Influence of timber plantations on high-altitude understorey insectivorous birds in the Nilgiris landscape

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CERTIFICATE

This is to certify that **Ms. Swapna Lawrence** of Sálim Ali Centre for Ornithology and Natural History (SACON) has carried out an original research work titled, '**Influence of timber plantations on high-altitude understorey insectivorous birds in the Nilgiris landscape'** in partial fulfilment of the M.Sc. (Ornithology & Conservation Biology) degree of Saurashtra University, Rajkot. This investigation was carried out under my supervision from December 2019 to August 2020. I also certify that this research work has not been submitted for any other degree to any university.

Date: 21 August 2020
Place: Coimbatore

(**Dr. SHOMITA MUKHEJREE**)
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SUMMARY

The Shola Sky Islands of the Western Ghats have undergone drastic land use changes for over a century due to several anthropogenic activities. One of the main reasons for significant habitat loss and fragmentation in this landscape is the establishment of plantations of many invasive and non-native species such as *Acacia spp*., *Pine spp.,* and *Eucalyptus spp*. These are major threats for numerous endemic species that are found in the region including the endangered Nilgiri Sholakili *Sholicola major* and Nilgiri Laughingthrush *Montecincla cachinnans*. This study is an attempt at understanding the effects of exotic tree species on high-elevation birds found in the Nilgiris. Under an occupancy framework, I examined the habitat variables that best predict the distribution and abundance of four species of high-elevation understorey insectivorous birds in the Upper Nilgiris Plateau. I sampled 30 sites between January 2020 and March 2020 and analysed the data using occupancy and n-mixture models. While variation in occupancy of Nilgiri Sholakili could not be explained by any habitat variables, its abundance seemed to be affected by basal area of acacia, percentage of canopy cover and elevation. Nilgiri Laughingthrush occupancy was best explained by basal area of acacia, wetness and presence of leaf litter whereas abundance was explained by basal area of acacia, percentage of canopy cover, elevation, wetness, presence of *Rubus ellipticus* and basal area of eucalyptus. There was indication of wetness of the grid positively affecting the presence of Nilgiri Flycatcher *Eumyias albicaudatus* while abundance could not be explained by any of the covariates used. Distribution and abundance of Black-and-orange Flycatcher *Ficedula nigrorufa* could not be explained by any of the habitat variables used. The detection of these species across sites was high (> 85%). Although results from the study are preliminary, it demonstrates that exotic plantations serve as alternative habitats for these endemic bird species.

1. INTRODUCTION

1.1. BACKGROUND

1.1.1. Threats to Tropical Forests

Habitat loss and fragmentation are the biggest threats to tropical forests (Gibson *et al.*, 2011). Although tropical forests harbour almost 50% of the world's biodiversity (Wright, 2005), around 68,000 sq. km of tropical forest is lost every year (FAO & JRC, 2012). Half of what still remains is known to be either degraded forest or secondary forest regenerating in areas that have been abandoned after human use (Lewis *et al.*, 2015). Between 2000 and 2010, agricultural land increased annually by 6 million hectares at the expense of 7 million hectares of tropical forest (FAO, 2016). There has also been a drastic increase in the conversion of these forests to plantations (Curtis *et al.*, 2018). This is a matter of concern given that 70% of the world's bird species are found in forests mainly in the tropics (BirdLife International, 2018). These threats are known to affect some species more significantly than others. Species that are rare and specialised in their habitats are particularly vulnerable to extinction following habitat loss (Owens & Bennett, 2000; Şekercioğlu *et al.*, 2004; Sodhi *et al.*, 2004). Tropical montane forests particularly are at a major risk because of their rich biodiversity and high endemicity (Kessler & Kluge, 2008).

The Western Ghats, a globally recognised biodiversity hotspot (Myers, 2003), is a mountain chain along south-western India. The Shola Sky Islands or the montane forests of the Western Ghats are characterized by a naturally bi-phasic ecosystem which features stunted evergreen forests (commonly known as *sholas*) interspersed with grasslands. These montane forests occur above an elevation of 1400 m, predominantly in the southern Western Ghats. This region is a unique habitat known to harbour a disproportionately high number of endemic species (Robin & Nandini, 2012). The Shola Sky Islands just like other tropical forests across the world have been subjected to severe habitat loss and fragmentation. Extensive felling of trees for wood is said to have reduced *shola* forest habitat by almost 50% between 1850 and 1995 (Sukumar *et al.*, 1995).

1.1.2. Invasion and Non-native Species

The transportation of several tree species by humans because of increasing demand for wood has led to the naturalization or invasion of many non-native species in their introduced habitat (Richardson & Rejmánek, 2011). Invasion by non-native species is being increasingly recognized as a major contributor to global change. Alien plants can have significant impacts at the species, community, and ecosystem level (Vilà *et al.*, 2011). Plantations composed of exotic species are often considered "biological deserts'' as they are known to decrease diversity and abundance of resident species and also alter vegetation structure and plant species composition (Hartley, 2002; Hejda *et al*., 2009; Vilà *et al*., 2011).

Colonial encounters with the *shola* ecosystem during the early nineteenth century resulted in changes in the land use regime of this landscape (Joshi *et al.,* 2018). The need for timber and the misconception that grasslands are wastelands led to wide scale plantations of non-native and invasive species including *Pine spp.*, *Eucalyptus spp*., and *Acacia spp*. Arasumani *et al.* (2019) found that the invasion of these tree species over a period of 45 years (1973 – 2017) has resulted in a loss of 38% of *shola* grasslands and 3% of *shola* forests.

1.1.3. Understorey Insectivorous Birds

Understorey birds are known to be particularly sensitive to forest fragmentation (Vergara & Simonetti, 2006). It has been predicted that understorey birds would decline with increasing disturbance and fragmentation (Şekercioğlu *et al*., 2002). Traits that make them more susceptible to anthropogenic disturbance compared to other forest guilds are their limited dispersal abilities, high habitat specificity and dietary specialisation. Understorey birds are also sensitive to changes in microclimate (Sodhi *et al*., 2008). Habitat structure is known to play a key role in determining bird species composition and several studies have shown that the lack of complexity and the homogeneity of plantations negatively affects bird species that are dependent on natural forest habitat (Terborgh, 1985; Deconchat *et al*., 2009).

The Shola Sky Islands are home to several understorey endangered bird species including the Nilgiri Sholakili *Sholicola major* and the Nilgiri Laughingthrush *Montecincla cachinnans*. These habitat specialist birds face the risk of extinction due to forest loss and fragmentation.

In some circumstances however, studies have shown that the presence of plantations in fragmented landscapes can help mitigate the effects of habitat loss and fragmentation (Deconchat *et al*., 2009; Volpato *et al*., 2010). Plantations that have developed an understorey structure and are structurally similar to natural forests could provide food resources and suitable habitat for several species (Duran & Kattan, 2005). These plantations could also act as “soft barriers'' allowing movement and bird dispersal between remnants of natural forests (Tomasevic & Estades, 2008).

Although these birds may be able to recover in secondary forests or plantations with understorey structure, these novel habitats remain suboptimal when compared to natural forests.

1.2. OBJECTIVES

The objective of this study is to understand the influence of non-native and invasive tree species (*Pine spp.*, *Eucalyptus spp*., and *Acacia spp*.) on the distribution and abundance of high-elevation forest understorey birds of the Shola Sky Islands. Under the occupancy framework, I examined the habitat characteristics that are associated with the presence of these understorey insectivores in these wooded habitats and determine how occupancy and abundance varies across different plantations.

1.3. LITERATURE REVIEW

A global assessment by Schirmel *et al*. (2016) found that invasive species are known to have a significant overall reducing effect on the diversity, abundance and fitness of animals. The effects of invasive species however vary depending on the type of ecosystem, taxa and feeding ecology of animals. Across taxa the influence of invasion was most evident for insects and birds. Bottom up effects of reduction in insect populations could result in decrease in bird diversity, abundance and fitness (Schirmel *et al.*, 2016). Bottom up effects of invasive plants on higher trophic levels also depends on the degree of their dependence on alien plants as a food resource (Vilà *et al*., 2011).

Invasive trees may not necessarily decrease species diversity but create changes in species composition by replacing native species with species that are able to tolerate disturbances in the invaded habitat, suggesting that simply looking at species richness or diversity between invaded and non-invaded habitats may not be an accurate assessment of the impact of invasive species (Hejda *et al.*, 2017).

While several studies have found that differences in vegetation between natural forests and plantations neither changed bird composition nor abundance (Duran & Kattan, 2005); others have noted that plantations can change species composition by increasing non-native species in plantations (Paritsis & Aizen, 2008). However, these studies were in plantation stands embedded within forests indicating that the results may differ in cases where there are larger plantations and smaller forest fragments.

Although birds are the best studied taxonomic group in the *sholas*, most studies are single-species studies focusing on only a few aspects of their biology (Robin & Nandini, 2012). While there have been a few bird community studies in the Anamalai region (Raman, 2006; Sidhu *et al*., 2010), similar studies in the Nilgiris landscape are scarce. A study on understorey insectivores in the Western Ghats found that compared to other guilds these birds were most affected across a land-use gradient of forests, plantations and agricultural lands (Sreekar *et al*., 2015).

Khan (1980) compared the avifauna of *sholas* with the neighbouring plantations and found that *shola* habitats had the highest number of species followed by tea plantations, eucalyptus and acacia. Zarri *et al*. (2005) have made annotated checklists of birds in the Nilgiris. Gokula (1998) studied bird communities in the lower elevation dry thorn forests of Mudumalai Wildlife Sanctuary in the Nilgiris Landscape. A study by Zarri *et al*. (2008) on the habitat suitability of Nilgiri Laughingthrushes is probably the only landscape level study on birds in the Upper Nilgiris. Therefore, a study looking at distribution patterns of multiple bird species at a landscape scale is much needed.

Occupancy studies are extremely useful in inferring patterns about distribution and range of species. Millan *et al*. (2015) found that the presence of native trees in the understorey and minimum understorey management practices in eucalyptus plantations in southeastern Brazil increased the probability of bird species occupying these plantations. A recent study by Lele *et al*. (2020) on the distribution of Nilgiri Pipit *Anthus nilghiriensis* in the Shola Sky Islands found that elevation was a significant factor in determining species presence and abundance. Citizen science data on species occurrences helped researchers map the distribution of several Western Ghats endemics and found that IUCN overestimated the geographical ranges of many species including the Black-and-orange Flycatcher *Ficedula nigrorufa*, and Nilgiri Flycatcher *Eumyias albicaudatus* (Ramesh *et al*., 2017). Occupancy studies therefore can be instrumental in understanding species-habitat relationships in a variety of contexts and landscapes.

2. STUDY AREA

The Upper Nilgiris landscape (11° 10' and 11° 32' N to 76° 25' and 77° 00' E) which forms a part of the southern Western Ghats chain is a mosaic of forests interspersed with grasslands. The *shola* forests are restricted to the folds and valleys of the mountains, and the *shola* grasslands cover the slopes and rounded hilltops. This plateau stretches around 50 km from east to west and 30 km from north to south and shows considerable variation in topography and climate (Das, 2015). Elevation ranges from 1500 m to 2590 m above sea level. Annual rainfall in the region varies between 5000 mm on the western side and 1500 mm on the eastern side (Das, 2015). The study site receives both southwest monsoon and northeast monsoon. Annual temperatures range from a minimum of 5°C in January to a maximum of 24°C in April (Joshi *et al*., 2018). Nocturnal frost is known to be quite common in the area during winter (November to March) (Caner *et al*., 2007). It has been proposed that frost plays a key role in maintaining the forest-grassland mosaic (Joshi *et al.*, 2020).

The vegetation in *shola* forests, classified as Southern Montane Wet Temperate Forest (Champion & Seth, 1968), is floristically dominated by members of Lauraceae, Rubiaceae, Symplocaceae, Myrtaceae and Euphorbiaceae families (Sukumar *et al*., 1995). The Nilgiris is known to harbour 20% of endemic trees of the Western Ghats. Among birds, while 20–23% of birds present in the *sholas* are endemic to the Western Ghats, the Endangered (BirdLife International, 2020) Nilgiri Laughingthrush is endemic to only the Nilgiris landscape (Robin & Nandini, 2012). Other Western Ghats endemic species found in the Nilgiris include Black-and-orange Flycatcher, Nilgiri Sholakili, Nilgiri Flycatcher, Nilgiri Pipit and Nilgiri Wood Pigeon *Columba elphinstonii*.

The current modified landscape is characterized by a matrix of native *sholas*, grasslands, agriculture, settlements, tea plantations and exotic plantations. Exotic plantations of *Pine spp*., *Eucalyptus spp*., and *Acacia spp*., cover 21% of the entire Nilgiris landscape (Arasumani *et al*., 2019). Between 2003–2017 the area of exotic plantations in the region increased by 48 sq. km (17% of total plantation cover) as a result of invasion.

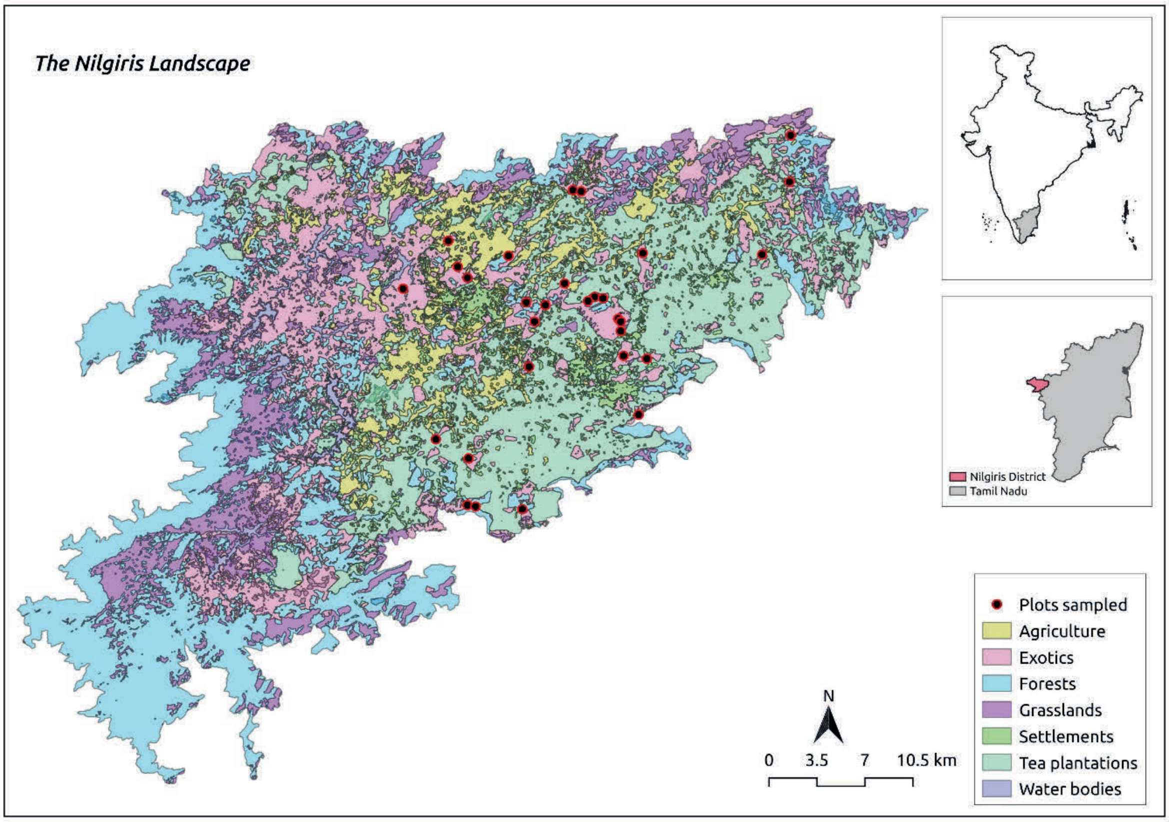

Figure 1: Location of study site and sampled plots.

Plate 1: Typical *shola* forest-grassland ecosystem. (Photo credit: Ritobroto Chanda)

Plate 2: Mixed habitat of *Acacia spp*. and *Pine spp*.

Plate 3: Understorey structure in a *shola* habitat.

3. METHODS

3.1. FOCAL SPECIES

The species of interest for this study are Black-and-orange Flycatcher *Ficedula nigrorufa*, Nilgiri Flycatcher *Eumyias albicaudatus*, Nilgiri Laughingthrush *Montecincla cachinnans* and Nilgiri Sholakili *Sholicola major*. These species are primarily insectivorous and are found in most abundance in the *shola* forests. They are usually found foraging between 0–5 m from the ground.

Plate 4: The four species of interest for this study. (From top left: Nilgiri Sholakili (Photo credit: Aravind PS); top right: Nilgiri Flycatcher (Photo credit: Ritobroto Chanda); bottom left: Nilgiri Laughingthrush (Photo credit: Roshna Mohandas); bottom right: Black-and-orange Flycatcher (Photo credit: Ritobroto Chanda).

3.2. STUDY DESIGN

Wooded habitats in the landscape comprising *shola* forests and plantations above 1400 m were mapped using GIS software. Classification of the *shola* forests and plantations was done by M. Arasumani and has been described in detail in Arasumani *et al.* (2019). Other land-use types — grasslands, tea plantations, settlements, water bodies and agriculture fields were excluded as the species of interest are predominantly understorey insectivorous birds found in forest habitats. The landscape was divided into grids of size 100 m x 100 m. The grid size was based on known territory sizes of these birds. A fraction of these grids (100 grids) was randomly picked for sampling. Grids that were either inaccessible or had less than 50% of wooded area were not sampled.

Data were collected between January 2020 and March 2020. Out of the 100 grids that were randomly picked for sampling, the total number of sites that I sampled was 30. Field work had to be stopped mid-way due to the lockdown imposed because of the global COVID-19 pandemic.

3.3. BIRD SAMPLING

Each site was sampled four times. The minimum time gap between replicates was six hours. During each survey, the observer reached the centre of the grid and did a call playback of the four species. After playback, the observer waited for a minute for the birds to respond, then walked the grid in a manner such that maximum area of the grid was covered and recorded the counts of each species based on visual and auditory detections. The weather (sunny, partly cloudy, cloudy), time and wind intensity (low, medium, high) were also recorded during each survey. The use of call playback was to maximise detection of the species of interest. Most of the calls used for playback were obtained from Macaulay library and Xeno Canto. Length of each playback call was approximately 30 seconds. Time spent surveying each grid varied between 10 and 20 minutes.

3.4. VEGETATION SAMPLING

Data for habitat variables were collected within two 7 m radius circular plots placed inside the grid and also at 15 randomly picked points within the grid. The habitat parameters recorded in the circular plots were: girth of trees, percentage of moss cover on each tree, number of freshly cut stumps, logs, canopy cover, and understorey cover; and parameters recorded at 15 random points inside the grid were: vegetation profile and presence of *Daphniphyllum spp.*, *Lantana camara*, ferns, fire, bamboo, leaf litter and wild raspberry *Rubus ellipticus*.

Girth at breast height (GBH) data was recorded by measuring the girth of all trees and snags > 30 cm, and liana > 10 cm. Trees were classified as native *shola*, *Pine spp.*, *Eucalyptus spp.*, *Acacia spp*., and snag. The percentage of moss on each tree was categorized into 5 different classes: 0–20%, 20–40%, 40–60%, 60–80%, and 80–100%. Moss was measured because species such as Nilgiri Laughingthrush and Nilgiri Sholakili are known to use moss to make their nests. Canopy cover was measured using the Android application HabitApp (Macdonald & Macdonald, 2016; Bianchi *et al*., 2017). In each vegetation plot, canopy cover was measured at five points: four cardinal directions and the centre of the plot. Understorey cover was recorded through woody stem count taken at a height of 1.5 m above ground along a swath of 1.5 m length. Woody stem count was noted by walking in all four directions from the centre of each plot. Within each plot, counts of fresh stumps and logs were also recorded. To measure vegetation profile, a 5 m pole that was marked at 30 cm intervals was placed at 15 randomly picked points and the points at which vegetation touched the pole were noted. Within 1 m radius of the pole the presence of leaf litter, *Lantana camara*, fern, fire, bamboo, *Daphniphyllum spp*., and wild raspberry *Rubus ellipticus* were also recorded. Fresh stumps, fire and *Lantana camara* were recorded as signs of human disturbance. *Daphniphyllum spp*. was recorded as an indication of *shola* forest regeneration in plantations. Presence of *Rubus ellipticus* was recorded as Nilgiri Laughingthrushes are known to feed on the berries.

The possible influence that these variables might have on the probability of occupancy and detection for each species is provided in Table 1.

Table 1: List of habitat variables and landscape variables and the possible effect of each on the occupancy, abundance and probability of detection for each species. N indicates that the covariate has no effect.

Variable	Definition	Data source	Methodology	Expected effect on Occupancy	Expected effect on Abundance	Expected effect on Detectability
Nilgiri Sholakili						
Foliage density	0–3m	Veg profile	Using 5 m calibrated rod	+	+	-
Canopy cover		App	Using Android application HabitApp	+	+	-
Wetness		GIS	Extract from DEM raster	+	+	N
Woody stems			Count number of woody stems	+	+	-
Elevation		GIS	Extract from DEM raster	+	+	N
Moss			Estimate percentage of moss on each tree	+	+	N

Basal area		DBH	Measure girth of trees	+	+	-
Black-and-orange Flycatcher						
Foliage density	0–2m	Veg Profile	Using 5 m calibrated rod	+	+	-
Wetness		GIS	Extract from DEM raster	+	+	N
Elevation		GIS	Extract from DEM raster	+	+	N
Fern		Veg Profile	Using 5 m calibrated rod	+	+	N
Woody stems			Count number of woody stems	+	+	-
Basal area		DBH	Measure girth of trees	+	+	-
Nilgiri Flycatcher						
Basal area		DBH	Measure girth of trees	+	+	-
Canopy cover		App	Using Android application HabitApp	+	+	-
Wetness		GIS	Extract from DEM raster	+	+	N
Elevation		GIS	Extract from DEM raster	+	+	N
Foliage density	2–5 m	Veg profile	Using 5 m calibrated rod	+	+	-
Woody stems			Count number of woody stems	+	+	-
Daphniphyllum spp.			Using 5 m calibrated rod	+	+	N
Nilgiri Laughingthrush						
Raspberry bushes		Veg profile	Using 5 m calibrated rod	+	+	N
Daphniphyllum spp.		Veg profile	Using 5 m calibrated rod	+	+	N
Foliage density	0–5m	Veg profile	Using 5 m calibrated rod	+	+	-
Leaf litter		Veg profile	Using 5 m calibrated rod	+	+	N
Canopy cover		App	Using Android application HabitApp	+	+	-

Wetness		GIS	Extract from DEM raster	+	+	N
Elevation		GIS	Extract from DEM raster	+	+	-
Basal area		DBH	Measure girth of trees	+	+	-
Woody stems			Count number of woody stems	+	+	-

+ positive; - negative

3.5. DATA ANALYSIS

3.5.1. Occupancy Estimation

Site-Occupancy model proposed by Mackenzie *et al.* (2002) was used to estimate the proportion of sites occupied by each species. The model uses maximum likelihood methods to estimate the probability of occupancy (Ψ) and detection (p) using the detection histories (1s and 0s for presence and absence) of species obtained from sampling several sites with multiple temporal replicates. Covariate information for both occupancy and detection were added to the model using a logit link function:

$$\text{logit } \Psi_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n$$

where β_i denotes the size of the effect of covariate x (MacKenzie *et al.*, 2002).

Occupancy methods are used to estimate the proportion of sites occupied by a species. However, when sampling sites for presence/absence, not detecting a species does not necessarily mean that the species is 'absent'. It is possible that species may go undetected at a site even when present. An advantage of using the occupancy model proposed by MacKenzie *et al.* (2002) is that it accounts for this imperfect detection by estimating detection probability.

As the first step of analysis, to check for collinearity I created a correlation matrix of all the habitat variables (Appendix 1). Variables that were highly correlated were not used together in a model. A total of 13 site covariates and two observation covariates (weather, windspeed) were used to run models. I ran null models where detection probability and occupancy were constant i.e., no site or observation covariates were used, after which I ran a global model with important covariates for each species (Table 1). The function dredge in R (version 3.6.2) (R Core Team 2019) package MuMIn (Barton & Barton, 2015) was used to run all combinations of the site and observation covariates and models were ranked based on their AIC. The model with the least AIC was chosen as the 'best-fit' model. The package Unmarked (Fiske & Chandler, 2011) in statistical software R (version 3.6.2) (R Core Team 2019) was used for analysis.

3.5.2. Abundance Estimation

I estimated species abundance using hierarchical n-mixture models under a frequentist framework. The Poisson-Binomial mixture model is a hierarchical model that has two components — the state process and the observation process (Kéry & Royle, 2015). The state process is modelled as a Poisson Generalized Linear Model (GLM) to account for the spatial variation in abundance. The observation process accounts for variation in counts observed at given sites and is modelled as a binomial GLM. Site and detection covariates are modelled as log-linear and logit functions for the Poisson and binomial GLMs respectively. The covariates used in the occupancy model were also used in the abundance models. After running a global model with important covariates, the dredge function in R (version 3.6.2) (R Core Team 2019) package MuMIn (Barton & Barton, 2015) was used to run all combinations of site and observation covariates. Models were ranked based on their AIC and the model with least AIC was chosen as the 'best-fit' model. Species abundances were estimated using the pcount function (Royle, 2004) in R (version 3.6.2) (R Core Team 2019) package Unmarked (Fiske & Chandler, 2011).

4. RESULTS

In this study I sampled 30 sites with a total of 120 surveys from January 2020 to March 2020. Nilgiri Sholakili, Nilgiri Laughingthrush, Nilgiri Flycatcher, and Black-and-orange Flycatcher were detected at least once in 15, 27, 29 and 30 sites respectively.

4.1. NILGIRI SHOLAKILI

Sholakili was detected in 50% of the sites sampled (15 out of 30). I found that none of the site and observation covariates could explain the variation in occupancy and detection probability.

Number of individuals counted across all grids ranged between 0 and 3. It was found that the abundance of Sholakili decreased with an increase in the basal area of acacia trees and the basal area of native *shola* trees. Number of individuals observed tended to increase with an increase in the canopy cover of the grid and elevation.

Table 2: Top 5 models for occupancy of Nilgiri Sholakili and the β estimates with standard error for each predictor variable. ac is the basal area of acacia, el is elevation, fd is foliage density, cc is canopy cover.

OCCUPANCY									
Model structure	null	β ac	β el	β fd	β cc	nPars	AIC	delta	AICwt
Null	0.405 (±0.515)					2	123.55	0	0.4
ac		-0.595 (±0.472)				5	124.82	1.27	0.21
el			0.5 (±0.529)			5	125.59	2.04	0.14
fd				0.464 (±0.488)		5	125.59	2.04	0.14
cc					0.319 (±0.510)	5	126.17	2.62	0.11

Table 3: Top 5 models for abundance of Nilgiri Sholakili and the β estimates with standard error for each predictor variable. ac is the basal area of acacia, sh is basal area of *shola*, cc is canopy cover, el is elevation, eu is basal area of eucalyptus, ws is mean number of woody stems.

ABUNDANCE										
Model structure	β ac	β sh	β cc	β el	β eu	β ws	nPars	AIC	delta	AICwt
ac.sh.cc.el	-0.968 (±0.328)	-0.435 (±0.255)	0.432 (±0.206)	0.362 (±0.196)			8	170.85	0	4.10E-01
ac.sh.cc	-0.918 (±0.317)	-0.608 (±0.295)	0.548 (±0.227)				7	172.37	1.51	1.90E-01
ac.cc.el	-0.865 (±0.323)		0.270 (±0.177)	0.409 (±0.179)			7	172.79	1.93	1.60E-01
ac.eu.ws	-0.826 (±0.340)				0.339 (±0.153)	0.281 (±0.115)	7	173.31	2.46	1.20E-01
ac.el	-0.988 (±0.348)			0.423 (±0.184)			6	173.47	2.61	1.10E-01

4.2. NILGIRI LAUGHINGTHRUSH

Nilgiri Laughingthrush was detected in 87% of the sites sampled. The probability of occupancy tended to decrease with an increase in the basal area of acacia trees and wetness and increased with an increase in the presence of leaf litter present in a site.

I counted between 0 and 5 individuals of Nilgiri Laughingthrush in the grids I sampled. Abundance of the species seemed to increase with an increase in the basal area of eucalyptus trees, canopy cover and elevation, and decrease with an increase in the basal area of *Acacia spp*., *Rubus spp.,* and wetness. Basal area of acacia, elevation and canopy cover were featured in all the top ranked models.

Table 4: Top 5 models for occupancy of Nilgiri Laughingthrush and the β estimates with standard error for each predictor variable. ac is the basal area of acacia, ru is presence of *Rubus spp.*, we is mean wetness of the grid, ll is presence of leaf litter, sh is basal area of *shola*, cc is canopy cover.

OCCUPANCY										
Model structure	β ac	β ru	β we	β ll	β sh	β cc	nPars	AIC	delta	AICwt
ac.ll.we	-29.3 (±75.0)		-28.5 (±57.5)	19.9 (±43.6)			7	156.85	0	0.28732
ac.ru.we	-22.1	-16.7	-18.2				7	156.87	0.021	0.28433

	(±33.9)	(±811.0)	(±27.8)							
sh.cc.ll				7.45 (±11.9)	131.20 (±122.3)	-9.39 (±12.8)	7	156.99	0.141	0.26782
ac.sh.ll.we	-11.87 (±32.5)		-14.48 (±34.4)	10.22 (±24.8)	8.97 (±52.5)		8	158.85	2.001	0.10565
ac.ru	-8.85 (±25.2)	-9.36 (±31.3)					6	160.2	3.345	0.05397

Table 5: Top 5 models for abundance of Nilgiri Laughingthrush and the β estimates with standard error for each predictor variable. ac is the basal area of acacia, cc is canopy cover, el is mean elevation of the grid, we is mean wetness of the grid, ru is presence of *Rubus ellipticus*, eu is basal area of eucalyptus.

ABUNDANCE										
Model structure	β ac	β cc	β el	β we	β ru	β eu	nPars	AIC	delta	AICwt
ac.eu.cc.el.ru .we	-0.403 (±0.127)	0.359 (0.110)	0.395 (±0.105)	-0.191 (±0.093)	-0.287 (±0.142)	0.161 (±0.104)	10	343.13	0	3.60E-01
ac.cc.el.ru.we	-0.367 (±0.117)	0.326 (±0.106)	0.422 (±0.103)	-0.178 (±0.093)	-0.221 (±0.130)		9	343.4	0.26	3.20E-01
ac.cc.el.we	-0.327 (±0.114)	0.347 (±0.108)	0.401 (±0.104)	-0.196 (±0.095)			8	344.78	1.64	1.60E-01
ac.cc.el.ru	-0.331 (±0.116)	0.287 (±0.104)	0.389 (±0.101)		-0.228 (±0.126)		8	345.46	2.33	1.10E-01
ac.cc.el	-0.285 (±0.113)	0.308 (±0.107)	0.362 (±0.102)				7	347.41	4.28	4.30E-02

4.3. NILGIRI FLYCATCHER

I detected Nilgiri Flycatcher in 90% of the sites that were sampled. Nilgiri Flycatcher's presence tended to increase with an increase in wetness of the grid.

Variation in abundance of this species across grids could not be explained by any of the habitat variables.

Table 6: Top 5 models for abundance of Nilgiri Flycatcher and the β estimates with standard error for each predictor variable. we is mean wetness of the grid, el is mean elevation of the grid, ac is the basal area of acacia, fo is the foliage density.

OCCUPANCY									
Model structure	β we	β el	null	β fo	β ac	nPars	AIC	delta	AICwt
we	7.36 (±6.07)					4	168.76	0	0.316
el		12.5 (±24.3)				4	168.79	0.028	0.312
null			3.12 (±1.58)			2	169.73	0.971	0.194
fo				-2.4 (±2.66)		4	172.6	3.835	0.046
ac					-0.86 (±0.798)	4	172.65	3.893	0.045

Table 7: Top 5 models for abundance of Nilgiri Flycatcher and the β estimates with standard error for each predictor variable. we is mean wetness of the grid, el is mean elevation of the grid, ac is the basal area of acacia, fo is the foliage density.

ABUNDANCE									
Model structure	null	β ac	β cc	β we	β ws	nPars	AIC	delta	AICwt
null	1.8 (±0.784)					2	261.22	0	0.711
ac		-0.173 (±0.148)				5	265.2	3.99	0.097
cc			0.009 (±0.010)			5	265.9	4.68	0.069
we				0.098 (±0.122)		5	266.07	4.86	0.063
ws					-0.103 (±0.145)	5	266.14	4.93	0.061

4.4. BLACK-AND-ORANGE FLYCATCHER

Black-and-orange Flycatcher was detected in all the grids that were sampled. Variation in occupancy and abundance of this species could not be explained by any of the habitat variables used in the model.

Table 8: Null model estimates of occupancy for Black-and-orange Flycatcher

Occupancy			
Estimate	SE	z	P(>|z|)
10.4	33.1	0.314	0.753
Detection			
Estimate	SE	z	P(>|z|)
0.44	0.187	2.35	0.0186
AIC: 164.7			

Table 9: Null model estimates of abundance for Black-and-orange Flycatcher

Abundance			
Estimate	SE	z	P(>|z|)
2.29	0.914	2.5	0.0123
Detection			
Estimate	SE	z	P(>|z|)
-2.24	1.01	-2.21	0.0273
AIC: 304.9			

5. DISCUSSION

In this study I explored patterns in the distribution and abundance of four species of high-elevation birds of the Western Ghats. While variation in occupancy of Nilgiri Sholakili could not be explained by any of the covariates, its abundance was best explained by basal area of acacia, percentage of canopy cover and elevation. Nilgiri Laughingthrush occupancy was shaped by basal area of acacia, presence of leaf litter, and wetness, while variation in abundance showed strong relationships with basal area of eucalyptus and acacia, canopy cover, elevation, wetness and presence of *Rubus spp*. Probability of occupancy of Nilgiri Flycatcher tended to increase with increasing wetness of the grid. However, variation in abundance could not be explained by any of the habitat variables. Both occupancy and abundance of Black-and-orange Flycatcher showed no significant relationships with any of the habitat variables.

The detection of the four species in a significant number of grids sampled is an indication that these species are able to utilize degraded/mixed habitats. Nilgiri Sholakili as well as the other three species were observed across a range of habitats, from eucalyptus plantations with an understorey of invasive *Solanum spp*. to highly disturbed *shola* habitats adjacent to human settlements and surrounded by plantations. This could also mean that these species are more common than previously thought. Presence of developed understorey in plantations is known to increase abundance of species by providing alternate habitats for such species (Simonetti *et al*., 2013).

Results of negative effect of basal area of acacia on occupancy and abundance of Sholakili and Nilgiri Laughingthrush differ from observations made by researchers in Kodaikanal where basal area of acacia seemed to have a positive effect on occupancy and abundance (Chanda, 2020; Harikrishnan, 2020). Zarri *et al*. (2008) also noted that Nilgiri Laughingthrushes utilized acacia plantations and mixed habitats.

The relationship between abundances of Sholakili and Nilgiri Laughingthrush with elevation is worth noting because tropical forest species are known to be particularly susceptible to changes in climate. These habitat specialist birds are therefore more vulnerable to warming climates and this calls for regular long-term monitoring of their populations to check for changes in their distribution.

Although none of the covariates used in the analysis show significant results and the sample sizes may be inadequate to make strong inferences, they do indicate the possibility of plantations acting as habitats for native and endangered birds. The understorey structure developed in these plantations provide food resources for several species. Given that there has been significant habitat loss in the Shola sky Islands, plantations may serve as alternative habitats and it is therefore important to consider the conservation value of plantations.

An important caveat for this study is that very similar sites were sampled and therefore I was unable to capture significant variation in the occupancy and abundance of species using habitat covariates. There is a possibility that with more sites sampled I may be able to clearly tease apart significance of different habitat variables to explain the variation in occupancy and abundance of the four species across the landscape. Other factors that could affect species distribution such as the surrounding habitat matrix were not taken into consideration due to lack of time. Including these variables in future studies could help us gain interesting insights on the distribution patterns of these endemic birds.

5.1. CONCLUSION

Habitat variables used in the analysis did not show significant results for most species. Except for Nilgiri Sholakili, the other three species were detected in more than 85% of the grids that were sampled. This indicates that species may be utilising these exotic plantations however the extent to which they are utilised is unknown. As Shola Sky Islands continue to lose critical habitat to the threat of invasion it is important to consider the conservation value of these plantations and their role in serving as alternative habitats for several species. However, while some species such as Nilgiri Sholakili and Black-and-orange Flycatcher may be able to benefit from these novel habitat other birds such as the grassland specialist Nilgiri Pipit may become more vulnerable to extinction. While the management has taken measures to restore *shola* grasslands that have been invaded, and prevent further invasion, these interventions need to be implemented with caution. A better understanding of the kind of species that utilise these plantations would help in developing more effective techniques to restore these habitats. Further studies looking at the distribution patterns of bird communities and other taxa at the landscape level would help in a better understanding of the impacts of invasive and non-native tree species.

REFERENCES

Arasumani, M., D. Khan, C.K. Vishnudas, M. Muthukumar, M. Bunyan, and V.V Robin. 2019. Invasion compounds an ecosystem-wide loss to afforestation in the tropical grasslands of the Shola Sky Islands. *Biological Conservation*, 230:141-150.

Barton, K. and M.K. Barton. 2015. Package 'MuMIn'. *Version*, *1*, p.18.

Bianchi, S., C. Cahalan, S. Hale, and J.M. Gibbons. 2017. Rapid assessment of forest canopy and light regime using smartphone hemispherical photography. *Ecology and Evolution*, 7(24):10556-10566.

BirdLife International. 2018. State of the world's birds: taking the pulse of the planet. Cambridge, UK: BirdLife International.

BirdLife International. 2020. Species factsheet: *Montecincla cachinnans*. <http://www.birdlife.org> [Accessed on 19/August/2020]

Caner, L., D.L. Seen, Y. Gunnell, B.R. Ramesh, and G. Bourgeon. 2007. Spatial heterogeneity of land cover response to climatic change in the Nilgiri highlands (southern India) since the Last Glacial Maximum. *The Holocene*, 17(2):195-205.

Champion, H.G. and S.K. Seth. 1968. *A revised survey of the forest types of India*. Govt. India Publication, Delhi. 404pp.

Chanda, R. 2020. Occupancy of understory birds in the Shola Sky Islands of Palani Hills, Tamil Nadu. Unpublished MSc. thesis submitted to Bharati Vidyapeeth Institute of Environment Education and Research, Pune, India. 65pp.

C.P. Harikrishnan, 2020. Impacts of exotic timber tree invasion on a sky island bird community. Unpublished MSc. thesis submitted to Indian Institute of Science Education and Research, Tirupati, India. 58pp.

Curtis, P.G., C.M. Slay, N.L. Harris, A. Tyukavina, and M.C. Hansen. 2018. Classifying drivers of global forest loss. *Science*, 361(6407):1108-1111.

Das, A., 2015. *The influence of environmental factors and landcover change on the distribution and metacommunity structure of upper montane (Shola) forests in the Western Ghats* (Doctoral dissertation, Manipal University, Ashoka Trust for Research in Ecology and the Environment (ATREE)). 186pp.

Deconchat, M., E.G. Brockerhoff, and L. Barbaro. 2009. Effects of surrounding landscape composition on the conservation value of native and exotic habitats for native forest birds. *Forest Ecology and Management*, 258:S196-S204.

Durán, S.M., and G.H. Kattan. 2005. A test of the utility of exotic tree plantations for understory birds and food resources in the Colombian Andes. *Biotropica: The Journal of Biology and Conservation*, 37(1):129-135.

Gibson L., T.M. Lee, L.P. Koh, B.W. Brook, T.A. Gardner, J. Barlow, C.A. Peres, C.J.A. Bradshaw, W.F. Laurance, T.E. Lovejoy, and N. Sodhi. 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*. 478(7369):378–381.

FAO and JRC. 2012. Global forest land-use change 1990–2005, by E.J. Lindquist, R. D'Annunzio, A. Gerrand, K. MacDicken, F. Achard, R. Beuchle, A. Brink, H.D. Eva, P. Mayaux, J. San-Miguel-Ayanz & H-J. Stibig. FAO Forestry Paper No. 169. Food and Agriculture Organization of the United Nations and European Commission Joint Research Centre. Rome, FAO.

Fiske, I., and R. Chandler. 2011. Unmarked: an R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software*, 43(10):1-23.

Food and Agriculture Organization, the United Nations, 2016. State of the world's forests 2016. *Forests and agriculture: land-use challenges and opportunities*. 107pp.

Gokula, V. 1998. *Bird communities of the thorn and dry deciduous forests in Mudumalai wildlife sanctuary South India* (Doctoral dissertation, Bharathiyar University, Sálim Ali Centre for Ornithology and Natural History (SACON)). 168pp.

Hartley, M.J., 2002. Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management*, 155(1-3):81-95.

Hejda, M., P. Pyšek, and V. Jarošík. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. *Journal of ecology*, 97(3):393-403.

Hejda, M., J. Hanzelka, T. Kadlec, M. Štrobl, P. Pyšek, and J. Reif. 2017. Impacts of an invasive tree across trophic levels: species richness, community composition and resident species' traits. *Diversity and Distributions*, 23(9):997-1007.

Joshi, A.A., J. Ratnam, H. Paramjyothi, and M. Sankaran, 2018. Climate and vegetation collectively drive soil respiration in montane forest-grassland landscapes of the southern Western Ghats, India. *BioRxiv*, p.486324

Joshi, A.A., M. Sankaran, and J. Ratnam. 2018. 'Foresting' the grassland: Historical management legacies in forest-grassland mosaics in southern India, and lessons for the conservation of tropical grassy biomes. *Biological conservation*, 224:144-152.

Joshi, A.A., J. Ratnam, and M. Sankaran. 2020. Frost maintains forests and grasslands as alternate states in a montane tropical forest–grassland mosaic; but alien tree invasion and warming can disrupt this balance. *Journal of Ecology*, 108(1):122-132.

Kéry, M., and J.A. Royle. 2015. *Applied Hierarchical Modeling in Ecology: Analysis of distribution, abundance and species richness in R and BUGS: Volume 1: Prelude and Static Models*. Academic Press. 808pp.

Kessler, M., and J. Kluge. 2008. Diversity and endemism in tropical montane forests-from patterns to processes. *Biodiversity and Ecology Series*, 2:35-50.

Khan, M.A.R., 1980. A comparative account of the avifauna of the Sholas and the neighbouring plantations in the Nilgiris. *Journal of the Bombay Natural History Society*, *75*(3):1028-1035.

Lele, A., M. Arasumani, C.K. Vishnudas, V. Joshi, D. Jathanna, and V.V. Robin. 2020. Elevation and landscape change drive the distribution of a montane, endemic grassland bird. *Ecology and evolution*, 10(14):7755-7767.

Lewis, S.L., D.P. Edwards, and D. Galbraith. 2015. Increasing human dominance of tropical forests. *Science*, 349(6250):827-832.

Macdonald, G., Macdonald, H., 2016. HabitApp. Available at: http://www.scrufster.com/habitapp/

MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J. Andrew Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83(8):2248-2255.

Millan, C.H., P.F. Develey, and L.M. Verdade. 2015. Stand-level management practices increase occupancy by birds in exotic Eucalyptus plantations. *Forest Ecology and Management*, 336:174-182.

Myers, N. 2003. Biodiversity hotspots revisited. *BioScience*, 53(10):916-917.

Owens, I.P., and P.M. Bennett. 2000. Ecological basis of extinction risk in birds: habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences*, 97(22):12144-12148.

Paritsis, J., and M.A. Aizen. 2008. Effects of exotic conifer plantations on the biodiversity of understory plants, epigeal beetles and birds in *Nothofagus dombeyi* forests. *Forest Ecology and Management*, 255(5-6):1575-1583.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Raman, T.R.S. 2006. Effects of habitat structure and adjacent habitats on birds in tropical rainforest fragments and shaded plantations in the Western Ghats, India. In: Hawksworth D.L., Bull A.T. (eds) *Forest Diversity and Management. Topics in Biodiversity and Conservation* vol 2. Pp. 517-547. Springer, Dordrecht.

Ramesh, V., T. Gopalakrishna, S. Barve, and D.J. Melnick. 2017. IUCN greatly underestimates threat levels of endemic birds in the Western Ghats. *Biological Conservation*, 210:205-221.

Richardson, D.M., and M. Rejmánek. 2011. Trees and shrubs as invasive alien species–a global review. *Diversity and Distributions*, 17(5):788-809.

Robin, V.V., and R. Nandini. 2012. Shola habitats on sky islands: status of research on montane forests and grasslands in southern India. *Current Science,* 103(12):1427-1437.

Royle, J.A., 2004. N-mixture models for estimating population size from spatially replicated counts. *Biometrics*, 60(1):108-115.

Schirmel, J., M. Bundschuh, M.H. Entling, I. Kowarik, and S. Buchholz. 2016. Impacts of invasive plants on resident animals across ecosystems, taxa, and feeding types: a global assessment. *Global Change Biology*, 22(2):594-603.

Şekercioğlu, Ç.H., P.R. Ehrlich, G.C. Daily, D. Aygen, D. Goehring, and R.F. Sandí. 2002. Disappearance of insectivorous birds from tropical forest fragments. *Proceedings of the National Academy of Sciences*, 99(1):263-267.

Şekercioğlu, Ç.H., G.C. Daily, and P.R. Ehrlich. 2004. Ecosystem consequences of bird declines. *Proceedings of the National Academy of Sciences*, 101(52):18042-18047.

Sidhu, S., T.R. Shankar Raman, and E. Goodale. 2010. Effects of plantations and home-gardens on tropical forest bird communities and mixed-species bird flocks in the southern Western Ghats. *Journal of the Bombay Natural History Society*, 107(2):91

Simonetti, J.A., A.A. Grez, and C.F. Estades. 2013. Providing habitat for native mammals through understory enhancement in forestry plantations. *Conservation Biology*, 27(5):1117-1121.

Sodhi, N.S., L.H. Liow, and F.A. Bazzaz. 2004. Avian extinctions from tropical and subtropical forests. *Annual Review of Ecology, Evolution, and Systematics*, 35:323-345.

Sodhi, N.S., M.R.C. Posa, T.M. Lee, and I.G. Warkentin. 2008. Perspectives in ornithology: Effects of disturbance or loss of tropical rainforest on birds. *The Auk*, 125(3):511-519.

Sreekar, R., U. Srinivasan, C. Mammides, J. Chen, U.M. Goodale, S.W. Kotagama, S. Sidhu, and E. Goodale. 2015. The effect of land-use on the diversity and mass-abundance relationships of understory avian insectivores in Sri Lanka and southern India. *Scientific reports*, 5:11569.

Sukumar, R., H.S. Suresh, and R. Ramesh. 1995. Climate change and its impact on tropical montane ecosystems in southern India. *Journal of Biogeography,* 22(2/3):533-536.

Terborgh, J. 1985. Habitat selection in Amazonian birds. In: M.L. Cody (Ed.), *Habitat Selection in Birds*. Pp. 311–338. Academic Press Inc., New York.

Tomasevic, J.A., and C.F. Estades. 2008. Effects of the structure of pine plantations on their "softness" as barriers for ground-dwelling forest birds in south-central Chile. *Forest Ecology and Management*, 255(3-4):810-816.

Vergara, P.M., and J.A. Simonetti, 2006. Abundance and movement of understory birds in a Maulino forest fragmented by pine plantations. *Biodiversity and Conservation*, 15(12):3937-3947.

Vilà, M., J.L. Espinar, M. Hejda, P.E. Hulme, V. Jarošík, J.L. Maron, J. Pergl, U. Schaffner, Y. Sun, and P. Pyšek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters*, 14(7):702-708.

Volpato, G.H., Prado, V.M. and dos Anjos, L., 2010. What can tree plantations do for forest birds in fragmented forest landscapes? A case study in southern Brazil. *Forest Ecology and Management*, 260(7):1156-1163.

Wright, S.J., 2005. Tropical forests in a changing environment. *Trends in Ecology and Evolution*, 20(10):553-560.

Zarri, A.A., A.R. Rahmani, and B. Senthilmurugan. 2005. Annotated avifauna of the Upper Nilgiris. *Western Ghats, Tamil Nadu, India ENVIS Newsletter: Avian Ecology & Inland Wetlands*, 10(1):1-46.

Zarri, A.A., A.R. Rahmani, A. Singh, and S.P.S. Kushwaha. 2008. Habitat suitability assessment for the endangered Nilgiri Laughingthrush: a multiple logistic regression approach. *Current Science,* 94(11):1487-1494.

Appendix 1: Correlation matrix of habitat variables. The size and shade of colour of the circles represents the strength of the correlation between variables. The colours range from red to blue (shades of red denote negative correlation and shades of blue denote positive correlation. The size of the circles increases with increasing correlation.