JEB
Journal of Environmental Biology

Journal Website : www.jeb.co.in
E-mail : editor@jeb.co.in
ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Temporal and spatial avian community composition in urban landscapes of the Bengaluru region, India

S. Rajashekara and M.G. Venkatesha*
Department of Studies in Zoology, Bangalore University, Jnana Bharathi Campus, Bengaluru-560 056, India
*Corresponding Author's E-mail: venkatmelally@gmail.com

Publication Info

Paper received:
02 July 2013

Revised received:
06 January 2014

Re-revised received:
04 April 2014

Accepted:
29 July 2014

Abstract

A study was undertaken to know the abundance, diversity and species richness of bird communities in urban landscapes of Bengaluru region, India. One hundred and eighteen species of birds belonging to 43 families under 78 genera was documented. Of them, *Gyps indicus*, *Neophron percnopterus* and *Parus nuchalis* were critically endangered, endangered, and vulnerable species. Among 19 landscapes, the mean population density (number of birds seen/km^2) was highest at Bannerghatta National Park and lowest at Kempegowda Bus Station. Species diversity, species evenness and richness of bird communities were significantly different between landscapes. Seasonal occurrence of bird species was not significantly different. The mean population density of birds was positively correlated with tree density and negatively correlated with canopy coverage, human population density and buildings.

Key words

Bird abundance, Bird diversity, Landscape characteristics, Seasonal occurrence, Species richness

Introduction

Birds are the potential umbrella group of species for biodiversity conservation (Branton and Richardson, 2011). Bird surveys are among the most widely used biodiversity inventories and serve as a basis for increasing proportion of pure and ecological research (Watson, 2003). Avian biodiversity studies are critical in determining the effects of urbanization on bird communities and in many other facets of biodiversity conservation.

Urbanization is a universal phenomenon and its negative effects on biodiversity, especially in terms of habitat fragmentation and loss, extermination of native and migratory species are slowly being understood (Sullivan and Flowers 1998; Mckinney, 2002; Faeth *et al*., 2005). Owing to fast urbanization, native species tend to become rare and are restricted to sites with high intensity development (Godefroid, 2001; Sodhi and Lim, 2003). Moreover, birds provide critical ecosystem functions like pollination (Subramanya and Radhamani, 1993) and insect control (Seedikkoya, *et al*., 2007). Growth of landscape-based approach for biodiversity assessment and management has significance in recent years as species are part of the landscape consisting of diverse elements (Forman, 1997).

As birds are good bioindicators, their communities in the Bengaluru region attract large number of species, these are ideal locations for undertaking avifaunal studies (Grimmett and Inskipp, 2007). Although bird species in some locations of Bengaluru have been recorded (George *et al*., 1994; Shyamal, 1994), however, their composition, abundance and diversity have not been studied comprehensively in major landscapes. Lack of scientific information on avifaunal communities of Bengaluru city has led us to take up the present study. The study aimed at exploring the composition of urban avifauna, species diversity and richness over a range of landscapes at different periods, and also, assessed the impact of anthropogenic disturbances on avian fauna.

Materials and Methods

Study area : Bengaluru, the capital of Karnataka state is located in the heart of South Deccan of Peninsular India. Over 9 million (Census of India, 2011) people inhabit about 2191 km^2 of the

metropolitan area. In Bengaluru, an average maximum and minimum temperature of 36º and 14º C, average rainfall of 800 mm and humidity range between 35-80%. Three main seasons are winter (December to February), summer (March to May) and monsoon (June to November). Dominant vegetation of Bengaluru region is dry deciduous forests and thorny scrub, with patches of moist deciduous forests along the streams. Nineteen study landscapes were chosen for avifaunal studies and area of each landscape is 2-3 km^2 (Table 1).

Surveys and sampling method : Ten observation locations were selected in each of the study areas. At each spot point count of birds was made for 6 to 10 min within the visible radius following the protocol of Urfi *et al*. (2005). Birds were counted at their point of first detection and care was taken to ensure that individual birds were not counted twice. Birds were recorded only if they perched or actively foraged at the sites. Call notes of birds were also used for locating birds (Ali, 1996). Besides point counts, four line transects (each with a kilometer long, and 20 m wide, on either side) in each landscape were also used to estimate bird diversity and density. At each site, prefixed transects were walked at a uniform pace of about 1-1.5 km h^{-1} in the morning (08.00-11.00hr) and in the afternoon (15.00-18.00h) and only birds, that were not sighted/heard during point count were recorded as followed by Verner (1985). Survey methods used fixed time-spans (30-40 min transect count), using 'standardized search' sampling effort across all sites (Watson, 2003). Recordings were not made at the time of drizzling/raining or wind exceeded a gentle breeze. Surveys were conducted once a fortnight at the identified locations, from February 2008 to January 2010. In addition, regular field observations were also made on the nests, nesting sites, feeding habitat, vegetations and food sources. Observations were also made on the natural predation of birds. Data recorded were analyzed as per MacKinnon and Philipps (1993): very common (Vc) – sighted 19-24 times, common (C) – sighted 13-18 times, uncommon (Uc) – 7-12 times and rare (Re) – sighted 1-6 times out of 24 visits during two years. The checklist of species was prepared according to Ali (1996). Nomenclature and taxonomy of birds was assigned according to BirdLife International (2009).

Vegetation survey : Line transect method was used as a criterion for determining tree vegetations, exactly at the locations where bird surveys were conducted at each site. Various vegetation types were identified up to species level. Tree density (No./ha.) for each landscape and species composition of tree communities was analyzed using various canopy trees [>10 cm DBH (diameter at breast height) at 1.37m above the ground level] at each sites. Canopy cover was measured for each species of live trees and shrubs along a horizontal transect. The mean canopy closure of sites was calculated using digital canopy photography by Engelbrecht and Herz (2001). At each site, canopy photographs were taken at ~10 locations along a randomly oriented straight-line transect using Digital Camera Olympus FEE-330 (Olympus Imaging Corporation, China). Canopy closure of each site was calculated by transforming all digital images. Percentage of canopy cover for each site was calculated by averaging ten values of ten images taken within a particular site.

Table 1 : Characteristics of urban landscapes in Bengaluru region (2008-2010)

Landscapes	Short form	Distance from (CRS) in km	Canopy closure (%)	No. of buildings	No. of nests	Mean tree density (No./ ha)	Human population demography (2001)	Landscape type
Anekal	AK	40	88.45	5000	400	2.0	33160	AF
Attibele	AB	35	89.06	400	100	1.2	3200	AF
Bannerghatta National Park	BNP	22	88.00	100	800	10.0	1000	F
Chandapura	CP	30	89.47	400	200	1.0	3200	A
Devanahalli	DH	39	89.71	4000	200	0.8	23190	AF
Hebbala	HB	07	89.26	800	250	0.16	2400	PDF
Hesaraghatta	HG	28	88.12	500	250	1.0	2000	AF
Hoskote	HK	27	87.14	2000	100	8.0	8000	AF
JnanaBharathi Campus	JBC	16	87.39	80	200	5.0	3000	F
Kempegowda Bus Station	KBS	0.5	88.53	6000	50	0.01	20000	GP
Kengeri	KG	16	89.65	500	100	1.0	5000	AF
Kethohalli	KH	28	87.97	100	80	0.2	2500	A
Krishnarajendra Market	KRM	02	87.99	6000	100	0.08	20000	GP
Lalbagh Botanical Garden	LBG	04	87.34	60	200	2.0	15000	PDF
Lord Cubbon Park	LCP	03	86.86	100	250	2.0	5000	PDF
Nelamangala	NM	28	86.47	2000	200	1.4	25287	AF
Sarjapura	SJP	40	87.32	400	100	2.0	8620	AF
Somanahalli	SM	28	87.39	400	100	2.5	6907	AF
Thippagondanahalli	TGH	40	91.05	100	300	1.8	500	F

A: Agriculture; AF: Agriculture and Forest; F: Forest; GP: Green patches; PDF: Partially disturbed forest

Landscape characteristics and anthropogenic disturbances: Landscape characteristics *i.e.*, landscape type, elevation, number of buildings, canopy cover of trees and mean tree density (density means the number of species seen per hectare even if each species is represented by just one individual) at each landscape, as habitat factors, was evaluated as effective tool to assess the sustenance of birds at different landscapes of Bengaluru city (Table 1).

Anthropogenic activities were given scores of 1, 2 or 3 based on the effect disturbance on bird communities. A score of '3' represented maximum, moderate were scored 2; disturbance caused by local people and ecotourists was considered to have least negative effect on bird communities, and was scored 1. Disturbance levels for each landscape where the survey of bird communities was assessed following the method of Shenoy, *et al*. (2006).

Statistical analyses : The mean population density (MPD) of birds seen km^{-2} for different landscapes was calculated (Verner, 1985; Gaston and Blackburn, 1997). The number and density of terrestrial bird species (density means the number of species seen per km^2 even if each species is represented by just one individual) in each landscape were estimated. Density was calculated by the formula given by Reynolds, *et al*. (1990):

$$D = n*10000/ \pi r^2 C$$

where D = bird density (numbers km^{-1}); n = total number of birds observed in all counts within the specific radius; r = specific radius (m); C = total number of counts conducted and $\pi = 3.14$.

Shannon-Weiner's diversity (SWD) and Fisher's alpha diversity (FAD), Sheldon's species evenness (SSE) and Margalef's species richness (MSR) indices of birds were estimated using PAST version 1.60 software (Hammer, *et al*., 2001). Incidence (encounter rate) is the number of times a species was encountered *i.e.*, number of intervals at which it was recorded divided by the total number of sampling intervals (Dawson, 1981). Difference in the values of diversity and other indices of bird population among different landscapes were statistically analyzed using one way ANOVA-Tukey HSD test and between two years analyzed by Student's t-test (SPSS Inc., 2008). Cluster analysis was carried out to create a dendrogram to assess similarity in the population of bird communities and canopy coverage among landscapes, using Biodiversity Professional Version 2.0 (McAleece *et al*., 1997). Characteristics of each landscape and anthropogenic disturbances were analyzed with bird density and other diversity indices, using Principal component analysis (PCA) (Hammer *et al*., 2001). Structure of bird assemblages and their habitat selection were studied by PCA, which helps to reduce a large number of species or ecological factors. MPD of avian communities was analyzed with landscape characteristics of Bengaluru region, using Pearson's linear correlation (SPSS Inc., 2008).

Results and Discussion

One hundred and eighteen species of birds belonging to 43 families and 78 genera were recorded at different landscapes of Bengaluru region (Table 2). The checklist of Bengaluru birds presented 341 species with 186 species as regularly occurring birds (George *et al*., 1994), which included the presently recorded 118 species. Thirty bird species were common at all the study sites. Total number of bird species recorded in 19 landscapes ranged from 33 to 115 (Fig. 1). Of 118 bird species, the frequency of occurrence of *Acridotheres tristis*, *Corvus macrorhynchos*,

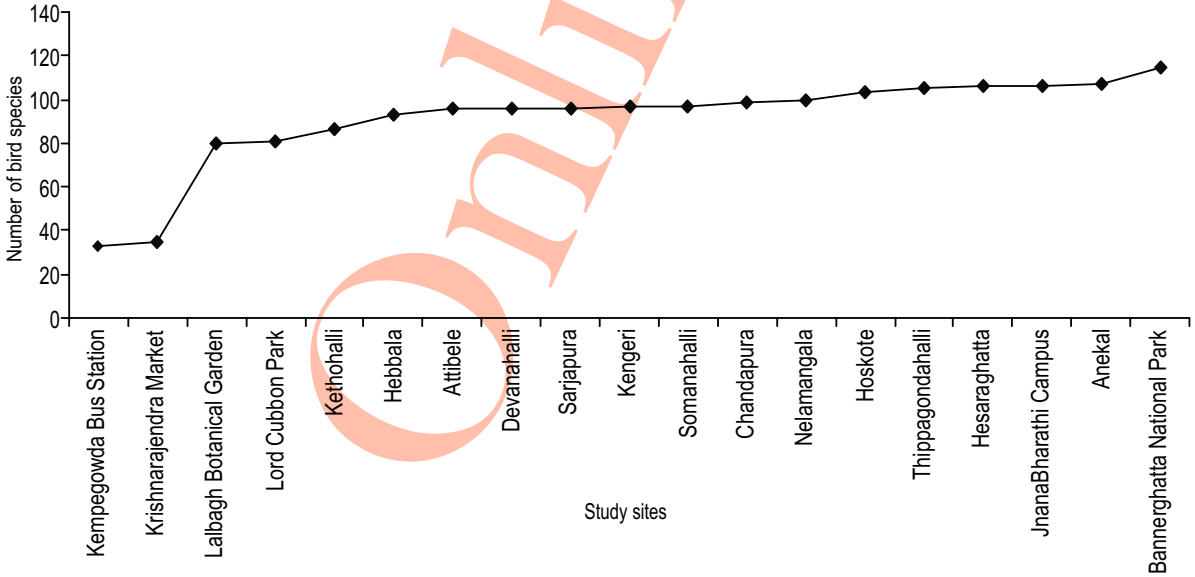

Fig. 1 : Total number of species recorded at different urban landscapes of Bengaluru region

Table 2 : Encounter rates, occurrence and residential status of avifaunal communities at different landscapes of Bengaluru region (2008-2010)

Bird species	Mean % frequency	Occurrence status	Residential status#	Bird species	Mean % frequency	Occurrence status	Residential status#
Bubulcus ibis	85.09	Vc	RM	*Apus affinis*	92.33	Vc	RM
Elanus caeruleus	20.61	Re	R	*Cypsiurus balasiensis*	21.27	Re	R
Pernis ptilorhyncus	13.38	Re	RM	*Alcedo atthis*	79.39	Vc	RM
Milvus migrans	100.00	Vc	R	*Pelargopsis capensis*	39.69	Uc	R
Haliastur indus	91.89	Vc	R	*Halcyon smyrnensis*	86.84	Vc	R
Accipiter badius	31.58	Uc	R	*Halcyon pileata*	18.64	Re	R
Accipiter nisus	14.25	Re	RM	*Merops orientalis*	76.75	Vc	R
Buteo rufinus	8.77	Re	RM	*Coracias benghalensis*	25.00	Re	R
Gyps indicus	0.44	Re	R	*Upupa epops*	71.03	C	RM
Neophron percnopterus	1.97	Re	RM	*Megalaima zeylanica*	56.36	C	R
Circus aeruginosus	20.61	Re	M	*Megalaima viridis*	100.00	Vc	R
Perdix perdix	19.74	Re	R	*Megalaima haemacephala*	73.90	C	R
Perdicula asiatica	31.80	Uc	R	*Celeus brachyurus*	96.71	Vc	R
Gallus sonneratii	77.63	Vc	R	*Dinopium benghalense*	73.25	C	R
Pavo cristatus	16.67	Re	R	*Mirafra erythroptera*	8.77	Re	R
Turnix suscitator	20.61	Re	R	*Eremopterix griseus*	13.82	Re	R
Columba livia	97.59	Vc	R	*Hirundo rustica*	87.06	Vc	RM
Streptopelia tranquebarica	34.87	Uc	R	*Hirundo smithii*	35.09	Uc	R
Stigmatopelia chinensis	84.21	Vc	R	*Hirundo daurica*	88.16	Vc	RM
Stigmatopelia senegalensis	58.99	C	R	*Lanius excubitor*	26.53	Uc	RM
Psittacula krameri	100.00	Vc	R	*Lanius cristatus*	84.65	Vc	M
Psittacula alexandri	19.74	Re	R	*Oriolus oriolus*	64.92	C	RM
Psittacula cyanocephala	18.42	Re	R	*Dicrurus adsimilis*	98.25	Vc	R
Cuculus micropterus	92.54	Vc	RM	*Dicrurus leucophaeus*	98.25	Vc	RM
Cuculus canorus	85.31	Vc	RM	*Sturnus malabaricus*	30.48	Uc	R
Eudynamys scolopaceus	99.56	Vc	R	*Sturnus pagodarum*	4.82	Re	R
Centropus sinensis	96.71	Vc	R	*Sturnus roseus*	23.03	Re	M
Tyto alba	85.53	Vc	R	*Acridotheres tristis*	100.00	Vc	R
Glaucidium radiatum	14.47	Re	R	*Acridotheres fuscus*	98.90	Vc	R
Athene brama	77.86	Vc	R	*Dendrocitta vagabunda*	85.97	Vc	R
Corvus splendens	100.00	Vc	R	*Orthotomus sutorius*	100.00	Vc	R
Corvus macrorhynchos	100.00	Vc	R	*Acrocephalus aedon*	33.11	Uc	M
Tephrodornis pondicerianus	28.07	Uc	R	*Acrocephalus stentoreus*	1.32	Re	R
Pericrocotus flammeus	41.89	Uc	R	*Acrocephalus agricola*	88.82	Vc	RM
Pericrocotus cinnamomeus	59.88	C	R	*Phylloscopus magnirostris*	89.47	Vc	M
Pericrocotus erythropygius	6.36	Re	R	*Phylloscopus trochiloides*	100.00	Vc	M
Aegithina tiphia	59.44	C	R	*Copsychus saularis*	93.86	Vc	R
Chloropsis aurifrons	46.93	Uc	R	*Saxicola caprata*	99.56	Vc	R
Chloropsis cochinchinensis	31.14	Uc	R	*Saxicoloides fulicatus*	98.90	Vc	R
Pycnonotus jocosus	87.72	Vc	R	*Turdus merula*	75.00	Vc	RM
Pycnonotus leucogenys	78.51	Vc	R	*Parus major*	91.45	Vc	R
Pycnonotus cafer	78.07	Vc	R	*Parus nuchalis*	1.97	Re	R
Pycnonotus luteolus	17.76	Re	R	*Anthus rufulus*	48.68	C	R
Dumetia hyperythra	73.68	C	R	*Anthus cervinus*	36.84	C	R
Turdoides caudata	87.28	Vc	R	*Dendronanthus indicus*	15.13	Re	RM
Turdoides malcolmi	86.62	Vc	R	*Motacilla cinerea*	85.75	Vc	M
Turdoides striata	86.84	Vc	R	*Motacilla alba*	87.72	Vc	RM
Turdoides affinis	89.47	Vc	R	*Motacilla madaraspatensis*	89.25	Vc	R
Muscicapa dauurica	81.80	Vc	RM	*Dicaeum agile*	91.45	Vc	R
Ficedula parva	7.02	Re	M	*Dicaeum erythrorhynchos*	92.11	Vc	R
Rhipidura euryura	86.84	Vc	R	*Nectarinia zeylonica*	96.93	Vc	R
Cyornis rubeculoides	76.32	Vc	R	*Nectarinia lotenia*	80.48	Vc	R
Cyornis tickelliae	84.43	Vc	R	*Nectarinia asiatica*	100.00	Vc	R
Eumyias thalassinus	30.26	Uc	R	*Zosterops palpebrosus*	49.56	Uc	R
Rhipidura aureola	89.04	Vc	R	*Passer domesticus*	84.21	Vc	R

Cont....

Rhipidura albicollis	87.06	Vc	R	*Ploceus philippinus*	78.07	Vc	R
Terpsiphone paradisi	56.14	C	RM	*Lonchura punctulata*	47.81	C	R
Prinia socialis	100.00	Vc	R	*Carpodacus erythrinus*	76.10	Vc	RM
Prinia subflava	100.00	Vc	R	*Prinia sylvatica*	88.82	Vc	R

0 - 25% as rare (Re); 26 - 50% as uncommon (Uc); 51 - 75 as common (C); 76 - 100% as very common (Vc). # - Ali (1996); M- Migrant, R- Resident, RM- Resident Migrant

Table 3 : Bird species belonging to different feeding guild in Bengaluru region

Feeding guild	Number of bird species	% of bird species
Carnivores	17	14.41
Carnivores/ Insectivores	6	5.08
Frugivores	9	7.63
Granivores	8	6.78
Insectivore/ Omnivore	1	0.85
Granivores/ Omnivores	2	1.69
Granivores/ Insectivores	1	0.85
Herbivores	2	1.69
Insectivores	40	33.9
Insectivores/ Arachinivores	2	1.69
Insectivores/ Nectivores	2	1.69
Omnivores	28	23.73
Total bird species	**118**	**100**

Corvus splendens, *Megalaima viridis*, *Milvus migrans*, *Nectarinia asiatica*, *Orthotomus sutorius*, *Phylloscopus trochiloides*, *Prinia socialis*, *Prinia subflava* and *Psittacula krameri* was 100%, whereas it was less (0.44%) in the case of *Gyps indicus* (Table 2). Based on percentage of frequency of occurrence of birds in different landscapes, 14 species were considered as common (C), 25- rare (Re), 14- uncommon (Uc) and 65- very common (Vc) (Table 2). *Gyps indicus*, *Neophron percnopterus* and *Parus nuchalis* were critically endangered, endangered and vulnerable species, while rest were of least concern (IUCN, 2010).

Accipitridae family dominated the avifaunal communities with highest number of bird species (Table 2). More number of bird species were found belonging to insectivorous (40 species) (Table 3) and resident (88 species) (Table 2) groups.

Of the various landscapes, highest number of species

Table 4 : Avifaunal density and diversity in different landscapes of the Bengaluru region (2008-2010)

Landscapes	Mean population Density of birds/km^{ñ}	Diversity indices							
		Shannon-Weiner's diversity$^{\#}$		Sheldon's evenness index$^{ï‰}$		Margalef's species richness$^{É‰}$		Fisher's alpha diversity$^{‰}$	
		2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
AK	2.77^{g,h}	3.94*	4.21*^{a,b}	0.69	0.68^{a}	9.71*	12.21*^{a,d,c}	15.35*	19.43*^{a,b,c}
AB	1.56^{b,c,d,e}	3.99*	4.31*^{b}	0.82	0.83^{b,j}	9.37*	11.70*^{a,b,d}	15.73*	19.36*^{a,b,c}
BNP	3.27^{h}	4.23*	4.44*^{c}	0.80	0.76^{c,d,i}	10.88*	13.40*^{c}	17.37*	21.45*^{c}
CP	1.62^{b,c,d,e}	3.96*	4.31*^{b}	0.79	0.82^{b,d,,i,j}	9.25*	11.87*^{a,b,d}	15.28*	19.69*^{a,b,c}
DH	1.83^{b,c,d,e,f}	3.96*	4.26*^{a,b}	0.79	0.79^{b,c,d,i}	9.11*	11.51*^{a,b,f}	14.81*	18.68*^{a}
HB	1.41^{b,c,d}	3.91*	4.25*^{a,b}	0.81	0.83^{b,d,l,j}	8.90*	11.19*^{a,b,f}	14.89*	18.48*^{a,c}
HG	2.19$_{e,f,g}$	3.91*	4.29*^{a,b}	0.72	0.74^{e}	9.41*	12.30*^{a,d}	15.22*	19.97*^{a,b}
HK	2.04^{d,e,f}	3.99*	4.31*^{b}	0.79	0.78^{c,d,f}	9.34*	12.16*^{a,b,d}	15.09*	19.81*^{a,b,c}
JBC	2.43^{f,g}	4.09*	4.34*^{b,c}	0.74	0.76^{e,f,}	10.73*	12.53*^{c,d}	17.68*	20.25*^{b,c}
KBS	0.66^{a}	2.69*	2.99*^{d}	0.65	0.68^{a}	3.61*	4.22*^{e}	5.17*	5.93*^{d}
KG	1.82^{b,c,d,e,f}	3.92*	4.25*^{a,b}	0.75	0.77^{c,d,e,f,}	9.40*	11.71*^{a,b,d}	15.45*	19.11*^{a,b}
KH	1.22^{a,b}	3.76*	4.1*^{a,g}	0.77	0.76^{c,d,e,f}	8.28*	10.75*^{b,f}	13.87*	17.83*^{a,e}
KRM	1.81^{b,c,d,e,f}	2.36*	2.7*^{e}	0.44	0.45^{g}	3.21*	4.18*^{e}	4.16*	5.55*^{d}
LBG	1.90^{c,d,e,f}	3.76*	3.97*^{g}	0.66	0.71^{a}	8.78*	9.54*^{f}	13.91	14.86^{e}
LCP	2.48^{f,g}	3.22*	3.47*^{f}	0.37*	0.42*^{h}	8.83*	9.38*^{f}	13.70	14.22^{e}
NM	1.90^{c,d,e,f}	4.00*	4.28*^{b}	0.79	0.78^{c,d,i}	9.57*	11.84*^{a,b,d}	15.77*	19.25*^{a,b,c}
SJP	1.31^{a,b,c}	3.97*	4.29*^{b}	0.80	0.81^{b,d,i,j}	9.24*	11.67*^{a,b,d}	15.28*	19.21*^{a,b}
SM	1.66^{b,c,d,e}	3.96*	4.30*^{b}	0.82	0.83^{j}	9.18*	11.82*^{a,b,d}	15.50*	20.07*^{a,b,c}
TGH	2.08^{e,f}	3.94*	4.31*^{b}	0.73	0.75^{e}	9.52*	12.39*^{a,c,d}	15.45*	20.26*^{a,b,c}

*Results in a row indicate significant difference ($P<0.05$) within indices between the years (t-test); Results in a column under various indices followed by different letters indicate significant differences among different landscapes at P<0.05 [{^{ñ}Mean population density of birds/km -(Tukey HSD, $F_{18, 437}$ = 19.412, $P<0.05$); $^{\#}$Shannon-Weiner's diversity - (Tukey HSD, $F_{18, 437}$ = 179.820, $P<0.05$)}; $^{ï‰}$Species evenness - (Tukey HSD, $F_{18, 437}$ = 281.929, $P<0.05$); $^{É‰}$Species richness - (Tukey HSD, $F_{18, 437}$ = 80.364, $P<0.05$); $^{‰}$Fisher's alpha diversity - (Tukey HSD, $F_{18, 437}$ = 91.869, $P<0.05$)}]

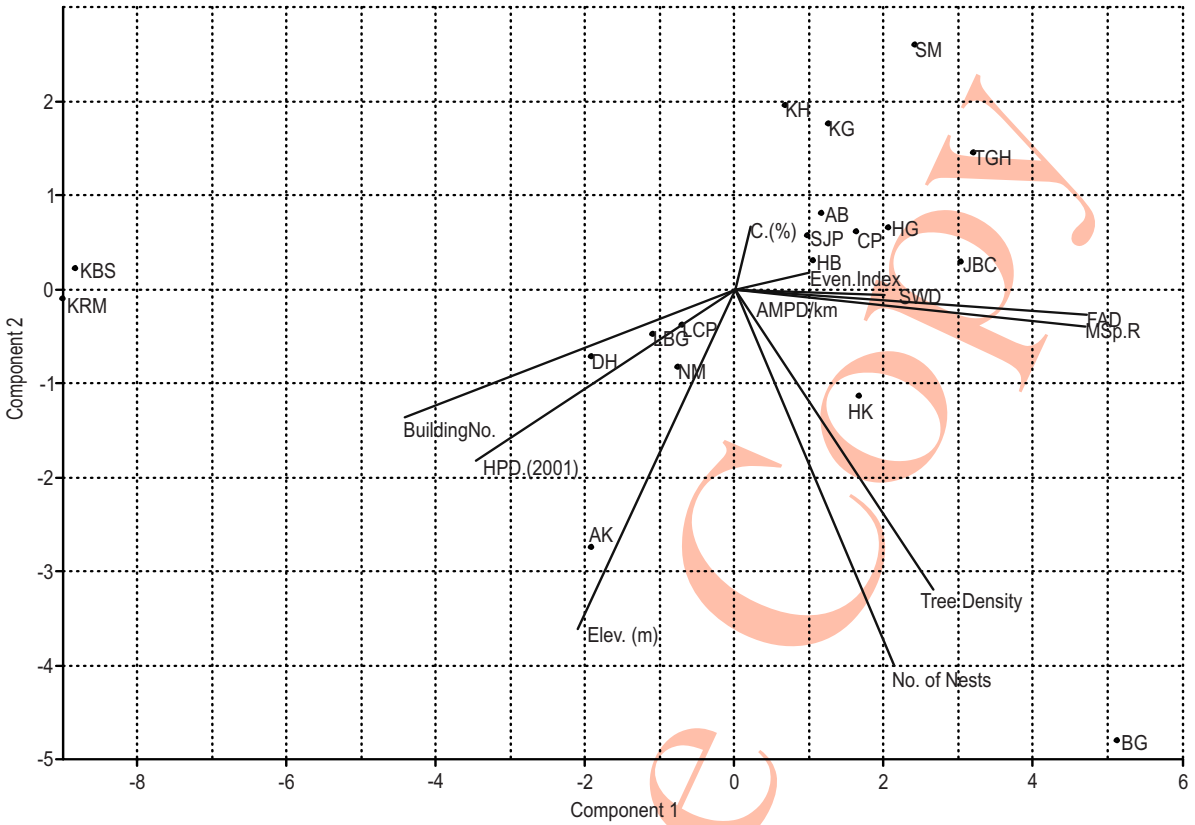

Fig. 2 : Principal component analysis of avian population density in relation to environmental factors in different landscapes of the Bengaluru region (for all abbreviation of the study landscapes, please see Table 1); Elev.(m) Elevation in meter, C.(%) Canopy percentage, BuildingNo. Building number, No.ofNests Number of nests, HPD.(2001) Human population density (2001), AMPD/km Avian mean population density per kilometer, SWD Shannon-Weiner diversity, MSp.R Margalaef's species richness, Even.Index Evenness Index, FAD Fisher's alpha diversity

(115), mean population density (3.27 of birds seen km^{-2}), species diversity (SWD-4.23 to 4.44; FAD-17.37 to 21.45) and species richness (10.88 to 13.40) were noted at Bannerghatta National Park (Table 4) because of less human interference, more density of dry deciduous trees and presence of thorny scrub forests with patches of moist deciduous forests, streams, shrubs and bushes of various plant species in the park. Habitat quality has strong influence on bird populations with availability of food sources (Vaclav *et al*., 2003). Whereas lowest diversity (SWD-2.36 to 2.70; FAD-4.16 to 5.55 in Krishnarajendra Market), species richness (3.21 to 4.18 in Krishnarajendra Market), mean population density (0.66 of birds seen km^{-2} in Kempegowda Bus Station) and lowest number of bird species was found at Kempegowda Bus Station (33) and Krishnarajendra Market (35) due to greater anthropogenic activities, more buildings and houses with fewer trees, more vehicular traffic and less availability of perching and roosting sites. Human activities and their direct interference strongly disturb the avifauna. Quality of habitat and anthropogenic activities as habitat dynamics in city landscapes is entirely dictated by human beings (Marin *et al*., 2007; Daniels, 2008). Urban bird communities are independent of bird diversity of adjacent landscapes and local features are important than surrounding backgrounds in determining bird species richness (Clergeau *et al*., 2001). Species richness and diversity decreases with increase in human disturbances (Blair, 1996).

Highest evenness index of bird species at Attibele and Somanahalli (0.82 to 0.83 each) (Table 4) may be due to wide cultivation of millets, paddy, grains, pulses, green vegetables, fruits and groundnuts that provide food sources and availability of insects and their larvae and especially, caterpillars in fields for nestlings and suitable nesting places. Standing crops provide shelter to variety of resident birds and also attract migratory species (Sivaperuman *et al*., 2007). Lowest evenness index of bird species at Lord Cubbon Park (0.37 to 0.42) (Table 4) may be due to existence of buildings and houses with heavy traffic roads and high anthropogenic activities; with good number of trees but limited availability of nesting sites and food sources.

The number of bird species recorded in summer was 105 (88.98% of total species), which increased up to 110 (93.22%)

Table 5 : List of flowering plants/trees regularly visited by birds in the Bengaluru region (2008-2010)

Families	Scientific names of trees/ plants
Bombacaceae	*Bombax ceiba* Linn.
Malvaceae	*Hibiscus rosa-sinensis* L.
	Thespesia populnea (L.) Sol. Ex Corr
	Firmiana colorata (Roxb.) R.Br.
Sterculiaceae	*Helicteres isora* Linn.
Moringaceae	*Moringa oleifera* Lamk.
Crassulaceae	*Bryophyllum calycinum* Salisb.
	Kalanchoe pinnata (Lamk.)
Fabaceae	*Erthyrina verigata* Lamk., *Erthyrina stricta* Roxb.
	Erthyrina crista-galli Linn.
	Erythrina subumbrans (Hassk.) Merr.
	Butea monosperma (Lamb.) Taub
	Delonix regia (Boj. Ex Hook) Rafin
	Caesalpina pulcherrima (L.) Swartz
	Bauhinia purpurea Linn., *Bauhinia racemosa* Lam.
	Bauhinia varigata L., *Acacia nilotica* Willd.
	Sesbania grandiflora (L.) Poiret
	Prosopis juliflora (Sw.) DC.
	Dalbergia sissoo Roxb., *Parkia biglandulosa* W. & A.
	Peltophorum pterocarpum (DC.), Backer ex K. Heyne, *Saraka asoka* Roxb.
	Cassia fistula L., *Cassia javanica* L.
	Amherstia nobilis Wall.
Caprifoliaceae	*Lonicera leschenaultii* Linn.
Lythraceae	*Woodfordia fruticosa* Linn.
	Lagerstroemia speciosa L.
Combretaceae	*Quisqualis indica* Linn.
Myrtaceae	*Eucalyptus globulus* Lab.
	Eucalyptus sp. L' Hen., *Callistemon lanceolatus* (DC.)
Onagraceae	*Fuchsia* sp. L.
Sonneratiaceae	*Sonnertia acida* L.f.
Apocynaceae	*Calotropis giganticus* (Linn.) R. Br.
	Calotropis procera (Aiton) W.T.Aiton
Platinaginaceae	*Russelia equisetifolia* Schelecht & Cham.
Bignoniaceae	*Muilimgtonia horstensis* Linn. F.
	Spathodea campanulata Beauv.
	Tecoma stans (Linn.), *Jacaranda mimosifolia* D. Don.
Lamiaceae	*Holmskioldea sanguinea* Retz.
	Salvia coccinea Tuss., *Leonotis nepetaefolia* Br.
Caricaeae	*Carica papaya* Linn.
Acanthaceae	*Adhatoda zeylonica* L.
Convolvulaceae	*Quamoclit cocinea* Moench =
Nyctaginaceae	*Bougainvillea spectabilis* Willd.
Verbenaceae	*Gmelina arborea* Linn., *Duranta plumieri* Jacq.
	Stachytarphata indica (Linn.) Vahl
	Stachytarphata mutabilis (Jacq.) Vahl
	Lantana camara Linn., *Petrea colubilis* (Linn.)
	Vitex pubiscens (Roxb.) R.Br.
Loranthaceae	*Loranthus obtusatus* Wall.
Ericaceae	*Rhododendron companulatum* (J. D. Hooker) D. F.
	Rhododendron arboreum L.
Cannaceae	*Canna indica* Linn.
Musaceae	*Musa paradisiaca* L.
Colchicaceae	*Gloriosa superba* Linn.
Proteaceae	*Grevillea robusta* A. Cunn.
Magnoliaceae	*Magnolia* sp. L.
Bixaceae	*Cochlosperumum gossyoium* DC.
Palmae	*Cocos nucifera* Linn.

Table 6 : List of bird-dispersed plant/tree species in the Bengaluru region (2008-2010)

Families	Scientific names of trees / plants
Fabaceae	*Acacia catechu* Willd.
	Acacia leucophloea Willd.
	Albizia saman F.Muell.
	Dalbergia sissoo Roxb.
	Dalbergia sps. L.f.
	Pithecelobium dulce (Roxb.) Benth.
	Pongamia pinnata Vent.*
	Tamarindus indica L.
Coniferae	*Araucaria cookii* R. Br. ex D. Don
Araucariaceae	*Araucaria* spp. Juss.
Meliaceae	*Azadirachta indica* A. Juss
	Swietenia macrophylla King
Poaceae	*Bambusa* spp.
	Bombax malabaricus DC.
Caesalpinaceae	*Caesia renigera* Wall. ex Benth.
Anacardiaceae	*Mangifera indica* L.
Moraceae	*Artocarpus integrifolia* J.R.Forster & G.Forster
	Erythrina indica L.
	Ficus bengalensis L.
	Ficus benjamin L.
	Ficus elastica Roxb.
	Ficus glomerata Roxb.
	Ficus religiosa L.
	Ficus variegata Bl.
Bignoniaceae	*Millingtonia hortensis* L.f.
	Tabebuia argentia (Silva Manso) Benth. & Hook.f. ex S.Moore
	Tabebuia impetiginosa (Mart. ex DC.) Standl.
	Tabebuia rosea DC
Magnoliaceae	*Michelia champaca* L.
Muntigiaceae	*Muntingia calabura* L.
Rutaceae	*Murraya koenigi* (L.) Sprengel
Arecaceae	*Phoenix sylvestris* Roxb.
Euphorbiaceae	*Phyllanthus emblica* L.
	Ricinus communis L.
Anonnaceae	*Polyalthia longifolia* Sonn.
Verbenaceae	*Tectona grandis* L.f.
Combretaceae	*Terminalia bellerica* (Gaertn.) Roxb.
	Terminalia microcarpa Decne.
Rutaceae	*Toddalia asiatica* (L.) Lam
Lyrthaceae	*Lagerstoemia indica* L.
	Lagerstroemia flos reginae King

during monsoon and 115 (97.46%) in winter; 100 species (84.75%) were common throughout the year. Highest number in winter was due to arrival of migratory birds. Occurrence of number of bird species between seasons was not significantly different (one way ANOVA, $F_{2,23} = 0.002$, $P > 0.05$).

Sixty eight species of perching plants (Table 5) belonging to 59 genera and 30 families, and 41 species of bird-dispersed plants and trees (Table 6) belonging to 29 genera and 19 families that regularly visited the landscapes of Bengaluru region were recorded by Subramanya and Radhamani (1993) in Western

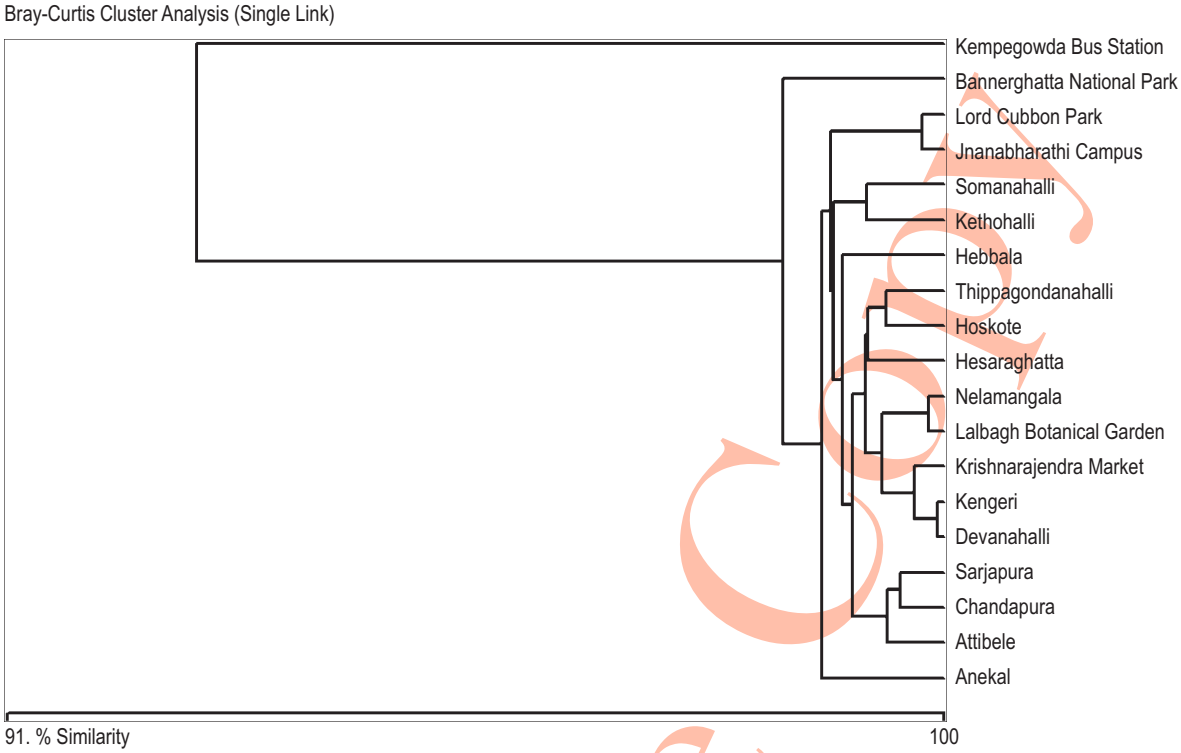

Fig. 3 : Dendrogram showing similarity based on the canopy closure and population density of avian communities in different landscapes of the Bengaluru region

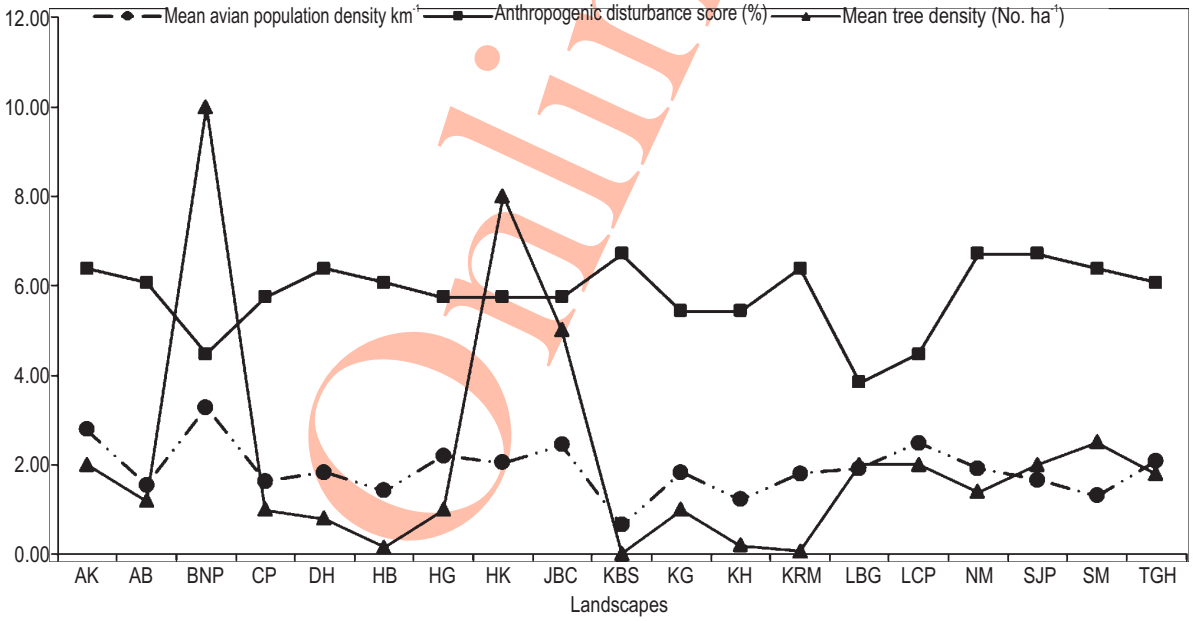

Fig. 4 : Avian density in relation to vegetation density and anthropogenic disturbances in the urban landscapes of the Bengaluru region (for all abbreviation of the study landscapes, please see Table 1)

Ghats. Bird diversity and species richness are closely correlated with the structural and floristic characteristics (Harvey and Gonzalez, 2007).

Highest mean tree density (10 of trees seen ha^{-1}) at Bannerghatta National Park (Table 1) favored the highest number of nests (800), which was responsible for more density of birds. Whereas, the lowest tree density (0.01 trees seen ha^{-1}) at Kempegowda Bus Station (50) and Krishnarajendra Market (80) affected bird activities.

Examination of landscape characteristics within Principal component analysis indicated landscape elevation, number of buildings, human population density were negatively correlated with avian population in Anekal, Devanahalli, Krishnarajendra Market, Lord Cubbon Park, Lalbagh Botanical Garden and Nelamangala (Fig. 2). Attibele, Bannerghatta National Park, Chandapura, Hebbala, Hesaraghatta, Hoskote, Kempegowda Bus Station, Kengeri, Kethohalli, Jnanabharathi Campus, Sarjapura, Somanahalli and Thippagondanahalli landscapes were positively correlated with canopy coverage, nests density, tree density, avian density, diversity, richness and evenness. The cumulative percentage of variance explained by the first four PC axes was 89.4693%, with the first axis accounting for 47.697% of the variation, and second axis explaining a further 22.228%. Variation in the population density of different bird communities, the landscape characteristics and anthropogenic factors of different landscapes was most closely correlated with axis 1 ($r = -1.0142$, $P \leq 0.01$), and resulted in clear differentiation of parameters and landscapes. Bird species respond to several environmental factors (both local and landscape) along a gradient of urban mosaic complexity (Aurora, et al., 2009). The number of species and bird diversity are positively related to tree density (Lundquist and Reich, 2006). A little variation in landscape elevation in Bengaluru region had no effect on mean population density of birds.

MPD of avian communities was positively correlated with tree density (0.648) ($P<0.01$) as well as with an increasing number of bird nests (0.795) ($P<0.01$) in Bengaluru region. Moreover, MPD was negatively correlated with canopy coverage of trees (-0.149), and with increased human population density (-0.018) and number of buildings (-0.188) in the urban landscapes, irrespective of landscape elevation (0.244).

Kempegowda Bus Station accounted for minimum (0.66) population density of birds seen km^{-2} with moderate canopy coverage (88.53%) of vegetation were belonging to one cluster, and the remaining 18 landscapes with moderate (1.23) to maximum (3.29) population density of birds seen km^{-2} and canopy coverage vegetation (86.47 to 91.05%) were formed another cluster. These two major clusters have a significant positive affinity (Fig. 3). Maximum bird density in Bannerghatta National Park was related to lesser anthropogenic factor and greater tree density (Fig. 4). Greater percentage of anthropogenic disturbances was related to less vegetation density, which in turn affected the avian density (Shochat *et al*., 2010). Canopy patterns can influence bird community composition, diversity and distribution at the landscape scale. Bird abundance and diversity were positively correlated to an increase in area of canopy openings (Daniel and Fleet, 1999).

Intense biotic and anthropogenic pressures around the metropolitan landscapes have made a negative impact on the avian community composition of urban ecosystem as reported by Mckinney (2006). Conservation of forest landscape and its vegetation in this urban environment acts as a corridor and edges for wildlife movement, and it supports the livelihood means of the avian community composition. Minimum width of metropolitan vegetation in the corridor and edges of urban ecosystem zone is very much essential to maintain the quality of environment and for biological conservation of species (Alvey, 2006).

Findings of this study divulge that availability of variety of food sources for both adults and nestlings, safe habitat for nesting/roosting in and around the landscapes are important for the occurrence and abundance of bird populations in the urban region. The present work, therefore, provides baseline information for further studies aimed at supporting management and conservation efforts in the urban ecosystem.

Acknowledgment

The authors are thankful to Dr. Lakshminarayana, School of Natural Science, Division of Integrated Biological Sciences, Bangalore University, Bengaluru for identifying plant and tree species.

References

Ali, S.: The Book of Indian Birds. 6th Edn., Oxford University Press, New Delhi, (1996).

Alvey, A.A.: Promoting and preserving biodiversity in the urban forest. *Urban Forest and Urban Greening*, **5**, 195–201 (2006).

Aurora, A.L., T.R. Simpson, M.F. Small and K.C. Bender: Toward increasing avian diversity: urban wildscapes programs. *Urban Ecosyst.*, **12**, 347-358 (2009).

BirdLife International: The BirdLife checklist of the birds of the world, with conservation status and taxonomic sources. Version 2, (2009).

Blair, R.B.: Land use and avian species diversity along an urban gradient. *Ecol. Appl.*, **6**, 506-519 (1996).

Branton, M. and J.S. Richardson: Assessing the value of the umbrella-species concept for conservation planning with Meta-Analysis. *Conser. Biol.*, **25**, 9-20 (2011).

Census of India: Provisional Population Totals: Cities having population 1 lakh and above (PDF). Government of India (2011).

Clergeau, P., J. Jokimäki and J.L. Savard: Are urban bird communities influenced by the bird diversity of adjacent landscapes? *J. Appl. Ecol.*, **38**, 1122-1134 (2001).

Daniel, R S. and R.R. Fleet: Bird and small mammal communities of four similar-aged forest types of the Caddo lake area in east Texas. *Texas J. Sci.*, **51**, 65-80 (1999).

Daniels, R.J.R.: Can we save the Sparrow? *Curr. Sci.,* **95**, 1527-1528 (2008).

Dawson, D.G.: The usefulness of absolute ('census') and relative ('sampling' or 'index') measure of abundance. *Stud. in Avian Biol.,* **6**, 554-558 (1981).

Engelbrecht, M.J. and H.M. Herz: Evaluation of different methods to estimate understory light conditions in tropical forests. *J. Trop. Ecol.,* **17**, 201–224 (2001).

Faeth, S.H., P.S. Warren, E. Shochat and W.A. Marussich: Trophic dynamics in urban communities. *Biosci.,* **55**, 299-407 (2005).

Forman, R.T.T.: *Land Mosaics: The ecology of landscapes and regions*. Cambridge University Press, Cambridge (1997).

Gaston, K. J. and T. M. Blackburn: How many birds are there? *Biodivers. Conserv.,* **6**, 615-625 (1997).

George, J., M.B. Krishna, S. Subramanya, J.N. Prasad, O.C. Naveein, S. Karthikeyan, S.H. Kumar, N. Srinivasan and T.S. Srinivasa: *Annotated checklist of the Birds of Bangalore* (Ed.: J. George). Birdwatchers' Field Club of Bangalore, Bangalore (1994).

Godefroid, S.: Analysis of the Brussels flora as indicator for changing environmental quality. *Landsc. Urban Plann.,* **52**, 203-224 (2001).

Grimmett, R. and T. Inskipp: Birds of Southern India. Om Books International, New Delhi, India (2007).

Hammer, Ø., D.A.T. Harper and P.D. Ryan: PAST: Palaeontological statistics software package for education and data analysis. *Palaeontol. Electr.*, **4**, 9 (2001).

Harvey, C.A. and V.J. Gonzalez: Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodivers. Conserv.,* **16**, 2257-2292 (2007).

IUCN: Bird Life International. The IUCN Red List of Threatened Species, Version **3** (2010).

Lundquist, J.E. and R.M. Reich: Tree diseases, canopy structure, and bird distributions in *Ponderosa pine* forests. *J. Sustain. For.,* **23**, 17-45 (2006).

MacKinnon, J. and K. Phillipps: A field guide to the birds of Borneo, Sumatra, Java and Bali, Oxford University Press, Oxford (1993).

Marin, G., L. Bastidas, L. Munoz, O. Oliveros, R. Navarro and B. Marcano: Ecological profile of the avifauna in the Venezuelan eastern plains as a function of anthropogenic impacts. *Interciencia,* **32**, 391-398 (2007).

McAleece, N., P.J.D. Lambshead, G.L.J. Paterson and J.D. Gage: Biodiversity Professional Version 2.0 free statistics software for ecology; The Natural History Museum and the Scottish Association for Marine Science, UK (1997).

McKinney, M.L.: Urbanization as a major cause of biotic homogenization. *Biol. Conserv.,* **127**, 247 –260 (2006).

Mckinney, M.L.: Urbanization, biodiversity, Conservation. *Bioscience*, **52**, 883-890 (2002).

Reynolds, R.T., J.M. Scott and R.A. Nussbaum: A variable circular-plot method for estimating bird numbers. *Condor.*, **82**, 309-313 (1980).

Seedikkoya, K., P. A. Azeez and E.A. Shukkur: Cattle egret as a biocontrol agent. *Zoo's Print J.*, **22**, 2864-2866 (2007).

Shenoy, K., S. Varma and K.V.D. Prasad: Factors determining habitat choice of the smooth-coated otter, *Lutra perspicillata* in a South Indian River system. *Curr. Sci.,* **91**, 637- 643 (2006).

Shochat, E., S. Lerman and E. Fernández-Juricic: Birds in Urban Ecosystems: Population dynamics, community structure, biodiversity and conservation. In: Urban Ecosystem Ecology (Eds.: J. Aitkenhead-Peterson and A. Volder), Agronomy Monograph, **55**, 75-86 (2010).

Shyamal, L.: The birds of the Indian Institute of Science campus changes in the avifauna. *Newsl. Birdwatchers,* **34**, 7-9 (1994).

Sivaperuman, C., K.L. Kankane, S. Kumar, N.S. Rathode and Q.H. Baqri: Diversity and abundance of avifauna in the Thar Desert, Rajasthan, India. *The Indian Forester,* **133**, 1350-66 (2007).

Sodhi, N.S. and H.C. Lim: Responses of avian guilds to urbanization in a tropical city. *Landsc. Urban Plann.,* **66**, 199-215 (2003).

SPSS Inc.: SPSS for windows, Rel. 17.0.0. SPSS Inc., Chicago (2008).

Subramanya, S. and T. R. Radhamani: Pollination by birds and bats. *Curr. Sci.,* **65**, 201-209 (1993).

Sullivan, B.K. and M. Flowers: Large iguanid lizards of urban mountain preserves in northern Phoenix, Arizona. *Herpetol. Nat. Hist.,* **6**, 13-22 (1998).

Urfi, A.J., S. Monalisa, A. Kalam and T. Meganathan: Counting birds in India: Methodologies and trends. *Curr. Sci*., **89**, 1997-2003 (2005).

Vaclav, R., H. Hoi and D. Blomquist: Food supplementation affects extra pair paternity in House Sparrows. *Behav. Ecol.,* **14**, 730-735 (2003).

Verner, J.: Assessment of counting techniques. In: *Current Ornithology*, (Ed.: R. F. Johnstone), Vol. **2**, Plenum Press, New York (1985).

Watson, D.M.: The 'standardized search: An improved way to conduct bird surveys. *Austral Ecol.,* **28**, 515-525 (2003).