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Foraging Habitat Selection of Shrubland Bird Community During the Dry Season in Tropical Dry Forests

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Abstract

Unmitigated climate change, coupled with habitat loss, has made the grassland and shrubland bird communities particularly vulnerable to extinction. Climate change-induced drought reduces net primary productivity, food availability, habitat quality, and alters vegetation structure. These factors collectively increase mortality in grassland and shrubland birds. However, limited data on habitat use by tropical birds hampers the development of effective management plans for drought-affected landscapes. We examined the foraging sites of 18 shrubland bird species, including two endemic and four declining species, across three shrubland forest sites in the Eastern Ghats of India during the dry season. We recorded microhabitat features within an 11 m radius of observed foraging points and compared them with random plots. Additionally, we examined the association between bird species and plant species where a bird was observed foraging. Foraging sites differed significantly from random plots, indicating active selection of microhabitats by shrubland birds. Using linear discriminant analysis, we found that the microhabitat features important for the bird species were presence of ground cover, shrub density, vegetational height, and vertical foliage stratification. Our results show that diet guild and foraging strata influence the foraging microhabitat selection of a species. Microhabitat attributes selected by shrubland specialist species differed from those of generalist shrubland users. Thirteen out of 18 focal species showed a significant association with at least one plant species. Birds were often associated with plants that were green during the dry season. Based on habitat selection and plant associations, we identified several habitat attributes that can be actively managed. Despite being classified as wastelands, the heavily degraded shrub forests can be rehabilitated through strategic and selective harvesting of forest products, targeting invasive species, and a spatially and temporally controlled livestock grazing regime.

Keywords: microhabitat; Eastern Ghats; drought; tropical dry forest management; yellow-throated Bulbul; endemic

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1. Introduction

Climate change is expected to be rapid and directional [1,2], causing the global area under drought to increase in the coming decades [3]. The increasing unpredictability of precipitation makes shrubland and grasslands one of the most vulnerable ecosystems [4]. Drought can induce widespread change in ecosystem structure through vegetation die off [5,6] which leads to poor habitat quality [2,7] and reduced net primary productivity

(NPP) [8]. These factors have strong effects on avifauna in semi-arid regions [2,6,9] as they are sensitive to changes in vegetation structure [4,10–12], leading to reduction in diversity, richness, and abundance of several avifauna species [8].

Niemuth et al. [13] observed a drop in grassland obligate species populations in the grasslands in North Dakota, USA, and Rosenberg et al. [14] reported that 74% of grassland birds and 60% of habitat specialists in North America have declined due to habitat loss and poor habitat quality. In developing tropical countries, an important indirect impact of recurrent drought is the loss of suitable habitat due to farmland encroachment [15]. Thus, the interaction of drought-induced poor habitat quality and extensive habitat loss will exacerbate the effects of climate change on tropical birds, especially the endemic sedentary lowland species [16–19], e.g., Yellow-throated Bulbul [20]. The Yellow-throated Bulbul is an endemic, shrubland obligate species found in the Eastern Ghats of India [21]. Eastern Ghats have suffered loss in habitat quality due to the combined effect of climate change-induced drought [22] and habitat loss due to anthropogenic disturbances [15,23,24].

Our study site in the Eastern Ghats was under drought conditions from 2013 to 2016 with the region receiving 35–49% less rainfall than the average [25]. The recurrent drought affects the vegetational vigor and structure [26,27] and invertebrate populations [28–30]. In addition, the recurrent drought leads to reduced crop production from existing farmlands, causing the rural communities to encroach upon the shrub forests for suitable farming lands [15]. The droughts have also exacerbated the financial stress, thereby increasing dependence on the shrub forests for firewood extraction, livestock grazing, and other non-timber forest produce (NTFP) [15,23]. These activities put considerable and widespread pressure on these forests [31,32]. Such extractive pressures can further cause changes in forest vegetation structure, composition, and physiognomy [31] with concomitant effects on forest flora and fauna including birds, mammals, and arthropods [33,34]. Though Deshwal et al. [35] have studied the foraging ecology of shrubland bird communities during the wet season, there is a knowledge gap regarding the foraging ecology of the shrubland bird communities during the dry season. Thus, it is also imperative to quantify the foraging ecology of shrubland bird communities during the dry season to build a comprehensive habitat management plan that encompasses the effects of climate change.

The main objectives of this study were to evaluate how the shrubland bird community utilizes the available resources during the dry season in the degraded landscape of the Eastern Ghats of India. This information will play a critical role in the development of habitat management policies for grasslands and shrublands under drought. We examined microhabitat characteristics of the foraging habitat of the bird community in the shrubland forests of this region of India. By quantifying habitat features of foraging sites and comparing these with those measured at randomly located sites during the dry season, we addressed four main questions: (1) Do shrubland birds show selection for sites with specific microhabitats? If yes, which microhabitat attributes are characteristic of foraging sites preferred by shrubland birds? (2) Does the diet guild or foraging strata of a species explain their microhabitat usage? (3) Does the foraging microhabitat used by shrubland specialist birds differ from generalist shrubland users? If yes, which microhabitat attributes are characteristic of foraging sites used by shrubland specialist species? (4) Is there an association between plant species and bird species at foraging sites?

2. Methods

2.1. Study Site

We investigated microhabitat selection of the most common shrubland birds at three shrubland forest sites in Chittoor, Andhra Pradesh, India, during the dry seasons of 2015 and 2016. The three sites were Rishi Valley (120 ha), Horsley Hill (503 ha), and Noorukuppalakonda Forest Reserve (333 hectares) (Figure 1). The latter two forest sites are classified as Important Bird Areas by Birdlife International [36,37]. The climate of the region is characterized as arid and semi-arid with an annual temperature range of 16 °C to 36.8 °C, with an average annual rainfall of 700 mm. The vegetation is a mixture of southern thorn forests and dry deciduous shrub forests [38]. The region experiences two distinct seasons—wet (July–November) and dry (December–June). During 2015 and 2016, the state government declared our study site as drought-affected [39].

2.2. Study Species

For a representative shrubland avian community, we chose 18 focal species (Table 1). Out of 18 species, 15 species were shrubland specialists, and three species were generalist shrubland users [21]. We selected these species because they were frequently observed in shrubland habitats during preliminary field observation and previous point count surveys by the first author (unpublished data). Furthermore, these species collectively represent the diversity of diet guilds and foraging strata occurring in the community (Table 1). Foraging strata, diet guild, and whether a species is a habitat specialist or generalist were obtained from existing literature [21] and Tobias et al. [40].

Table 1. Summary of focal bird species, their feeding guild, foraging stratum, and whether they are specialist or generalist shrub forest users [21,40]. The column "N" indicates the number of foraging locations used to quantify microhabitat for each species.

Common Name	Scientific Name	Species Code	N	Feeding Guild	Foraging Stratum	Preference for Shrub Forest
Common Babbler	*Argya caudata*	CB	18	Omnivore	Ground	Specialist
Yellow-billed Babbler *	*Argya affinis*	YBB	18	Insectivore	Ground	Specialist
Yellow-eyed Babbler	*Chrysomma sinense*	YEB	18	Omnivore	Shrub	Specialist
Tawny-bellied Babbler	*Dumetia hyperythra*	TBB	21	Insectivore	Shrub	Specialist
Red-vented Bulbul	*Pycnonotus cafer*	RVB	21	Frugivore	Shrub	Generalist
Red-whiskered Bulbul	*Pycnonotusjocosus*	RWB	24	Frugivore	Tree	Generalist
White-browed Bulbul	*Pycnonotusluteolus*	WBB	15	Frugivore	Shrub	Specialist
Yellow-throated Bulbul *	*Pycnonotus xantholaemus*	YTB	7	Frugivore	Shrub	Specialist
Plain Prinia	*Prinia inornata*	PP	19	Insectivore	Shrub	Generalist
Jungle Prinia	*Priniasylvatica*	JP	19	Insectivore	Shrub	Specialist
Purple-rumped Sunbird	*Leptocoma zeylonica*	PRS	18	Nectarivore	Tree	Specialist
Purple Sunbird	*Cinnyris asiaticus*	PS	16	Nectarivore	Tree	Specialist
Laughing Dove	*Spilopelia senegalensis*	LD	22	Granivore	Ground	Specialist
Indian Robin	*Saxicoloides fulicatus*	IR	15	Insectivore	Ground	Specialist
Green Bee-eater	*Merops orientalis*	GBE	10	Insectivore	Tree	Specialist
Bay-backed Shrike	*Lanius vittatus*	BBS	10	Insectivore	Shrub	Specialist
Blyth's Reed Warbler **	*Acrocephalus dumetorum*	BRW	20	Insectivore	Shrub	Specialist
Sirkeer Malkoha	*Taccocua leschenaultii*	SM	12	Insectivore	Ground	Specialist

* Endemic birds of the region. ** Non-breeding winter migrant.

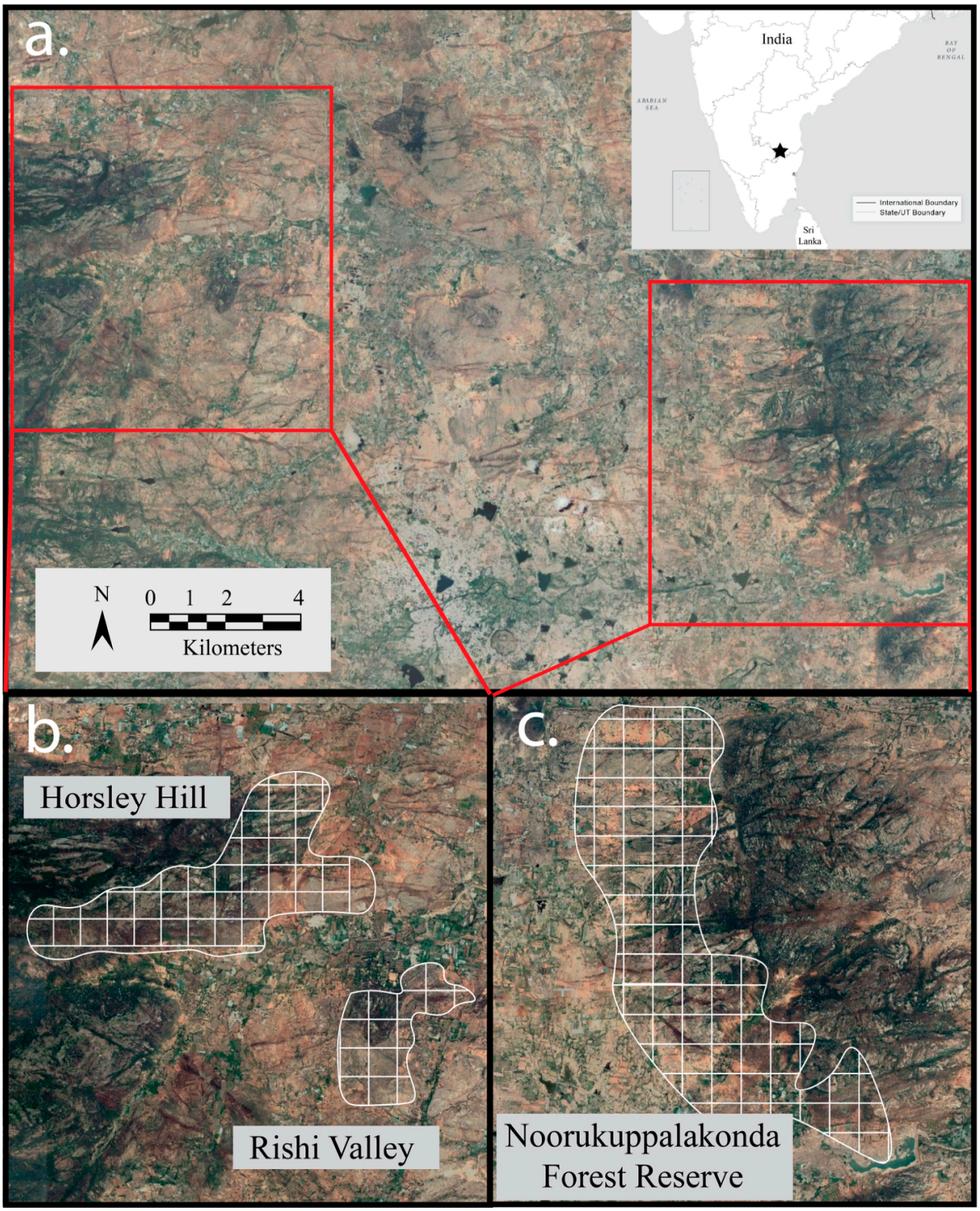


Figure 1. (**a**) Map of study area in Chittoor District, Andhra Pradesh, India. (**b**,**c**) The map shows three main shrubland forest sites sampled for the study with the overlaying grid used to sample foraging observations of shrubland bird community. This image has been adapted from Deshwal et al. [41].

2.3. Bird Surveys and Microhabitat Vegetation Data

We quantified the vegetation structure of foraging locations of focal bird species during the dry seasons (December–June) of 2015 and 2016. The three study sites were divided into 12 ha grids using ArcGIS (ESRI, 2013) [41] (Figure 1). We surveyed randomly selected grids by slowly walking from one end of each grid to other in lines ~100 m apart, thus

covering the total area [15,35]. Although this did not eliminate the chance of observing the same bird more than once, it did ensure that birds throughout the grid had an equal chance of being observed during each session. We marked the locations of foraging birds from 5:00 a.m. to 8:00 a.m., the period of high foraging activity during the day. We considered foraging location if an individual was observed foraging successfully in the habitat [15,41]. We did not survey the same grid twice in the season to ensure independence of foraging observations. Where birds were encountered foraging in flocks, the foraging microhabitat of only one individual of a species was included in the analysis. In a few cases where two or more species were observed foraging at the same location, data from a single plot were used to describe a single observation for each species [15,35]. We did not conduct surveys on days with inclement weather (raining or high winds > 20 kmph). We collected approximately 20 foraging observations for each species across the three sites [15,35].

The foraging location of an individual served as the center of an 11 m radius vegetation sampling plot (~0.04 ha) [42–44]. Within each plot, we recorded the plant species on which a bird was observed foraging and measured a total of 17 variables to quantify vegetation structure. We recorded height and diameter at breast height (DBH) of the shrub where the bird was observed foraging. We recorded the distance to the tallest tree within the plot from the center of the plot. The rest of the vegetation variables were measured at 44 random points within each sampling plot. These 44 locations were distributed in four orthogonal line transects originating at the center of the plot. The first transect was defined following the direction indicated by a random twirl of the compass [44]. At each of these 44 points, we measured canopy height, canopy cover, ground cover type, grass height, shrub density, and the number of leaves touching each section of a calibrated pole described below. These measurements were used to calculate average canopy height, canopy height evenness, average grass height, percent rock cover, percent barren cover, shrub density, stem evenness, stem variability, and vertical and horizontal foliage evenness. The ground cover was classified as the presence or absence of grass, barren ground, or rock cover at 44 random locations viewed from a hollow cylinder with cross hairs. Canopy cover was estimated visually at 44 random locations when viewed vertically from a hollow cylinder with cross-hairs. These presence or absence data were converted to calculate the percentage of ground and canopy cover, respectively, at each sampling plot.

We estimated average shrub density by calculating the mean of the number of stems intersecting a meter-long stick held horizontally at waist height (~1 m) at the 44 locations. Stem variability and stem evenness were calculated using the stem count observations at 44 locations. Stem evenness represents the pattern of scrubbiness in the sample plot; higher values show an even distribution of woody vegetation and low values indicate an irregular patchy pattern [44,45]. Stem variability represents the amount of scrubbiness between the four orthogonal sectors in a plot [44]. It was calculated by summing the absolute values of the difference in number of stems between successive transects of the plot [15,35]. If the index of shrub variability was high it demonstrated that the variability of scrubbiness between the sectors was significant, while low values indicated a uniform level of scrubbiness [15,35].

To estimate vertical and horizontal foliage stratification, we used foliage evenness indices described by Deshwal [15], Deshwal et al. [35], James [44]. The calibrated metal pole was 3 m long and 10 mm in diameter and was marked off into 0.6 m intervals [15,41]. The 0.6 m intervals were accentuated using different colored paints. The pole was positioned vertically from the ground at the 44 random points in the plot and the total numbers of leaves touching it in each of the 0.6 m intervals were recorded in five sections (0.0–0.6 m, 0.6–1.2 m, 1.2–1.8 m, 1.8–2.4 m, and 2.4–3.0 m) [41]. Horizontal and vertical foliage evenness were calculated using Shannon's diversity index. Vertical foliage evenness was based on

the sum of the number of leaves touching the pole at the *ith* height intervals at 44 random locations per plot [35,44] and horizontal foliage evenness was based on the sum of leaves touching the pole in each of four transects [15,35]. This produced a measure of vegetation distribution across sectors within the plot, with a low evenness value indicating a very patchy distribution and a high value indicating a uniform distribution. For each of the plots, we also recorded the species of shrub where the bird was found foraging [15,35].

To compare habitat features of foraging sites with those potentially available, a total of 59 random plots across three sites were sampled to quantify the microhabitats available to the birds. Each random plot was located at a randomly selected distance and direction from the center of the study site [35,45]. To reduce potential edge effects, all the random plots and foraging plots were at least 100 m away from the nearest boundary with farmland or any other land use.

2.4. Statistical Analysis

All microhabitat vegetation variables were tested for normality and transformed as necessary before analysis using the bestNormalize package in R [46]. We tested for correlation between the vegetation variables and removed the highly correlated variables ($r^2 > 0.70$) of stem variability [35]. The remaining 16 variables were used in the analysis. All statistical analyses were carried out in R software, version 3.6.1 [47].

To identify whether a vegetation variable was significantly different between each species group and random plots, we ran ANOVA tests on each of the 16 vegetation variables with the vegetation variable as a response variable and the species as predictor variable [35]. Except for three variables (barren ground cover, distance to tallest tree, and canopy cover), each vegetation variable differed significantly between species. Hence, we removed barren ground cover, distance to tallest tree, and average canopy cover from further analysis because they did not explain the variance in the data.

To test whether the foraging microhabitat used by members of the shrubland bird community was different from random plots, we pooled together vegetation variables of foraging plots for all bird species and compared these to vegetation variables for random plots. This comparison was performed using the MANOVA test on 13 variables as response variables and bird or random plot as the predictor variable.

We used linear discriminant analysis (LDA) to differentiate the habitat selected by each bird species and how it differed from the available habitat. The objective was to identify linear combinations of the variables that separate the groups. LDA identifies axes that maximize the variance in the data and also maximizes the separation between the multiple classes [35,43,48]. The habitat data for all avian plots were multiplied by the discriminant weights obtained for each factor from the LDA and the products were summed to produce a single discriminant score for each foraging observation [35,43]. Despite showing differences in the habitat selected by foraging birds in the available habitat, LDA offers no information on whether or not these differences are significant. To test whether the foraging plots selected by birds were significantly different among bird species and with random plots, we performed a post hoc univariate one-way ANOVA on each vegetation variable [35].

To examine the effect of feeding guild (Table 1) on the selection for vegetation structure, we ran a one-way ANOVA followed by Tukey HSD with LD1 and LD2 values of each foraging observation as the response variable and the feeding guild of the bird as a predictor variable [35]. Similarly, to examine the effect of foraging strata (Table 1) on the selection for vegetation structure, we ran a one-way ANOVA followed by Tukey HSD with LD1 and LD2 values of each foraging observation as the response variable and known foraging strata of the bird as the predictor variable. We tested for the effect of whether the species is a specialist or generalist shrubland species (Table 1) on the selection for vegetation

structure, using a one-way ANOVA followed by Tukey HSD with LD1 and LD2 values of each foraging observation as the response variable and specialist or generalist shrubland species as the predictor variable.

To determine associations between plant and bird species, we conducted an association test between plant species on which each bird was observed foraging and the bird species using a Chi-square test. If the value of standardized residuals was greater than or equal to two, then there was a significant association between plant and bird species.

3. Results

We quantified vegetation characteristics associated with 303 foraging plots for 18 shrubland bird species and 59 random plots. Each species was observed at all three sites. Univariate one-way ANOVA on each vegetation characteristic showed that there was a statistically significant difference in the 13 vegetation characteristics among bird species (Table 2). The MANOVA test showed that the foraging microhabitat used by the shrubland bird community differed significantly from random sites ($F_{13,342} = 2.51$, $p = 0.002$).

Table 2. Analysis of variance (ANOVA) on 13 vegetation characteristics of foraging plots for 18 shrubland bird species across three shrub forests in the Eastern Ghats of India. The F-value and *p*-value of ANOVA test on the 13 vegetation characteristics are shown. All the following 13 characteristics were significantly different between the bird groups.

Vegetation Characteristic	F-Value	*p*-Value
% Rock Cover	2.74	<0.001
Shrub Height	3.58	<0.001
Diameter at Breast Height	2.28	0.002
Average Shrub Density	3.27	<0.001
Average Ground Cover	4.24	<0.001
Average Grass Height	2.23	0.002
Stem Evenness	2.84	<0.001
Vertical Foliage Evenness	1.78	0.02
Horizontal Foliage Evenness	3.85	<0.001
Canopy Height Evenness	2.37	0.001
Average Canopy Height	1.741	0.03
Grass Height Evenness	1.611	0.05
Average Dry Grass Cover	2.11	<0.01

3.1. Microhabitat Selection and Characteristics of Preferred Foraging Sites

Linear discriminant function analysis described microhabitat variables contributing the most to the difference between each bird species and random plots. The first three linear discriminants (LD) explained 65.2% of the variance (Table 3). LD1 was an index of ground cover as indicated by strong positive factor loadings for average ground cover with grass. LD2 had a high positive factor loading for shrub density, and a negative factor loading for vertical foliage evenness. LD3 had a high negative factor loading for shrub height. Species distribution along LD1, LD2, and LD3 axes indicated that the interaction between average ground cover, shrub density, vertical foliage evenness, and shrub height separates the species from each other as well as from random plots (Figure 2). For example, the Bay-backed Shrike (*Merops orientalis*) prefers an open site with even vertical foliage and low ground cover.

Table 3. Factor loadings and percentage of variance explained by the first three linear discriminant (LD) axes for variables characterizing vegetation structure of the foraging microhabitat of shrubland bird community in the Eastern Ghats of India. Bold figures indicate variables with the highest loadings.

Linear Discriminants	1	2	3
% of Variation	31.20	18.90	15.13
Cumulative % of Variation	31.20	50.10	65.23
Variables	LD1	LD2	LD3
% Rock Cover	0.35	0.10	0.03
Shrub Height	−0.03	0.53	**−0.97**
Diameter Breast Height	0.46	−0.02	0.00
Average Shrub Density	−0.43	**0.67**	0.38
Average Ground Cover	**0.66**	−0.12	−0.05
Average Grass Height	0.20	0.13	0.16
Stem Evenness	0.23	0.27	0.00
Vertical Foliage Evenness	0.16	**−0.60**	0.20
Horizontal Foliage Evenness	0.24	−0.42	0.24
Canopy Height Evenness	0.15	0.21	0.14
Average Canopy Height	0.20	0.05	0.07
Grass Height Evenness	−0.10	0.02	0.41
Average Dry Grass Cover	−0.01	0.16	−0.34

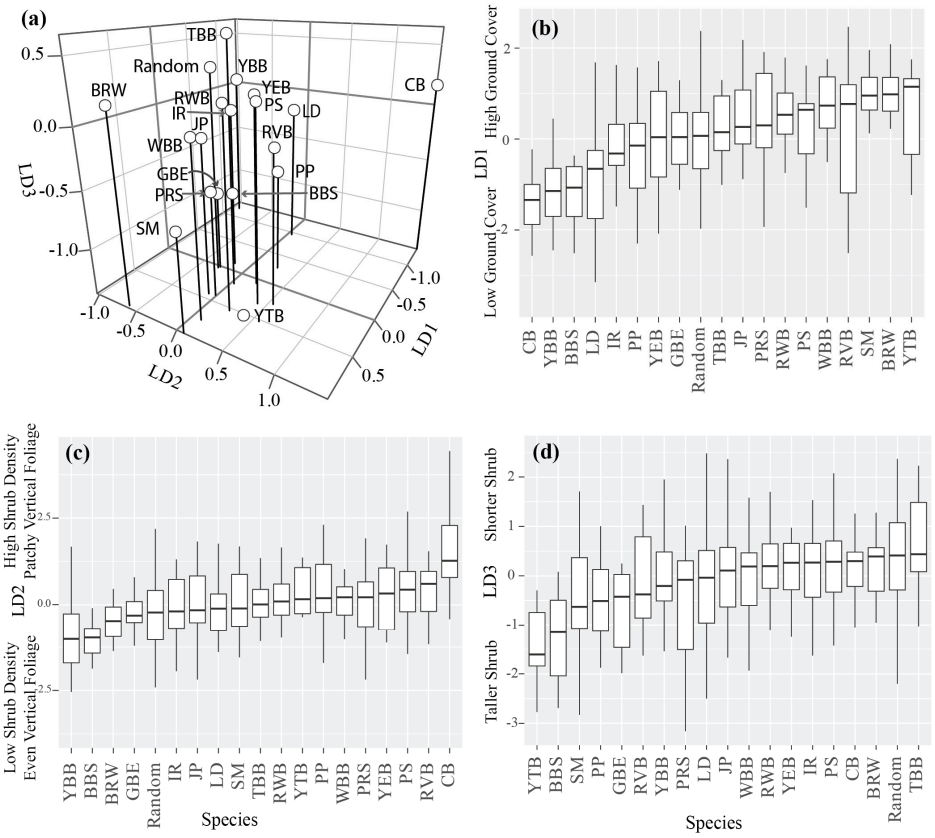


Figure 2. (**a**) Three-dimensional representation of ordination of foraging plots for shrubland birds and random plots based on LDA analysis on 13 vegetation characteristics, (**b**) ordination of shrubland bird community based on LD1 scores, (**c**) ordination of shrubland bird community based on LD2 scores, and (**d**) ordination of shrubland bird community based on LD3 scores. Code names of shrubland species of the Eastern Ghats of India (CB: Common Babbler, GBE: Green Bee-eater, IR: Indian Robin, JP: Jungle Prinia, LD: Laughing Thrush, PP: Plain Prinia, PRS: Purple-rumped Sunbird, PS: Purple Sunbird, RVB: Red-vented Bulbul, RWB: Red-whiskered Bulbul, TBB: Tawny-bellied Babbler, WBB: White-browed Bulbul, YBB: Yellow-billed Babbler, YEB: Yellow-eyed Babbler). Box plots depict minimum, first quartile, median, third quartile, and maximum, with outliers depicted as single points.

3.2. Effect of Diet Guild, Foraging Strata, and Specialist/Generalist Species

The effect of diet guild on LD1 scores (ANOVA: $F_{(4,298)} = 11.15$, p-value < 0.001) and LD2 scores (ANOVA: $F_{(4,298)} = 10.07$, p-value < 0.001) was significant. When looking at habitat preferences of the avian community according to their diet preference, granivore and omnivore foraged in vegetation with low ground cover, while frugivores foraged in regions with high ground cover (Figure 3a). Insectivore species preferred low shrub density as compared to omnivores (Figure 3d). The effect of foraging strata on LD1 score (ANOVA: $F_{(2,300)} = 22.67$, p-value < 0.001) was significant. Birds foraging on ground strata had significantly lower LD1 scores than birds foraging in taller shrubs or trees, implying that species foraging on the ground preferred sites with low ground cover to those foraging in tree or shrub strata (Figure 3b). Habitat variables represented by LD2 did not differ significantly between birds foraging at different strata (ANOVA: $F_{(2,300)} = 0.411$, p-value = 0.663). There was significant difference in LD1 scores for generalist or specialist shrubland birds (ANOVA: $F_{(1,301)} = 9.771$, p-value < 0.01). However, the LD2 scores (ANOVA: $F_{(1,301)} = 0.062$, p-value = 0.80) had no significant difference for specialist and generalist species. Shrub specialists foraged at sites with low ground cover (Figure 3f).

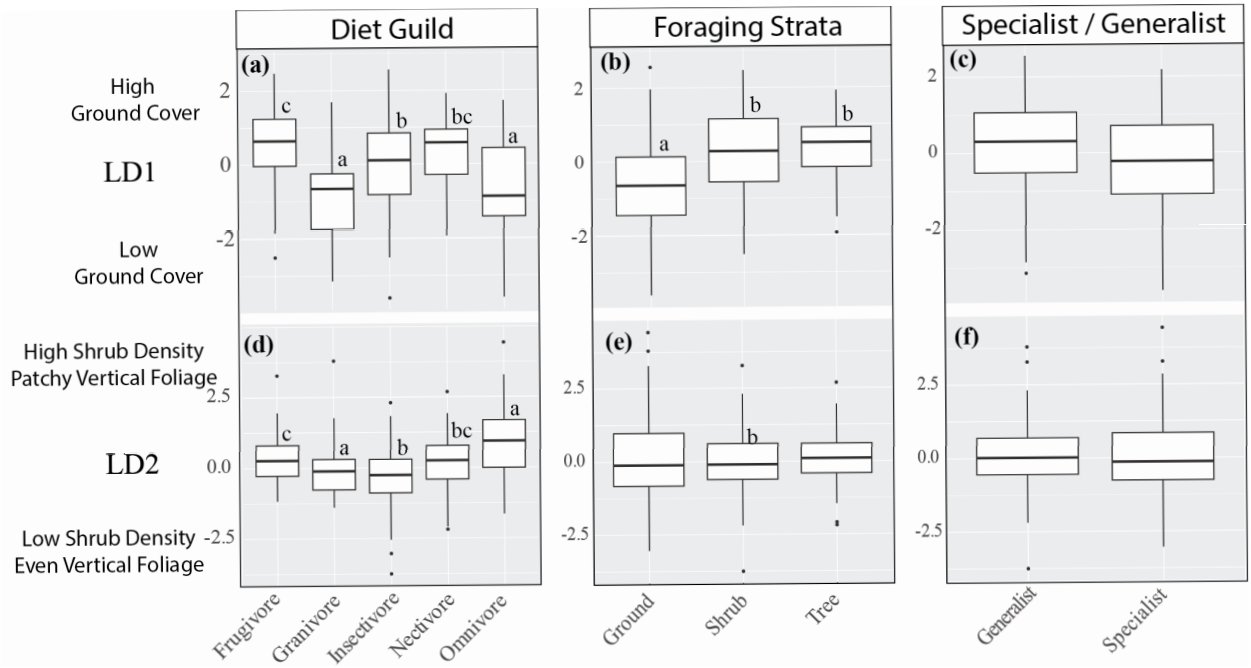


Figure 3. Linear discriminant analysis of the effect of diet guild (**a**,**d**), foraging strata (**b**,**e**), and generalist/specialist shrubland bird species (**c**,**f**) on linear discriminant 1 and 2 in the shrubland bird community of the Eastern Ghats of India. Different lowercase letters (above boxes) indicate significant difference (based on Tukey HSD pairwise comparison), for example, box labelled "a" is significantly different from box labelled "c" but neither differs significantly from box labelled "ac". Box plots depict minimum, first quartile, median, third quartile, and maximum, with outliers depicted as single points.

3.3. Association Between Bird Species and Plant Species

There was a strong association between bird species and plant species in the shrubland forests of the Eastern Ghats ($\chi^2 = 565.72$, df = 442, p-value < 0.001). The results of the association test were plotted using a mosaic plot (Figure 4). The thickness of the box represents variance of the plant species used for foraging, and the length of the box represents the variance of a particular bird species in choosing corresponding plant species for foraging. Each box represents the degree of association between each plant and bird species pair.

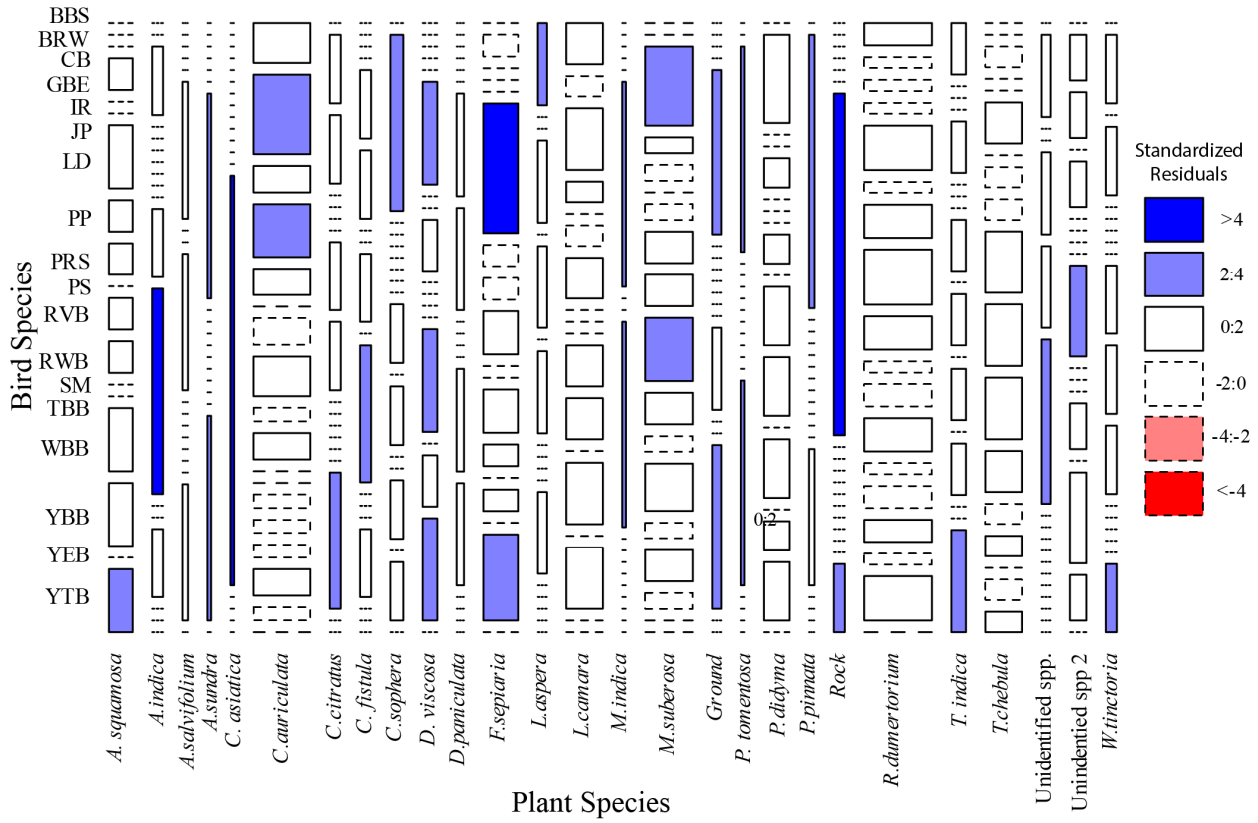


Figure 4. Mosaic plot showing associations between shrubland bird species and plant species at foraging sites. Each box represents a bird–plant species pair, where the width reflects the variance explained by the plant species, and the height reflects the variance explained by the bird species. The area of each box indicates the degree of association. Significant associations are indicated by standardized residuals $\geq |2|$, suggesting that a bird species forages more or less frequently on a given plant species than expected by chance.

4. Discussion

We found that the microhabitat characteristics of foraging sites for all focal species were significantly different from the randomly selected sites during the dry season. This difference suggests that each species selects for a set of microhabitat characteristics at their foraging sites. Ground cover, shrub height, vertical foliage evenness, and shrub density were key explanatory variables in the model for the focal species. For example, the Yellow-billed Babbler foraged at sites with low ground cover and shrub density. Fifty percent of the focal species foraged at sites with high ground cover. Six out of 18 species foraged at sites with high shrub density. Fourteen out of 18 species foraged at sites with tall shrubs or trees.

During the dry season, the overlap in preferred foraging habitat between species was higher than observed by Deshwal et al. 2022 [35] in the wet season. The dry season may lead to an increased inter-species interaction because of the decrease in available habitat [49,50] and poorer habitat quality of the available habitat [7]. The dry season reduces available food resources through a decline in the invertebrate populations and foliage [29,30,51], thereby affecting the resource and habitat partitioning [52,53] among the avian community. The shrubland birds face high physiological stress due to reduced food availability/quality [54]. The two mechanisms used by the avian community to avoid increased competition for resources and to avoid increased mortality during the dry season are as follows: (1) migration to suitable habitats by migratory species; (2) sedentary species modify their foraging ecology and behavior [2,55]. Granivores, frugivores, and

gleaning insectivores are most prone to reduction in food availability/quality during the dry season [54,56]. These species are often found foraging in similar microhabitat conditions that mimic the wet season, e.g., Red-whiskered Bulbul foraged in regions with high shrub density and even vertical foliage stratification during the wet season [41] and during the dry season they foraged in plots with high ground cover, shrub density, and low vertical foliage evenness.

The specialist shrubland species such as Sirkeer Malkoha and Yellow-throated Bulbul foraged at sites with higher ground cover, shrub density and patchy vertical foliage as compared to generalist shrubland species such as Red-vented Bulbuls (Figure 2). Bay-backed Shrike, a shrubland specialist, usually feeds on lizards and large invertebrates [21], and forages in open habitats with low shrub density and tall shrubs (Figure 2) that provide it with an exposed perch to look for prey [21]. We had few datapoints for foraging plots of the endemic shrubland specialist, Yellow-throated Bulbul due to low population density [20]. However, since it is an endemic species in decline, we decided to include it in the analysis as this information will be helpful in managing the landscape for its recovery. Yellow-throated Bulbul foraged in open sites with high shrub density, patchy vertical foliage, and tall vegetation. Our results agree with observations by Ali et al. [21], in which they were found foraging with Red-vented Bulbul and Red-whiskered Bulbuls. Blyth's Reed Warbler was the only migratory species in this study. This insectivorous species foraged at sites with high ground cover, uniform vertical foliage, and low shrub density. This shy species forages in bushes and thick undergrowth [21] thus explaining its preference for short shrubs with uniform foliage.

Ground-foraging insectivores such as the Yellow-billed Babbler foraged at sites with short vegetation and low ground cover. Our results are consistent with the findings of Antos, et al. [57] who noted that ground-foraging species forage in gaps between shrubs and tall grasses, presumably because such features of the vegetation confer advantages as foraging sites [57]. These open areas may offer increased visibility to detect predators, thus reducing the probability of being depredated [57], and an efficient foraging habitat for invertebrate prey [57–59].

Ground foraging species foraged at sites with significantly lower ground cover than species foraging at the other two strata (Figure 3b). Ground foraging granivores such as the Laughing Dove foraged in regions with low ground cover because most shrubs and trees shed leaves during the dry season [30] make it difficult to find the seeds [57]. Ground foraging insectivores (Common Babblers and Yellow-billed Babblers) prefer to forage close to shrubs with low ground cover for similar reasons as ground foraging granivores; the probability of finding invertebrates at sites with low ground cover will be higher given high leaf litter.

Insectivores such as the Green Bee-eater and Bay-backed Shrike that forage by catching prey through aerial maneuvers prefer the increased visibility of their prey offered by low shrub density. The propensity of aerial foraging maneuvers is negatively impacted by the constraints imposed by foliage structure [60–62]. The Green Bee-eater did not have any preference for ground cover, shrub density, or vertical foliage structure. This may be because the absence of foliage provides relatively higher visibility and thus the amount of available suitable habitat is higher than that present post-monsoon [15]. Understory insectivores such as the Tawny-bellied Babbler and Yellow-eyed Babbler prefer to feed close to the ground. Dense vegetational cover provides these birds with the necessary cover to avoid predators. The difference in vertical stratification preference for the Plain Prinia and Tawny-bellied Babbler might be due to different prey-catching techniques used by these species [21] and will need to be tested through empirical studies.

Nectarivores (Sunbirds) and frugivores (Bulbuls) foraged in regions with high shrub density and tall vegetation. Within the nectarivores, both species foraged at more open sites. Purple Sunbird preferred higher shrub density and patchy vertical foliage, and Purple-rumped Sunbird had no preference. Purple-Sunbird forages primarily in shrub forests [21] while Purple-rumped Sunbird is often found foraging in secondary forests and along forest edges [21]. Our results were consistent with those reported by Barth et al. [63]. Frugivores such as the Red-vented Bulbul are commonly found in gardens and urban settings [21] and hide in tall and dense shrubs; they are often found foraging in tall trees [21]. Dense shrubs often provide necessary cover from predators as well as the fruit crop required by the frugivores.

4.1. Plant Associations

Thirteen out of 18 focal species were strongly associated with one of the plant species. Laughing Dove was associated with an unidentified plant and was often observed feeding on the seeds of this plant during fieldwork. Laughing Dove and Yellow-throated Bulbul were often found foraging near a large rock boulder; similarly, Yellow-billed Babbler and Indian Robin were often observed foraging on the ground with no vegetation close by. Ten out of 18 species had a weak negative association with *Lantana camara*, an invasive plant species. Ali et al. [21] describe that Yellow-billed Babbler were often found in close proximity to *L. camara*, but our data did not show any such association. Three species, Jungle Prinia, Yellow-eyed Babbler, and Tawny-bellied Babbler, were positively associated with *Dodonea viscosa*, and two species, Blyth's Reed Warbler and Green Bee-eater, were associated with *Cassia auriculata*. Neither of these plant species shed their leaves, and the presence of foliage from these species during the dry season offers multiple advantages. Foliage provides shade, creating microclimatic conditions for the invertebrates to remain active, which in turn provides prey for insectivorous species. The burrowing invertebrates, such as earthworms, stay near the surface in these shaded regions because of relatively high soil moisture in these microhabitats [54]. It also provides cover to the shy species such as Blyth's Reed Warbler and Tawny-bellied Babbler. Twelve out of 13 bird species associated with plants were associated with at least one plant species that started greening up by end of April, two months before the monsoons. Five of 18 species, White-browed Bulbul, Plain Prinia, Purple-rumped Sunbird, Indian Robin, and Sirkeer Malkoha, did not show any strong association with plant species.

4.2. Conservation Implications

Our results show that most birds in this shrubland community are selecting foraging habitat non-randomly and their foraging guilds can explain much of the variation. Herein, we demonstrate how some of the important foraging microhabitat variables can be actively managed by manipulating the predominant anthropogenic land use practices of the region. For example, shrub density, which is important to particular species/groups, especially during the dry season, where dense shrub structure acts as a proxy for absent foliage cover. Thus, it probably protects species such as Yellow-throated Bulbul from thermal shock or dehydration. Birds foraging in dense vegetation have poorer thermal tolerance [64] and higher evaporative loss [65] than those in open habitat. Shrub density can be managed by implementing spatially selective harvesting of firewood. This will result in an available continuum of shrub densities ranging from high density where collection is banned to low density where collection is encouraged.

In addition, firewood collection could focus on removal of invasive plant species such as *L. camara* or *Prosopis*, that are not associated with the preferred foraging habitat for any of the bird community. Even though the aromatic flowers of *L. camara* are present

throughout the year [66], providing a food source for nectarivores birds when native species may not be flowering, and *L. camara* forms dense thickets [67,68] which provides cover from potential predators, we did not observe any direct association between the birds and *L. camara.* Increased drought events cause restructuring in plant communities that facilitate invasive species such as *L. camara* [26,54]. Hence, proactive management steps need to be taken to prevent the invasive species from outcompeting the native plant community. Removal of these invasives would provide opportunities for more beneficial native shrubs to regenerate. By promoting native vegetation such as *Dodonea viscosa* that never sheds leaves, we can ensure vegetational cover for the high vertical foliage-evenness-preferring species such as the migratory Blyth's Reed Warbler.

We can facilitate rehabilitation of the Yellow-throated Bulbul by planting plants with which they have high association, such as *Annona squamosa* and *Wrightia tinctoria*. Stone quarries for the extraction of granite are a major threat to Yellow-throated Bulbul populations at our study site (A. D., pers. obs.). By regulating stone mining in the Eastern Ghats, we can protect the preferred habitat for this declining endemic species categorized by IUCN [20].

A more regulated livestock-grazing regime has the potential of manipulating the availability of native herb cover, a habitat characteristic important for ground foraging granivore and omnivore species [57,69,70]. Creating zones with exclusion of grazing or establishing regions with different gradients of grazing would allow species such as *Wrightia tinctoria* to flourish [69,70]. A similar regime could be implemented for grass harvest to discourage over-harvesting from a single spot that might benefit ground-foraging species by protecting suitable habitat.

Studies on the dry season ecology of shrubland and grassland birds during drought periods remain a high priority for grassland and shrubland bird conservation [71] as densities of birds in these communities are susceptible to changes in local habitat characteristics [4,56]. Though it is unrealistic to expect restoration of all the shrublands [72], development of a framework of interaction between shrubland birds and their habitat along with management techniques will play a critical role in their conservation in human dominated landscapes.

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