Zoology and Ecology

ISSN: 2165-8005 (Print) 2165-8013 (Online) Journal homepage: http://www.tandfonline.com/loi/tzec20

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ZOOLOGY AND ECOLOGY, 2017
https://doi.org/10.1080/21658005.2017.1380366

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Impact of threats on avifaunal communities in diversely urbanized landscapes of the Bengaluru city, south India

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ABSTRACT

Identification of threats contributing to occurrence and range distribution of avifaunal communities is poorly known in diversely urbanized landscapes of the Bengaluru city, south India. For the first time, we investigated the disturbance scores along the low (LDS) to high disturbance sites (HDS) with respect to various parameters, i.e. canopy cover, vegetation structure and its composition. We examined their habitat associations and the potential effects on them corresponding to various threats including human development pressure and other habitat suitability indices in urban landscapes of the Bengaluru region. HDS with a lower number of bird species harbour more threat scores than the LDS with the highest number of bird species. Habitat alteration, practice of monoculture plantations, improper waste management and grass cutting were more commonly observed threats in landscapes of the Bengaluru region. The maximum number of perching plant species was characteristic of low disturbance sites with a greater fraction of moist deciduous species. Canopy coverage of plants/trees and the structure of canopy cover were the highest in LDS with the highest strata of the vegetation cover. Human development pressure was the highest in HDS. Management further includes several approaches for the maintenance of urban landscapes for avian communities to minimize bird problems and promote management options that favour bird diversity.

ARTICLE HISTORY
Received 8 August 2016
Accepted 12 September 2017

KEYWORDS
Canopy cover; diversity indices; habitat suitability index; species diversity and richness; threat index; vegetation structure

Introduction

The greediness of humankind provides footprints for industrialization and modernized agricultural farming in the present urban landscapes of the world. Adaptation and modification in the wildlife habitat within urban areas via replacement of forest area and native vegetation with lawns, constructions, roads, and other impermeable surfaces postures one of the extreme threats to avian populations on a global scale (Czech, Krausman, and Devers 2000). Avian communities are the potential contestant species for the study of biodiversity and conservation to identify the health of the urban ecosystem by documenting their occurrence, abundance and frequencies for all species (Lerman et al. 2014; Rajashekara and Venkatesha 2015).

Analysis of threats for any biological organisms is also known as a gap analysis extended by including different environmental variables that are quantified based on each variable's possible impact on conservation. It is designed for the assessment of the present and future of any taxa/species responses to human developmental pressure on organisms (Theobald 2003). Therefore, threat ranking is a method for unambiguously considering the degree to which each direct threat affects biodiversity of species or targets at a particular study site. Further it involves in identifying systematically a set of criteria to the direct threats so that conservation activities can be engaged if they are maximum needed (IUCN Redlist of Threatened Species 2009). The ability of citywide surveys to rapidly prioritize species has to be tested according to their sensitivity to development and the impact of humans on bird diversity in urban areas (Turner2003).

Our understanding of habitat and bird relationships forms a traffic lane for both of them in urban landscapes, hence unbearable effective conservation plans aimed at improving habitat within the city regions (Margoluis and Salafsky 1998). Birds are highly perceptible and fairly sensitive to changes in habitat structure and composition. Therefore, they are excellent indicators of modifications and pressures in the urban ecosystem (Savard and Falls 1982; Clergeau et al. 1998). Bird species richness in urban ecosystems is influenced both by local and landscape-level characteristics, and a multi-scale approach is critical to their proper management (Savard, Clergeau, and Mennechez 2000). Understanding and forecasting the temporal and spatial dynamics and composition of avian populations remains a central goal in avian biology

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of different landscapes of the urban Bengaluru region (Rajashekara and Venkatesha 2015).

This provides a detailed understanding of how demographic rates vary through space and time as well as the underlying causes. This affords the answer to the particular question: How does spatial and temporal environmental heterogeneity influence avian diversity at different scales? (Sutherland et al. 2013).

Urban bird communities and their underlying processes is the major concern of current avian ecology, but we made an attempt at reviewing the present background and limited its conservation implication and readership to a single city. Although natural and man-made threats in some locations of oriental India have been simply mentioned (Karr 1976; Gaston 1986; Sridhar and Karanth 1993; Lalitha et al. 1999; Mahabal and Vasanth 2001; Arunchalam et al. 2004; Awan et al. 2004; Das, Saikia, and Bhagawati 2005; Rajkumar 2005; Narang, Akhtar, and Kumar 2008; Ramesh and Sathyanarayana 2009; Acharya and Vijayan 2010; Bharali and Khan 2011; Jan, Uniyal, and Chauhan 2011; Menon and Mohanraj 2016), their quantification and their effect on the composition, abundance and diversity of birds have not been thoroughly studied in major landscapes of the urban region. The need for scientific information related to several threats on urban bird communities in the Bengaluru region has engaged us to start the present study. Since few studies on avian diversity, interaction with perching plants, role of threats have been conducted, it is important to emphasize the impacts of perceptible threats.

For the present study, precisely we have (1) identified the vegetation composition (perching plants/trees for birds), structure, and landscape features associated with the presence of a complement of representative bird species based on an extensive literature review in Indian context, (2) quantified the characteristics of landscapes in nineteen study sites across the disturbance gradients using a collection of primary datasets and assessment for the urban planning program, (3) exhibited the habitat suitability indices for representative bird species in urban forest monitoring plots, validated the habitats, and compared habitat suitability indices among study landscapes, and (4) tested whether the ranking of threats changed over time for low to high disturbance sites.

Finally, our study objective was answered through (1) investigation of the response of avian communities to human-induced activities and impact of threats on the activities and patterns of avian composition of differently urbanized landscapes in the metropolitan Bengaluru city, south India. Furthermore, this study aimed (2) to describe and validate threats in diverse landscapes along disturbance gradients of the urban region, and (3) to demonstrate their applicability for improving the urban bird diversity of the Bengaluru city, India.

Materials and methods

Study area

Bengaluru is located in the South Deccan plateau of the Peninsular region of India (Figure 1), occupying an area of 2191 km^2 of metropolitan area inhabiting 9 million population (Census of India 2011) and set in the midst of valleys with the rivers of Arkavathi, Kumadavathi and Vrishabhavathi flowing from the Nandi Hills (Devanahalli) to Kengeri (Mysuru Road) (Figure 1). This city is composed

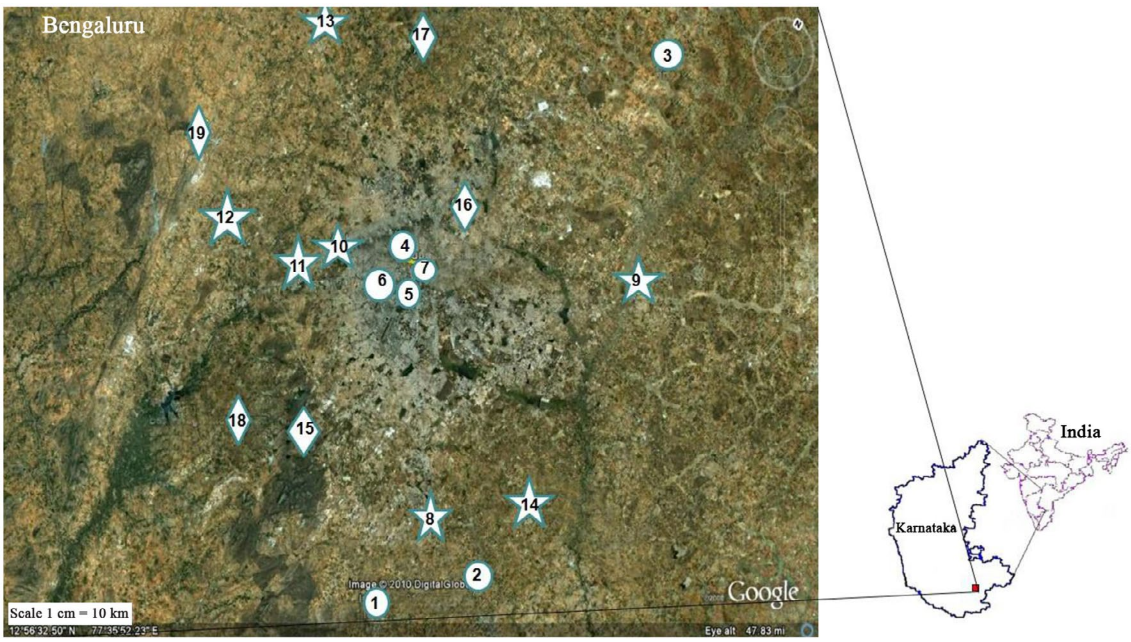

Figure 1. Map showing the study sites with reference to threats across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India. [Map data: Google, DigitalGlobe].
Note: Circles represent high disturbance sites (HDS: 1-AK, 2-AB, 3-DH, 4-KBS, 5-KRM, 6-LBG, 7-LCP), stars represent medium disturbance sites (MDS: 8-CP, 9-HK, 10-JBC, 11-KG, 12-KH, 13-NM, 14-SJP), and rhombi represent low disturbance sites (LDS: 15-BNP, 16-HB, 17-HG, 18-SM, 19-TGH).

of urban landscapes from dry deciduous forests scrub with open to closed canopy evergreen forests along the streams, urban to semi-urban regions. Winter (December to February), summer (March to May) and monsoon (June to November) are three main seasons occurring in this region. An average maximum and minimum temperature is 36° and 14° C, respectively. Rainfall of the Bengaluru region has an average of 800 mm and humidity range is 35–80% in this region.

The floral species play a major role in maintaining the carbon sink in terms of plant biomass (density or area) with various kinds of trees distributed in various urban landscapes of the Bengaluru region. This city has a lush green vegetation cover with numerous species comprising bushes, shrubs and trees. The flora has generated a successful local amalgamated symbiotic relationship with associated fauna of this region including mammals, birds, reptiles, amphibians and several species of invertebrate fauna.

Usage of indices for assessing threat ranking in urban landscapes

A preliminary observation was made to document the category of threats, including anthropogenic activities and disturbance score obtained for each site/landscape in the urban region of Bengaluru, Karnataka, south India, following methods of Shenoy, Varma, and Prasad (2006) and Rajashekara and Venkatesha (2013). Surveys of threats and other scores for the assessment of several indices were conducted once a month from February 2008 to January 2010. All the study sites experienced various categories of anthropogenic activities affecting the avian distribution of different landscapes of the urban zone. Although several study landscapes are located in the protected areas such as national parks and botanical gardens, etc., the intensity of anthropogenic activities in those regions is found to be higher due to the presence of tourism centres. Hence, anthropogenic activities were given scores based on the impact of disturbance on avian communities. Various types of disturbances were categorized into ranks: 1 for light disturbance, 2 for moderate where a few reiterations were found, and 3 for severe replications of threats. The disturbance level for each study site was calculated using the following relation:

Disturbance level= $\sum_{i=1}^{3} \text{score}_i$ * total number of incidents of activity i /observer effort (Rajashekara and Venkatesha 2013), where i = various types of disturbances in each site, score i = sum of the score given to each site based on intensity of disturbances.

Disturbance scores given to each site/landscape by qualitatively assessing various disturbances (encroachment of landscapes, gaming and other recreational activities (including photography), grass cutting, livestock grazing, monoculture plantations, open and wood-log fire occurrence, over-extraction of resources, tourists and settlements (anthropogenic activities), and bridle pathways) were ranked into rare (1), occasional (2), and frequent (3) levels of disturbances. Study landscapes were classified into different anthropological disturbance categories: high disturbance sites (HDS) for scoring high ranks, moderate disturbance sites (MDS) for middle ranks, and low disturbance sites (LDS) for low ranks with the help of the disturbance index which was based on the minimum and maximum values of observed disturbance parameters.

The index of decline was based on the local-scale reduction in an area of occupancy of bird species in face of human-induced habitat loss as followed by earlier works (Martof et al. 1980; Conant and Collins 1991; Mitchell 1991; Brown and Dickson 1994; Greenlaw 1996; Petranka1998; Blackburn, Nanjappa, and Lannoos 2001; IUCN Redlist of Threatened Species 2009). The index of decline was calculated and the values were expressed in units of 0.1, range from 0.1–1.0, and represented the probability an individual bird would be excluded from a habitat as a result of human development based on expert opinion. This index was used to derive a projected percentage habitat reduction using the formula: Development Pressure = %ΔHousing units.

%ΔHousing Units = (No. of housing units in 2008 – No. of housing units in 2000)/(No. of housing units in 2000)*100 (Surasinghe et al. 2012).

Percentage Range Unprotected = Species distribution within study area that is protected/Total distribution within study area. Percentage Habitat Reduction = Development Pressure * Percentage Range Unprotected * Index of Decline.

Models for threat analysis were based on the development rate of housing units in the study area, the habitat suitability index for each species, and protection rank in the study area distribution of each species (Baldwin and deMaynadier 2009). A similar approach was used for the habitat reduction model to calculate development pressure for these models, but there was used a county-specific growth rate of housing units (Surasinghe et al. 2012). We generated Habitat Suitability Indices based on habitat suitability for bird species as determined by the earlier works (Blackburn, Nanjappa, and Lannoos 2001; IUCN Redlist of Threatened Species 2009). We ranked the suitability of each major habitat type on an ordinal suitability ranging from very high to low suitability, and assigned a fixed value for each habitat that happened within the distribution range of each species. Habitat suitability values were assigned as follows: 1 – very high, 0.75 – high, 0.50 – moderate, and 0.25 – low suitability.

We reconsidered the study region into five groups based on management authority: centrally owned, state owned, protected private lands, protected lands with unknown ownership, and unprotected areas to govern the distribution of bird species. Based on land use practices allowed by different management authorities (e.g. recreational use, hunting, harvesting), we derived values from 1 to 5 to indicate the likelihood that selected species would be safeguarded from future anthropogenic disturbance.

Thus, Threat Index = (Growth Rate of Housing Units*Habitat Suitability Index)/Protection Status. There are some standards for threat ranking using the absolute system using scope, severity, and irreversibility with the following definitions and scoring methods as follows:

(a) **Scope:** The proportion of the target that can reasonably be expected to be affected by threats within ten years, given the continuation of current situations and trends. The proportion of the target's occurrence/population for bird species was measured for different landscapes in the Bengaluru region.
(b) **Severity:** Within the scope, the level of damage to the target from threats that can reasonably be expected given the continuation of current circumstances and trends. The degree of destruction/degradation of the target for bird species within the scope was typically measured for different landscapes in the urban region.
(c) **Irreversibility (Permanence):** The degree to which the effects of a threat can be reversed and the target affected by the threat restored for a particular landscape. Effects of threats cannot be reversed, it is very doubtful the target can be restored, and/or it would take more than 100, 21–100, 6–20, or 0–5 years to achieve this, e.g. wetlands converted to a shopping centre or playgrounds, wetlands converted to agriculture, draining of wetland, or off-road vehicles trespassing in wetland, respectively.

For the above three scoring methods, we used the four-scale measurements as given below: 4 = very high, 3 = high, 2 = medium, and 1 = low, for which the threat is likely to be pervasive in its scope, affecting the target across all or most (71–100%, 31–70%, 11–30%, and 1–10%, respectively) of its occurrence.

Finally, we compared all the direct threats using scope, severity, and irreversibility in a given site to one another across each measure adapted by the method of Margoluis and Salafsky (1998). This method involves a detailed ranking of each threat, using a four-point absolute scale and applying a series of algorithms to convert the ratings into an overall threat rating. The method used by Microsoft Excel software is a simplified version of this threat rating method using the following formula: Tota l = 2*(Scope + Severity) + Irreversibility. Based on this formula, the classification of threats into categories is as: 4 = very high, 3 = high, 2 = medium, and 1 = low.

Field sampling for avian communities

Furthermore, low to high disturbance sites were subjected to avian survey in order to assess dynamics in different landscapes of the urban region with respect to disturbance sites (Figure 1). Four stripe transects are laid for the study of avifaunal species documentation in diversely urbanized landscapes. Each stripe transect was trailed of one km^2 (20 m wide on either side of the prefixed transect) arrayed in low, moderate and high disturbance sites. Prefaced transects were marched at an even speed of about 1–1.5 km h^{-1} in the before-noon (08.00–11.00 h) and in the afternoon (15.00–18.00 h) as followed by Verner (1985). Bird surveys were conducted once a fortnight from February 2008 to January 2010. Standardized sampling methods were used for survey methods in fixed time-spans (30–40 min transect count) with sampler's effort transversely in all the study sites (Watson 2003). Call notes of bird species were also used for locating them (Ali 2012). Nomenclature and taxonomy of birds was assigned according to BirdLife International (2014).

Further, mosaic diversity as a measure of landscape complexity can be assessed as a compositional diversity pattern using affinity analysis (Scheiner 1992). This measures compositional pattern diversity in which the arrangements of subunits in the mathematical space are defined by the site-species composition matrix. Species richness (S) is the total number of bird species recorded in a particular study landscape. In the same site, the number of endangered bird species (including critically endangered, threatened, and vulnerable according to IUCN Redlist of Threatened Species 2009) is noted down. The ratio of endangered and normal number of bird species is calculated. Consecutively, the number of families, genera and species, proportions of genus and species, family and species, and family and genus are calculated. Data on bird species were analyzed for relative frequency, abundance, and species distribution ratio, as well as the species importance value index (SIVI) (relative frequency + relative abundance + relative species distribution ratio) was calculated (Curtis and McIntosh 1951). Similarly, the collected data on birds were transferred for calculation of the family importance value index (FIVI) (relative family abundance + relative family richness) to understand the community organization in relation to competitive ability using a method of Curtis and McIntosh (1951).

Diversity can be measured by grouping species into several subunits in an ecological unit also known as differentiation diversity (Whittaker 1960). Beta diversity quantifies how many subunits there would be if the total species diversity and mean species diversity per subunit remained the same, but the subunits shared no species or turnover (Tuomisto 2010). Fisher's alpha diversity of bird populations was calculated at each site, using the formula $S = a*\ln(1 + n/a)$, where S is the number of taxa, n is the number of individuals, and a is the Fisher's alpha (Fisher, Corbet, and Williams 1943; Magurran 2004), using PAST version 1.60 software (Hammer, Harper, and Ryan2001).

Vegetation sampling

Flowering plants (>10 cm in diameter at breast height (DBH) at 1.37 m above the ground level) were sampled precisely at the locations where bird surveys were conducted in each sampling site excluding grasses, epiphytes, seedlings and herbs (Nagendra and Gopal 2010). Canopy cover is one of important parameters in the measurement of disturbance (Fiala, Garman, and Gray 2006) and quantified by digital canopy photography (Engelbrecht and Herz 2001). Canopy coverage (in %) for each site was calculated by averaging ten values of ten images taken within a particular site and was expressed in range and mean ± standard error. Vegetation cover (%) was measured after Lynch, Morton, and Van der Voort (1985) at different strata (St1: 0–0.4, St2: 0.4–0.8, St3: 0.8–1.2, St4: 1.2–1.6, St5: 1.6–2.0, St6:>2.0 m). Six strata of vegetation were classified into two variables of lower vegetation (%) at 0–1.2 m high (VgL: St1–3) and higher vegetation (%) at >1.2 m high (VgH: St4–6) for simplicity (Kurosawa 2007). The number of perching plant species per site and the number of plant species dependent on birds for dispersal of fruits and seeds were estimated.

Statistical analyses

The difference in the values of species diversity and richness, canopy structure, development pressure, percentage range unprotected, habitat suitability index, and disturbance scores (levels) (as a categorical variable) of avifaunal communities among diversely urbanized landscapes (response variable) along the various disturbance gradients was statistically analyzed using one-way analysis of variance (ANOVA) – Tukey's Honestly Significant Difference (HSD) test (SPSS Inc. 2008). We evaluated the influence of various environmental variables such as the number of buildings (n), human population density (n), total number of bird species (n), protected birds (%), number of endangered species (n), protected area (%), site disturbance score (%), tree density (%) (No./ha), index of decline (%), species diversity of birds, threat index (%), scores for degree of suitability, area (in km^2), endemicity value (%), number of bird families, number of genera in a particular bird family were subjected to the Pearson correlation coefficient to understand the relationship between them (SPSS Inc. 2008). All these data were logarithm 10 base transformed prior to analyses to better approach a normal distribution, then the correlation of various parameters with the bird populations was analyzed (SPSS Inc. 2008). Ward's method of Bray-Curtis Cluster Analysis was carried out to create a dendrogram to assess the similarity within various threats faced by the density of birds among study landscapes of the Bengaluru region using PAST version 1.60 software (Hammer, Harper, and Ryan 2001).

The relationships between attributes of bird community composition (as response variables) and environmental/disturbance parameters (as explanatory variables) such as protected area (%), log10 tree density (%)(No./ha), log10 disturbance score (%), log10 index of decline (%), log10 threat index (%), log10 scores for degree of suitability, log10 area (in km^2), log10 endemicity value (%), log10 number of buildings (n), log10 human population density (n) were assessed using Multiple Linear Regression Models (MLRM) (Lehmann, Overton, and Austin 2002; Lehmann, Overton, and Leathwick 2003). This Multiple Linear Regression Model is explained as given below:

Suppose we have a sample consisting of n pairs of observations

$$(x_1, y_1), (x_2, y_2), \ldots \ldots, (x_n, y_n).$$

We propose the model that each y_i is an observation from a random variable

$$Y_i = \beta_0 + \beta_1 x_i + E_{i,}$$

where the E_i's are independent normally distributed random variables with expected value 0 and common variance σ2. Thus we can express each y_i as

$$y_i = \beta_0 + \beta_1 x_i + e_{i,}$$

where e_i is an observation from E_i. We call y_i the response variable, x_i the declaring variable, and e_i the remainder term.

Thus, the fitted multiple linear regression line is $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_{10} x_{10}$. The goodness-of-fit and statistical significance of best models were assessed using the relevant statistics (R^2 test) (SPSS Inc. 2008).

This type of linear regression models (McCullagh and Nelder 1989) can be used to determine the relationship between the response variables and explanatory variables (Jachmann 2008) in order to extrapolate levels of site-wise disturbance gradients over time. Regression methods can be effective in estimating group size, and the slope of the regression of group size (or log group size) on distance tends to have a positive slope (as group size increases with distance), and on detection probability a negative slope. Sometimes the sign of the slope is reversed. This happens when observers underestimate the size of groups and the degree of underestimation increases with distance. Even in this case, however, using regression should give a valid estimate of mean group size (Jachmann 2008).

Results

Usage of indices for assessing threat ranking in urban landscapes

A proportional analysis between the disturbance scores notching for threats in different landscapes of the Bengaluru region, south India reveals that high disturbance sites (HDS) (five out of seven sites) harbour more threat scores (20 to 24) than the other disturbance sites

Table 1. Disturbance scores (1 = low; 2 = moderate; 3 = high) for 19 study landscapes in the Bengaluru region, Karnataka, south India.

Disturbance sites	Study landscapes	Acronyms	Landscape encroachment	Gaming and other recreational activity (including photography)	Grass cutting	Livestock grazing	Monoculture populations	Open fire	Resource over-extraction	Tourists/pilgrims and settlements (anthropogenic activities	Use of bridle pathways	Wood-log fire	Total scores*
	Anekal	AK	3	3	0	3	3	2	3	3	3	0	23
	Attibele	AB	3	2	0	3	3	2	3	3	3	0	22
	Devanahalli	DH	3	3	0	3	3	2	3	3	3	0	23
High disturbance sites (HDS)	Kempegowda Bus Station	KBS	3	3	3	1	3	1	3	3	3	3	24
	Krishna Rajendra Market	KRM	3	3	2	2	0	2	3	3	3	2	23
	Lalbabh Botanical Garden	LBG	1	3	3	1	0	0	1	1	3	2	15
	Lord Cubbon Park	LCP	1	3	3	1	0	0	2	1	3	3	17
	Chandapura	CP	2	2	0	3	3	2	3	3	2	0	20
	Hoskote	HK	1	3	0	3	3	0	3	3	2	2	20
Moderate disturbance sites (MDS)	Jnana Bharathi Campus	JBC	2	2	3	3	0	3	2	3	2	0	20
	Kengeri	KG	2	2	2	2	2	0	3	3	2	1	19
	Kethohalli	KH	2	2	1	2	3	0	3	3	2	1	19
	Nelamangala	NM	3	3	0	3	3	3	3	3	3	0	23
	Sarjapura	SJP	3	3	0	3	3	3	3	3	2	0	23
Low disturbance sites (LDS)	Banneraghatta National Park	BNP	2	3	0	2	0	2	3	2	1	0	15
	Hebbala	HB	2	3	1	3	2	2	3	3	1	0	20
	Hesaraghatta	HG	1	3	2	3	3	0	3	2	1	1	19
	Somanahalli	SM	2	3	0	3	3	3	3	3	2	0	22
	Thippagondanahalli	TGH	1	3	3	3	3	2	3	1	1	0	20

*Results in a column under various disturbance scores indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one-way ANOVA, $F_{2,16} = 0.669$, $p > 0.05$).

(15 to 20) (Table 1). Of which, resource over-extraction (collection of food sources, fibre, firewood, fuel wood, and fodder extraction), unrestricted livestock grazing, human activities including developmental activities (roads and fly-overs) and recreational activities, and landscape encroachment (habitat loss, fragmentation, degradation and adaptation) were recorded as common threats in all the landscapes. Both open landscape fire (highest in three sites of MDS) and wood-logging fire (highest in one study site from HDS) were found in the Bengaluru region. Furthermore, the occurrence of disturbance scores was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.669$, $p > 0.05$).

A dendrogram showing similarity in the disturbance scores for threats faced by the birds of different landscapes with three major clusters showed significant negative affinities. Grass cutting and wood-log fire accounted for low disturbance scoring belonging to the first cluster; landscape encroachment, use of bridle pathways and open fire accounted for moderate scoring in the second cluster, whereas human interferences such as monoculture practices, gaming and other recreational activities, handling livestock grazing and tourists and other settlements accounted alone for the third cluster with a high disturbance scoring (Figure 2). Furthermore, principal threats to terrestrial bird fauna, i.e. habitat alteration, crop cultivation, monoculture plantations (except BNP, HG and TGH), improper waste management and grass cutting were more common in almost all the urban landscapes (16 sites) of the study region. Other threats, i.e. building construction and firewood collection affected bird population in the urban region.

Population variations in urban bird species

During the study period, different landscapes of the Bengaluru region, Karnataka, south India had 118 bird species belonging to 78 genera and 43 families distributed in various disturbance sites (Appendix 1). A comparative analysis between the disturbance sites reveals that LDS harboured more species of birds (115) than the HDS (33 spp.) did (Table 2). Out of recorded bird species, 115 (97.46%) were found exclusively in LDS with a greater fraction of moist deciduous species (Table 2). Species richness of avifaunal communities among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 3.817$, $p < 0.05$). Correspondingly, the highest diversity of birds (Fisher's Alpha and Beta diversity – 16.20 and 1.95) was recorded in the LDS (BNP) with the highest genus (76) and species (115) richness compared to the other MDS and HDS. Moreover, species diversity of bird species among 19 study landscapes along the various disturbance gradients was significantly different (Fisher's alpha diversity – Tukey HSD, $F_{2, 16} = 4.360$, $p < 0.05$ and Whittaker's Index – Tukey HSD, $F_{2, 16} = 3.766$, $p < 0.05$). Beyond 68 tree species, the maximum number of perching plant species was characteristic of LDS with a greater fraction of moist deciduous species and native plant/tree species (Table 2). The canopy coverage of plants/trees and the structure of canopy cover were the highest in LDS (TGH – 78.49 to 99.99 and 91.05 ± 1.80, respectively) with the maximum strata of the vegetation cover (>2.0 m). In addition, the canopy coverage of vegetation structure was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.7353$, $p > 0.05$).

Columba livia (12.03), *Acridotheres tristis* (10.41), and *Corvus splendens* (10.27) showed the highest species importance value index (SIVI), whereas *Gyps indicus* (0.01) showed the lowest value (Appendix 1). On the contrary, 33 species of birds (27.96%) were confined to HDS with the presence of generalist number of pioneer species, while 32 (27.19%) bird species were common to both areas (Appendix 1). Furthermore, Accipitridae had the highest family importance value index (FIVI) (13.95) and relative species richness (9.45) with the highest number of bird genera and species (9 and 10, respectively) (Appendix 2). However, Muscicapidae had the highest relative abundance (5.59%) than the other families. And

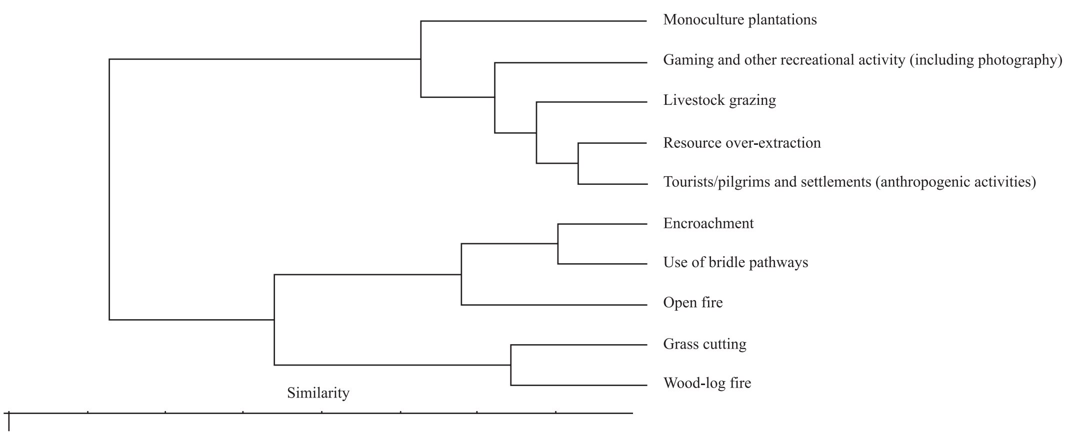

Figure 2. Dendrogram showing the contribution of threats across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, southern India.

Table 2. Survey sites and composition patterns of avifauna and vegetation across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India.

	High disturbance sites (HDS)							Medium disturbance sites (MDS)							Low disturbance sites (LDS)				
Avian composition	AK	AB	DH	KBS	KRM	LBG	LCP	CP	HK	JBC	KG	KH	NM	SJP	BNP	HB	HG	SM	TGH
Study landscapes																			
Species richness[a]	107	96	96	33	35	80	81	99	103	106	97	86	100	96	115	93	106	97	105
Number of endangered species	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0
Number of genera	43	42	42	21	21	37	38	42	43	42	40	39	42	42	43	40	42	43	42
Number of families	71	65	65	28	30	55	55	66	69	71	65	57	67	64	76	60	71	65	70
Genus: species	0.66	0.68	0.68	0.85	0.86	0.69	0.68	0.67	0.67	0.67	0.67	0.66	0.67	0.67	0.66	0.65	0.67	0.67	0.67
Family: species	0.40	0.44	0.44	0.64	0.60	0.46	0.47	0.42	0.42	0.40	0.41	0.45	0.42	0.44	0.37	0.43	0.40	0.44	0.40
Family: genus	0.61	0.65	0.65	0.75	0.70	0.67	0.69	0.64	0.62	0.59	0.62	0.68	0.63	0.66	0.57	0.67	0.59	0.66	0.60
Endangered species: number of bird species	0.009	0.000	0.000	0.000	0.000	0.013	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.010	0.000
Fisher's alpha diversity[b]	15.67	15.32	14.60	4.23	4.09	11.96	11.70	15.65	15.61	15.81	14.87	13.87	15.34	15.21	16.20	15.13	15.88	15.27	15.85
Whittaker's Index[c]	1.81	1.63	1.63	0.56	0.51	1.36	1.37	1.68	1.75	1.80	1.64	1.46	1.69	1.63	1.95	1.58	1.80	1.64	1.78
Vegetation composition																			
Number of perching plant species	63	63	65	24	26	68	65	61	61	63	57	42	63	63	68	60	63	58	65
Number of plant species dependent on birds for dispersal of fruits and seeds	41	41	41	35	36	41	40	41	41	41	41	37	41	41	41	41	41	41	41
Canopy cover (range = minimum to maximum)	78.59–97.26	81.67–97.52	81.67–99.30	81.67–97.14	79.53–97.14	78.52–97.14	71.83–100.00	81.67–97.52	75.14–100.00	65.74–99.63	81.00–99.73	79.42–97.14	76.12–97.26	72.08–97.52	70.68–100.00	81.67–97.26	74.04–100.00	78.52–97.52	78.49–99.99
Canopy cover[d] (mean ± standard error)	88.45 ± 1.35	89.06 ± 1.35	89.71± 1.48	88.53 ± 1.77	87.99 ± 1.74	87.34 ± 1.14	86.86 ± 1.92	89.47 ± 1.39	87.14 ± 1.53	87.39 ± 1.35	89.65 ± 1.79	87.97 ± 1.74	86.47 ± 1.79	87.32 ± 1.72	88.00 ± 1.59	89.26 ± 1.29	88.12 ± 1.16	87.39 ± 1.40	91.05 ± 1.80
Vegetation strata (meter)	1.6–2.0	1.6–2.0	1.2–1.6	0.0–0.4	0.0–0.4	0.4–0.8	0.4–0.8	0.8–1.2	1.2–1.6	1.2–1.6	1.2–1.6	1.2–1.6	0.8–1.2	0.8–1.2	>2.0	>2.0	>2.0	>2.0	>2.0
Classification of stratum	St 5	St 5	St 4	St 1	St 1	St 2	St 2	St 3	St 4	St 4	St 4	St 4	St 3	St 3	St 6	St 6	St 6	St 6	St 6

[a]Results in a column under species richness indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 3.817$, $p < 0.05$);
[b]Results in a column under Fisher's alpha diversity of birds indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 4.360$, $p < 0.05$);
[c]Results in a column under Whittaker's Index indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 3.766$, $p < 0.05$);
[d]Results in a column under canopy coverage of vegetation indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one way ANOVA, $F_{2, 16} = 0.7353$, $p > 0.05$).

20 families of birds (1.00 each) showed the highest ratio of genus and species (Appendix 2).

Moreover, the development pressure (%ΔHousing Units) was the highest in HDS (KBS and KRM – 21.82 each) (Table 3). Furthermore, the development pressure among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 4.252$, $p < 0.05$). Also, the habitat suitability index was the highest in four study sites from HDS (three) and in one LDS (1.00 each). Moreover, the habitat suitability index was not significantly different for 19 study landscapes of the Bengaluru region (one-way ANOVA, $F_{2, 16} = 0.354$, $p > 0.05$). Similarly, habitat reduction is totally absent in four study sites (0%). In addition to this, the index of decline was higher in seven disturbance sites (7.19% each). On the contrary, the percentage of unprotected range was the highest in one LDS with '5' (BNP –91.30%). Also, the value of '5' indicates the highest protection level in LDS (Table 3). Besides this, the percentage of range protection among 19 study landscapes along the various disturbance gradients was significantly different (Tukey HSD, $F_{2, 16} = 2.499$, $p < 0.05$). Besides, the ranking of threat indices scored for maximum in all HDS (16–20), and in these sites it was categorized as very high (Table 4). After subjecting to the threat index and ranking scores, still LDS come under the medium category (6–9).

Influence of environmental variables on bird species richness and diversity

Besides this, the total number of bird species showed a significant positive correlation with the protected area, tree density, degree of habitat suitability, study area and species endemicity values, and a significant negative correlation with the threat index and the number of buildings in urban landscapes of the Bengaluru region (Table 5). Species diversity of birds showed a significant positive correlation with the total number of bird species, number of bird species, number of genera in a particular bird family, protected birds and area, tree density, degree of habitat suitability and species endemicity values, and a significant negative correlation with the number of buildings. The number of bird families and the number of genera in a particular bird family showed a significant negative correlation with the number of buildings and threat index (Table 5). Protected birds showed a significant negative correlation with the threat index and the number of buildings. Also, protected area of landscapes showed a significant negative correlation with the index of decline and threat index. Tree density showed a significant negative correlation with the number of buildings. The index of decline showed a significant negative correlation with the protected birds, protected area and endemicity values. The threat index showed a significant negative correlation with six parameters such as total number of bird species, number of bird families and genera in a particular bird family, protected birds and area, species endemicity values, and a significant positive correlation with the human population density. The study area showed a significant negative correlation with the index of decline. The endemicity values of birds showed a significant negative correlation with the index of decline and threat index. In contrast, the number of buildings showed a significant positive correlation with increase in the human population density. Human population density showed a significant negative correlation with the protected area and species endemicity values, and a significant positive correlation with the threat index and tree density (see Table 5).

Many big metropolitan cities including Bengaluru city of India are relatively known as heterogeneous in terms of environmental awareness and change in the land use patterns for needs of human population. There was a significant positive correlation between the number of buildings and houses and increasing local human population density in Bengaluru city ($n = 19$, $r^2 = 0.4416$, $y = 0.4784\times + 2.6951$, $p < 0.000$) (Figure 3(a)).

There was no significant association between human population density and total number of bird species (Figure 3(b)). Human population density did not vary significantly with variations in patches of urban greenery areas in the urban region. The total number of bird species was significantly correlated with the study area (Figure 3(c)). As well as there was a significant association of the study area with the total avian species richness, but the proportion of protected areas was not correlated with the total avian species richness (here, only four sites – BNP, HG, LLBG, and TGH are protected areas). However, there was no significant negative correlation between the human population density and tree density (Figure 3(d)) showing that increase in urbanization correlated with increase of deforestation. Tree density was in a significant positive correlation with the total number of bird nests in the urban region (Figure 3(e)) and the number of bird species (Figure 3(f)). There was no significant association between canopy coverage and tree density in the urban region (Figure 3(g)). Other correlations between bird population indices and environmental factors are presented in the Figure 3(h–s).

Existence of avian communities across the disturbance gradients of different landscapes was explained with three major clusters. The number of genera, species and families forming the first sub-cluster mainly dependent on the threat index, index of decline and endemicity value form the important factors for diversity of bird species; protected birds and area in the other first sub-cluster showed negative relationship with the second cluster comprising the scores for the degree of suitability, tree density, number of endangered species and study area, and the third cluster alone with human population density and the number of buildings (Figure 4).

For the first attribute (e.g. bird species richness), the variation explained by the fitted multiple linear regression line is 99.90% (Table 6). For all the cases, R^2

Table 3. Assessment of the study landscapes for calculation of the habitat suitability indices.

Habitat type	Study landscapes	Development Pressure (%ΔHousing Units)[a]	Percentage Range Unprotected[b]	Index of Decline (Percentage)	Percentage Habitat Reduction	Habitat Suitability Values[c]	Protection Status (Values on Conservation Potential)[d]	Protected lands with unknown ownership
Dry scrub/shrub thicket	AK	18.12	85.98	5.40	21.82	1.00	2	Protected lands with unknown ownership
Dry scrub/shrub thicket	AB	1.11	88.54	3.96	1.42	1.00	2	Protected lands with unknown ownership
Dry scrub/shrub thicket	BNP	0.00	91.30	3.60	0.00	1.00	5	Federal lands
Closed canopy evergreen forest/woodland	CP	1.11	80.81	6.83	1.18	0.50	3	Private conservation lands
Open canopy/recently cleared forest	DH	14.42	89.58	3.60	18.85	0.75	4	State lands
Urban residential	HB	2.59	89.25	3.60	3.36	0.25	3	Private conservation lands
Closed canopy evergreen forest/woodland	HG	1.48	90.57	3.60	1.98	0.50	4	State lands
Closed canopy evergreen forest/woodland	HK	7.03	90.29	3.60	9.33	0.50	3	Private conservation lands
Closed canopy evergreen forest/woodland	JBC	−0.07	90.57	3.60	−0.10	0.50	4	State lands
Urban residential	KBS	21.82	60.61	4.68	13.05	0.25	1	Unprotected lands
Closed canopy evergreen forest/woodland	KG	1.48	79.38	7.19	1.52	0.50	2	Protected lands with unknown ownership
Closed canopy evergreen forest/woodland	KH	0.00	76.74	7.19	0.00	0.50	3	Private conservation lands
Urban residential	KRM	21.82	71.43	3.60	18.13	0.25	1	Unprotected lands
Closed canopy evergreen forest/woodland	LBG	−0.15	75.00	7.19	−0.14	0.50	4	State lands
Closed canopy evergreen forest/woodland	LCP	0.00	75.31	7.19	0.00	0.50	4	State lands
Open canopy/recently cleared forest	NM	7.03	80.00	7.19	7.32	0.75	3	Private conservation lands
Open canopy/recently cleared forest	SJP	1.11	79.17	7.19	1.13	0.75	3	Private conservation lands
Open canopy/recently cleared forest	SM	1.11	79.38	7.19	1.14	0.75	3	Private conservation lands
Dry scrub/shrub thicket	TGH	0.00	90.48	3.60	0.00	1.00	4	State lands

[a]Results in a column under development pressure indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 4.252$, $p < 0.05$).
[b]Results in a column under percentage range protection indicate significantly different among diversely urbanized landscapes at $p < 0.05$ (Tukey HSD, $F_{2, 16} = 2.499$, $p < 0.05$).
[c]Each habitat occupied by the selected species was assigned a numerical value reflecting the degree of suitability of that habitat as following: 1 – very high suitability, 0.75 – high suitability, 0.50 – moderate suitability and 0.25 – low suitability; Results in a column under various habitat suitability index indicate not significantly different among diversely urbanized landscapes at $p > 0.05$ (one way ANOVA, $F_{2, 16} = 0.354$, $p > 0.05$).
[d]Protection levels based on the management authorities of lands (see text reference).

Table 4. Assessment of the study landscapes using threat indices.

Study Landscapes	High disturbance sites (HDS)							Medium disturbance sites (MDS)							Low disturbance sites (LDS)				
	AK	AB	DH	KBS	KRM	LBG	LCP	CP	HK	JBC	KG	KH	NM	SJP	BNP	HB	HG	SM	TGH
Scope	4	3	4	4	4	4	4	2	2	2	3	3	3	3	1	1	1	1	1
Severity	4	3	4	4	4	4	4	3	3	2	3	3	4	4	1	2	2	2	2
Irreversibility	4	4	4	4	4	4	4	3	3	2	3	3	4	4	2	3	2	2	2
Total†	20	16	20	20	20	20	20	13	13	10	15	15	18	18	6	9	8	8	8
Classification of threats	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High	High	Medium	High	High	Very high	Very high	Medium	Medium	Medium	Medium	Medium

†Total = 2 * (scope + severity) + irreversibility.

Table 5. Pearson's Correlation Coefficient analysis for the interaction of avian community composition and habitat suitability indices.

	log10 total bird species (n)	log10 species diversity of birds	log10 number of bird families	log10 number of genera in a particular bird family	log10 protected birds (%)	log 10 number of endangered species (n)	log10 protected area (%)	log10 tree density (%) (No./ha)	log10 site disturbance score (%)	log10 index of decline (%)	log10 threat index (%)	log10 scores for degree of suitability	log10 study area (in km²)	log10 endemicity value (%)	log10 number of buildings (n)	log10 human population density (n)
log10 total bird species (n)	1	0.993**	0.991**	0.997**	0.991**	0.153	0.807**	0.813**	−0.064	0.053	−0.471*	0.696**	0.486*	0.830**	−0.596**	−0.427
log10 species diversity of birds	0.993**	1	0.995**	0.984**	0.977**	0.112	0.773**	0.764**	−0.097	0.104	−0.444	0.666**	0.411	0.797**	−0.608**	−0.423
log10 number of bird families	0.991**	0.995**	1	0.983**	0.973**	0.163	0.761**	0.796**	−0.075	0.123	−0.407	0.698**	0.413	0.788**	−0.600**	−0.378
log10 number of genera in a particular bird family	0.997**	0.984**	0.983**	1	0.992**	0.148	0.824**	0.833**	−0.023	0.019	−0.482*	0.719**	0.511*	0.846**	−0.570*	−0.421
log10 protected birds (%)	0.991**	0.977**	0.973**	0.992**	1	0.107	0.880**	0.809**	−0.055	−0.077	−0.511*	0.681**	0.525*	0.899**	−0.556*	−0.455
log 10 number of endangered species (n)	0.153	0.112	0.163	0.148	0.107	1	−0.069	0.394	0.159	0.312	−0.060	0.319	0.332	−0.053	−0.317	0.108
log 10 protected area (%)	0.807**	0.773**	0.761**	0.824**	0.880**	−0.069	1	0.666**	−0.021	−0.531*	−0.589**	0.525*	0.597**	0.998**	−0.330	−0.493*
log10 tree density (%) (No./ha)	0.813**	0.764**	0.796**	0.833**	0.809**	0.394	0.666**	1	0.148	0.029	−0.369	0.703**	0.552*	0.690**	−0.563*	−0.274
log10 site disturbance score (%)	−0.064	−0.097	−0.075	−0.023	−0.055	0.159	−0.021	0.148	1	−0.024	0.127	0.364	0.130	−0.019	0.262	0.293
log10 index of decline (%)	0.053	0.104	0.123	0.019	−0.077	0.312	−0.531*	0.029	−0.024	1	0.392	0.091	−0.398	−0.483*	−0.257	0.283
log10 threat index (%)	−0.471*	−0.444	−0.407	−0.482*	−0.511*	−0.060	−0.589**	−0.369	0.127	0.392	1	−0.194	−0.559*	−0.574*	0.427	0.788**
log10 scores for degree of suitability	0.696**	0.666**	0.698**	0.719**	0.681**	0.319	0.525*	0.703**	0.364	0.091	−0.194	1	0.501*	0.541*	−0.329	−0.190
log10 study area (in km²)	0.486*	0.411	0.413	0.511*	0.525*	0.332	0.597**	0.552*	0.130	−0.398	−0.559*	0.501*	1	0.580**	−0.231	−0.386
log10 endemicity value (%)	0.830**	0.797**	0.788**	0.846**	0.899**	−0.053	0.998**	0.690**	−0.019	−0.483*	−0.574*	0.541*	0.580**	1	−0.355	−0.485*
log10 number of buildings (n)	−0.596**	−0.608**	−0.600**	−0.570*	−0.556*	−0.317	−0.330	−0.563*	0.262	−0.257	0.427	−0.329	−0.231	−0.355	1	0.665**
log10 human population density (n)	−0.427	−0.423	−0.378	−0.421	−0.455	0.108	−0.493*	−0.274	0.293	0.283	0.788**	−0.190	−0.386	−0.485*	0.665**	1

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level.

values are highly significant. Therefore, our model of fitness holds good for all the analyzed data. These patterns are consistent with analyses of attributes of bird community composition (as response variables) and environmental/disturbance parameters (as explanatory variables).

Discussion

Usage of indices for assessing threat ranking in urban landscapes

The patterns of avian species richness in different landscapes of the Bengaluru region, south India were examined using anthropogenic and ecological covariates. The

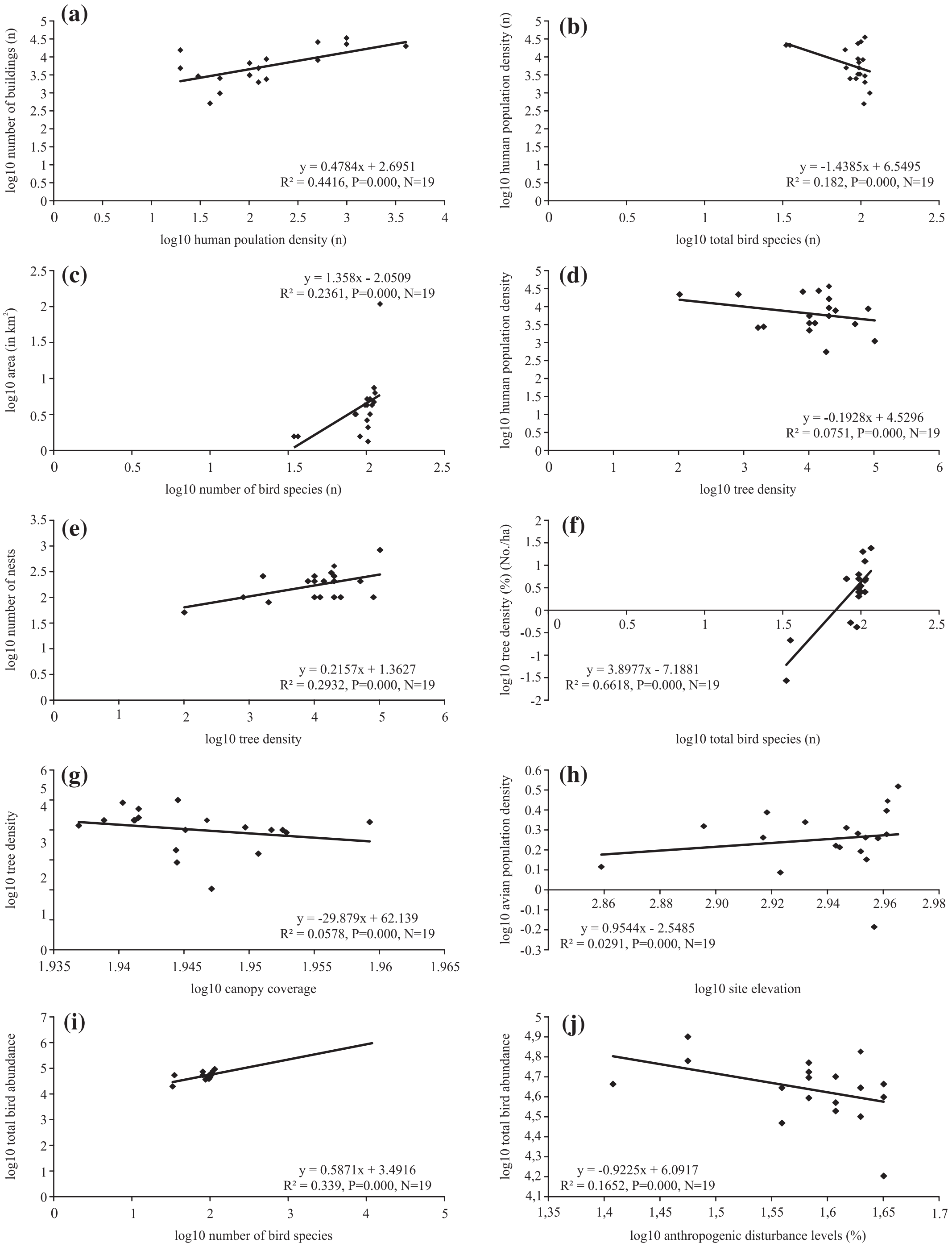

Figure 3. Correlations between: the number of buildings and human population density for Bengaluru region (a); the number of bird species and human population density for Bengaluru region (b); the number of bird species and study site area (c); the human population density and tree density (d); the number of nests and tree density (e); the number of bird species and tree density (f); tree density and canopy coverage (g); avian population density and study site elevation (h); total bird abundance and the number of bird species (i); total bird abundance and anthropogenic disturbance scores (j); total bird species and protected bird species (k); the number of endangered bird species and protected area (l); total bird species and disturbance scores (m); total bird species and the index of decline (n); the diversity of bird species and the index of decline (o); threat index for bird species and scores for degree of suitability (p); total bird species and endemicity value of birds (q); the number of genera in a particular site and the number of bird families (r); mean number of bird species per family and species richness of birds in a particular family (s).

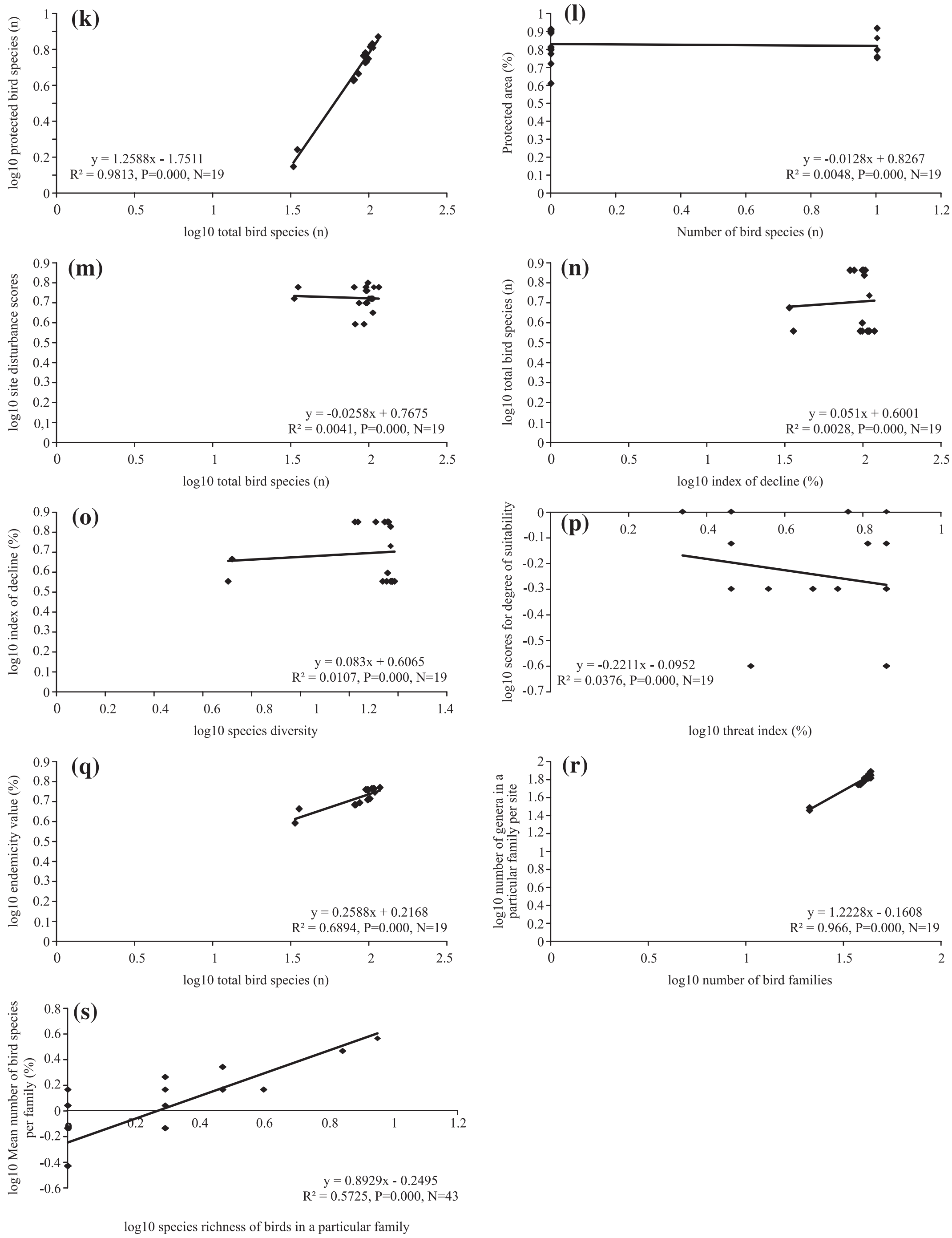

Figure 3 . (*Continued*).

main threats to avian fauna of urban landscapes such as habitat alteration, resource over-extraction including collection of timber, firewood, cultivation, fodder extraction, monoculture plantations, fuel wood collection, improper waste management, grass cutting, fire, and unrestricted livestock grazing, and other human activities including developmental activities (roads and fly-overs) and recreational activities, and landscape encroachment (habitat loss, fragmentation, degradation and adaptation) in the urban region were recorded as common in all landscapes and were also reported earlier in other regions of India (Mahabal and Vasanth 2001; Narang, Akhtar, and Kumar 2008; Ramesh and Sathyanarayana 2009; Acharya and Vijayan 2010; Bharali and Khan 2011; Jan, Uniyal, and Chauhan 2011; Rajashekara and Venkatesha 2013; Menon and Mohanraj 2016). Further, HDS harboured more threat scores than the other disturbance sites. Improved road communications and vehicles closeness to the breeding and roosting areas of birds have increased and they disturbed often as reported by Sridhar and Karanth (1993) in open woodlands and scrublands of the Bangalore region.

Habitat fragmentation is a principal threat used as a model for any species that share distributional, ecological or life-history features and may enable more effective conservation of bird species (Tworek 2002). The major cause of endangerment for many of the world's threatened species is habitat destruction and fragmentation due to encroachment and mining activities (stone quarry) (Losos et al. 1995; Fahrig 1997). This in turn can benefit in the indirect conservation of these bird species which are endemic (any of these endangered/near threatened/vulnerable ones) in different landscapes of the Bengaluru region.

The habitat of a species can be defined as that portion of a multi-aspects apprehensive location that is occupied by a given species (Whittaker, Levin, and Root 1973). Species richness is an important and widely used indicator of where conservation initiatives and funding need to be directed (Rosenzweig 1995). Further, expansion of agricultural lands including monoculture or mixed agriculture practices, expansion of real estate for houses/buildings, exploitation of landscapes for the construction of roads through Reserve Forests to improve the urban landscape and greenery lead to the dwindling of bird species (Rajashekara 2006, 2011; Rajashekara and Venkatesha 2008, 2011, 2013; Menon and Mohanraj 2016).

Man-made fires, lopping of trees, non-timber forest produce collection practices and frequency of human intrusions into the forests and management of habitats for a specific species are contributing to change in the quality of habitats. Combined factors, *viz*. habitat loss, development, fragmentation and restricted distribution pose considerable threats to avian fauna in the urban landscapes of the Bengaluru region as reported earlier by Mahabal and Vasanth (2001) in Nilgiri Biosphere Reserve of south India. The loss of greenery in urban areas was known to affect the composition, abundance and distribution of birds (Narang, Akhtar, and Kumar 2008). Habitat fragmentation and the changing heterogeneity of landscape would have synergistic effects on the physical, chemical and biotic factors that affect the distributions of birds in complex ways (Boulinier et al. 1998).

Population variations in urban bird species

Low disturbance sites (BNP, HB, HG, SM and TGH) harboured more species of birds than the HDS. Also, the highest diversity of birds was recorded in LDS with the highest number of genera and species compared to MDS and HDS. Bird communities in different landscapes are most conspicuously different in the LDS and most similar in the most urbanized sites (Blair 1996, 2001). From the earlier studies we confirmed that the maximum bird density was observed in sites with a lesser anthropogenic factor and greater tree density (Rajashekara and Venkatesha 2015). On the contrary, a greater percentage of anthropogenic disturbances was interrelated to lower vegetation density, which in turn affected the avian density (Shochat, Lerman, and Fernández-Juricic 2010; Rajashekara and Venkatesha 2014, 2015). The total population of bird species richness decreases with increasing human population size as reported by McKinney (2008). The number of globally threatened bird species richness is positively associated with human population size, but this correlation is not significant when controlling the overall region bird species richness (Pautasso and Dinetti 2009). Human population density is negatively correlated with species richness in avian studies at fine spatial scales, but plant richness is positively correlated with species richness of birds when analyzing at coarse spatial scales (Pautasso 2007; Rajashekara and Venkatesha 2015; Menon and Mohanraj 2016).

Influence of environmental variables on bird species richness and diversity

A wide range of human activities forms the strong distribution of avian fauna in the urban landscapes (Marin et al. 2007). A high positive correlation between plant and bird species diversity and linear deterioration was obtained (Venkataraman and Ramaswamy 1993). Structural and floristic characteristics were more closely correlated with the diversity and species richness of birds (Harvey, Gonzalez, and Jorge 2007). Similarly, an increase in the area of canopy openings positively correlated with the abundance and diversity of birds (Daniel and Fleet 1999). Species richness of birds increases with structural complexity of the habitat and influenced by plant species richness (O'Reilly et al. 2006; Rompré et al. 2007). Further, bird species richness increases with structural complexity of habitat diversity (Rajashekara and Venkatesha 2011, 2016). Canopy patterns can influence the communities of bird composition, abundance or distribution at the landscape scale (Lundquist and Reich2006). The population density of birds was positively correlated with tree density and negatively correlated with canopy coverage, human population density, and buildings (Rajashekara and Venkatesha 2015).

Ehrlich and Pringle (2008) found out threats to the future of biodiversity which included habitat conversion, environmental toxification, climate change, and direct exploitation of wildlife, etc. The surrounding habitat type, fruiting phenology and the level of human disturbance also influenced the presence and abundance of individual species and accounted for differences in the composition of bird communities among habitats (Trager and Mistry 2003). The threshold effects of landscape change on relative influences of habitat loss and habitat configuration on species conservation in forest dominated landscapes are reported by Boutin and Hebert (2002).

Species richness, density and diversity of bird communities were influenced more strongly by mature forest area than by fragmentation, although both the area and fragmentation of mature forest at the landscape level are strongly related to the diversity of bird communities (Cushman and McGarigal 2003). Birds mainly respond to vegetation structure and composition, and urban areas that retain native vegetative characteristics preserve more native species than those that are overgrown with exotic vegetation (Mills, Dunning, and Bates 1989). A uniform diversity between urban landscapes occurs due to overlapping of habitats, less remoteness, altitudinal similarity and majority vegetation composition and its structure as in the reserve of Nanda Devi Biosphere, Uttarakhand (Jan, Uniyal, and Chauhan2011).

Bird species richness and diversity was unimodal in an urban region implying that birds increase to their maximum richness/diversity at a moderate urbanization level and then decrease with further increasing urbanization (Blair 2004; McKinney 2008). The nature of vegetation, canopy cover, tree density, availability of food and water sources are factors that determine the survival of terrestrial bird communities in a particular habitat (Verghese and Chakravarthy 1978). Also, species richness of birds is positively correlated to the canopy coverage, canopy depth, and composition of tree density (Van Bael et al. 2007). Our study revealed that the local variation of bird richness and diversity in microhabitats among the urban landscapes showed significant differences with various disturbance sites. It is similar to that of abundances of bird species, and mainly residents with large canopy nesters increased with increasing amounts of disturbance within forested landscapes (Rodewald and Yahner2001). The processes contributing to urbanization mainly included changes in the vegetation pattern, habitat fragmentation, exotic plants, nest predation, visitation disturbances, changes in food supply abundance, changes in predator assemblage, human activities and other factors that lead to decline in avian communities (Chace and Walsh2006).

The sum of all scores that depicted the highest ranks in HDS exposes the high level of anthropogenic disturbance, and low ranks in LDS express low disturbance. LDS bear similarity to the surrounding forests, both in terms of vegetation composition as well as species composition and diversity. There is habitually a strong positive correlation between the structure of native vegetation and native bird diversity and species richness (Mills, Dunning, and Bates 1989). A lower diversity and a lower number of bird species in HDS was probably due to a lower niche diversity with more human disturbances. Also, habitat suitability for bird species is potentially exaggerated by human recreational activities in the various disturbance gradients. Patten, Silva, and Smith-Patten (2009) described that ongoing deforestation is the cause for species turnover. Human impacts on different landscapes include direct impacts on habitats such as land conversion and fire use, habitat modification, changes in habitat fragmentation as well as changes in species composition of vegetation structure (Sutherland et al. 2013). Small sized bird species which depend on grasses may face threats when grasses are heavily grazed (Vickery et al. 1999). Human activities and road constructions were additional threats for terrestrial birds in the urban environment as reported by Forrest and St Clair (2006).

Table 6. Goodness of fit of multiple linear regression model analysis for the bird community attributes (as response variables) against environmental/disturbance parameters (as explanatory variables): protected area (%), log10 tree density (No./ha), log10 disturbance score (%), log10 index of decline (%), log10 threat index (%), log10 scores for degree of suitability, log10 area (in km^2), log10 endemicity value (%), log10 number of buildings (n), log10 human population density (n).

Bird community attributes	R^2 value	Percentage	Model for goodness-of-fit
log10 total bird species (n)	0.999	99.90%	Good
log10 species diversity	0.996	99.60%	Good
log10 number of bird families	0.991	99.10%	Good
log10 number of genera in a particular family	0.998	99.80%	Good
log10 protected birds (%)	0.999	99.90%	Good
log10 number of endangered species	0.661	66.10%	Moderate

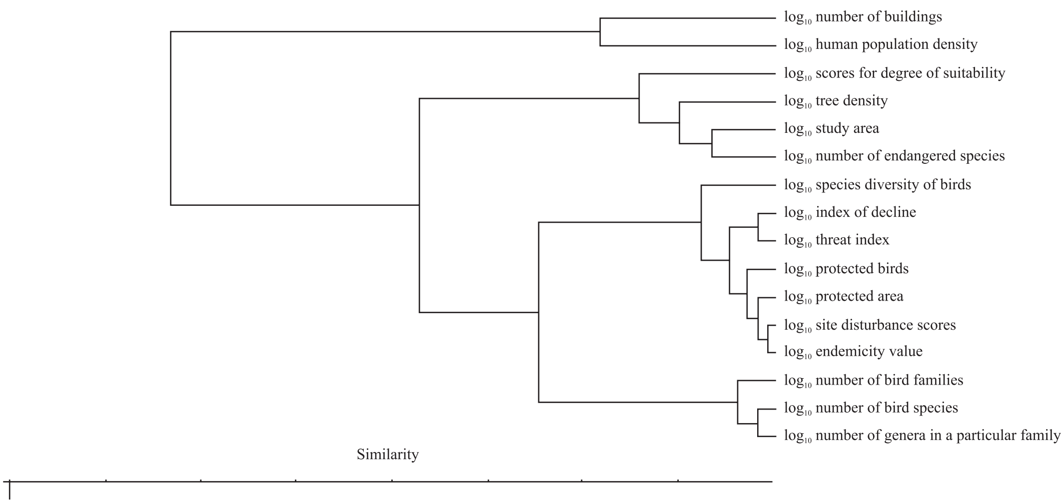

Figure 4. Dendrogram showing the contribution of various parameters to the existence of avian communities across the disturbance gradients of diverse landscapes in the Bengaluru region, Karnataka, south India.

Species-specific studies focusing on population status, habitat requirements and assessment of threats are necessary for the execution of conservation measures (Acharya and Vijayan2010). Both local and landscape-level resources remained important in shaping the distribution of birds in urban areas (McKinney 2008). Parks, reserves and the adjacent inhabited areas should be combined into urban planning and development designs to maintain resident avian fauna and overall species diversity in city environments (Melles, Glenn, and Martin 2003). Thus, the assessment of anthropogenic scoring (threat) index forms an important factor in correlating the diversity of avian fauna in an urban ecosystem indicating that threats tend to be focused on the region's most important areas for biodiversity conservation (Rajashekara and Venkatesha 2013). In spite of threats posed by urbanization, major cities across the world still harbour a good percentage of native bird species, thus providing opportunities for regional and global biodiversity conservation, restoration and education (Aronson et al. 2014).

Conclusions

Our method helps in evaluation and ranking of the study sites in terms of their conservation values and in identifying priority areas. Hence, habitat conservation plans (HCPs) afford one response to the conflict between conservation and development plans to protect scrub habitats, and a greater focus is given to a few endangered species and their habitat requirements. HCPs provide a regional landscape plan for protecting essential habitats (Root, Akçakaya, and Ginzburg 2006). Also, enhancement of biodiversity in urban ecosystems has a positive influence on the quality of life and education of city inhabitants, and thus facilitates the preservation of biodiversity in natural ecosystems (Savard, Clergeau, and Mennechez 2000).

With increasing focus on biodiversity conservation and setting priority areas, a site-wise comparison along with repeated studies of the same area over a longer time period will help in defining the status of the site in terms of diversity and in identifying priority sites for conservation (Rosenzweig 1995). Long-term planning for threat management is essential for operative conservation of avian biodiversity and biological resources through environmental education. Hence, there is a requirement to take compulsory steps to save them from all possible threats, primarily by ensuring safe and sufficient food, rehabilitating habitats and protecting the environment.

This paper answers some of the questions related to ecosystem impacts on species decline; interspecific interactions between composition of vegetation and avian fauna, and the impact of major threats between them (Sutherland et al. 2008). Conserving biodiversity over a long term means we should take into account future value while deciding whether to exploit a particular biological resource irreversibly (Faith 2013; Geeta et al. 2014).

This paper also summarizes the impacts of human activities within urban landscapes as indicated by the level of threats faced by avian communities including endangered species. The present study helps in designing the shape, structure and size of corridors to optimize bird use, planning of residential parks to increase bird diversity, policy for building to reduce bird collisions, strategies for the type, structure and distribution of vegetation to favour birds, and insuring building architecture harmonious with birds (Savard, Clergeau, and Mennechez2000). Management suggestions mainly involve encouragement of long-term conservation education among local people. The main attributes of local people that influence the option value for attitudes, habitat management and resource harvest should be identified in conservation strategies. Management further includes several approaches for the maintenance of urban landscapes for avian communities, *viz*. reduce lighting of buildings at night during migration periods, manage waste to reduce bird problems, plant vegetation in urban parks, green corridors and along streets, and promote other management options that favour bird diversity (Savard, Clergeau, and Mennechez 2000).

Author declaration

SR and MGV conceived and designed the experiments. SR performed the experiments. SR analyzed the data. SR wrote the manuscript and other author provide editorial advice.

Acknowledgements

We thank Mr. Sadiq Pasha, Research Scholar, Department of Statistics, Bangalore University for analysis of data and the anonymous referees for critical comments on the manuscript.

Disclosure statement

The authors declare that they have no conflict of interests.

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Appendix 1. Species Importance Value Index (SIVI) for the urban birds in the landscapes of the Bengaluru region

Bird species	Species Important Value	Bird species	Species Important Value
Accipiter badius	0.97	*Merops orientalis*	2.20
Accipiter nisus	0.42	*Milvus migrans*	8.03
Acridotheres fuscus	6.10	*Mirafra erythroptera*	0.32
Acridotheres tristis	10.41	*Motacilla alba*	2.53
Acrocephalus aedon	1.24	*Motacilla cinerea*	2.29
Acrocephalus agricola	3.13	*Motacilla madaraspatensis*	2.51
Acrocephalus stentoreus	0.03	*Muscicapa dauurica*	2.73
Aegithina tiphia	1.69	*Nectarinia asiatica*	4.51
Alcedo atthis	2.00	*Nectarinia lotenia*	2.14
Anthus cervinus	1.27	*Nectarinia zeylonica*	4.37
Anthus rufulus	1.74	*Neophron percnopterus*	0.05
Apus affinis	4.90	*Oriolus oriolus*	1.70
Athene brama	2.16	*Orthotomus sutorius*	3.84
Bubulcus ibis	5.80	*Parus major*	2.76
Buteo rufinus	0.25	*Parus nuchalis*	0.93
Carpodacus erythrinus	2.96	*Passer domesticus*	8.11
Celeus brachyurus	2.88	*Pavo cristatus*	0.39
Centropus sinensis	2.44	*Pelargopsis capensis*	1.38
Chloropsis aurifrons	1.34	*Perdicula asiatica*	1.10
Chloropsis cochinchinensis	1.04	*Perdix perdix*	0.63
Circus aeruginosus	0.47	*Pericrocotus cinnamomeus*	1.53
Columba livia	12.03	*Pericrocotus erythropygius*	2.04
Copsychus saularis	2.79	*Pericrocotus flammeus*	0.26
Coracias benghalensis	0.60	*Pernis ptilorhyncus*	0.39
Corvus macrorhynchos	8.23	*Phylloscopus magnirostris*	3.20
Corvus splendens	10.27	*Phylloscopus trochiloides*	4.45
Cuculus canorus	2.40	*Ploceus philippinus*	2.38
Cuculus micropterus	2.66	*Prinia socialis*	4.18
Cyornis rubeculoides	2.25	*Prinia subflava*	4.25
Cyornis tickelliae	2.79	*Prinia sylvatica*	3.51
Cypsiurus parvus	0.70	*Psittacula alexandri*	0.92
Dendrocitta vagabunda	2.17	*Psittacula cyanocephala*	0.82
Dendronanthus indicus	0.48	*Psittacula krameri*	9.46
Dicaeum agile	2.88	*Pycnonotus cafer*	2.52
Dicaeum erythrorhynchos	3.45	*Pycnonotus jocosus*	3.04
Dicrurus adsimilis	2.83	*Pycnonotus leucogenys*	2.36
Dicrurus leucophaeus	2.75	*Pycnonotus luteolus*	0.66
Dinopium benghalense	1.89	*Rhipidura albicollis*	3.53
Dumetia hyperythra	2.17	*Rhipidura aureola*	3.17
Elanus caeruleus	0.60	*Rhipidura euryura*	2.66
Eremopterix griseus	0.39	*Saxicola caprata*	3.50
Eudynamys scolopaceus	2.84	*Saxicoloides fulicatus*	3.73
Eumyias thalassinus	1.01	*Stigmatopelia chinensis*	2.79
Ficedula parva	0.21	*Stigmatopelia senegalensis*	1.73
Gallus sonneratii	2.34	*Streptopelia tranquebarica*	1.04
Glaucidium radiatum	0.38	*Sturnus malabaricus*	1.11
Gyps indicus	0.01	*Sturnus pagodarum*	0.16
Halcyon pileata	0.48	*Sturnus roseus*	2.36
Halcyon smyrnensis	2.27	*Tephrodornis pondicerianus*	0.89
Haliastur indus	2.20	*Terpsiphone paradisi*	1.51
Hirundo daurica	3.13	*Turdoides affinis*	3.75
Hirundo rustica	3.14	*Turdoides caudata*	3.32
Hirundo smithii	1.59	*Turdoides malcolmi*	3.19
Lanius cristatus	2.50	*Turdoides striata*	3.25
Lanius excubitor	0.95	*Turdus merula*	2.13
Lonchura punctulata	1.75	*Turnix suscitator*	0.73
Megalaima haemacephala	1.94	*Tyto alba*	2.89
Megalaima viridis	5.19	*Upupa epops*	1.64
Megalaima zeylanica	1.56	*Zosterops palpebrosus*	1.38

Appendix 2. Family Importance Value Index (FIVI) for the urban bird populations in the landscapes of the Bengaluru region

Bird family	Number of genera	Number of species belonged to genera (S)	Relative % abundance (RA)	Relative species richness (RSR)	Family Importance Value (FIV = RA + RSR)	Genus: species
Accipitridae	9	10	4.50	9.45	13.95	0.90
Aegithinidae	1	1	0.39	0.00	0.39	1.00
Alaudidae	2	2	0.20	1.49	1.69	1.00
Alcedinidae	3	4	1.47	3.52	4.99	0.75
Apodidae	2	2	2.12	1.13	3.25	1.00
Ardeidae	1	1	2.47	0.00	2.47	1.00
Campephagidae	2	4	1.04	3.66	4.70	0.50
Chloropseidae	1	2	0.49	1.33	1.82	0.50
Cisticolidae	1	3	4.19	2.11	6.30	0.33
Columbidae	3	4	7.23	3.01	10.25	0.75
Coraciidae	1	1	0.09	0.00	0.09	1.00
Corvidae	2	3	8.59	1.98	10.57	0.67
Cuculidae	3	4	2.71	3.31	6.02	0.75
Dicaeidae	1	2	2.01	1.14	3.14	0.50
Dicruridae	1	2	1.51	1.17	2.68	0.50
Estrildidae	1	1	0.43	0.00	0.43	1.00
Fringillidae	1	1	0.98	0.00	0.98	1.00
Hirundinidae	1	3	2.57	2.22	4.78	0.33
Laniidae	1	2	0.94	1.23	2.17	0.50
Meropidae	1	1	0.60	0.00	0.60	1.00
Monarchidae	1	1	0.30	0.00	0.30	1.00
Motacillidae	3	6	2.91	5.47	8.39	0.50
Muscicapidae	7	8	5.59	7.20	12.79	0.88
Nectariniidae	1	3	3.72	2.14	5.86	0.33
Oriolidae	1	1	0.38	0.00	0.38	1.00
Paridae	1	2	1.73	1.15	2.89	0.50
Passeridae	1	1	3.45	0.00	3.45	1.00
Phasianidae	4	4	1.16	3.61	4.77	1.00
Picidae	2	2	1.26	1.19	2.45	1.00
Ploceidae	1	1	0.73	0.00	0.73	1.00
Psittacidae	1	3	4.64	2.09	6.73	0.33
Pycnonotidae	1	4	2.50	3.33	5.84	0.25
Ramphastidae	1	3	2.82	2.20	5.01	0.33
Rhipiduridae	1	3	3.17	2.17	5.34	0.33
Strigidae	2	2	0.62	1.29	1.91	1.00
Sturnidae	2	5	7.70	4.00	11.70	0.40
Sylviidae	3	6	5.32	5.17	10.49	0.50
Timaliidae	2	5	5.38	4.13	9.51	0.40
Turdidae	1	1	0.61	0.00	0.61	1.00
Turnicidae	1	1	0.15	0.00	0.15	1.00
Tytonidae	1	1	0.75	0.00	0.75	1.00
Upupidae	1	1	0.31	0.00	0.31	1.00
Zosteropidae	1	1	0.30	0.00	0.30	1.00
Total	78	118	100.00	100.00		