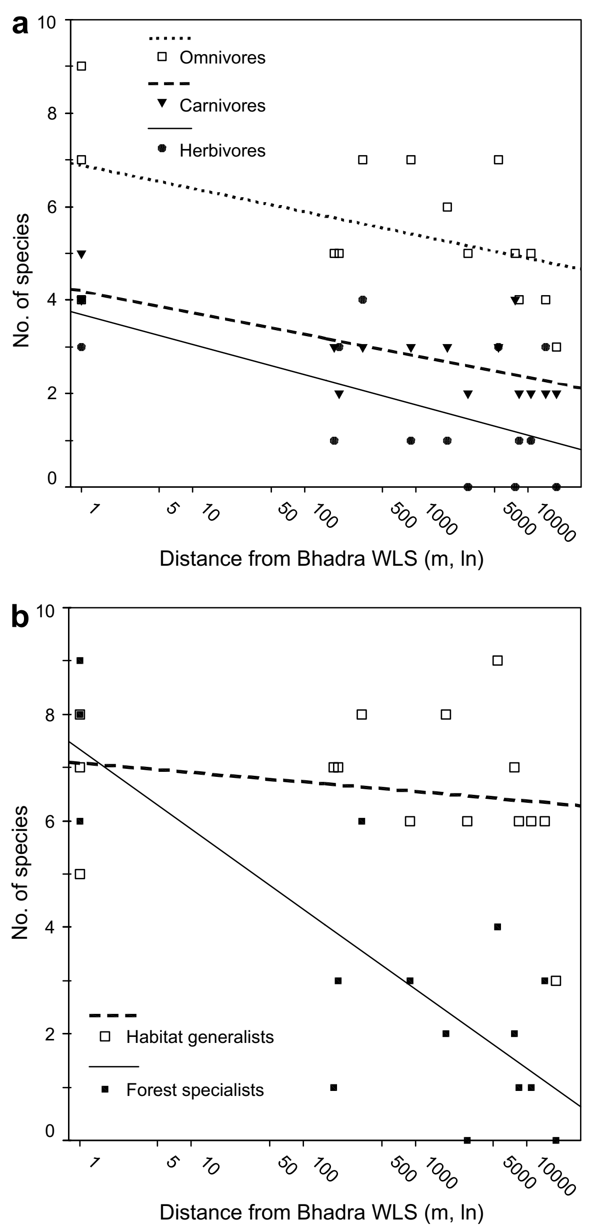


**Fig. 3 – Variations in mammal species richness with distance from Bhadra WLS for (a) omnivores ($R^2$ = 0.21, $p$ = 0.07), herbivores ($R^2$ = 0.43, $p$ = 0.008) and carnivores ($R^2$ = 0.56, $p$ = 0.001); and (b) habitat generalists ($R^2$ = 0.036, $p$ = 0.50) and forest specialists ($R^2$ = 0.69, $p$ = 0.000).**

civet (Table 2). Out of 36 track plot nights in each estate, an average of 65% (±20%) had visitation by small mammals. The percentage of track plots visited in an estate showed no significant correlation with distance from Bhadra WLS ($r = 0.25$, $p = 0.40$) or any vegetation characteristic ($r = 0.06$ to $-0.44$, $p > 0.05$ for all, $n = 14$).

Total number of encounters pooled across 12 belt transects ranged from 46 to 181, with an average of 98 (±42.6) encounters per estate. For 11 species, which were recorded from at least 6 estates, we examined the relationship of encounter index estimated from belt transects with distance from Bhadra WLS and vegetation characteristics (Table 3). Distance was the most important factor significantly influencing the encounter index, negatively for four species and positively for palm civets. The percentage of silver oak influenced the abundance of bonnet macaque negatively, and that of porcupine positively. The abundance of bonnet macaque was also positively related with mean basal area of fruit trees, used as an index of fruit production. The abundances of relatively small species (small Indian civet, blacknaped hare and jungle striped squirrel) were not related either to distance or to any vegetation characteristic.

## 4. Discussion

The study shows that a rich pool of mammal species makes use of coffee estates. At least 28 species of non-volant mammals were recorded, including the endemic jungle-striped squirrel, brown mongoose and probably the brown palm civet. This fauna includes most species of mammals occurring in the moist deciduous and dry deciduous forests in the study area. Proximity to the Bhadra WLS seems to be primary factor that determines mammalian species richness in coffee plantations around it, specially the forest specialists.

It has been suggested that the species richness and abundance of mammals in coffee plantations are mainly governed by the distance from the forest, local vegetation characteristics, and other anthropogenic factors such as hunting, logging, pesticides and other disturbances (Gallina et al., 1996; Ricketts, 2001; Daily et al., 2003). We did not find species richness to be related with vegetation diversity, unlike Gallina et al. (1996). This could be because more than 50% of 24 mammal species recorded by them in coffee plantations in Mexico were frugivores, and no large mammal was recorded. In contrast, we recorded only two species that had fruits as a significant part of their diet. The abundance of these two frugivores (bonnet macaque and palm civets) showed significant positive correlation with vegetation characteristics such as abundance of *Ficus* trees. The abundance of other small species showed no relationship to distance from forest or vegetation. However, these species are preferred targets for local hunters and, therefore, hunting may have a strong influence on their abundances (Kumara and Singh, 2004).

We failed to find any negative influence of silver oak abundance; the carnivores even showed a positive influence of silver oak. This could be because of two reasons. Firstly, the estates with a high proportion of silver oak were located very close to the protected area and had highest species richness recorded (Estate 3, 8). Secondly, the current levels of silver oak in the landscape, averaging about 30% of standing trees, might not be significantly impacting mammalian fauna. The forest specialists, which included all large mammals, possibly use coffee plantations only as feeding or resting grounds, or as corridors to move between forest fragments. These animals generally have large home ranges and plantations adjacent to forests could be part of their home ranges. Bhadra WLS may also have a rescue effect (Daily et al., 2003) for species such as chital and wild pig, which were recorded up to large distances from forest, as these species are also hunted avidly. The generalist mam-

**Table 3 – Pearson's correlation matrix: correlations between (a) mammal species richness, and (b) abundance of individual species, with distance from Bhadra WLS (n = 15) and vegetation characteristics (n = 14)**

| | Distance from Bhadra WLS | Silver oak (%) | Tree species richness | Trees/plot | Tree species/plot | Fruit trees/plot | Basal area/plot |
|---|---|---|---|---|---|---|---|
| *(a) Mammal species richness* | | | | | | | |
| Overall | −0.71** | 0.39 | −0.20 | −0.02 | −0.46 | −0.65* | −0.01 |
| Habitat generalists | −0.19 | 0.16 | −0.13 | −0.31 | −0.54* | −0.59* | 0.34 |
| Forest specialists | −0.83** | 0.41 | −0.17 | 0.11 | −0.33 | −0.55* | −0.16 |
| Herbivores | −0.66** | 0.08 | 0.02 | −0.09 | −0.27 | −0.33 | 0.05 |
| Carnivores | −0.75** | 0.62* | −0.26 | 0.44 | −0.11 | −0.43 | −0.37 |
| Omnivores | −0.45 | 0.19 | −0.05 | −0.23 | −0.48 | −0.56* | 0.18 |
| *(b) Abundance of individual species* | | | | | | | |
| Bonnet macaque | 0.05 | −0.67* | 0.05 | −0.46 | −0.03 | 0.21 | 0.52* |
| Palm civets | 0.61* | −0.06 | −0.11 | 0.26 | 0.30 | 0.18 | 0.31 |
| Small Indian civet | 0.18 | −0.11 | −0.07 | −0.03 | −0.04 | −0.02 | 0.24 |
| Leopard | −0.69** | 0.36 | 0.03 | 0.63* | 0.44 | 0.22 | −0.40 |
| Spotted deer | −0.48 | 0.39 | −0.31 | −0.22 | −0.41 | −0.41 | 0.23 |
| Muntjac | −0.66** | 0.42 | −0.26 | −0.07 | −0.34 | −0.54* | −0.02 |
| Wild pig | −0.77** | 0.49 | −0.42 | 0.35 | −0.12 | −0.27 | −0.18 |
| Blacknaped hare | −0.08 | 0.21 | −0.19 | −0.16 | 0.05 | 0.06 | 0.20 |
| Porcupine | −0.50 | 0.58* | −0.40 | 0.45 | −0.21 | −0.43 | −0.10 |
| Giant squirrel | −0.51 | 0.40 | −0.32 | −0.23 | −0.45 | −0.55* | 0.17 |
| Jungle striped squirrel | 0.04 | 0.02 | 0.28 | 0.21 | 0.33 | 0.25 | 0.08 |

* Significant at $p = 0.05$.
** Significant at $p = 0.01$.

**Table 4 – Results of multiple regression for mammal species richness in 14 estates**

| Dependent variable | Independent variables | Slope | $R^2$ | *p*-value |
|---|---|---|---|---|
| Overall mammal species richness | Distance | −0.59 | 0.48 | 0.001 |
| | Fruit trees per plot | −0.14 | 0.81 | 0.001 |
| Forest specialists | Distance | −0.58 | 0.66 | 0.000 |
| | Fruit trees per plot | −0.09 | 0.87 | 0.001 |
| Habitat generalists | Fruit trees per plot | −0.05 | 0.37 | 0.027 |
| | Basal area per plot | 0.00 | 0.55 | 0.013 |
| Herbivores | Distance | −0.26 | 0.38 | 0.018 |
| Carnivores | Distance | −0.16 | 0.53 | 0.006 |
| | Silver oak (%) | 0.03 | 0.70 | 0.029 |
| Omnivores | Fruit trees per plot | −0.06 | 0.31 | 0.038 |

mals, which included most small to medium sized species with smaller home ranges, are mostly resident in coffee plantations. Availability of resources throughout the year and reduced predation pressure are likely to be the important factors influencing their occurrence, rather than proximity to forests.

Coffee plantations may serve as primary habitat for small generalist mammals, and an extension of habitat and dispersal corridors for large mammals. As a matrix, it increases overall connectivity of natural habitats considerably. While many studies have appreciated shade coffee plantations for their resident biodiversity and value as a high quality matrix (Perfecto and Vandermeer, 2002), their potential as a buffer zone around protected areas has received only little attention (Vandermeer and Carvajal, 2001). By definition, buffer zones around protected areas are 'multiple-use' areas. Coffee plantations, even though privately owned, are used by both humans and animals. It is clear that the coffee plantations act as a buffer around the protected areas as far as large mammals are concerned, protecting them from the direct effects of more intensive agriculture and higher-density human settlements.

### 4.1. *Threats to the conservation values*

The conservation values of shade grown coffee are threatened by the intensification of production, especially the mechanisation of cultivation process and the reduction or elimination of shade trees (Perfecto et al., 1996; Rice, 1997). Coffee plantations in the Western Ghats are not amenable to mechanization, and the monsoon-driven rain with prolonged dry periods does not allow coffee to be grown without a dense shade (Jayarama and D'Souza, 2006). Thus, coffee cultivation here has remained a traditional agriculture activity. However, the natural shade is being substituted with non-native timber species, which provide few or no resources for resident wildlife. Such conversions not only lead to the loss of biodiversity values of these plantations, but also severely affect the integrity of the adjoining protected areas (O'Brien and Kinnaird, 2003). While the Specialty Coffee Association of America (SCAA) has certified traditional Indian coffee cultivation system as environment-friendly, it does not evaluate the sustainability of the modern cultivation practices (Damodaran, 2002). Especially in current times of financial crisis in the coffee plantation sector, these biodiversity refuges have become more vulnerable.

Support for shade coffee plantations poses a threat to remnant forests in some countries as farmers demand conversion of forest reserves into coffee plantations (Rappole et al., 2003). This again does not affect Indian coffee systems, as the forestlands in India cannot be converted to any other land-use according to the law and this is very effectively enforced. This paper argues for retention of natural shade coffee plantations as opposed to their conversion into either silver oak shade plantations or some other land-use. We do not suggest that forestlands be converted into coffee plantations because of the latter's biodiversity values. In fact, as the decline in species richness with distance from the protected area demonstrates, coffee plantations can be a good buffer around, but cannot be an alternative to, protected areas as far as mammals are concerned.

### 4.2. Conservation actions

There is a growing campaign to promote shade-grown coffee as a means for preserving biodiversity in the tropics (Sherry, 2000; Rappole et al., 2003). This campaign needs to be actively promoted in areas such as the Western Ghats where all coffee is shade grown. Such coffee plantations are an ecologically sustainable buffer zone around protected areas and a high quality matrix that can increase connectivity among protected areas. There is a need to increase awareness among planters and labourers about the conservation values of coffee plantations and make planters partners in the conservation of wildlife outside the sanctuaries. Planters should be encouraged by means of incentives to retain diverse shade of native trees and restore vegetation in monocultures of silver oak. In addition, we recommend strict enforcement of wildlife laws to combat hunting.

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## Appendix A

Vegetation characteristics estimated from 36 plots (25 $m^2$) in each of the 14 estates

| Estate no. | Tree species in 36 plots | Fruit tree species in 36 plots | Trees/ plot | Tree species/ plot | Basal area/ plot ($cm^2$) | Fruit trees/ plot | Ficus trees/ plot |
|---|---|---|---|---|---|---|---|
| 1 | 31 | 12 | 4.7 | 3.5 | 1431 | 1.3 | 0.6 |
| 2 | 31 | 11 | 4.4 | 3.4 | 915 | 1.7 | 0.4 |
| 3 | 20 | 10 | 4.7 | 2.4 | 1192 | 0.6 | 0.4 |
| 4 | 27 | 12 | 2.5 | 2.3 | 1971 | 1.3 | 0.5 |
| 5 | 24 | 11 | 3.2 | 2.8 | 1558 | 1.3 | 0.5 |
| 6 | 36 | 13 | 3.2 | 2.9 | 2083 | 1.5 | 0.4 |
| 7 | 38 | 19 | 3.0 | 2.7 | 1126 | 1.4 | 0.5 |
| 8 | 22 | 9 | 2.7 | 2.1 | 1600 | 0.5 | 0.2 |
| 9 | 31 | 16 | 3.7 | 2.8 | 990 | 1.2 | 0.4 |
| 10 | 25 | 12 | 3.1 | 2.6 | 2998 | 1.5 | 0.7 |
| 11 | 24 | 8 | 3.1 | 2.5 | 1069 | 0.9 | 0.3 |
| 12 | 36 | 15 | 2.8 | 2.3 | 1496 | 0.8 | 0.3 |
| 13 | 24 | 10 | 2.3 | 1.8 | 2646 | 0.8 | 0.4 |
| 14 | 17 | 6 | 3.3 | 2.2 | 478 | 0.7 | 0.2 |

## Appendix B

List of tree species recorded from 14 estates

| Species | % of total trees recorded from 36 plots in 14 estates (*N* = 1681) |
|---|---|
| *Grevillea robusta* | 30.1 |
| *Erythrina lithosperma* | 8.5 |
| *Ficus glomerata* | 5.0 |
| *Artocarpus integrifolia* | 4.6 |
| *Citrus sp.* | 4.3 |
| *Sapindus laurifolius* | 4.2 |
| *Toona ciliata* | 3.1 |
| *Bischofia javanica* | 2.8 |
| *Areca catechu* | 2.5 |
| *Ficus infectoria* | 2.5 |
| *Syzigium cuminii* | 2.5 |
| *Terminalia bellarica* | 2.5 |
| *Mangifera indica* | 1.9 |
| *Dalbergia latifolia* | 1.8 |
| *Lagerstroemia lanceolata* | 1.6 |
| *Maesopsis eminii* | 1.6 |
| *Caryota urens* | 1.5 |
| *Ficus drupacea* | 1.4 |
| *Diospyros montana* | 1.2 |
| *Terminalia alata* | 1.2 |
| *Ficus amplissima* | 1.1 |
| *Ficus microcarpa* | 1.0 |
| *Garuga pinnata* | 1.0 |
| *Ricinus communis* | 1.0 |
| *Albizzia odoratissima* | 0.9 |

## Appendix B – *continued*

| Species | % of total trees recorded from 36 plots in 14 estates (N = 1681) |
|---|---|
| *Gliricidia maculata* | 0.9 |
| *Ficus lacor* | 0.7 |
| *Chukrasia tabularis* | 0.5 |
| *Grewia tiliaefolia* | 0.5 |
| *Macaranga indica* | 0.5 |
| *Pongamia pinnata* | 0.5 |
| *Cinnamomum zeylanicum* | 0.4 |
| *Delonix regia* | 0.4 |
| *Kydia calycina* | 0.4 |
| *Michelia champaca* | 0.4 |
| *Pterocarpus marsupium* | 0.4 |
| *Chrysophyllum roxburghii* | 0.4 |
| *Tectona grandis* | 0.4 |
| *Emblica officinalis* | 0.3 |
| *Ceiba pentandra* | 0.3 |
| *Acacia rugata* | 0.2 |
| *Albizzia lebbek* | 0.2 |
| *Annona squamosa* | 0.2 |
| *Bauhinia sp.* | 0.2 |
| *Eucalyptus grandis* | 0.2 |
| *Mallotus philippinensis* | 0.2 |
| *Musa sp.* | 0.2 |
| *Syzigium montanum* | 0.2 |
| *Tamarindus indica* | 0.2 |

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