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Habitat patch size and tree species richness shape the bird community in urban green spaces of rapidly urbanizing Himalayan foothill region of India

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Abstract
Rapid urbanization is emerging as one of the leading threats to the biodiversity globally. But is especially a cause of concern for tropical countries which are urbanizing much faster and with relatively less urban planning than temperate ones. Urban green spaces are established to reduce the negative impacts of urbanization by conserving a large suite of species. Yet our knowledge on the significance of urban green spaces for supporting urban fauna and enhancing species richness is lacking for tropical countries such as India. We examined how landscape and local scale features of urban green spaces influence bird species richness, density, fine-foraging guild richness and composition during breeding and non-breeding season in Dehradun, India. We quantified landscape level variables in the 250 m buffer around 18 urban green spaces. We sampled vegetation and bird community during breeding and non-breeding season through 52 intensive sampling point spread across 18 urban green spaces. Size of the urban green space at landscape level and tree species richness at the local scale emerged as important predictors influencing bird species richness, density and richness of imperilled insectivorous guild across seasons. Urban green spaces within education institutions and offices experiencing less vegetation management supported higher bird species richness and density whereas city parks were species poor. Community composition was affected more strongly by built-up cover and barren area in the landscape matrix and also by tree species richness at the local scale within urban green spaces. City planners should focus on allocating green spaces within urban settings and expand the formal green spaces. Existing green spaces could be improved by augmenting compositional and structural heterogeneity of vegetation as well as conservation of large old native trees.

Keywords Species-area effect · Urban green spaces · City parks · Uttarakhand · Habitat heterogeneity

Introduction

Urban expansion is one of the biggest threats to biodiversity (Kang et al. 2015). In 2018, 55% of the worlds' population was living in urban areas, which is projected to increase to 68% by 2050 (DESA 2018). A sizeable amount of this expansion is expected from developing countries like India, China, and Nigeria. Urban areas are characterized by an admixture of grey and green spaces harbouring a large suite of generalist faunal and floral species (Devictor et al. 2007; Morelli et al. 2016). However, urban areas are also inhabited by threatened plant and animal species (Ives et al. 2016). Both common and threatened species play significant role in urban ecosystem functioning and provide a multitude of ecosystem services. For example, in an experimental study conducted across three towns of UK, reported a higher level of carcass removal in the presence of three urban vertebrate scavengers than in their absence (Inger et al. 2016). Varying in size and shape, green spaces in urban areas ranging from city parks, remnant forest patches, golf courses to cemeteries, act as biodiversity hotspots (Gallo et al. 2017; Wurth et al. 2020). Variety of green habitats in urban areas covered partially or completely by any type of vegetation under private or public ownership are collectively known as "urban green spaces".

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In the past decade, urban green spaces have received much required attention as a conservation tool for urban biodiversity as they support endemic native bird species (Carbó-Ramírez and Zuria 2011), mitigate the urban heat island effect (Park et al. 2017; Xiao et al. 2018), ensure mental wellbeing of the users (Carrus et al. 2015) and prevent loss of human-nature interactions for urban dwellers (Soga and Gaston 2016). Studies focusing on habitat characteristics of urban greens paces can improve biodiversity conservation potential (Aronson et al. 2017).

Previous studies have investigated the habitat features of green spaces largely at patch scale. Urban green space size emerges as a universal predictor across studies that improve biodiversity potential of green spaces, conforming species-area relationship in urban ecosystems (Chamberlain et al. 2007; Dale 2018; La Sorte et al. 2020; Matthies et al. 2015; Nielsen et al. 2014). Other than size of the park, habitat diversity within the urban green space and its age also enhances the biodiversity (Zivanovic and Luck 2016). Degree of connectivity among urban green spaces increases richness by allowing immigration of species from source habitats to other potential habitats (Braaker et al. 2017; Shanahan et al. 2011).

Urban green spaces are nested in varied matrix of habitat types that ranges from completely urban to remnant forest patches which has been shown to substantially influence species richness and composition within the green spaces. For example, higher proportion of "built-up" area in the matrix negatively affects the richness of bird species within urban green spaces at the community (Murgui 2009) and guild level (Amaya-Espinel et al. 2019; Chamberlain et al. 2007; Fischer et al. 2016; Pellissier et al. 2012). Matrix with no or low management interventions such as fallow land or abandoned successional habitats often provide distinct resources and thereby elevate species richness of certain taxa (Melliger et al. 2017).

At the local scale, habitat heterogeneity within the urban green spaces in the form of vegetation structure and complexity increases the richness and diversity of multiple taxa (Kang et al. 2015; Nielsen et al. 2014). Additionally, increase in tree and shrub diversity support faunal diversity at the local scale (Nielsen et al. 2014). Shrub cover could have different effects on richness depending on the focal taxa. Increasing shrub cover especially in highly urbanized matrix improved richness of imperilled insectivorous bird guild (Pellissier et al. 2012) but reduced bee richness by reducing their nesting resources (Banaszak-Cibicka et al. 2016).Exotic plant species constitute a large proportion of urban vegetation and have been shown to negatively (Khera et al. 2009) influence bird species diversity and in some cases elevated abundance of non-native birds (White et al. 2005; Daniels and Kirkpatrick 2006). In contrast, native vegetation and large old trees has been shown to improve bird species richness (Ferenc et al. 2014; Narango et al. 2017). Information on habitat features that improve the biodiversity potential of urban green spaces could help urban planners and managers at design and maintenance stages of urban greening projects (Callaghan et al. 2018).

In this study, we investigated how habitat features of urban green spaces at landscape and local scale affects the bird community and fine-foraging guilds during breeding and non-breeding seasons. Additionally, we investigated whether bird species composition varies across urban green spaces and if so, which factors are responsible for the differences. We selected birds owing to the ease of quantification as well as their property of being a good surrogate of overall biodiversity (Eglington et al. 2012). Birds are also important ecosystem service providers especially in tropical countries where majority of plants depend on birds for seed dispersal (Sekercioglu et al. 2016; Whelan et al. 2008), prevention of fruit crop damage from arthropods (Maas et al. 2016) and pollination (Anderson et al. 2016). Therefore, conservation of birds through urban green spaces ensures maintenance of diverse ecosystem services in urban areas. Our aim was to examine whether and how urban green spaces can be planned and managed to improve species richness, density, and guild richness in urban ecosystems.

Materials and methods

Study area

We carried out this study in Dehradun city (30.3165° N, 78.0322° E) which is the capital of the northern state, Uttarakhand, India. It is located at the foothills of Himalaya flanked by two important rivers, Yamuna and Ganga. Dehradun is a valley spread across an area of 3088 km^2 with moderate variation in elevation (410–700 m). The city is characterized by mild weather throughout the year, but winter temperatures could be as low as 0–1 °C and the maximum temperature in summer could be as high as 40 °C. However, from past two decades the minimum temperature during winter season have been consistently increasing (Nautiyal et al. 2021). The area receives an average annual rainfall of 2073 mm, largely during the monsoon season (July–August).

Uttarakhand state was carved out from Uttar Pradesh in year 2000 and Dehradun was designated its capital. The change in its political status resulted in a surge of developmental activities at the cost of the agricultural, forest and open areas. Between the years 2001 and 2011 Dehradun experienced rapid population growth (Dutta et al. 2015). Though Dehradun has 64 city parks (Government of India 2016), most of these are small parks (range 0.1–0.3 ha) constructed within residential colonies. Majority of urban green spaces in Dehradun–and other cities within India—are in the form of personal gardens, fruit orchards, tea gardens, tree belts along *nallahs* and reserved forests. In recent years, green spaces in Dehradun have shrunk due to increasing built-up cover for residential, commercial, and industrial purposes (Dutta et al. 2015). However, abutting Himalayan foothills, Dehradun harbors 42% (567 of 1338) of the avifaunal diversity of India and 82% (567 of 688) of Uttarakhand state (www.ebird.org/India). Different habitats within the city provide safe breeding and wintering ground to the summer and winter migratory birds (Mohan 2007).

Study site selection

We selected sites across a size gradient using satellite imagery of Google Earth (Google Earth Pro 2018). We made sure that the sites were evenly distributed across the city. Sites were visited for ground-truthing to assess the suitability in terms of accessibility and vegetation type. We avoided orchard of cash crops which generally lack shrub layer and are not open to public. We did choose one old tea plantation due to its large size, presence of native trees and continuous reporting of rare birds (e.g., Himalayan Griffon *Gyps himalayensis*, Yellow-eyed Babbler *Chrysomma sinense*). Out of 28 urban green spaces identified using Google Earth imagery, 18 sites were shortlisted for the study (Fig. 1). Using ArcGIS 10.6 (ESRI 2017) we measured the area of selected sites. We quantified the matrix composition around each urban green space within a buffer of 250 m. The following landuse types—agricultural field, green cover (including woodland), open (scrubland) areas, water cover, built-up and barren were digitized using polygon tool of Google Earth and later quantified for their extent using the ArcGIS 10.6 (ESRI 2017).

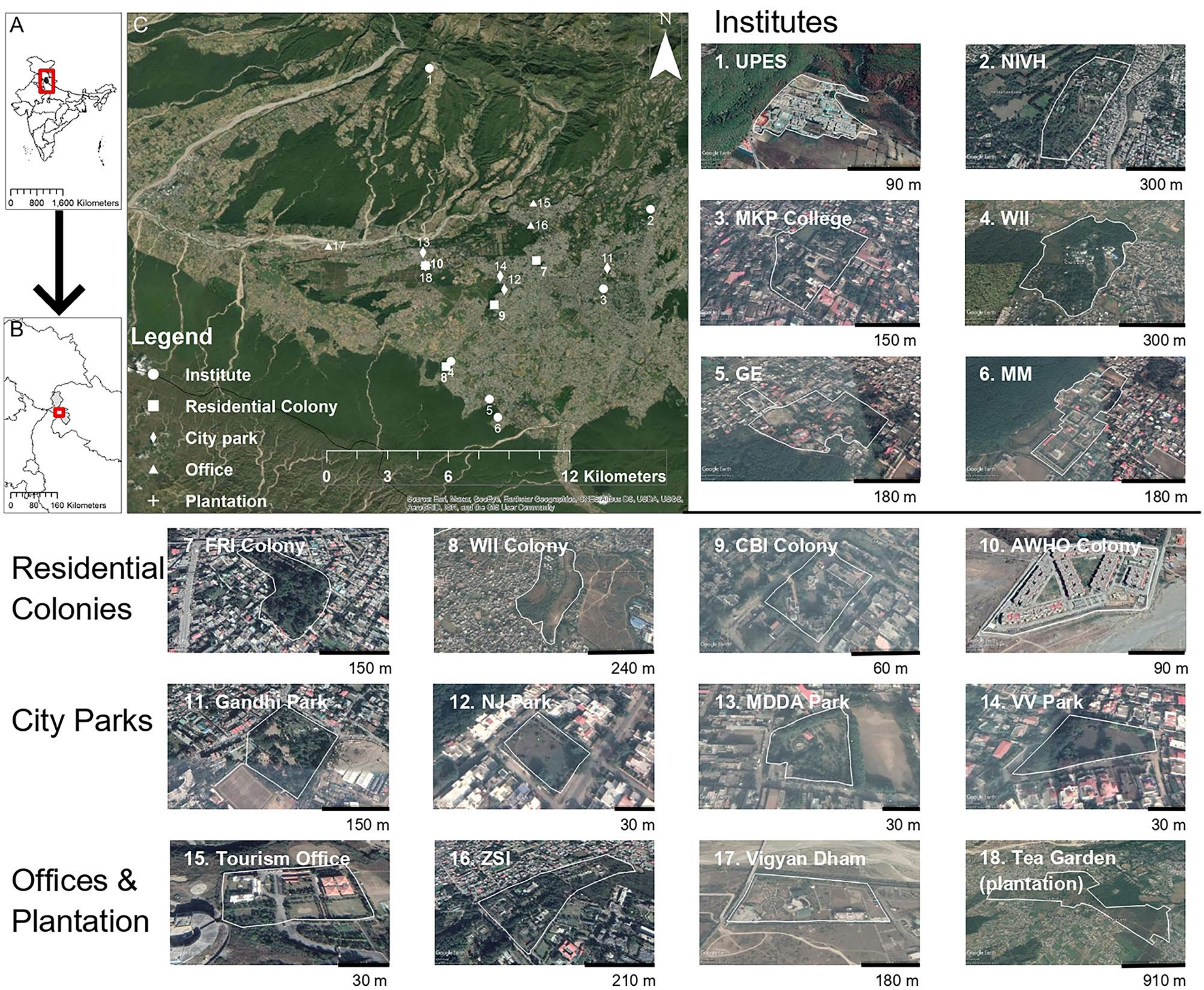

Fig. 1 Map of study area showing 18 urban green spaces selected for bird and vegetation sampling in Dehradun, Uttarakhand, India. The number allotted to each urban green space represents its location on the map

Quantification of habitat structure and composition

Each urban green space was divided into sampling grids of 200 m and the centroids of the grid were selected for intensive vegetation and bird sampling. At each plot, we recorded structural and compositional features of the vegetation by quantifying the trees and shrubs within concentric plots of 20 m and 5 m radius, respectively. For structural features of the tree layer, we recorded girth at breast height, total and bole height and canopy spread in two perpendicular axes. We used an altimeter for quantification of bole and total height of each tree. For shrub structural features we recorded average height for each shrub species and its spread within 5 m radius plot. We recorded each tree and shrub to species level with the help of available field guides (Kanjilal and Gupta 1979).

Sampling bird community

We sampled bird community using the variable radius point transect method centered on the vegetation sampling plots. We chose point transects for sampling birds, as well-spaced point transects could provide finer information than line-transects about the bird-habitat relationship if habitat parameters are quantified around the points (Bibby et al. 2000).

All the point transects were conducted by a single observer in one season (ST: non-breeding season and KM: breeding season) to avoid observer bias. Species were recorded for 7 min after 3 min of acclimatization time. All species seen or heard were recorded at the point and radial distance of each observation was quantified using a laser rangefinder. Bird sampling was carried out in morning hours (6:00–9:00 am) during breeding (March–May 2019) and non-breeding season (September–December 2018). Each site was visited four times both during breeding and non-breeding season. To capture the maximum species variation within a season, each site was revisited after a week. The order of visiting the points was reversed on each morning to negate the bias due to flushing of birds by observer. A total of 416 (52 points × 4 times × 2 seasons) variable radius point transects were undertaken during the study period.

Data analysis

We first assessed the sampling adequacy of the bird community during breeding and non-breeding season by plotting species accumulation curves using package "vegan" (Oksanen et al. 2013). For each urban green space, we estimated the richness of bird, tree and shrub species. We estimated bird species richness separately for each season using first-order jackknife richness estimator. We estimated overall bird density for each urban green space using the program DISTANCE 7.3 (Thomas et al. 2010). Separate detection functions were fitted for each urban green space and for each season using conventional distance sampling method. Appropriate right truncation was used for each test. A detection model was selected after examining the fit of estimated detection function to the data. Guild densities were estimated by pooling species with similar detection distances together (Alldredge et al. 2007; Mohan 2007). Three groups based on their detection behavior were species detected (i) closer to the observer (within 30 m distances; i.e., warblers, prinias), (ii) at medium distances (from 30 to 50 m distances; i.e., bulbuls, woodpeckers) and (iii) at farther distances (beyond 50 m; i.e., crows, drongos). Later each species was assigned into a foraging guild and densities were summed for all the species for a particular guild (Kaushik 2016). Model selection was based on minimum Akaike information criteria (AIC).

We used a linear modelling approach to evaluate the relationship between landscape and local scale variables on bird species richness, overall bird density and richness of fine-foraging guild. We used coefficient of variation (CV) of tree height (vertical heterogeneity) and coefficient of variation (CV) of tree girth and canopy cover (horizontal heterogeneity) as measures of structural complexity (Mensah et al. 2020). We also quantified densities of large old trees (> 50 cm girth), native trees and exotic trees for each urban green space as local scale predictors for bird species richness.

We categorized birds into their fine-foraging guilds following Mohan (2007). We used generalized linear models with Poisson family for modelling the guild species richness. Area of urban green space was log transformed for all analysis. We first tested for correlation between predictor variables using Pearson correlation method (see Tables S1 and S2). Considering the differences in spatial scales, we built models separately for landscape and local scale variables for each season (see Tables S3–S6).

We built models with only uncorrelated variables and selected the best model through model selection approach (Burnham and Anderson 2010). We used Akaike information criterion for small sample sizes (AICc) for model selection since the ratio of sample size (n) and number of parameters (K) was small (i.e., < 40; (Burnham and Anderson 2010)). The model with the lowest AICc value and within 2 ΔAICc was selected as the best model(s). To estimate model coefficients, we used model averaging whenever there were more than one models within 2 ΔAICc values. Model averaging was performed using package "MuMIn" in R (Barton and Barton 2015). We estimated the back transformed estimate and standard error of variables in the best model using package "*arm*" (Gelman et al. 2018).

We used Non-Metric Multidimensional Scaling (NMDS) to explore differences in bird species composition across each urban green space and the associated landscape and local-scale variables. We choose Bray–Curtis dissimilarity index, which works well with the abundance data (Anderson 2001). Rare and vagrant species seen only once during the study period were removed for performing this analysis. We explored the relationship between NMDS axis and the habitat covariates using the function *envfit* in package vegan. We used *adonis* test to explore if the bird species composition varied with the size and type of the urban green space. All statistical analyses were performed using program the R version 3.6.0 (R Core Team 2019) and graphical visualization were created using ggplot2 (Wickham 2016).

Result

Habitat characterization of the urban green spaces

We selected 18 urban green spaces of which six were educational institutions, four city parks, four residential complex, three office parks and one abandoned tea plantation. The area of urban green spaces varied from 0.3 to 224 ha (Table 1), abandoned tea plantation was the largest urban green space. The matrix around urban green spaces had relatively higher proportion of built-up than other land use types. The second most abundant land use type in the matrix was green cover that varied from 5.96 to 60%. Agricultural area was the least dominant land use type and ranged between 0 to 16%. We recorded a total of 92 tree species and 112 shrub species from the study area.

Table 1 Average value of landscape and local scale variables across 18 urban green spaces of Dehradun, Uttarakhand, India

Variable	Mean ± SD	Range
Landscape level variable		
Perimeter of urban green space(km)	1.74 ± 224	21.8–1024
Area of urban green space(ha)	21 ± 52	0.3–224.5
Buffer area (ha)	81 ± 118	4–490.8
Barren land (ha)	18 ± 51	0.3–219.8
Built-up area (ha)	32 ± 23	0.2–86.4
Green area (ha)	22 ± 19	3.5–88.1
Open area (ha)	0.3 ± 8	0–36
Area under water (ha)	1 ± 4	0–17.4
Agricultural land (ha)	6 ± 12	0–43.20
Local level variable		
Tree G.B.H (cm)	87.33 ± 61.21	31–480
Tree Height (m)	12.54 ± 5.95	1–35
Tree Bole height (m)	4.43 ± 3.60	0–18.5
Tree Canopy cover (m^2)	52.06 ± 76.21	0–980.95
Tree species richness (Jacknife 1)	12.94 ± 10.09	1–29.2
Shrub height (m)	1.01 ± 0.95	0.1–6
Shrub cover (m^2)	3.36 ± 3.70	0.01–19.63
Shrub species richness (Jacknife 1)	12.35 ± 9.86	1– 40.5
Native tree density	16.94 ± 33.02	0–142
Exotic tree density	11.06 ± 9.21	0–33
Large old tree density (> 50 cm GBH)	20.72 ± 22.77	0–95
CV of tree G.B.H	56.28 ± 29.06	7.95–115.7
CV of canopy cover	99.17 ± 48.95	24.55–197.96
CV of tree height	54.75 ± 32.13	20.56–143.0

Bird species richness and density

A total of 139 (4399 detections) species were recorded during the study period covering breeding and non-breeding season. Species accumulation curve for both seasons approached asymptote indicating sampling adequacy for the 18 green spaces in the study area (Fig. S1). Bird species richness was higher during the breeding (123 species) than the non-breeding season (103 species) (Fig. 2a). Old government institutes for education and research had the highest bird species richness whereas city parks had the lowest richness, consistently across breeding and non-breeding season. Overall bird density per hectare varied from $11.54_{Mean} \pm 10.43_{\%cv}$ to $143.02\ _{Mean} \pm 19.36_{\%cv}$ during breeding season and $17.84_{Mean} \pm 20.44_{\%cv}$ to $154.83\ _{Mean} \pm 16.99_{\%cv}$ during non-breeding season. Urban green spaces within institutes and residential complexes had higher density during the breeding season than non-breeding season (Fig. 2b). City parks exhibited a high variation in bird density during the breeding season than non-breeding season.

At the landscape level, the model containing only the urban green space size best explained the variation in bird species richness during breeding and non-breeding season (Table 2). The top model for the species richness explained 99% and 96% of the variation during breeding and non-breeding season, respectively (Table S3). Moreover, the effect size was more pronounced for the breeding than the non-breeding season (Table 2, Fig. 3).

At the local level, two models containing tree species richness and a combination of tree and shrub species richness explained the variation in bird species richness during breeding season. However, during non-breeding season three models containing tree species richness, a combination of tree and shrub species richness and coefficient of variation of tree GBH explained the variation in bird species richness. Top models cumulatively explained 80% and 79% of the variation in the bird species richness during breeding season and non-breeding season respectively.

During breeding season, overall bird density was explained by the urban green space size at the landscape level (Table 2, Fig. 4a) and by additive effect of tree and shrub richness at the local level (Table 2, Fig. 4b, c). During the non-breeding season, percentage of open area in the matrix explained the variation in overall density at the landscape level (Table 2, Fig. 4d). However, none of the local variables explained variation in density during non-breeding season (Table 2). The

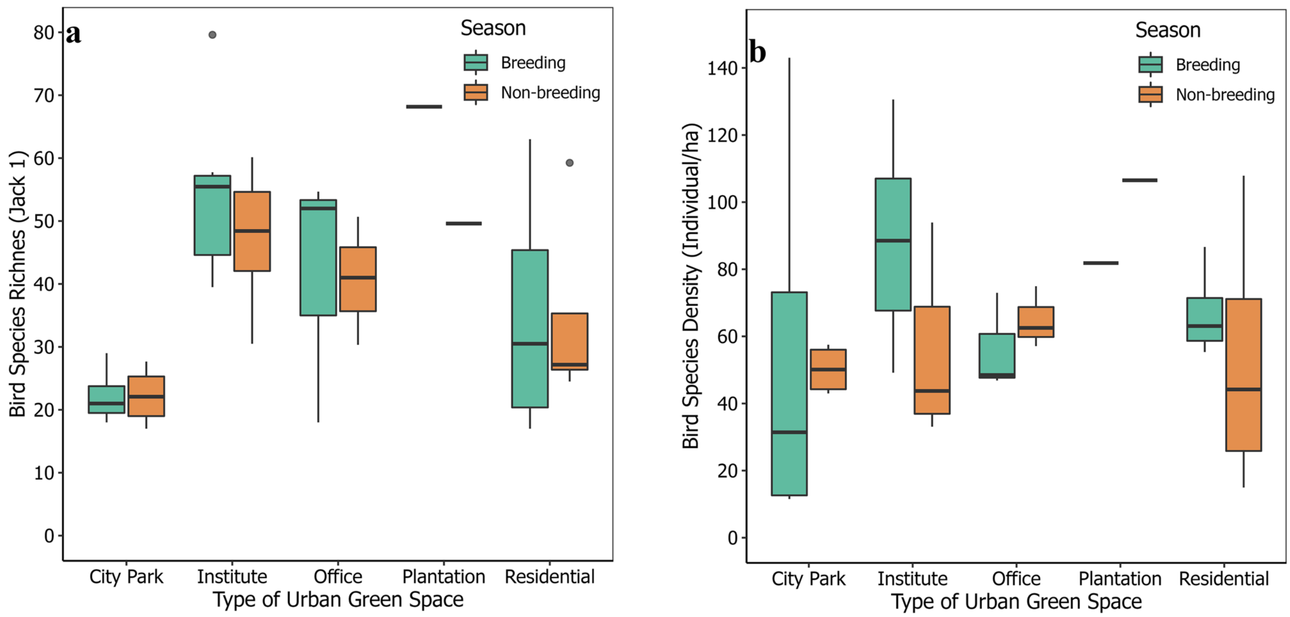

Fig. 2 **a** Overall bird species richness and **b** density across urban green space types during breeding and non-breeding season

top model containing landscape level variables explained 50% and 88% of the variation in the overall bird density during breeding and non-breeding season respectively (see Table S4). At the local level, the top model explained 94% of the variation in the overall bird density during the breeding season and no model was selected during the non-breeding season (see Table S4).

Richness of all insectivore guilds except ground insectivore increased with urban green space size across breeding (Table 3) and non-breeding seasons (Table 4). Percentage of barren area in surrounding matrix elevated richness of sallying insectivore and granivore guild during breeding season. However, during non-breeding season only ground insectivore guild richness increased with percentage of

Table 2 Summary of the best model showing variables, coefficient estimates, standard error, and associated t-value for effect of landscape and local scale variables on bird community features during breeding and non-breeding season

Community feature	Scale	Season	Variable of best model	β-estimate	SE	t-value
Bird species richness	*Landscape*	Breeding	Area of urban green space	10.13	1.61	6.30
		Non-breeding	Area of urban green space	6.46	1.41	4.58
	Local	Breeding	Tree richness	1.32	0.36	3.39
			Shrub richness	0.58	0.36	1.48
		Non-breeding	Tree richness	0.75	0.30	2.30
			Shrub richness	0.41	0.30	1.24
			CV of tree GBH	0.24	0.10	2.13
Bird density	*Landscape*	Breeding	Area of urban green space	12.72	5.37	2.37
		Non-breeding	% of open area	3.02	0.62	4.91
	Local	Breeding	Tree richness	2.14	0.66	2.99
			Shrub richness	0.84	0.69	1.11
		Non-breeding	Null Model	–	–	–

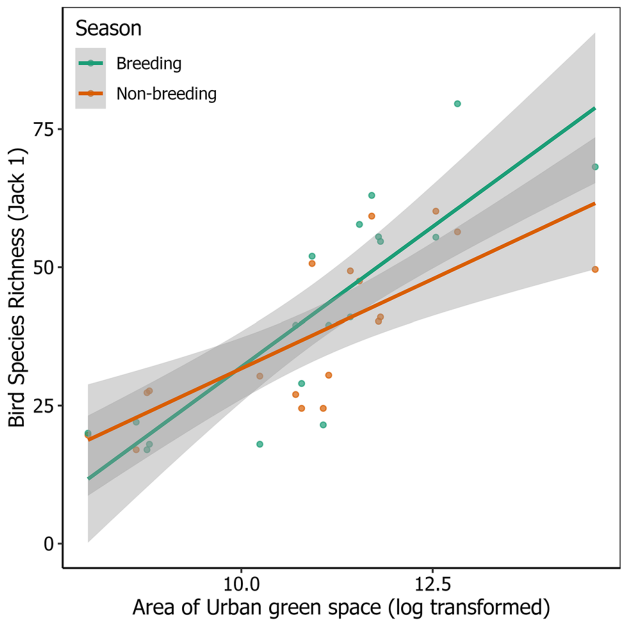

Fig. 3 Relationship between bird species richness and area of the urban green spaces across breeding and non-breeding season

barren area in the surrounding matrix. Increase in percentage of built-up area in the matrix caused decline in richness of ground insectivore guild (Table 4). Frugivore-insectivore guild's richness during non-breeding season increased with increasing percentage of agricultural area in the matrix. At local-scale tree species richness positively influenced richness of insectivorous guild during breeding and non-breeding season (Tables 3 and 4). Richness of few guilds such as nectar-insectivore, fruit-seed-nectar and fruit-seed-nectar-insectivore was not explained by either landscape or local-scale variables (see electronic supplementary material S5 and S6).

Bird species composition

Bird community composition in this study varied with urban green space size and type (educational institutions, residential complex, city parks, office parks and plantation). Urban green spaces of large, medium and small size differed in bird species composition both during breeding ($r=0.32$, $p=0.001$) and non-breeding season ($r=0.32$, $p=0.005$). Bird species composition also varied between urban green space types for breeding ($r=0.40$, $p=0.01$) and non-breeding season ($r=0.56$, $p=0.001$). We choose two dimensional NMDS because its correlation with the original data was only slightly lower than for a three-dimensional solution (*breeding season*: Linear fit $R^2=0.92$ vs. 0.95; *non-breeding season*: Linear fit $R^2=0.88$ vs. 0.92), while being easier to interpret. Overall goodness-of-fit calculated as *stress* of the solution was low across seasons (*breeding season*: Stress = 0.11; *non-breeding season*: Stress = 0.14).

Spread of urban green spaces followed a similar pattern across seasons where large and medium sized urban green spaces clustered together but small-sized urban green spaces clustered in opposite direction (Fig. 5a, b). Yet, there were a few sites that fell between the two clusters. Although geographically apart, large urban green spaces clustered closely to each other whereas medium and small-sized urban green spaces showed huge variation in their bird composition.

Landscape and local scale habitat parameters in this study significantly correlated with the NMDS axes. Interestingly some habitat parameters i.e., tree species richness, percentage of barren area, percentage of built-up and percentage of water, caused the differences in species composition across seasons. Whereas urban green space size and percentage of agricultural area in the matrix influenced the community composition only during breeding season and average tree girth during non-breeding season. NMDS 1 strongly positively correlated with green space size, percentage of agricultural areas in the matrix and tree richness during breeding season aligning with large sized urban green spaces. In both seasons, small urban green spaces aligned along a gradient of percentage of built-up in opposite direction to large and medium sized urban green spaces (Fig. 5a, b).

Discussion

With increasing urbanization, it is becoming urgent to create and maintain spaces for urban biodiversity. Most importantly, such decision for planning and development of urban green spaces need to have its foundation in scientific knowledge. Information on urban green space features that improves their biodiversity potential has accumulated over the past few decades (Callaghan et al. 2018; Nielsen et al. 2014; Threlfall et al. 2017). Yet our knowledge is skewed due to paucity of information from megadiverse developing countries (Callaghan et al. 2018). This study aims at investigating the role of landscape and local scale variables in improving the overall and specialist guild richness in rapidly urbanizing Himalayan foothill region of northern India.

In line with the previous studies, our findings establish the value of landscape as well as local level variables in influencing the bird species richness in urban green spaces (Callaghan et al. 2018; Dale 2018; Mayorga et al. 2020). We found that urban green space size plays an overwhelmingly important role in supporting higher bird species richness, density, and richness of specialized foraging guilds. A more encouraging result of this study is the significant role of tree and shrub richness at local level for the breeding and non-breeding bird community (Table 2).

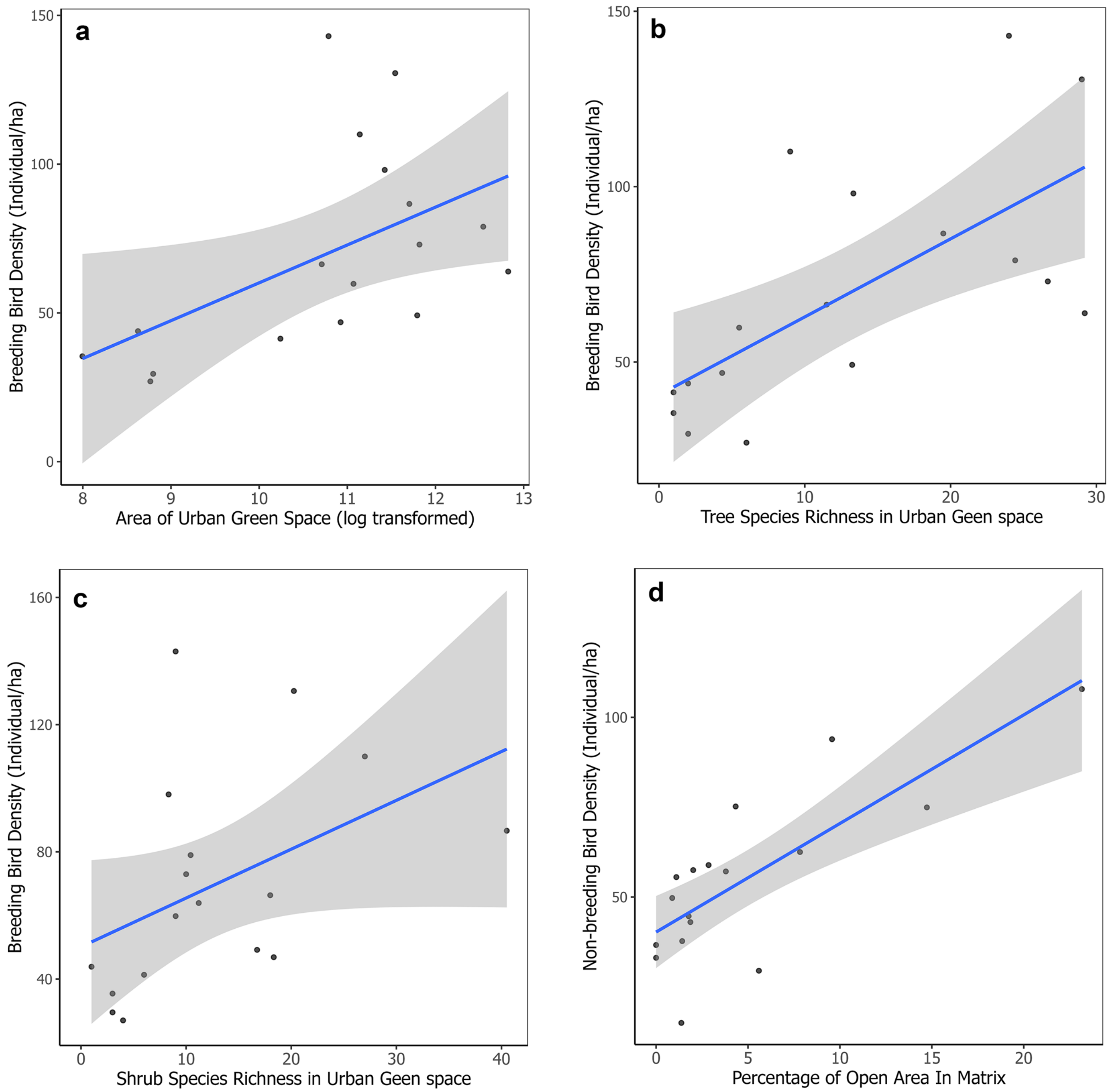

Fig. 4 Relationship of overall bird density with parameters of the best models **a**, **b** and **c** for breeding and **d** non-breeding season

Landscape level determinants of bird community characteristics

Species-area effect has been observed in studies conducted within urban green spaces of a single city and across cities as well. Callaghan et al. (2018) used citizen science data from 112 urban green spaces spread across 51 cities and observed a significantly positive association between bird species richness and urban green space size. Larger urban green spaces are expected to have diverse habitat providing foraging and nesting resources to a diversity of bird species (Matthies et al. 2017). Habitat heterogeneity or patchiness could provide safe refuges to birds for evading predation consequently leading to higher richness over long term (Willson et al. 2001). Although, we did not quantify habitat diversity within urban green spaces but larger sites in this study had variety of habitats ranging from regenerating forest areas, grasslands, scrubs, and vacant plots.

Another mechanism for larger urban green spaces to support higher bird richness is through increased within patch structural heterogeneity, a property of rich plant community. In this study, we too observed a strong

Table 3 Variable estimates, standard errors, and Z-value of the predictor variables of the best model(s), for fine-foraging guild richness modelled against landscape and local variables during breeding season at 18 urban green spaces in Dehradun, Uttarakhand

Fine-foraging guild	Variable of best model	β-estimate	SE	Z-value
Landscape scale				
Understory insectivore	Area of UGS	1.21	1.06	3.11
Sallying insectivore	Area of UGS	1.28	1.11	2.12
	% of barren	1.02	1.01	2.06
Canopy insectivore	Area of UGS	1.47	1.11	3.60
Ground insectivore	Null model	–	–	–
Frugivore insectivore	% of barren	−1.03	1.02	−1.52
	Area of UGS	1.19	1.09	1.83
	% of agriculture	1.03	1.03	1.15
Trunk-bark foragers	Null Model	–	–	–
Trunk-bark foragers[a]	Area of UGS	1.82	1.34	2.03
Granivore	% of barren	1.02	1.01	2.08
Granivore	% of agriculture	1.05	1.03	1.28
Omnivore	Area of UGS	1.27	1.09	2.63
Nectar insectivore	Null model	–	–	–
Fruit-seed-nectar	Null model	–	–	–
Fruit-seed-nectar-insectivore	Null model	–	–	–
Local scale				
Understory insectivore	Tree richness	1.06	1.01	3.28
Sallying insectivore	Tree richness	1.03	1.01	2.15
	Tree girth	−1.01	1.00	−1.77
Canopy insectivore	Tree richness	1.03	1.01	2.20
	Shrub cover	1.21	1.06	2.78
	Shrub richness	1.02	1.02	1.08
Ground insectivore	Average tree height	−1.17	1.06	−2.58
Frugivore insectivore	Null Model	–	–	–
Trunk-bark foragers	Null Model	–	–	
Trunk-bark foragers[a]	Tree richness	1.05	1.02	2.10
Granivore	Null model	–	–	–
Omnivore	Null model	–	–	–
Nectar insectivore	Null model	–	–	–
Fruit-seed-nectar	Null model	–	–	–
Fruit-seed-nectar-insectivore	Null model	–	–	–

[a]Model built without one extremely disturbed urban green space. Only guilds for which removal resulted a change in best model is depicted here in addition to the analysis with all sites

correlation between tree ($r=0.80$, $p<0.001$) and shrub richness ($r=0.55$, $p=0.02$) with the urban green space size. Larger urban green spaces with higher forage and nesting resources would have a direct effect on the abundance of the individual species. We also observed this effect of size on overall bird density during breeding season when the two imminent requirements of the bird are food and suitable nest site. Overall bird density in this study increased with urban green space size during breeding season with percentage of open area in the matrix during non-breeding season (Fig. 4a, d). This effect of park size on breeding bird abundance have been reported in other studies as well (Amaya-Espinel et al. 2019; Leveau and Leveau 2016; Mayorga et al. 2020).

Linear relationship between urban green space size with breeding bird density could be attributed to productivity that is higher in green versus grey spaces (Shochat et al. 2006). Urban green spaces are also characterized by increased availability of provisioned food, lower diversity and density of natural predators, prolonged breeding period of birds due to lack of seasonality subsequently leading to higher abundance of birds, especially urban exploiters, and adapters. Studies conducted in urban areas usually find the density of few urban exploiters contributing to this overall increase. In our study too, during breeding season 14% of species (17 out of 123) contributed to 67% and 63% (14 out of 103) of the total bird abundance during breeding and non-breeding season, respectively.

Table 4 Variable estimates, standard errors, and Z-value of the predictor variables of the best model(s), for fine-foraging guild richness modelled against landscape and local variables during non-breeding season at 18 urban green spaces in Dehradun, Uttarakhand

Fine-foraging guild	Variable of best model	β-estimate	SE	Z-value
Landscape scale				
Understory insectivore	Area of UGS	1.23	1.06	3.49
Sallying insectivore	Area of UGS	1.21	1.08	2.47
Canopy insectivore	Area of UGS	1.32	1.13	2.14
	% of open area	1.14	1.07	1.76
Ground insectivore	% built up	−1.02	1.01	−2.21
	% barren	1.02	1.01	2.42
Frugivore-insectivore	% barren	−1.02	1.02	−1.14
	% agriculture	1.09	1.03	2.66
	Area of UGS	1.32	1.12	2.25
Trunk-bark foragers	Null Model	–	–	–
Trunk-bark foragers[a]	Area of UGS	1.65	1.21	2.61
Granivore	Null Model	–	–	–
Omnivore	Null Model	–	–	–
Omnivore[a]	Area of UGS	1.32	1.13	2.17
Nectar-insectivore	Null Model	–	–	–
Fruit-seed nectar	Null Model	–	–	–
Fruit-seed nectar insectivore	Null Model	–	–	–
Local scale				
Understory insectivore	Tree species richness	1.03	1.01	3.84
Sallying insectivore	Tree species richness	1.04	1.01	3.65
Canopy insectivore	Tree species richness	1.03	1.01	2.36
Ground insectivore	Average tree girth	1.01	1.00	−2.37
Frugivore-insectivore	Tree species richness	1.03	1.01	2.37
Trunk-bark foragers[a]	Tree species richness	1.04	1.01	2.37
Granivore	Average tree girth	1.01	1.00	1.87
Granivore	Tree species richness	1.03	1.01	1.97
Granivore	Shrub richness	1.03	1.02	1.81
Omnivore	Null Model	–	–	–
Nectar-insectivore	Null Model	–	–	–
Fruit-seed nectar	Null Model	–	–	–
Fruit-seed nectar insectivore	Null Model	–	–	–

[a]Model built without one extremely disturbed urban green space. Only guilds for which removal resulted a change in best model is depicted here in addition to the analysis with all sites

All these highly abundant species (*Acridotheres tristis, Columba livia, Spilopelia chinensis, Orthotomus sutorius, Corvus splendens, Pycnonotus cafer* etc.) were also characterized by widespread presence in majority of the sites.

During non-breeding season, overall bird density in this study increased with percentage of open area in the matrix, a land use with no or minimal management of vegetation. Non-breeding season in our study area is marked by harsh winters and influx of 80% of the Himalayan birds to foothills and plains, avoiding even harsher winters in their breeding grounds. On arrival winter migrants in this region form mixed-foraging flocks with resident birds and show strong heterospecific attraction (Kaushik et al. 2012). These migrants often utilize low and medium intensity agricultural fields than primary forest (Elsen et al. 2017).

Smaller urban green spaces in this study were interspersed within the highly urbanized matrix, characterized by a higher percentage of built-up area (see Fig. 5a, b). Although we did not find an impact of built-up area on the overall bird species richness, but we did find a significant association with the bird species composition. Built-up area acts as barrier for movement between urban green spaces especially for disturbance sensitive ground dwelling and dispersal limited species (Rottenborn 1999). We indeed, observed a decline in ground insectivore guild richness with increasing built-up cover in the matrix (Table 4). Although the study area is urbanizing at a fast rate, the presence of reserve forests around the boundary, remnant agricultural areas, old institutes with ample green cover and practices of home gardening seems to compensate for the effect of sealed area.

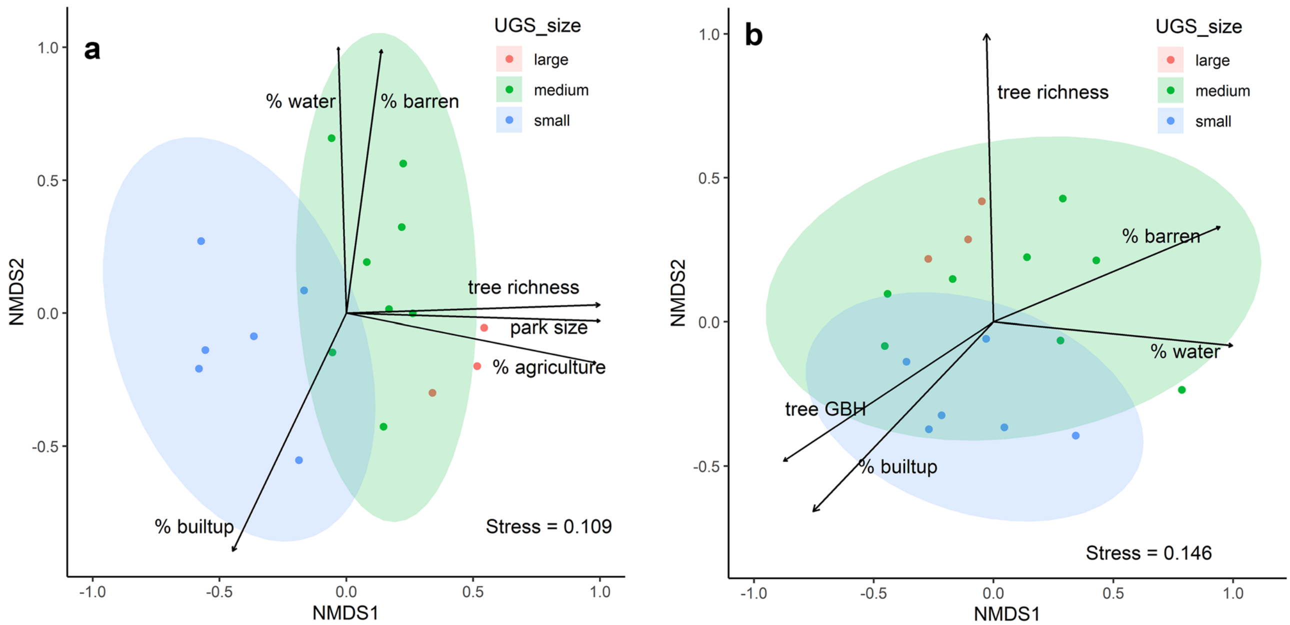

Fig. 5 Nonmetric multidimensional scaling (NMDS) ordination of the bird community during **a** breeding and **b** non-breeding season at the 18 urban green space in Dehradun, Uttarakhand. Plots represents sites according to their similarity in species composition. The arrows are vectors of habitat parameters arrows represent vectors of the significant factors that contributed to the ordination ($p < 0.05$)

Local scale determinants of bird community characteristics

At local scale, tree species richness emerged as an important predictor improving overall bird species richness, richness of fine-foraging guilds and overall density across seasons. Additionally, tree species richness explained the bird community compositions across urban green spaces for both seasons. This positive relationship between tree species richness and community characteristics is also observed in other studies (da Silva et al. 2020; de Toledo et al. 2012; Khera et al. 2009). Increasing tree species richness results in increase food and nesting resources for bird species. Tree species richness is also positively related to foliage height diversity (Daniels et al. 1992) and therefore provide different foraging niches to the birds (MacArthur and MacArthur 1961). Effect of tree species richness was more pronounced on the fine-foraging guilds and the species composition in our study. Richness of insectivorous birds foraging in all stratum (understory, canopy, trunk-bark, air) increased with tree species richness. Tree species richness potentially influence the richness of insectivorous guild by (1) increasing the foliage height diversity, (2) providing diverse food resources and by (3) providing cover from the predators (Evans et al. 2009). Other than tree species richness, disturbance could negatively influence this group especially trunk-bark foraging guild (e.g., nuthatches, woodpeckers). The largest site in this study was an old, abandoned tea plantation with high native tree species richness but the trees are heavily used for collecting firewood and fodder leading to lower richness of this specialized guild.

Contrary to our expectations, we did not find effect of shrub richness on understory insectivore guild. We believe that this lack of relationship is due to the frequent park maintenance activity in the urban green spaces especially during the monsoon season to get rid of the insect and other pests.

Vegetation structural complexity in both vertical and horizontal dimensions has long been established to improve bird species richness (MacArthur and MacArthur 1961; Wiens and Rotenberry 1981). Even within urban green spaces increasing vertical (Suarez-Rubio and Thomlinson 2009) and horizontal complexity in vegetation structure elevated bird species richness (Schütz and Schulze 2015).Vegetation heterogeneity provides variety of microhabitats and resources for different bird species (Berg et al. 1994). In our study too, canopy heterogeneity within park increased bird species richness during the non-breeding season (Table 1). Although, vertical heterogeneity was not included in the top model, but it too had marginally positive effect on the bird species richness during breeding season ($\beta = 0.20 \pm 0.09$ (SE), $t = 2.05$, $r^2 = 0.17$).

Large old trees have been identified as keystone structure in urban parks as they provide disproportionately higher number of food and nesting resources for birds and also increase structural complexity. Stagoll et al. (2012) in urban parks of Canberra, Australia found linear relationships between bird community features and old large trees. In our study, although the top model had only vegetation richness as predictor variables, but density of large old trees (> 50 cm GBH) had a positive effect on the bird species richness only during breeding season ($\beta = 0.49 \pm 0.18$(SE), $t = 2.74$, $r^2 = 0.29$). Retention and planting of native vegetation could potentially benefit the avifaunal community in urban areas. A higher proportion of native *Eucalyptus* tree in suburbs of Canberra, Australia led to higher bird species richness (Burghardt et al. 2009; Ikin et al. 2013). These community level effects could be explained by higher insect abundance on native plants (Burghardt et al. 2009; Narango et al. 2017). Native tree density was not selected as the best model in our study it had a positive effect on bird species richness during breeding ($\beta = 0.34 \pm 0.12$(SE), $t = 2.78$, $r^2 = 0.30$).

Management implications

Our study provides further support for park size as an important factor for conserving large part of the bird diversity in urban areas. This finding is relevant for the city planners during planning stage as large urban green spaces can support a much larger array of bird species than the small ones. Additionally, green spaces within university campuses, offices, residential complexes can further contribute to urban bird diversity. Although urban sprawl is expected to reduce the amount of barren and open areas but certain features of these land use type such as low or no management of shrubs could be incorporated in one portion of the urban green space. Another important finding of this study was the overwhelming role of tree species richness in improving the bird community characteristics at guild and community level. This finding could be used to improve the habitat quality of the small and medium parks for enhancing their conservation potential for bird community. Additionally, periodical planting of native vegetation or supporting natural regeneration could help in increasing the vertical and horizontal heterogeneity of habitat and subsequently supporting a greater number of bird species.

Considering the lack of space for planning large urban green spaces within already planned cities, focus should be on increasing native tree and shrub cover to protect the imperiled ground insectivore guild. Urban park managers should pay special attention on retaining the native and large old trees for improving biodiversity potential of the green spaces.

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Author contributions MK conceptualized and designed the study. Data was collected by ST and KM under the supervision of MK. Data analysis was carried out by ST, KM and MK. The first draft of the manuscript was written by MK and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

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