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RESEARCH ARTICLE

Foraging habitat selection of shrubland bird community in tropical dry forest

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Abstract

Habitat loss due to increasing anthropogenic disturbance is the major driver for bird population declines across the globe. Within the Eastern Ghats of India, shrubland bird communities are threatened by shrinking of suitable habitats due to increased anthropogenic disturbance and climate change. The development of an effective habitat management strategy is hampered by the absence of data for this bird community. To address this knowledge gap, we examined foraging sites for 14 shrubland bird species, including three declining species, in three study areas representing the shrubland type of forest community in the Eastern Ghats. We recorded microhabitat features within an 11 m radius of observed foraging points and compared these data with similar data from random plots. We used chi-square to test the association between plant species and bird species for sites where they were observed foraging. We observed significant differences between foraging sites of all the study species and random plots, thus indicating selection for foraging habitat. Using linear discriminant analysis, we found that the microhabitat features important for the bird species were shrub density, vegetational height, vertical foliage stratification, grass height, and percent rock cover. Our results show that diet guild and foraging strata influence the foraging microhabitat selection of a species (e.g., ground-foraging species differed significantly from other species). Except for two species, all focal birds were associated with at least one plant species. The plant-bird association was based on foraging, structural, or behavioral preferences. Several key factors affecting foraging habitat such as shrub density can be actively managed at the local scale. Strategic and selective harvesting of forest products and a spatially and temporally controlled livestock grazing regime may allow regeneration of scrubland and create conditions favorable to birds.

KEYWORDS
bird assemblage, dry forest management, eastern Ghats, linear discriminant analysis, microhabitat, vegetation structure

TAXONOMY CLASSIFICATION
Applied ecology; Biodiversity ecology; Community ecology; Conservation ecology

1 | INTRODUCTION

One of the defining environmental challenges of the 21st century is slowing the loss of biodiversity. Habitat loss, climate change, and unregulated harvest are the major causes of the decline in biodiversity, with profound effects on ecosystem functioning and services (Bellard et al., 2012; Dobson et al., 2006; Leaver et al., 2019). Reduction in available habitat for ground-foraging species due to landscape fragmentation is causing declines in their populations (Antos et al., 2008; Ford et al., 2001; Reid, 1999; Robinson & Traill, 1996). Declines in abundance can degrade ecosystem integrity, reducing vital ecological, evolutionary, and economic and social services that organisms provide to their environment (Bauer & Hoye, 2014; Daily, 1997; Galetti et al., 2013; Gaston & Fuller, 2008; Hooper et al., 2012; Inger et al., 2015; Whelan et al., 2015). Given the current pace of habitat loss and degradation of remaining habitat, quantifying the habitat use of poorly known animal communities is essential to designing effective conservation strategies.

Species select for habitat attributes at multiple spatial scales to fulfill their requirements for survival and reproduction. Factors that contribute to selection of foraging habitats include the cost associated with foraging, the abundance and energetic value of food, the risk of predation, and the density of competitors (Mangel, 1990; Rosenzweig, 1987). Studies of the foraging ecology and foraging habitats of bird species have enhanced our understanding of the interactions between species, the partitioning of resources among species and the organization of communities (Ford et al., 1986; Frith, 1984; Recher & Majer, 1994; Robinson, 1992; Serrano & Astrain, 2005; Wooller & Calver, 1981). Such studies also provide insights into the management of habitats for biodiversity conservation.

However, the absence of habitat use data for several avian communities, especially in understudied regions of the world, hinders any planning for habitat management even though these communities may be facing pressure from rapid human development. Scrub forests in the heavily fragmented landscapes of the Eastern Ghats in India are an example of such a region where the absence of data on shrubland bird communities impedes habitat management plans. The Eastern Ghats are a discontinuous mountain range along the eastern coast of southern India. They have undergone tremendous change in land use and land cover due to deforestation, increasing urbanization, construction of dams, and mining (Ramachandran et al., 2018). Increased mining and human settlement not only causes over exploitation of the resources but also leads to degradation of forest habitat and loss of biodiversity (Palmer et al., 2010). Recurrent droughts (Kumar et al., 2019) and prevailing socioeconomic conditions have led to agricultural encroachment into shrub forests (Deshwal, 2019). The socioeconomic conditions also cause the local people to be dependent upon the scrub forests for firewood extraction, livestock grazing, and other Non-Timber Forest Produce (Deshwal, 2019; Paul, 2012). These activities put considerable and widespread pressure on these forests (Borghesio, 2008; Shahabuddin & Kumar, 2007). Such extractive pressures can cause changes in forest vegetation structure, composition, and physiognomy (Shahabuddin & Kumar, 2007) with concomitant effects on forest flora and fauna including birds, mammals, and arthropods (Chazdon, 2003; Hansen et al., 1995). Conservation of suitable habitats and the maintenance of habitat quality is contingent upon the species-level knowledge of habitat requirements.

Our main objective was to evaluate how the shrubland bird community utilizes the available resources in the degraded landscape of the Eastern Ghats. 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, we addressed three main questions: (1) Do shrubland birds show selection for sites with specific microhabitats? If yes, what characteristics of foraging microhabitat are preferred by shrubland birds? (2) Does the diet guild or the foraging strata explain the microhabitat usage? (3) 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 wet seasons of 2015 and 2016. The three sites were the Rishi Valley (120 ha), Horsley Hill (503 ha), and the Noorukuppalakonda Forest Reserve (333 hectare; Figure 1). The latter two forest sites are classified as Important Bird Areas by Birdlife International (2021a, 2021b). All three study sites experience similar disturbance due to human presence. The climate of the region is characterized as arid and semi-arid with an annual temperature range of 16 to 36.8°C, and an average annual rainfall of 700 mm. The vegetation is a mixture of southern thorn forests and dry deciduous scrub forests (Champion & Seth, 1968). The region experiences two distinct seasons—wet (May–Nov) and dry (Dec–May).

2.2 | Study species

For a representative shrubland avian community, we chose 14 focal species (Table 1). These species were selected because they were (1) the most common species, based on point counts done by the senior author before the start of this study, and (2) were easily detectable. These species were also chosen because their diet guild and foraging strata span the available range of strategies occurring in the community (Table 1). Foraging strata and diet guild of each species were obtained from existing literature (Ali et al., 1987).

2.3 | Bird surveys and microhabitat vegetation data

We quantified the vegetation structure of foraging locations of 14 shrubland bird species during the wet seasons (May–Nov) of 2015 and 2016. The three study sites were divided into 12 ha (300 × 400 m)

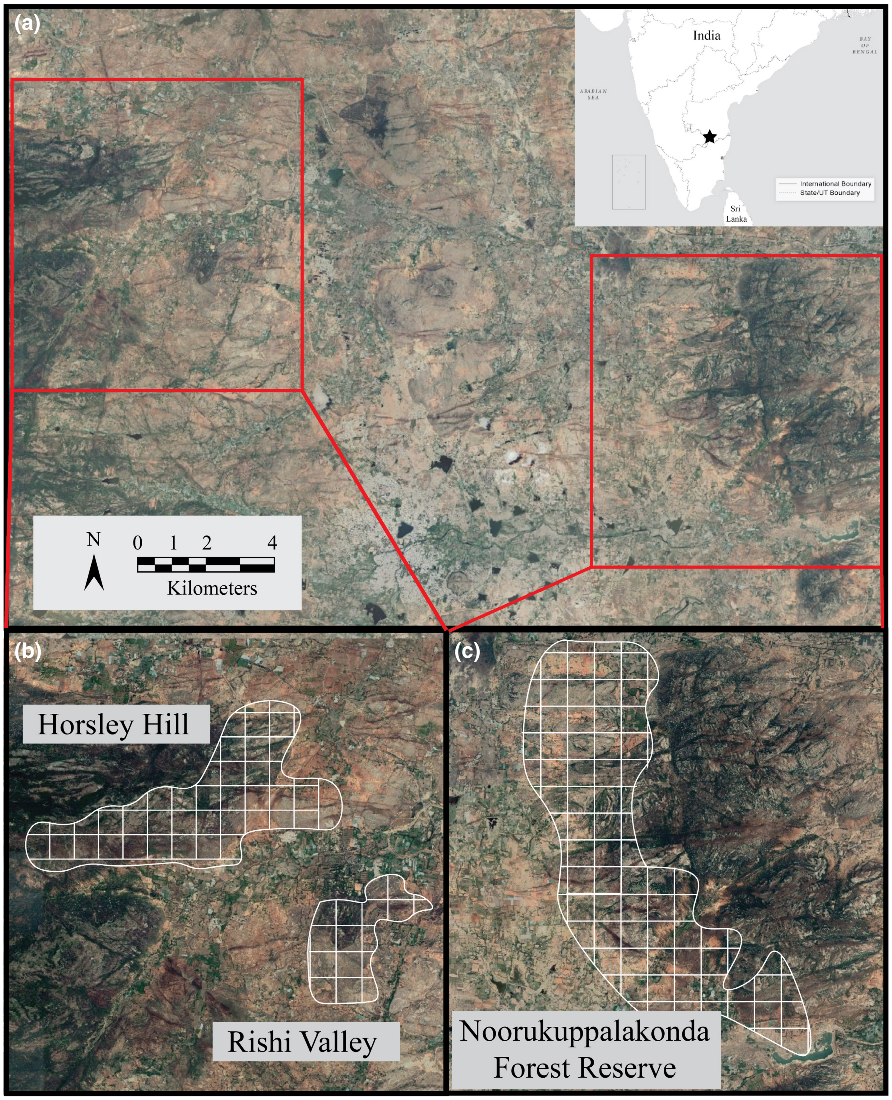

FIGURE 1 (a) Map of study area in Chittoor District, Andhra Pradesh, India. (b, c) The map shows three main shrubland forest sites sampled for the study with the overlaying grid used to sample foraging observations of shrubland bird community.

grid using ArcGIS (ESRI, 2013; 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. Although this did not eliminate the risk of observing the same bird more than once, it ensured that birds throughout the grid had an equal chance of being observed during each session. We only sampled a 12 ha plot for birds if the plot had more than 90% area as shrubland. We used aerial images from Google maps to determine land cover and ground-truthed them during the field visits. We marked the locations of foraging birds from 5:00 a.m. to 8:00 a.m. We considered foraging location if an individual was observed foraging successfully in the habitat. Successful foraging was recorded if the bird was found feeding on fruits/nectar or observed catching its prey by the preferred foraging strategy (such as perch-and swoop, glean, sallying) of each species described in literature (Ali et al., 1987). 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 in the same location or on the same species of plant, data for one plot were used to describe one observation of each species. 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 (Deshwal, 2022).

The foraging location of an individual served as the center of an 11 m radius vegetation sampling plot (~0.04 ha; James, 1992; James & Shugart, 1970; Smith, 1977). Within each plot, we measured 14 variables to quantify vegetation structure. We recorded height and Diameter at Breast Height (DBH) of the shrub where the bird was observed foraging and the distance to the tallest tree within the plot from the center of the plot. Remaining 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 diameter (James, 1992). At each of these 44 points, we measured canopy height, 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,

Common name	Scientific name	Species code	Feeding guild	Foraging stratum	N
Common Babbler	*Turdoides caudata*	CB	Omnivore	Ground	20
Yellow-billed Babbler	*Turdoides affinis*	YBB	Insectivore	Ground	19
Yellow-eyed Babbler	*Chrysomma sinense*	YEB	Omnivore	Shrub	15
Tawny-bellied Babbler	*Dumetia hyperythra*	TBB	Insectivore	Shrub	19
Red-vented Bulbul	*Pycnonotus cafer*	RVB	Frugivore	Shrub	21
Red-whiskered Bulbul	*Pycnonotus jocosus*	RWB	Frugivore	Tree	19
White-browed Bulbul	*Pycnonotus luteolus*	WBB	Frugivore	Shrub	20
Plain Prinia	*Prinia inornata*	PP	Insectivore	Shrub	20
Jungle Prinia	*Prinia sylvatica*	JP	Insectivore	Shrub	18
Purple-rumped Sunbird	*Leptocoma zeylonica*	PRS	Nectarivore	Tree	21
Purple Sunbird	*Cinnyris asiaticus*	PS	Nectarivore	Tree	17
Laughing Dove	*Spilopelia senegalensis*	LD	Granivore	Ground	20
Indian Robin	*Saxicoloides fulicatus*	IR	Insectivore	Ground	21
Green Bee-eater	*Merops orientalis*	GBE	Insectivore	Tree	19

Note: Where birds were encountered in flocks, the foraging microhabitat of only one individual of species was included in analysis.

TABLE 1 Summary of focal bird species, their feeding guild, foraging stratum, and number of individuals found foraging (*N*).

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 crosswire sighting tube held perpendicular to the ground (Shugart & James, 1973; Winkworth & Goodall, 1962). The presence or absence data were converted to calculate the percentage of ground cover at each sampling plot.

We estimated average shrub density by calculating the mean of 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 (Harvey & Weatherhead, 2006; James, 1992). Stem evenness was calculated using Shannon's diversity index based on the proportion of total stems occurring in each of the four transects in plot (James, 1992). Stem variability represents the amount of scrubbiness between the four orthogonal sectors in a plot (James, 1992). The measure of stem variability was calculated by summing the absolute values of the differences in number of stems between successive transects in the plot. Starting with a transect, the number of stems in that transect was subtracted from the number of stems in the adjacent transect in the circle. The absolute value of that difference was then summed with the absolute value of the difference between the second and its adjacent transect in the circle, and so forth until four such values were totaled from the four transect comparisons. If this index of shrub variability was high it showed that there was considerable variation in scrubbiness between sectors in the plot circle, a low value indicated the existence of a rather uniform scrubbiness throughout the plot (James, 1992).

To estimate vertical and horizontal foliage stratification, we used foliage evenness indices described by James (1992), where data are collected for the number of leaves touching a calibrated pole at different heights. The calibrated metal pole was 3 m long and 10 mm in diameter and marked at 0.6 m intervals. 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, 0.6–1.2, 1.2–1.8, 1.8–2.4, and 2.4–3.0 m). Vertical foliage evenness was calculated using Shannon's diversity index based on the sum of the number of leaves touching the pole at the *i*th height intervals at 44 random locations per plot (James, 1992). Horizontal foliage evenness was calculated using Shannon's diversity index on the sum of leaves touching the pole in each of four transects. This produced a measure relating to the distribution of vegetation from sector to sector over the plot, where a low evenness value depicts a very patchy distribution of vegetation among sectors and a high value indicates a uniform distribution of vegetation between sectors in the plot. For each of the plots, we also recorded the species of shrub where the bird was found foraging.

To compare habitat features of foraging sites with those potentially available, a total of 42 random plots across three sites were sampled to quantify the microhabitats available to the birds. The number of random plots varied between the three study sites: Rishi Valley ($n = 7$), Horsley Hills ($n = 20$), and Noorukuppalakonda Forest Reserve ($n = 15$). Each random plot was located at a randomly selected distance and direction from the center of the study site (Harvey & Weatherhead, 2006). 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 (Peterson, 2017). We tested for correlation between the 14 vegetation variables and removed the highly correlated variables ($r^2 > 0.70$) of shrub DBH, stem variability, and grass cover evenness. The remaining 11 variables were used in the analysis. All statistical analyses were carried out in R software, version 3.6.1 (R Core Team, 2019).

To identify whether a vegetation variable was significantly different between each species group and random plots, we ran ANOVA tests on each of the 11 vegetation variables with the vegetation variable as a response variable and the species as predictor variable. Except for one, variable (barren ground cover), at least one species significantly differed from other species for each vegetation variable. Hence, we removed percent of barren ground cover from further analysis because it 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 them to vegetation variables for random plots. This comparison was performed using the MANOVA test on 10 vegetation variables as response variables with 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 maximize the separation between the multiple classes (James, 1971; Smith, 1977). 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 (Smith, 1977). Despite showing differences in the habitat selected by foraging birds in the available habitat, LDA offers no information on whether 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.

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, LD2, and LD3 values of each foraging observation as the response variable and the feeding guild of the bird as a predictor variable. 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, LD2, and LD3 values of each foraging observation as the response variable and known foraging strata of the bird as the predictor variable.

To determine associations between plant and bird species, we conducted a chi-square test between plant species on which each bird was observed foraging and the bird species. The strength of association is a measure of how much the observed values deviate from the values in case of independence, and we used Pearson's standardized residuals (difference between the observed and expected values divided by square root of the expected value) to measure the departure of each cell from independence (Agresti, 2013). If the value of Pearson's standardized residuals was greater than or equal to two, then there was a significant positive association between plant and bird species (Agresti, 2013). We used the mosaicplot function from the built-in R package "graphics" to represent the contingency table and standard residuals from chi-squared test (Friendly, 1994).

3 | RESULTS

We quantified vegetation characteristics associated with 269 foraging plots for 14 shrubland bird species (137 plots in 2015 and 132 in 2016) and 42 random plots (22 plots in 2015 and 20 plots in 2016). Each species was observed at all three sites. Univariate one-way ANOVA on each vegetation characteristics showed that there was a statistically significant difference in the 10 vegetation characteristics among bird species (Table 3). The MANOVA test showed that the foraging microhabitat used by the shrubland bird community differed significantly from random sites ($F_{10,283} = 7.32$, $p < .001$).

3.1 | Microhabitat selection and characteristics of preferred foraging sites

Linear discriminant (LD) function analysis described microhabitat variables contributing the most to the difference between each bird species and random plots. The first three LDs explained 71% of the variance (Table 2). LD1 was an index of shrub density as indicated by strong positive factor loadings for shrub height and average shrub density. LD2 had a high positive factor loading for vertical stratification and a negative factor loading for rock cover. LD3 had a high negative factor loading of average grass height, vertical stratification, and rock cover. Species distribution along LD1, LD2, and LD3 axes indicated that the interaction between shrub density, shrub height, rock cover, vertical foliage evenness, and average grass height separates the species from each other as well as from random plots (Figure 2). For example, the Green Bee-eater (*Merops orientalis*) prefers short vegetation with low shrub density, even vertical foliage, and low rock cover. The mean and standard

TABLE 2 Factor loadings and percentage of variance explained by the first three LD axes for variables characterizing vegetation structure of the foraging microhabitat of shrubland bird community in the eastern Ghats of India.

Linear discriminants	1	2	3
% of variation	34.1	19.9	17
Cumulative % of variation	34.1	54	71
Variables	**LD1**	**LD2**	**LD3**
% Rock cover	0.21	**−0.82**	**−0.89**
Shrub height	**0.64**	0.58	−0.002
Average shrub density	**0.76**	0.23	0.68
Average grass cover	0.25	−0.26	−0.38
Average grass height	−0.04	−0.32	**0.91**
Stem evenness	0.06	−0.28	−0.16
Vertical foliage evenness	0.09	**1.94**	**−3.08**
Coarse evenness	0.26	0.22	−0.25
Canopy height evenness	−0.30	−0.14	−0.29
Average canopy height	−0.06	0.05	−0.10

Note: Bold figures indicate variables with the highest loadings.

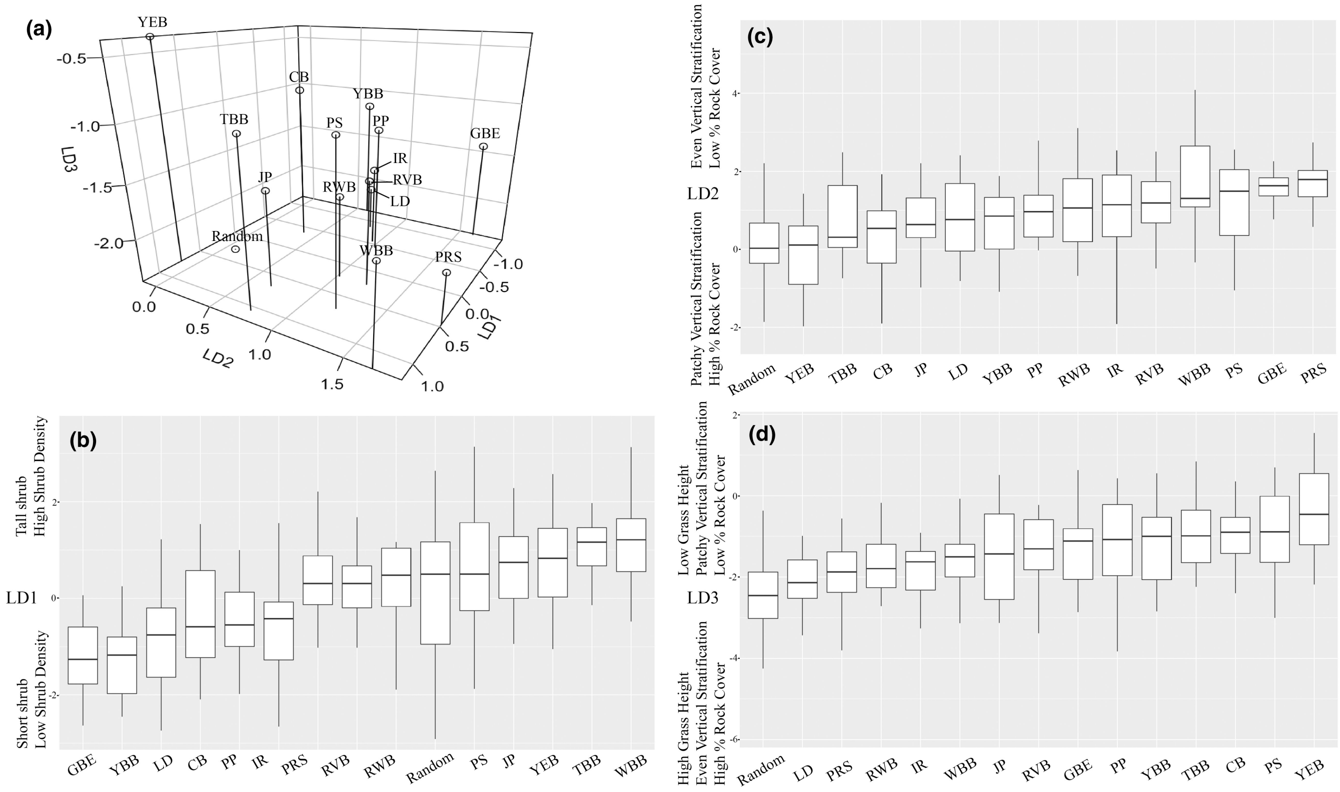

FIGURE 2 (a) 3D representation of ordination of foraging plots for shrubland birds and random plots based on LDA analysis on 10 vegetation characteristics, (b) ordination of shrubland bird community based on LD1 scores, (c) ordination of shrubland bird community based on LD2 scores, and (d) ordination 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.

TABLE 3 Analysis of variance (ANOVA) on 10 vegetation characteristics of foraging plots for 14 shrubland bird species across three shrub forests in the eastern Ghats of India. The *F*-value and *p*-value of ANOVA test on the 10 vegetation characteristics are shown. All the following 10 characteristics were significantly different between the bird groups.

Vegetation characteristic	*F*-value (df = 14)	*p*-value
% Rock Cover	4.913	<.001
Shrub Height	8.136	<.001
Average Shrub Density	8.09	<.001
Average Grass Cover	2.817	<.001
Average Grass Height	4.559	<.001
Stem Evenness	4.56	<.001
Vertical Foliage Evenness	3.77	<.001
Coarse Evenness	1.93	.02
Canopy Height Evenness	2.321	.004
Average Canopy Height	2.899	<.001

deviation of the vegetation variables with the high factor loading on LDs have been summarized in Supplemental data (Table A).

3.2 | Effect of diet guild and foraging strata

The effect of diet guild on LD1 scores (ANOVA: $F_{[4]} = 10.9$, *p*-value <.001), LD2 scores (ANOVA: $F_{[4]} = 10.92$, *p*-value <.001), and LD3 score (ANOVA: $F_{[4]} = 6.78$, *p*-value <.001) was significant. The effect of foraging strata on LD1 score (ANOVA: $F_{(2)} = 27.96$, *p*-value <.001), LD2 scores (ANOVA: $F_{(2)} = 17.55$, *p*-value <.001), and LD3 score (ANOVA: $F_{(2)} = 3.77$, *p*-value = .02) was significant. Birds foraging on ground strata had significantly different LD1 scores than birds foraging in shrubs, taller shrubs, or trees. Species foraging on the ground preferred vegetation with short shrub height and lower shrub density than those foraging in shrub or tree strata (Figure 3). Species foraging in tall shrubs or in trees preferred evenly distributed vertical foliage relative to species foraging on the ground or in shorter shrub habitats (Figure 3b). When looking at the avian community according to their diet preference, insectivores and granivores foraged in shorter shrubs with lower shrub density, while frugivores, nectarivores and omnivores foraged in taller shrubs and were associated with higher shrub density (Figure 3d). Nectarivore and frugivore species preferred evenly distributed vertical foliage compared to insectivore, granivores, and omnivores (Figure 3e). All diet guilds had significant preference for high grass height, even vertical foliage, and high percent of rock cover except omnivores (Figure 3f).

3.3 | Association between bird species and plant species

Some bird species showed strong associations with the plant species in the shrubland forests of the Eastern Ghats. The results of the chi-square test and Pearson's standardized residuals were plotted using a mosaic plot (Figure 4).

4 | DISCUSSION

We found that microhabitat characteristics of foraging sites for our 14 focal species were significantly different from the randomly selected sites. This difference suggests that each species was selecting for a set of microhabitat characteristics at their foraging sites. Shrub density, shrub height, vertical stratification of foliage, percent rock cover, and grass height were key explanatory variables in the model for the focal species. For example, the White-browed Bulbul (*Pycnonotus luteolus*) foraged at sites with high shrub density, tall vegetation, even vertical foliage, and low rock cover. Seven out of 14 species foraged at sites with high shrub density and tall vegetation. All focal species except one species, the Yellow-eyed Babbler (*Chrysomma sinense*), foraged at sites that had high vertical foliage evenness and low rock cover.

Ground-foraging insectivores and granivores such as the Yellow-billed Babbler (*Turdoides affinis*) or Laughing Dove (*Spilopelia senegalensis*) foraged at sites with short vegetation and low shrub density. Our results are consistent with the findings of Antos et al. (2008) 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 (Antos et al., 2008). These open areas may offer increased visibility to detect predators and thus reduce the probability of being predated (Antos et al., 2008) while providing efficient foraging habitat for invertebrate prey (Antos et al., 2008; Beck & George, 2000; Morris et al., 2001).

Ground foraging granivores such as the Laughing Dove may be disadvantaged by high leaf litter in regions with high foliage or shrub density as the seeds are more difficult to find (Antos et al., 2008). However, ground foraging insectivores (Common Babblers [*Turdoides caudata*] and Yellow-billed Babblers) and omnivores (Indian Robin [*Saxicoloides fulicatus*]) prefer to forage close to shrubs as they offer multiple advantages. Leaf litter from the shrubs is an important habitat for the invertebrates (Antos et al., 2008; Ballinger & Yen, 2002; McIntyre et al., 2004; Recher & Lim, 1990) upon which this species feeds. The ground foraging omnivores may also be able to use the seeds and fruits fallen on the ground from shrubs to their advantage.

Insectivores such as the Green Bee-eater that forage by catching prey through aerial maneuvers prefer the increased visibility of their prey offered by low shrub density and short vegetation. The propensity of aerial foraging maneuvers is negatively impacted by the constraints imposed by foliage structure (Holmes & Robinson, 1981; Remsen & Robinson, 1990; Whelan, 2001). Insectivores such as the Tawny-bellied Babbler (*Dumetia hyperythra*), Yellow-eyed Babbler, and Prinias are understory birds that prefer to feed close to ground. Dense vegetational cover perhaps provides these birds with the necessary cover to avoid predators.

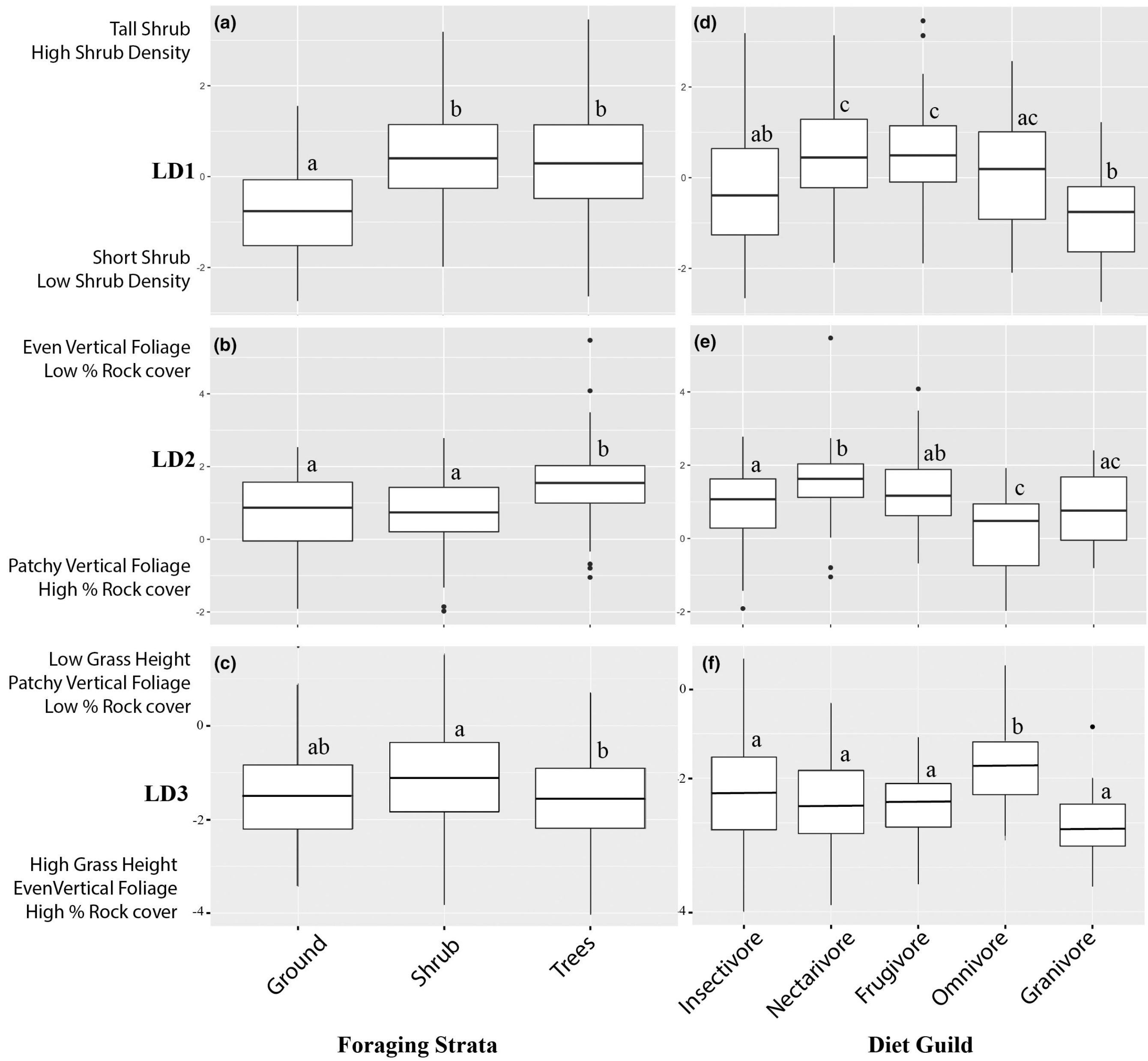

FIGURE 3 Linear discriminant analysis of the effect of foraging strata or diet guild on linear discriminant 1, 2 and 3 in the shrubland bird community of the eastern Ghats of India. (a) LD1 scores for different foraging strata (b) LD2 scores for foraging strata (c) LD3 scores for foraging strata, d) LD1 scores for diet guilds, (e) LD2 scores for diet guilds, and (d) LD3 scores for diet guilds. Different lowercase letters (above boxes) indicate significant difference (based on Tukey HSD pairwise comparison), for example, box labeled "a" is significantly different from box labeled "c" but neither differs significantly from box labeled "ac." Box plots depict minimum, first quartile, median, third quartile, and maximum, with outliers depicted as single points.

The difference in vertical stratification preference for the Prinias might be due to prey catching techniques 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, the Purple-rumped Sunbird (*Leptocoma zeylonica*) had a relatively higher preference for uniform vertical foliage than the Purple Sunbird (*Cinnyris asiaticus*). The Purple-rumped Sunbird is often found foraging in secondary forests and along forest edges (Ali et al., 1987), while the Purple-Sunbird forages primarily in scrub forests (Ali et al., 1987). Frugivores such as the White-browed Bulbul are shy birds (Ali et al., 1987) and hide in tall and dense shrubs; they are often found foraging in tall trees (Ali et al., 1987). Dense shrubs often provide necessary cover from predators and the fruit crop required by the frugivores.

4.1 | Plant associations

All the focal species except for the Red-vented Bulbul (*Pycnonotus cafer*) and the White-browed Bulbul were associated with one or more plant species. The Laughing Dove was associated with *Croton*

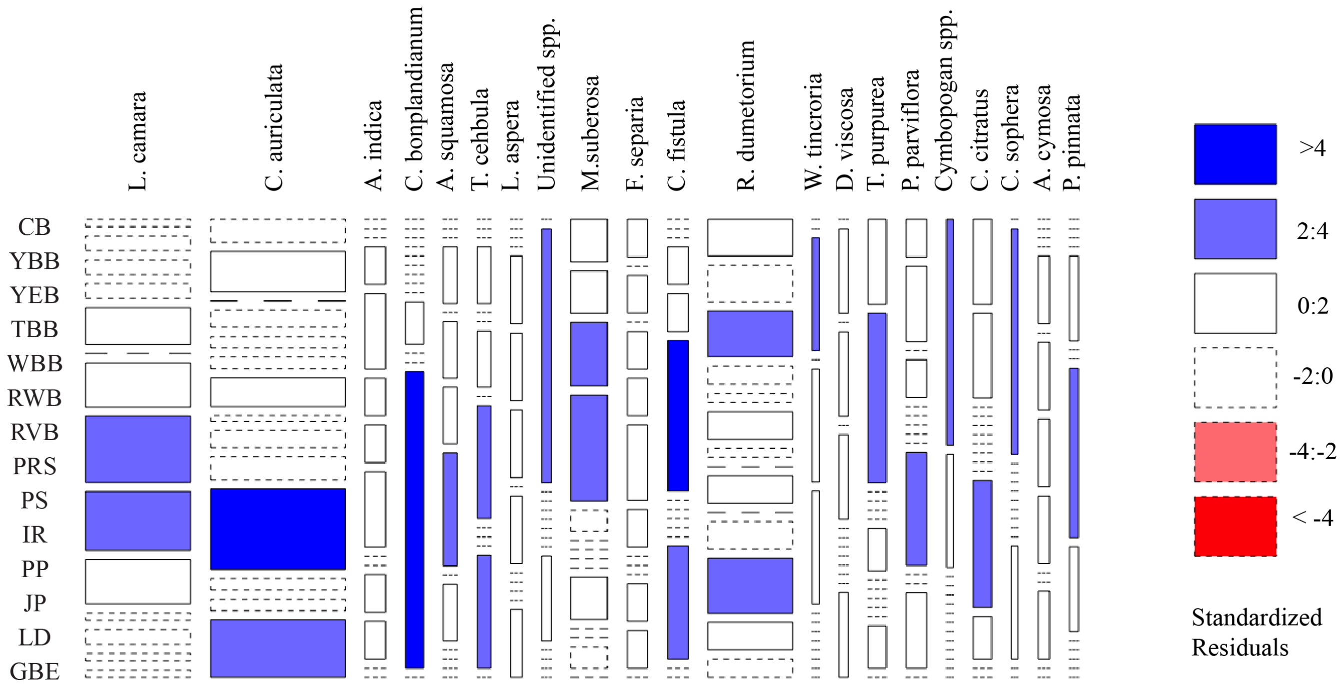

FIGURE 4 Association between bird species and plant species in the shrubland bird community of the eastern Ghats of India. The width of box represents the percentage of a single plant species among all observed plant species used by foraging birds and height of the box represents proportion of a plant species used by a bird species. Each box represents the degree of association between each plant and bird species. If the value of standardized residuals is greater than or equal to two, then there is a significant association between plant and bird species. 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). Plant species: *Lantana camara*, *Cassia auriculata*, *Azadyractus indica*, *Croton bonplandianum*, *Annona squamosa*, *Terminalia chebula*, *Leucas aspera*, *Mundelia suberosa*, *Flacourtia sepiaria*, *Cassia fistula*, *Randia dumetorum*, *Wrightia tinctoria*, *Dodonea viscosa*, *Tephrosia purpurea*, *Plectronia parviflora*, *Cymbopogon citratus*, *Cassia sophera*, *Argyreia cymosa*, *Pongamia pinnata*.

bonplandianum and often was observed feeding on the seeds of this plant by the senior author. *Croton bonplandianum* is a short plant that grows up to 30 cm in height. For the Yellow-billed Babbler, Tawny-bellied Babbler, and Jungle Prinia (*Prinia sylvatica*) the structural configuration of the plant species with which these birds were associated was similar to the structural vegetation configuration preferred by the birds. For example, the Tawny-bellied Babbler was associated with *Mundelia suberosa*, a shrub with a high density of branches and thus providing a uniform vegetational cover. The Yellow-billed babbler was associated with *Cassia Sophera*, while the flock would feed on the ground a sentry would sit on the tallest part of a *C. sophera* to look for potential predators (Ali et al., 1987). The branches of *Cassia auriculata* provide a perching spot for the Green Bee-eater while overlooking the open region, thus allowing it to easily spot the prey and then aerially catch it. Although the site had two major invasive plant species—*Lantana camara* and *Prosopis*, it was *L. camara* that was more widespread at the study site (Deshwal, unpubl. data). The extensive presence of *L. camara* at the site is an indication of the high anthropogenic disturbance in the region (Negi et al., 2019). Both species of sunbirds were associated with *L. camara*. The aromatic flowers of *L. camara* are present throughout the year (Negi et al., 2019), thus acting as the food source for nectarivores birds when native species may not be flowering. *Lantana camara* forms dense thickets (Aravind et al., 2010; Holm et al., 1977) which provides cover for the sunbirds from potential predators.

Further research is needed in other parts of Eastern Ghats to understand foraging ecology of shrubland bird community at micro and macro scale in the region. Our study investigates habitat selection of shrubland birds in a degraded and disturbed part of the Eastern Ghats. The selection in degraded habitat can be adaptive or maladaptive on large landscape level, hence, further investigations and experimental approach is needed in to test if these habitat selections are maladaptive for a species.

4.2 | Conservation implications

Our results show that most birds in this scrubland community are selecting foraging habitat non-randomly and that their foraging guild can explain much of the variation. Herein we demonstrate how some of the important foraging microhabitat variables might be actively managed by manipulating the predominant anthropogenic land use practices of the region. For example, shrub density, which is important to certain species/groups, could potentially be managed by implementing spatially selective harvesting of firewood. This could 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 as preferred foraging plant species for most of the bird community. Removal of these invasive species would likely provide opportunities for beneficial native shrubs to regenerate. A similar regime could be implemented for grass harvest to provide a continuum of grass density to the benefit of ground-foraging species. Promoting habitat heterogeneity through habitat management practices can benefit different functional group in bird community (Stirnemann et al., 2015; Tuanmu & Jetz, 2015).

A more regulated livestock grazing regime has the potential to manipulate the availability of native herb cover, a habitat characteristic important for ground foraging granivore and omnivore species (Antos et al., 2008; McIntyre et al., 2004; Yates et al., 2000). Creating zones with exclusion of grazing or establishing regions with different gradients of grazing might allow species such as *C. bonplandianum* to flourish (McIntyre et al., 2004, Yates et al., 2000).

Scrub forests have largely been ignored by the conservation community as they are often regarded as wastelands. Management plans would benefit from input by local communities as they interact closely with the scrub forest and their participation is critical in the success of the scrubland bird community.

AUTHOR CONTRIBUTIONS

Anant Deshwal: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (equal); resources (equal); software (lead); validation (lead); visualization (equal); writing – original draft (lead); writing – review and editing (equal). **Steven L. Stephenson:** Funding acquisition (equal); supervision (lead); writing – review and editing (equal). **Pooja Panwar:** Data curation (equal); formal analysis (equal); methodology (equal); software (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Brett A. DeGregorio:** Formal analysis (supporting); writing – review and editing (equal). **Ragupathy Kannan:** Conceptualization (supporting); writing – review and editing (supporting). **John D. Willson:** Writing – review and editing (equal).

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CONFLICT OF INTEREST

None of the authors have any conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The dataset used for this research is posted on Dryad. https://doi.org/10.5061/dryad.7m0cfxpxb.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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