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## Micro-scale patterns and drivers of bird visitation on street fig trees in Delhi, India

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### ABSTRACT

Street trees have been used as a means of mitigating the negative effects of urbanization on biodiversity, particularly bird fauna. Despite their widely acknowledged benefits for birds, studies so far have been largely limited to relatively coarse scales, with an understanding of the role of local environments and individual tree characters lacking. We studied the patterns of bird visitation at individual street *Ficus* (fig) trees, providers of keystone resources in tropical landscapes, in Delhi, India, and their drivers at different scales (tree characteristics, local and landscape variables). Three common fig species were surveyed for bird visitors across 3 sites with varying urban patterns. Fig trees were found to be a relatively common street tree choice, and the 106 trees surveyed were visited by 29 bird species, including 7 obligate frugivores. We found that reducing green cover in surrounding landscape and increasing noise did not deter birds from visiting these trees. Instead, variables at finer scales like tree canopy diameter, tree species and local resource density had sizable and significant effects on both species richness and abundance of bird visitors. Our results highlight how bird assemblages, guilds and individual species respond differently to a range of ecological variables, and an understanding of these responses at different scales is useful for maximising the value of street trees for urban birds. Thus, coarse-scale studies can provide insights into bird diversity of city landscapes, but micro-scale studies are important in helping make fine scale management decisions, like selection of street trees.

### 1. Introduction

Urban areas have experienced a rapid expansion in area during the past few decades in Asia, but they may have limited potential to support biodiversity (Pauchard et al., 2006; Seto et al., 2011). Increased urban sprawl corresponds with reduced native vegetation and a parallel increase in ornamental and exotic vegetation, which support lower diversity of native fauna (Pauchard et al., 2006; Yan et al., 2019). Increase in urban areas is also correlated with a rise in impervious surfaces, which in turn, corresponds to a decline in species diversity across many floral and faunal taxa (McKinney 2008). Populations of wild species in urban landscapes are known to be adversely affected due to increase in predators, loss of key resources and disruptions to dispersal (Marzluff and Ewing 2008). While urbanization has localized effects on biodiversity, these effects are predicted to become more widespread and acute with rapid expansion of urban landscapes in the coming decades (McDonald et al., 2008).

Although the negative effects of urbanization on biodiversity are widely prevalent, it may be possible to retain high biodiversity in urban areas with proper planning and urban design (Marzluff and Ewing 2008; Garrard et al., 2018). Remnant woodlands, managed parks, and home gardens can contribute immensely to urban biodiversity, through their provision of natural and semi-natural habitats (Tiwary and Urfi, 2016). Along with parks, remnant woodlands, and wetlands, street trees are one of the critical components of urban areas that expand habitat for fauna. Street trees are planted abundantly in many urban landscapes, and are capable of reducing the negative effects of urbanization (Pena et al., 2017). Street trees provide an important source of food for birds in an urban landscape (Young et al., 2007; Wood and Esaian 2020). Frugivorous and insectivorous birds, in particular, have been shown to feed on street trees, even those that are distant from forest patches; such resources may be tracked seasonally (Walther et al., 2018; Mackay et al., 2018). Street trees also add refugia to the urban landscape, by providing nesting sites for a diverse array of birds (Shackleton 2016) and are

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shown to aid ecological connectivity in an urban landscape, facilitating movement between green spaces and more built-up spaces (Fernández-Juricic, 2000).

All tree species are not equally preferred by birds in an urban landscape. Birds show preference for tree species based on fruit size and nutritive quality, tree structure and phenology (Soh et al., 2002; Young et al., 2007; Walther et al., 2018). Large trees are thought to be particularly important, being considered as 'keystone structures' as they provide habitat complexity and abundant food resources (Stagoll et al., 2012). As a result, birds prefer streets with higher density and diversity of large street trees (Murgui 2007; Pena et al., 2017). In particular, streets with higher number of native trees are found to support a richer community of birds (Ikin et al., 2013). Further, tree characteristics such as canopy cover, canopy volume and tree height can significantly affect tree utilization by birds (Menon et al., 2019; Murgui 2007; Pena et al., 2017), which then affect their foraging on fruiting trees.

Apart from preferences for particular tree species and physical characteristics, avian use of tree resources also depends on landscape features, both at local and landscape scales. Higher diversity and complexity in street vegetation are found to have a positive impact on bird visitation of street trees (Fernández-Juricic, 2000; Shackleton 2016). At finer scales, birds may respond to the availability of food resources in the immediate neighbourhood (Støstad et al., 2017), as well as local physical disturbance (such as by movement of traffic and people) (Zhou and Chu 2012). Isolation from other green patches is also found to affect bird communities due to possible constraints on dispersal (Shackleton 2016). Bird occupancy in urban areas is widely found to vary with the green cover in the proximate area (Tiwary and Urfi, 2016). Birds also respond to the socio-economic conditions of the residential areas, as patterns of street tree planting often depend on these conditions (Wood and Esaian 2020).

*Ficus*, or figs, are one of the most widespread genera of woody plants, with over 800 species worldwide (Janzen 1979). Fig species are considered keystone resources due to their large size, asynchronous fruiting pattern and short intervals between fruiting, and can provide a year-round food resource in tropical areas (Lambert and Marshall 1991). Globally, over a thousand vertebrate species have been recorded feeding on figs, with a large majority being birds (Janzen 1979; Shanahan et al., 2001). Figs continue to maintain their keystone role in human-modified landscapes (Peabotuwage et al., 2019). They have been shown to attract much higher numbers and diversity of birds compared to other tree species in urban landscapes, especially during their fruiting stages (Chong et al., 2021). Additionally, their role as keystone resources for avifauna may be amplified in urban areas, compared to natural regions, likely due to paucity of other resources (Peabotuwage et al., 2019).

Studies which focus on intra-urban bird diversity patterns have largely studied the responses of species richness or abundances to landscape-level urban gradients. Such relatively larger scale studies present important results, but simplify urban landscapes, masking their high heterogeneity at a finer scale (Beninde et al., 2015). Although greener landscapes do support higher bird diversity, the extent of green space, and its quality, can vary in urban landscapes (Gupta et al., 2012). Human decisions at finer scale, like the choice of street tree species, can influence bird communities and their patterns observed at a larger scale, making studies at this scale vital (Hostetler 1999). More studies are required at finer scales in order to disentangle the patterns observed at the landscape scale (Hostetler and Holling 2000). In particular, knowledge of tree features preferred by birds can immensely improve management of city landscapes for biodiversity.

In the current study, we investigate the bird visitations on fig trees belonging to three species and explore a range of tree characteristics and, local and landscape-level factors, which may influence bird visitation on fig species in the urban landscape of Delhi city in India. For this, we selected three sites with varying urban configuration within Delhi. First, we studied the species richness and abundance of street fig trees at these sites. We then estimated bird visitation on individual trees

of fig species, and assessed the influence of various tree characteristics and local and landscape-level variables on bird visitations. We studied the influence of these variables on bird species richness and abundance at three levels – all bird species, frugivorous guild of birds and individual species. Specifically, we hypothesised that larger trees (taller, with larger canopy and girth at breast height (GBH)) would host more bird visitations, and that birds may prefer certain fig species over others. We also hypothesised that higher neighbourhood green cover, and presence of more fruiting and flowering trees in the neighbourhood would have a positive effect on bird visitation numbers and richness. We expected anthropogenic noise (emanating from traffic, human and construction) to have a detrimental effect on bird visitation on trees. Finally, we also expected habitat factors (green cover and isolation) to have a greater effect on frugivorous species in comparison to the total bird community, given their requirements for larger habitat area, and need for tracking fruiting trees.

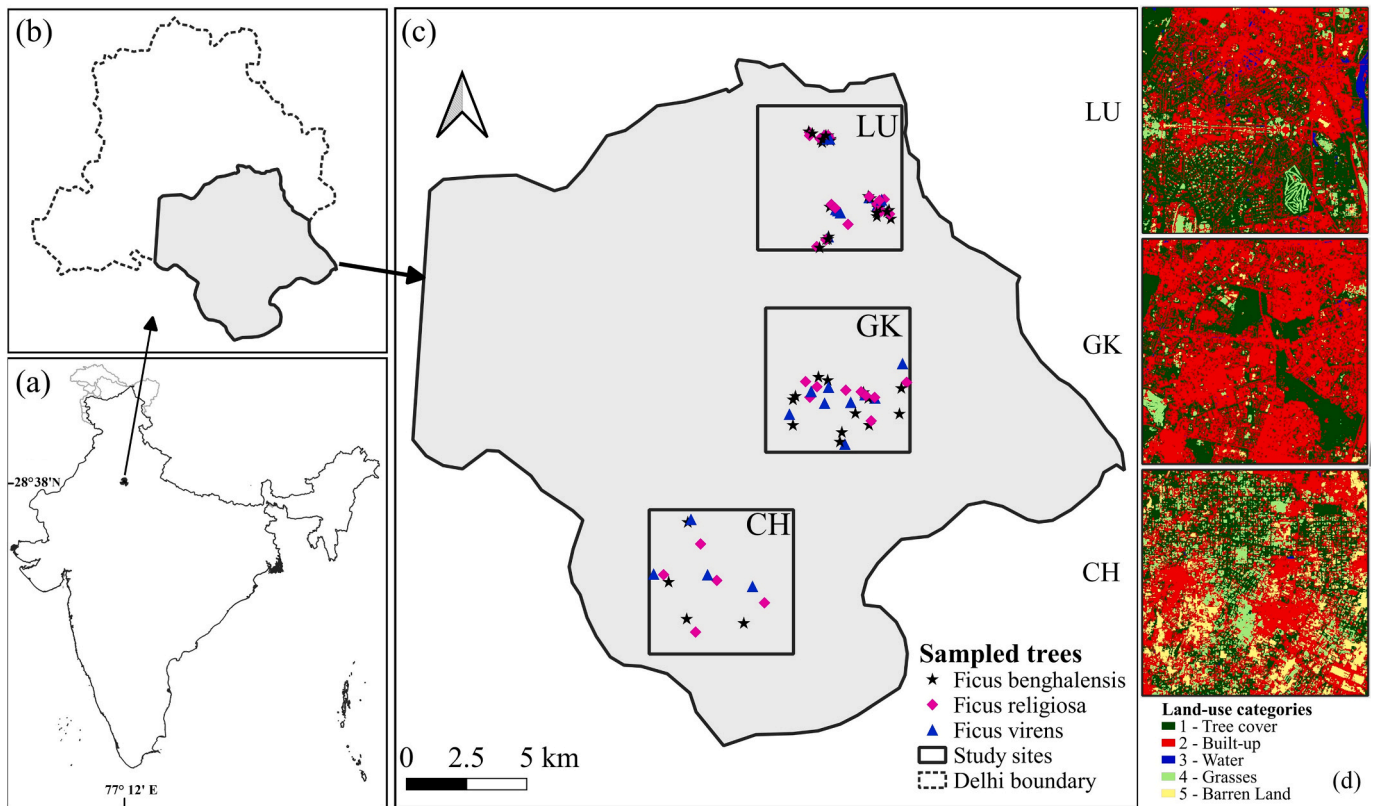
## 2. Methods

### 2.1. Study area and sites

National Capital Territory of Delhi (hereafter referred to as Delhi) is a megacity sprawling over an area of 1483 sq. km., and is divided into nine districts (Ministry of Home Affairs 2011). The native vegetation of Delhi comprises tropical dry deciduous and thorn scrub forests, which reached a state of degradation by the mid-1800's. However, large numbers of street trees were planted and parks were created in Delhi when it was declared the capital during British era (Champion and Seth 1968; Singh et al., 2009).

In the recent decades, Delhi has experienced rapid increase in built-up area, that was only partially planned (Jain et al., 2016). Such varying patterns of urban growth have had a differential effect on the green spaces of the region (Paul and Nagendra 2015). For this study, we selected four districts – Central Delhi, New Delhi, South Delhi and South-west Delhi due to the varying urban planning designs that they exhibit (Fig. 1a). Central Delhi and New Delhi were historically planned with high proportion of green areas and wooded avenues; these two districts have also experienced the least urban sprawl over the past few decades. On the other hand, South Delhi and South-west Delhi have experienced considerable sprawl (both planned and unplanned) relative to Central and New Delhi (Jain et al., 2016; Ghertner 2021). Additionally, change in green cover has been dissimilar across Delhi, with certain areas also experiencing a greater growth in green cover over the years (Paul and Nagendra 2015).

We first prepared a land-use map for our focal area using Sentinel-2 imagery (February 18, 2021, 10-m resolution) downloaded from Earth Explorer (<https://earthexplorer.usgs.gov/>). The semi-classification plugin in QGIS version 3.2 was used to perform supervised classification and create a land-use map for the three sites. The sites were classified into 5 land-use categories – green canopy cover, grass cover, built-up area, water, and exposed or fallow land. With the help of this map, we visually identified three sites of 36 sq. km. each (6 km × 6 km) showing varying urban patterns in terms of distribution and extent of green/built-up area (Fig. 1 b-1d). The first site (LU, Lutyens) covered parts of Central and New Delhi and is one of the best-planned areas in Delhi in terms of its street trees, density of neighbourhood parks and diversity of planted trees (Bhalla and Bhattacharya 2015). It also has lower density of buildings and broader streets. The second site (GK, Greater Kailash) was located in South Delhi and is one of the relatively more densely populated residential parts of Delhi. GK has a few intact green spaces, but with much denser urban built-up sprawl outside these green areas. The third site (CH, Chhatarpur) is a peri-urban area, where unplanned and in some cases unauthorized development has led to a distinct urban landscape. This area is an unorganized mosaic of urban settlements, villages, agriculture, and large private farmhouses. Most of the greenery in residential streets exists within the private properties, with street



**Fig. 1.** Study area and location of the three study sites in Delhi city to explore bird visitation on fig trees. (a) Outline of India with location of Delhi, (b) Districts selected within Delhi (highlighted in grey) for selecting sites (c) three sites of  $6 \times 6$  km marked with site code, along with location of trees surveyed. (d) Classified land use maps for the three study sites – LU (Lutyens, well-planned area with high green cover and wooded avenues), GK (Greater Kailash, densely populated area with few intact green spaces) and CH (Chhatarpur, peri-urban area with an unorganized mosaic of different urban and rural elements).

trees largely present along major commute roads. There is also much more open land in the form of private lawns and fallows in CH (Ghertner 2021).

## 2.2. Vegetation sampling

To estimate densities of the different fig species in each of the study sites, each site was divided into 36 smaller cells of one sq. km each, and of these, 9 were randomly selected for sampling. Sampling of trees was undertaken using 200 m long belt transects of 6 m width. Street tree densities can vary between streets in different settings; for instance, highways show significant difference in planting history in comparison with residential streets (Nagendra and Gopal 2010). Hence the streets selected for sampling trees were stratified based on the extent of each type of street - highways or residential. The Roads layer in Google Earth was used to distinguish streets into highways (major) and residential streets (minor). The length of highways and residential streets selected for sampling was in proportion to their existing ratio within each 1 sq. km grid. Finally, the total transect length within each 1 sq. km grid was approximately 20% of total street length in that cell.

For tree sampling, the delineated 200 m transects were traversed at a slow pace along the edge of the road. Fig trees were enumerated along with their species. All trees with their trunks within 3 m of transect, including street trees and trees within private properties, were counted. A total of 183 transects (36.6 km) were sampled across the 3 sites, 44 in CH, 89 in GK, 50 in LU. Five fig tree species were recorded during our study: *Ficus religiosa*, *F. benghalensis*, *F. virens*, *F. amplissima* and *F. racemosa*.

## 2.3. Focal tree selection

Results of vegetation sampling (see Results) helped to identify the fig species that occurred in all three study sites. Of the five species identified, we focussed on three species that occurred most commonly – *F. benghalensis*, *F. religiosa* and *F. virens* – for bird sampling. At a given site, fig trees of any of the above three species that were in peak fruiting stage, were selected opportunistically for bird observations. This sampling strategy was necessitated due to the asynchronous nature of fruiting among individuals for each of the selected fig species through the year. Bird observations were carried out on a total of 106 trees (42 *F. benghalensis*; 36 *F. religiosa*; 28 *F. virens*) across the three sites (see Fig. 1 and Table S1). Sixty-two focal trees were surveyed for bird visitors in Site LU, 31 in Site GK and 13 in Site CH, over the study period.

## 2.4. Bird observations

Bird visitors were surveyed on each focal tree on a single day between 0700 and 1100 h from November 6, 2020 – April 6, 2021. Surveys were not carried out on rainy or foggy days when bird activity is low. Three scans of 10-min each, separated by at least 30 min between the end and start of two consecutive scans, were carried out. All birds found feeding on figs or perching on the focal tree during the scans were counted. Two observers carried out the bird surveys independently in the three different study sites. Individual biases in bird surveys were unlikely as all of the recorded species occur commonly in Delhi and could be identified without difficulty. A few birds that could not be identified were photographed; they were identified later with the help of a field guide (Kazmierczak, 2000). For a given focal tree, all observations across the three scans were pooled for creating the bird species abundance-focal tree matrix. Bird species known to be primarily

frugivorous were delineated based on published literature on their natural history in addition to our own observations in Delhi area (Ali and Ripley, 1983; Grimmer et al., 1998).

Species richness of birds associated with a given focal tree was calculated as the total number of species observed across the three scans. The abundance of a given bird species on a focal tree was calculated as the highest number seen across any of the three scans on the tree on the sampling day.

## 2.5. Quantification of local and landscape factors

The study period from November 6, 2020 to April 6, 2021, was split into two seasons by studying daily temperature records: winter (6th November–10th February) and spring/summers (11th February – 6th April). Each focal tree was assigned to the relevant season, based on the date of the bird survey. Height was calculated by marking 1-m height on the tree trunk, and then visually estimating the height by taking the marking as reference. Canopy diameter was calculated by measuring the distance between the widest points on tree canopy circumference. Both these calculations were done by the same observer for all trees to avoid observer bias in estimation. Tree GBH was taken of each focal tree using a metre tape. Ambient noise was measured using Sound Meter App (DevTools) on a Vivo U20 Android phone. During the three scans, noise was recorded for a minute during each scan, and was then averaged over the 3 min. Numbers of fruiting and flowering trees (of any species including figs) within 50 m of a focal tree were manually counted on the day of the bird survey (hereafter referred to as ‘resource tree density’). Green cover within 200 m of each focal tree was calculated using Raster analysis tools in QGIS using the land-use map prepared earlier. A map of woodland was prepared for the entire study site by clustering continuous connections of green canopy pixels in QGIS, and retaining only those which added to a minimum area of 5 ha, as this is the minimum area considered beneficial for most generalist woodland species (Whytock et al., 2018). Distance of each tree from the edge of the nearest woodland was then calculated using NNJoin Plugin in QGIS.

## 2.6. Analysis

All of the data analyses were carried out in R (R Core Team, 2020). First, bird species richness within each site, and on each tree species, was determined using species accumulation curves and Chao 2 estimator using the package ‘fossil’ (Vavrek 2011). We used Chao 2 estimator using incidence data which provides a more accurate estimate of species richness even for small samples (Colwell and Coddington 1994). The species accumulation curves created, as above, also helped to explore sampling efficacy.

We then evaluated the differences in total bird richness and abundances for across our sites and across the three study fig species. Significant differences in bird species richness and abundance were checked using Kruskal-Wallis H test, and a post-hoc Dunn test in package ‘FSA’ was done to identify the sites and fig species which showed significant difference in richness and abundance from the other two (Ogle et al., 2021). Additionally, we also calculated the total diversity of birds, and of frugivores on the three fig species using Shannon-Wiener diversity index.

To study the influence of the predictor variables (relating to tree-related, local and landscape factors) on the richness and abundance of birds, we used Generalized Linear Models (GLM) using package ‘MASS’ (Venables and Ripley 2002). All of the study variables are listed in Table 1. First, we checked for correlation amongst pairs of variables by preparing a correlation matrix of Spearman’s coefficient between the seven numeric variables using ‘cormat’ function and obtained the p-value for the correlations using ‘rcorr’ in package ‘dplyr’ and ‘Hmisc’ respectively (Harrell 2021; Wickham et al., 2021). A Spearman’s Correlation value of  $r \geq |0.7|$  and  $p \leq 0.05$  was used to identify strong significant correlations. Based on the result of correlation (Table S2), we

**Table 1**

A summary of the predictor variables that were tested for their influence on bird visitation on fig trees. Variables marked with ‘\*\*’ were selected for analysis.

Sl no.	Variable	Unit
<i>Tree characteristics</i>		
1	Height*	Metres
2	Canopy diameter*	Metres
3	GBH	Centimetres
4	Fig species*	Categorical
<i>Local habitat variables</i>		
5	Noise*	Decibels
6	Resource tree density*	Number
<i>Landscape variables</i>		
7	Green cover (in area within 200 m radius)*	%
8	Distance to woodland	Metres
9	Site*	Categorical
<i>Temporal variable</i>		
10	Season*	Categorical

retained five numeric variables – tree height, tree canopy diameter, noise, resource tree density, and proportion of green cover within 200 m radius. In addition, we used three categorical variables in the model – site, fig species and season-as each of these are likely to influence bird visitation. We ran GLMs with these eight predictor variables, and evaluated their effect on species richness and abundances of both groups of birds (all birds and frugivorous guild). For each GLM, we checked for spatial autocorrelation by calculating Moran’s I on model residuals of models with species richness and abundances for both groups of birds using package ‘DHARMA’ (Hartig 2021). For each response variable we ran two models, and diagnosed the better models by testing for overdispersion and Akaike Information Criteria for small sample sizes (AIC<sub>c</sub>) using packages ‘AER’, ‘DHARMA’ and ‘MASS’ (Kleiber and Zeileis 2008). In addition, the GLMs were also run for a selected suite of individual species that occurred in at least 10% of the focal trees. For individual species, we checked for zero inflation by estimating the number of zeros using the fitted model and compared it to the observed zero values. We retained models where the difference between estimated and actual values was  $\leq 5$ , and there were at least over 10 non-zero values (~10% of total sample size).

## 3. Results

### 3.1. Street tree species composition

A total of 6977 trees were recorded across the three study sites, of which 9.1% (632) were of *Ficus* spp. *F. benghalensis*, *F. religiosa* and *F. virens* formed 15.5%, 43.7% and 29.9% respectively of all fig trees recorded in the transects, and were taken up for bird observations, as the other two species did not provide an adequate sample size for bird observation (7% *F. racemosa*, 4% *F. amplissima*).

The density of total fig trees per transect was significantly lower in CH (mean = 1.5, sd = 2.19) in comparison to GK (mean = 3.9, sd = 3.7; Dunn test:  $p < 0.001$ ) and LU (mean = 4.38, sd = 5.77; Dunn test:  $p < 0.002$ ) (Fig. 2a). We did not find a significant difference in fig tree density between highways and residential streets (Kruskal-Wallis test:  $p = 0.08$ ). However, the relative abundance of fig species varied across the three study sites, with *F. religiosa* being much more common in LU compared to the other two sites, and *F. virens* being more common in GK (Fig. 2b).

### 3.2. Bird diversity

During our surveys, we recorded 1198 individuals of birds belonging to 29 species, including seven frugivores, here defined as species that primarily feed on fruit. The frugivores found in our study sites included the Yellow-footed Green Pigeon *Treron phoenicoptera*, Indian Grey Hornbill *Ocyrceros birostris*, Brown-headed Barbet *Megalaima zeylanica*,

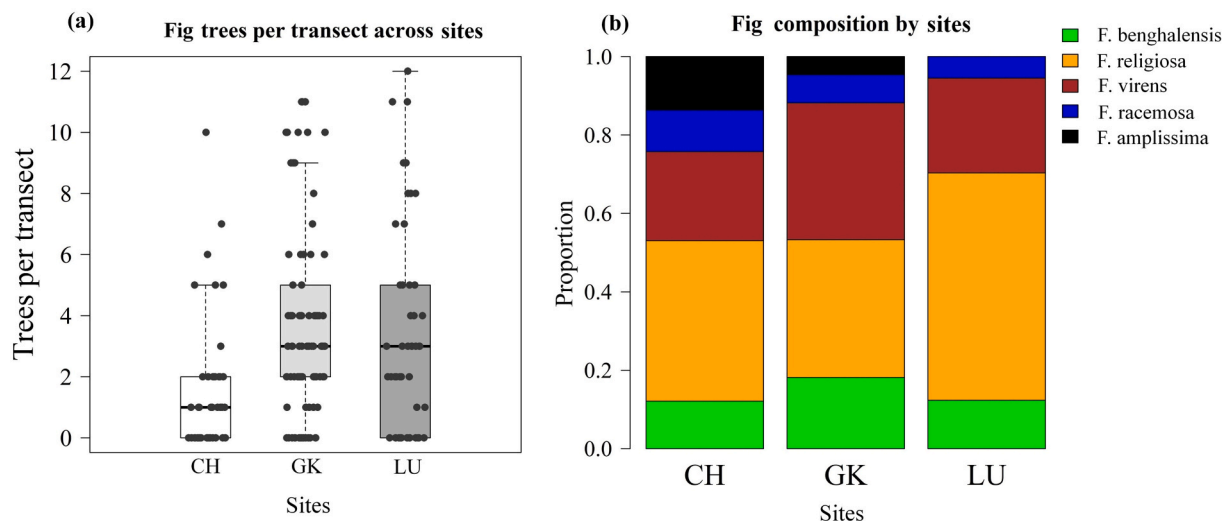


Fig. 2. (a) Boxplot showing total number of fig trees recorded per transect in the three study site and (b) proportion of each of the five recorded fig species.

Coppersmith Barbet *Megalaima haemacephala*, Rose-ringed Parakeet *Psittacula krameria*, Red-vented Bulbul *Pycnonotus cafer* and Red-whiskered Bulbul *Pycnonotus jocosus*. Common Myna *Acridotheres tristis* (14.9% of total abundance) and Yellow-footed Green Pigeon *Treron phoenicoptera* (14.6%) were the most abundant species across our study sites, followed by House Crow *Corvus splendens* (10.5%), Red-whiskered Bulbul *Pycnonotus jocosus* (10.1%), Red-vented Bulbul *Pycnonotus cafer* (10%) and Brown-headed Barbet (7.9%). Only a single individual was observed for two species – Indian Peafowl *Pavo cristatus* and Red-breasted Flycatcher *Ficedula parva*. Common Myna (62.3% of total surveyed trees) was observed at the maximum number of trees, followed by House Crow (59.4%), Brown-headed Barbet (44.3%), Red-vented Bulbul (30.2%) and Yellow-footed Green Pigeon (28.3%). At four trees, no birds were observed during the survey. 49.8% of the individuals observed were frugivores, and at least one frugivore was present at 74.5% of trees sampled. The list of bird species that were recorded during the study can be seen in Table S3, with the frugivores indicated.

### 3.3. Species richness and abundance

The species accumulation curves created for all sampled tree species pooled across three sites, shows saturation (Fig. 3a). The estimated Chao 2 species richness is  $30.5 \pm 2.3$ , which indicates our sampling was sufficient, as the species we recorded account for 88–100% of estimated total species richness (see Fig. 4).

Estimated bird species richness was not significantly different among fig species (Kruskal-Wallis test:  $p = 0.134$ ). However, species richness differed significantly across the three study sites (Kruskal-Wallis chi-square = 15.86,  $p < 0.001$ ). Bird species richness was found to be significantly higher in CH compared to LU (Dunn test:  $z = 3.98$ ,  $p < 0.001$ ). *F. religiosa* (diversity index = 2.66) had the most diverse bird visitors (total bird community), followed by *F. virens* (2.58) and *F. benghalensis* (2.44). Similarly, *F. religiosa* (1.68) and *F. virens* (1.61) had higher diversity of frugivore visitors compared to *F. benghalensis* (1.39).

Abundances were also found to be significantly different across sites (Kruskal-Wallis test: chi-squared = 17.77,  $p < 0.001$ ), and were significantly higher in CH compared to LU (Dunn test:  $z = 4.02$ ,  $p < 0.001$ ). Bird abundances did not differ significantly across fig species (Kruskal-Wallis test:  $p = 0.12$ ).

### 3.4. Predictors of bird visitation

#### 3.4.1. Spatial auto-correlation

Auto-correlation tests with residuals showed no spatial autocorrelation in any of the four models, showing that there were no spatial effects on bird occurrence within or across sites that needed to be accounted for ( $p$  values: Total richness = 0.29, Total abundance = 0.81, Frugivore richness = 0.47, Frugivore abundance = 0.83).

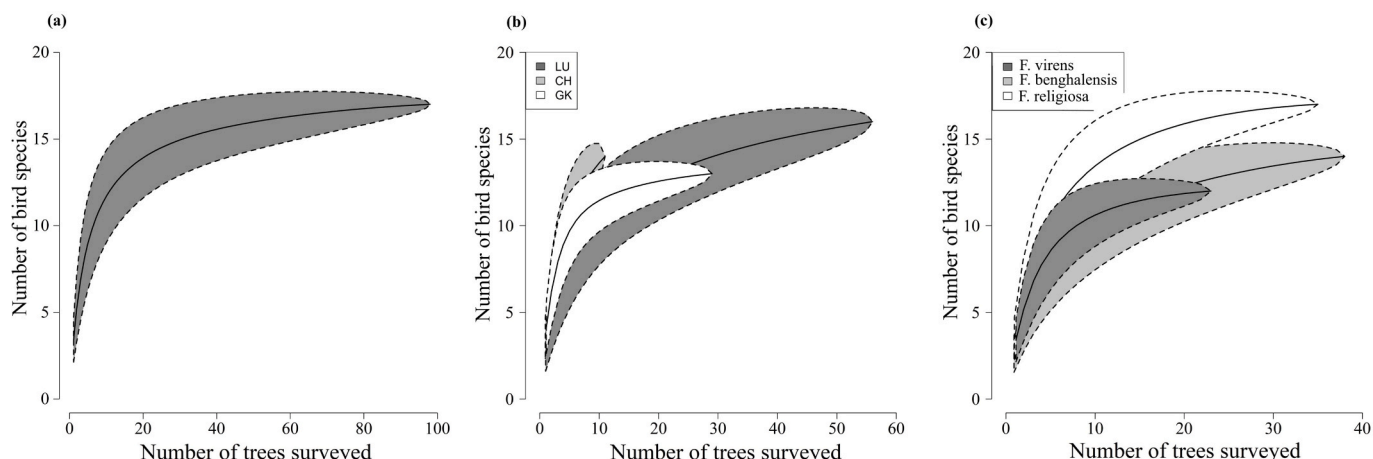


Fig. 3. Bird species accumulation curves for (a) all the sites combined, (b) the three sites individually and (c) the three fig species studied.

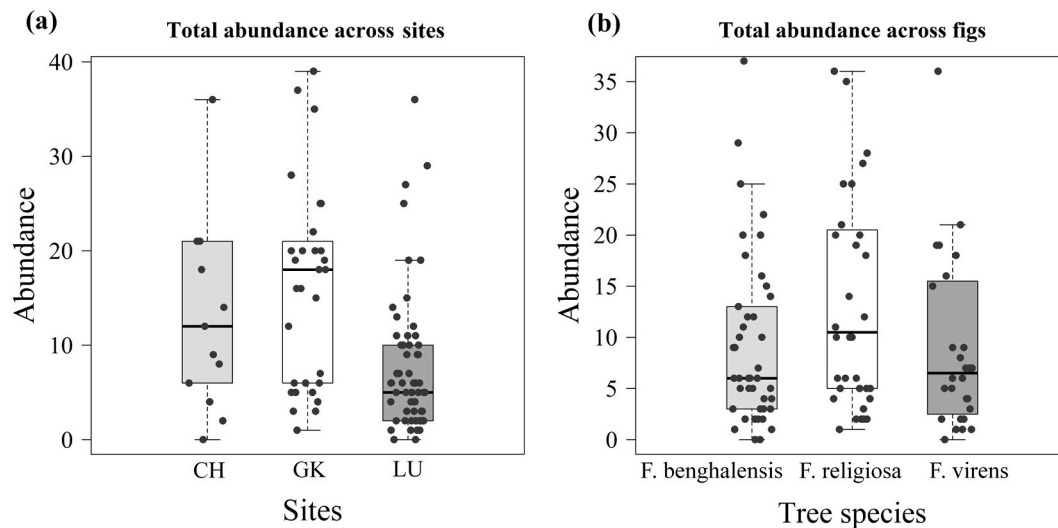


Fig. 4. Boxplots comparing total bird abundance among (a) the three sites and (b) among the three fig species.

### 3.4.2. Bird species richness

Species richness of bird visitors was significantly influenced by site identity, with most bird species being recorded in the site GK (Table 2). Of the three fig species, *F. religiosa* recorded more bird species. Bird species richness was also positively influenced by tree canopy diameter; but tree height had no significant effect. Further, resource tree density negatively influenced the total bird species observed on focal trees. Similar to complete bird communities, GK and *F. religiosa* were positive predictors for richness of frugivores. Additionally, the summer season also positively predicts the frugivore species richness.

### 3.4.3. Bird abundance

Similar to the case of bird species richness, *F. religiosa* and canopy diameter were significant positive predictors on bird abundances, with resource tree density having a significant negative effect (Table 2). Frugivore abundances, similar to other response variables, were positively affected by *F. religiosa*, in addition to being negatively affected by site LU. The abundance of frugivores was also highest on *Ficus religiosa* and least in site LU. Local resource tree density showed a significant negative effect on frugivore abundance, a pattern similar to that seen for all species. Additionally, there were weak positive effects of canopy size and of green cover on frugivore abundance.

### 3.4.4. Individual species' responses

Site identity and fig species were found to have varied effects on visitation of Common Myna, House Crow, Purple Sunbird *Cinnyris asiaticus*, Red-vented Bulbul, Red-whiskered Bulbul, Rose-ringed Parakeet and Yellow-footed Green Pigeon. Summer season had a positive effect of three frugivore species-red-vented bulbul, red-whiskered bulbul and rose-ringed parakeet (Table 3). Among the tree structural variables, canopy diameter influenced the abundance of several bird species, positively affecting visitations of Yellow-footed green pigeon, Rose-ringed parakeet, House Crow and Purple Sunbird *Cinnyris asiaticus*. However, tree height had a positive effect on only a single species –

Rose-ringed parakeet. In terms of landscape effects, only two frugivore species Brown-headed Barbet and Grey Hornbill showed weak effects of green cover. The Rock pigeon *Columba livia* was negatively influenced by green cover. Rock Pigeon and House Crow were the only species significantly affected, both negatively, by local resource tree density. Jungle babbler *Turdoides striata* was affected negatively by noise levels; the only species or group to be significantly affected by the variable.

## 4. Discussion

Our study shows the importance of three common fig street tree species in providing fruit resources for urban birds. The set of species that benefit from fruiting fig trees range from generalist feeders such as House Crows and Common Mynas to obligate frugivores such as Brown-headed Barbets, Yellow-footed Green Pigeons and Grey Hornbills. Fig trees were seen to provide fruit to birds in both winter and summer seasons, due to their asynchronous phenology, thus emphasizing their possible role as keystone guild of trees in the city.

Our study highlights the importance of individual tree characteristics for urban bird visitation. Additionally, differences in responses of overall bird communities and individual bird species highlights how tree-planting may be planned in urban landscapes to allow for a diversity of bird species. We found that tree characteristics and species identity may be more important than landscape variables in determining bird visitors on fruiting trees. Most of the existing work on street trees is confined to regional-scale correlations between bird assemblages and remotely sensed land cover (Tiwary and Urfi, 2016). However, our study provides micro-scale data on bird-tree relationships that explains such regional patterns and shows the value of trees in determining bird visitations.

### 4.1. Figs as avenue trees

Nearly 1 in every 10 street trees we observed in our study sites

Table 2

GLM results for richness and abundance for both total birds and frugivores. Results are given as estimate<sup>significance</sup> († - < 0.1, \* - < 0.05 and \*\*\* - < 0.01), and are only given for significant variables. Subscript on species indicates the family used in model (1 – poisson, 2 – negative binomial, 3 – binomial).

Variables	Intercept	GK	LU	F. religiosa	Sum-mer	Canopy diameter	Green cover	Resource tree density	Explained deviance
Total richness <sup>1</sup>	0.85	0.67**		0.25*		0.04**		-0.03*	34.10%
Frugivore richness <sup>1</sup>	-1.39	1.12*		0.37*	0.7*		0.81†	-0.04†	33.29%
Total abundance <sup>2</sup>	1.93*			0.34*		0.07*		-0.05*	39.15%
Frugivore abundance <sup>2</sup>	-0.6		-1.35**	0.55*		0.06†	1.16†	-0.05†	39.33%

**Table 3**

GLM results for individual species. Results are given as estimate<sup>significance</sup> (p-values; ‘†’ = 0.05–0.1, ‘\*\*’ = 0.01–0.05 and ‘\*\*\*’ < 0.01), and are only given for significant variables. Subscript on species indicates the family used in model (1 – poisson, 2 – negative binomial, 3 – binomial).

Variables	Intercept	GK	LU	F. religiosa	F. virens	Summer	Canopy diameter	Height	Green cover	Resource tree density	Noise	Explained deviance
Brown-headed Barbet <sup>2</sup>	-2.51 <sup>†</sup>								1.38 <sup>†</sup>			16.62%
Common Myna <sup>2</sup>	0.2		-1*									11.94%
Common Tailorbird <sup>1</sup>	-1.52	1.76 <sup>†</sup>		1.14 <sup>†</sup>	1.26 <sup>†</sup>							47.74%
House Crow <sup>1</sup>	0.08	1.45*	1.88**				0.13**			-0.05*	-0.03 <sup>†</sup>	30.37%
Hume's Warbler <sup>3#</sup>	-7.74											61.47%
Indian Grey Hornbill <sup>3</sup>	-10.82*	3.53 <sup>†</sup>							4.84 <sup>†</sup>	-0.45 <sup>†</sup>		40.75%
Jungle Babbler <sup>2</sup>	5.8 <sup>†</sup>									-0.15 <sup>†</sup>	-0.12***	61.1%
Purple Sunbird <sup>1#</sup>	-20.96			2.87**			0.2**					55.06%
Red-vented Bulbul <sup>2</sup>	-3.69	1.93 <sup>†</sup>	-2.11*	2.45**	1.83**	2.23*						44.01%
Red-whiskered Bulbul <sup>2</sup>	-6.39 <sup>†</sup>	4.83**		2.11**	2.18**	3.15*		0.15 <sup>†</sup>				39.29%
Rock Pigeon <sup>2#</sup>	-34.67								-4.16*	-0.16*		34.37%
Rose-ringed Parakeet <sup>1</sup>	-4.04*	2.94**				1.61*	0.14**	0.12*				39.08%
Yellow-footed Green Pigeon <sup>2</sup>	3.91				-1.93**		0.23**					28.67%
<b>Variables</b>	<b>Intercept</b>	<b>GK</b>	<b>LU</b>	<b>F. religiosa</b>	<b>F. virens</b>	<b>Summer</b>	<b>Canopy diameter</b>	<b>Height</b>	<b>Green cover</b>	<b>Resource tree density</b>	<b>Noise</b>	<b>Explained deviance</b>

belonged to the genus *Ficus*, which points to the popularity of this genus of trees for avenue-planting. Abundance of fig street trees in Delhi is comparable with those that were observed in Karachi (Pakistan), another Asian megacity which has experienced tremendous development post-British era, where *F. virens*, *F. religiosa* and *F. benghalensis* were also found to be the most common fig species after *F. benjamina* (Shams 2016). Interestingly, we did not find major differences between highways and residential streets in fig tree densities, as seen in other Asian cities (Nagendra and Gopal, 2010; Shams et al., 2020). Since our study was limited to selected areas in Delhi, further investigations are required to unveil the complete picture.

4.2. Diversity of bird visitors to fruiting figs

A city-wide assessment of Delhi by Tiwary and Urfi, (2016) recorded 115 species of birds, which included birds of open and wetland habitat. In our study we recorded a quarter of that number, despite focussing on only three species of fig trees in a portion of Delhi, revealing the disproportionately high value of fig trees for birds in this urban landscape. In addition to obligate frugivores, which almost always visited the sampled trees for feeding on their fruit, we also observed an array of birds which are primarily nectarivores (e.g. Purple Sunbird), granivores (e.g. Rock Pigeon) and omnivores (e.g. House Crow and Common Myna). Fig trees, in addition to fruits, can also be an important source of insects, which could explain the diversity of birds visiting the sampled trees (Mackay et al., 2018). Apart from feeding, many birds were also observed visiting the tree for perching and nesting, highlighting the wide range of uses of street fig trees for birds in Delhi.

4.3. Differences across fig species

Although total bird abundances did not differ across the three fig species, *F. religiosa* did record highest abundance and diversity of frugivores (abundance = 304) compared to *F. benghalensis* (174) and *F. virens* (119), despite not having the highest sample size (Table S1). Additionally, GLM results further strengthen this result, indicating a significant positive effect for both frugivores and total bird assemblages. The relatively smaller size of *F. religiosa* fruits (pers. obsv.) might make it easier to feed on, and hence attract a greater richness and abundance of birds. In addition to ease of feeding, its higher nutritional richness in

certain components may make it a more attractive part of the diet (Duhan et al., 1992).

4.4. Effect of structural variables on bird visitations

Of the two structural variables investigated, only tree canopy diameter had a significant positive effect on overall bird numbers and richness, indicating that birds respond strongly to tree canopy size, possibly due to larger fruit crop size and greater degree of protection from predators. Our results add to the growing evidence for the positive influence of large street trees on urban bird abundance and richness (Stagoll et al., 2012; Pena et al., 2017). Yellow-footed Green Pigeons, House Crows and Rose-ringed Parakeet are known to prefer trees with large canopies for both nesting and roosting, and we observe a similar pattern in our study (Soh et al., 2002; Devi and Saikia 2012; Dodaro and Battisti, 2014). Additionally, Rose-ringed Parakeets tend to perch and feed at higher sites within the tree canopy (Paker et al., 2014), and were found to be the only species significantly affected by tree height in our study.

4.5. Local variables

Contrary to our predictions, resource tree density had strong negative effects on total species richness and abundance of bird visitors. It is possible that presence of other fruiting and flowering trees may cause birds to spread out in the neighbourhood, instead of congregating on individual trees. Urban adapter species like House Crow and Rock Pigeon were particularly deterred by increased resource tree density of varied species, possibly because of their omnivorous feeding habits. Future studies should parallelly study bird visitation on individual trees and street-level bird diversity to further explore these patterns, as it could help understand the significance of having many resource trees in a small neighbourhood. Increased noise levels, contrary to observations elsewhere, was found to have no effect on bird visitation on fig trees (Newport et al., 2014; Pena et al., 2017). Only the Jungle Babbler, a flocking bird species, was seen to be affected by ambient noise levels, indicating that urban avifauna may be willing to adapt to noisier areas for important resources like fig fruits.

#### 4.6. Seasonality

Richness of frugivores was positively affected by arrival of summer season, with Red-vented Bulbul, Red-whiskered Bulbul and the Rose-ringed Parakeet particularly showing a response to seasonal change. The arrival of summer season coincided with the breeding season of all frugivores in our study, and may indicate increased fruit requirement during this period (Ali and Ripley 1983). Feeding preferences of birds can also change seasonally. For instance, in Durban (South Africa) Rose-Ringed Parakeets are found to feed on different types of food items, from different trees, at different time of the year (Shivambu et al., 2021). Understanding seasonal feeding requirements of birds can help identify street trees for plantation which provide resources when required the most.

#### 4.7. Landscape effects

Contrary to our prediction, green cover within 200 m of sampled trees was found to be an insignificant predictor of overall bird assemblages. Species like Brown-headed Barbet, Yellow-footed Green Pigeon and Indian Grey Hornbill are known to be restricted to well-wooded areas within cities, including suburban parks and forests, and in urban centres having high green cover (Bellanthudawa et al., 2019). The weak effects of green cover in our study points to the importance of street fig trees in providing fruit to the frugivores: they appear to be able to utilize fruiting resources even in densely inhabited residential areas located away from urban woodlands and parks. Further, birds could also be responding to green cover over much larger scales than 200 m radius, as seen in numerous forest studies, or landscape-scale effects on birds may weaken under heavy urbanization, as observed in wetland habitats in Delhi (Menon and Shahabuddin 2021; Rawal et al., 2021). Frugivores such as the Red-vented Bulbul, Red-whiskered Bulbul and the Rose-ringed Parakeet are far more adaptable, being found in residential gardens and fallows in addition to parks and suburban forests; expectedly their visitation rates did not show much correlation with green cover. At the other extreme of habitat preference, Rock Pigeon is known to prefer urban structures for nesting and is actually deterred by areas with high green cover (Tang et al., 2018); our data reflect similar preference in this species. Increasing green cover may indirectly help in management of this invasive species. Additional dispersal and movement data on obligate frugivores in urban contexts will also be useful for further understanding the underlying reasons for these patterns.

Since figs are among the popular street trees in Delhi region, being easy to grow, relatively hardy, and also native to the Delhi region, we suggest that these trees be taken up for planting. Our results are consistent with other studies which have showcased the value of native street trees for improving bird diversity in other tropical and subtropical cities (Ikin et al., 2013; Shackleton 2016; Pena et al., 2017; Walther et al., 2018; Wood and Esaian 2020). Planting such indigenous trees with keystone functions, as against exotic species, would be an important strategy for improving biodiversity in this rapidly expanding metropolis of Delhi. Further, street trees should be allowed to grow to larger sizes, so that larger numbers of bird species can utilize them. It is necessary to expand such studies to a wider range of resource tree species in the city, so that inputs can be provided to biodiversity conservation plans for this region.

#### Credit statement

**Prakhar Rawal:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Deepali Chatrath:** Data curation, Investigation. **Ghazala Shahabuddin:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability

Data will be made available on request.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.actao.2022.103875>.

#### References

- Ali, S., Ripley, S.D., 1983. Handbook of the Birds of India and Pakistan. Oxford University Press and BNHS, Mumbai.
- Bellanthudawa, B., Nawalage, N., Subanky, S., Panagoda, P., Weerasinghe, H., Tharaka, L., Handapangoda, H., Silva, H., Dissanayake, D., Abeywickrama, M., 2019. Composition and diversity variation of avifauna, along different vegetative habitat types in a human-modified area University of Kelaniya, Sri Lanka. *International Journal of Zoology* 1–16.
- Beninde, J., Veith, M., Hochkirch, A., 2015. Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecol. Lett.* 18 (6), 581–592.
- Bhalla, P., Bhattacharya, P., 2015. Urban biodiversity and green spaces in Delhi: a case study of new settlement and Lutyens' Delhi. *J. Hum. Ecol.* 52 (1–2), 83–96.
- Champion, H.G., Seth, S.K., 1968. A Revised Survey of the Forest Types of India. Manager of publications.
- Chong, K.Y., Ng, W.Q., Yee, A.T., Yong, D.L., 2021. The community structure of bird assemblages on urban strangler figs. *Biotropica* 53 (1), 255–265.
- Colwell, R.K., Coddington, J.A., 1994. Estimating terrestrial biodiversity through extrapolation. *Phil. Trans. Roy. Soc. Lond. B Biol. Sci.* 345 (1311), 101–118.
- Devi, O.S., Saikia, P.K., 2012. Notes on the nesting behaviour of Yellow footed green pigeon *Treron phoenicoptera* at jeypore reserve forest, Assam, India. *J. Threat. Taxa* 4 (3), 2470–2475.
- Dodaro, G., Battisti, C., 2014. Rose-ringed parakeet (*Psittacula krameri*) and starling (*Sturnus vulgaris*) syntopics in a Mediterranean urban park: evidence for competition in nest-site selection? *Belg. J. Zool.* 144 (1), 5–14.
- Duhan, A., Chauhan, B.M., Punia, D., 1992. Nutritional value of some non-conventional plant foods of India. *Plant Foods Hum. Nutr.* 42 (3), 193–200.
- Fernández-Juricic, E., 2000. Avifaunal use of wooded streets in an urban landscape. *Conserv. Biol.* 14 (2), 513–521.
- Garrard, G.E., Williams, N.S., Mata, L., Thomas, J., Bekessy, S.A., 2018. Biodiversity sensitive urban design. *Conservation Letters* 11 (2), e12411.
- Ghertner, D.A., 2021. 8 regularization and the fictions of planning “unauthorized Delhi”. In: *Land Fictions*. Cornell University Press, pp. 161–179.
- Grimmett, R., Inskipp, C., Inskipp, T., 1998. Birds of the Indian Subcontinent. Oxford University Press, Delhi.
- Gupta, K., Kumar, P., Pathan, S.K., Sharma, K.P., 2012. Urban Neighborhood Green Index—A measure of green spaces in urban areas. *Landsc. Urban Plann.* 105 (3), 325–335.
- Harrell Jr., F.E., 2021. Hmisc: harrell miscellaneous. R package version 4.5-0. <https://CRAN.R-project.org/package=Hmisc>.
- Hartig, F., 2021. DHARMA: residual diagnostics for hierarchical (Multi-Level/mixed) regression models. R package version 0.4.1. <https://CRAN.R-project.org/package=DHARMA>.
- Hostetler, M., 1999. Scale, birds, and human decisions: a potential for integrative research in urban ecosystems. *Landsc. Urban Plann.* 45 (1), 15–19.
- Hostetler, M., Holling, C.S., 2000. Detecting the scales at which birds respond to structure in urban landscapes. *Urban Ecosyst.* 4 (1), 25–54.
- Ikin, K., Knight, E., Lindenmayer, D.B., Fischer, J., Manning, A.D., 2013. The influence of native versus exotic streetscape vegetation on the spatial distribution of birds in suburbs and reserves. *Divers. Distrib.* 19 (3), 294–306.
- Jain, M., Dimri, A.P., Niyogi, D., 2016. Urban sprawl patterns and processes in Delhi from 1977 to 2014 based on remote sensing and spatial metrics approaches. *Earth Interact.* 20 (14), 1–29.
- Janzen, D.H., 1979. How to be a fig. *Annu. Rev. Ecol. Systemat.* 10 (1), 13–51.
- Kazmierczak, K., 2000. A Field Guide to the Birds of India, Sri Lanka, Pakistan, Nepal, Bhutan, Bangladesh, and the Maldives. Om Book Service.

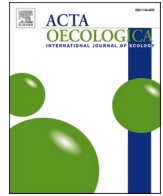
- Kleiber, C., Zeileis, A., 2008. *Applied Econometrics with R*. Springer Science & Business Media.
- Lambert, F.R., Marshall, A.G., 1991. Keystone characteristics of bird-dispersed Ficus in a Malaysian lowland rain forest. *J. Ecol.* 793–809.
- Mackay, K.D., Gross, C.L., Rossetto, M., 2018. Small populations of fig trees offer a keystone food resource and conservation benefits for declining insectivorous birds. *Global Ecology and Conservation* 14, e00403.
- Marzluff, J.M., Ewing, K., 2008. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. In: *Urban Ecology*. Springer, Boston, MA, pp. 739–755.
- McDonald, R.I., Kareiva, P., Forman, R.T., 2008. The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biol. Conserv.* 141 (6), 1695–1703.
- McKinney, M.L., 2008. Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosyst.* 11 (2), 161–176.
- Menon, T., Shahabuddin, G., 2021. Assessing woodpeckers as indicators of bird diversity and habitat structure in managed forests. *Biodivers. Conserv.* 30 (6), 1689–1704.
- Menon, T., Sridhar, H., Shahabuddin, G., 2019. Effects of extractive use on forest birds in Western Himalayas: role of local and landscape factors. *For. Ecol. Manag.* 448, 457–465.
- Ministry of Home Affairs, 2011. *Census of India, Office of the Registrar General. Ministry of Home Affairs, New Delhi, India*. <http://censusindia.gov.in/2011census>.
- Murgui, E., 2007. Factors influencing the bird community of urban wooded streets along an annual cycle. *Ornis Fenn.* 84 (2), 66.
- Nagendra, H., Gopal, D., 2010. Street trees in Bangalore: density, diversity, composition and distribution. *Urban For. Urban Green.* 9 (2), 129–137.
- Newport, J., Shorthouse, D.J., Manning, A.D., 2014. The effects of light and noise from urban development on biodiversity: implications for protected areas in Australia. *Ecol. Manag. Restor.* 15 (3), 204–214.
- Ogle, D.H., Wheeler, P., Dinno, D., 2021. FSA: fisheries stock analysis. R package version 0.8.32. <https://github.com/droglenc/FSA>.
- Paker, Y., Yom-Tov, Y., Alon-Mozes, T., Barnea, A., 2014. The effect of plant richness and urban garden structure on bird species richness, diversity and community structure. *Landsc. Urban Plann.* 122, 186–195.
- Pauchard, A., Aguayo, M., Peña, E., Urrutia, R., 2006. Multiple effects of urbanization on the biodiversity of developing countries: the case of a fast-growing metropolitan area (Concepción, Chile). *Biol. Conserv.* 127 (3), 272–281.
- Paul, S., Nagendra, H., 2015. Vegetation change and fragmentation in the mega city of Delhi: mapping 25 years of change. *Appl. Geogr.* 58, 153–166.
- Peabotuwage, I., Goodale, U.M., Goodale, E., 2019. Is the keystone role of figs maintained across a gradient of increasing human disturbance? *Biotropica* 51 (3), 300–303.
- Pena, J.C.D.C., Martello, F., Ribeiro, M.C., Armitage, R.A., Young, R.J., Rodrigues, M., 2017. Street trees reduce the negative effects of urbanization on birds. *PLoS One* 12 (3), e0174484.
- Rawal, P., Kittur, S., Chatakonda, M.K., Sundar, K.G., 2021. Capital ponds: site-level habitat heterogeneity and management interventions at ponds regulate high landscape-scale bird diversity across a mega-city. *Biol. Conserv.* 260, 109215.
- Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global urban land expansion. *PLoS One* 6 (8), e23777.
- Shackleton, C., 2016. Do indigenous street trees promote more biodiversity than alien ones? Evidence using mistletoes and birds in South Africa. *Forests* 7 (7), 134.
- Shams, Z.I., 2016. Changes in diversity and composition of flora along a corridor of different land uses in Karachi over 20 years: causes and implications. *Urban For. Urban Green.* 17, 71–79.
- Shams, Z.I., Shahid, M., Nadeem, Z., Naz, S., Raheel, D., Aftab, D., Fraz, T.R., Roomi, M. S., 2020. Town Socio-Economic Status and Road Width Determine Street Tree Density and Diversity in Karachi, Pakistan, 47. *Urban Forestry & Urban Greening*, 126473.
- Shanahan, M., So, S., Compton, S.G., Corlett, R., 2001. Fig-eating by vertebrate frugivores: a global review. *Biol. Rev.* 76 (4), 529–572.
- Shivambu, T.C., Shivambu, N., Downs, C.T., 2021. Aspects of the feeding ecology of introduced Rose-ringed Parakeets *Psittacula krameri* in the urban landscape mosaic of Durban, KwaZulu-Natal Province, South Africa. *J. Ornithol.* 162 (2), 397–407.
- Singh, M., Mukherjee, R., Kapoor, P., 2009. *New Delhi, Making of a Capital*. Lustre Press.
- Soh, M.C., Sodhi, N.S., Seoh, R.K., Brook, B.W., 2002. Nest site selection of the house crow (*Corvus splendens*), an urban invasive bird species in Singapore and implications for its management. *Landsc. Urban Plann.* 59 (4), 217–226.
- Stagoll, K., Lindenmayer, D.B., Knight, E., Fischer, J., Manning, A.D., 2012. Large trees are keystone structures in urban parks. *Conservation Letters* 5 (2), 115–122.
- Støstad, H.N., Aldwinckle, P., Allan, A., Arnold, K.E., 2017. Foraging on human-derived foods by urban bird species. *Hous. Theor. Soc.* 64 (2), 178–186.
- Tang, Q., Low, G.W., Lim, J.Y., Gwee, C.Y., Rheindt, F.E., 2018. Human activities and landscape features interact to closely define the distribution and dispersal of an urban commensal. *Evol. Appl.* 11 (9), 1598–1608. <https://doi.org/10.1111/eva.12650>.
- Tiwary, N.K., Urfi, A.J., 2016. Spatial Variations of Bird Occupancy in Delhi: the Significance of Woodland Habitat Patches in Urban Centres, 20. *Urban Forestry & Urban Greening*, pp. 338–347.
- Vavrek, M.J., 2011. fossil: palaeoecological and palaeogeographical analysis tools. *Palaeontol. Electron.* 14. [http://palaeo-electronica.org/2011\\_1/238/index.html](http://palaeo-electronica.org/2011_1/238/index.html).
- Venables, W.N., Ripley, B.D., 2002. *Modern Applied Statistics with S*. Springer.
- Walther, B.A., Geier, J., Chou, L.S., Bain, A., 2018. The figs of winter: seasonal importance of fruiting fig trees (*Ficus: moraceae*) for urban birds. *Acta Oecol.* 90, 28–34.
- Whytock, R.C., Fuentes-Montemayor, E., Watts, K., Barbosa De Andrade, P., Whytock, R. T., French, P., Macgregor, N.A., Park, K.J., 2018. Bird-community responses to habitat creation in a long-term, large-scale natural experiment. *Conserv. Biol.* 32 (2), 345–354.
- Wickham, H., François, R., Henry, L., Müller, M., 2021. *dplyr: a grammar of data manipulation*. R package version 1.0.5. <https://CRAN.R-project.org/package=dplyr>.
- Wood, E.M., Esaian, S., 2020. The importance of street trees to urban avifauna. *Ecol. Appl.* 30 (7), e02149.
- Yan, Z., Teng, M., He, W., Liu, A., Li, Y., Wang, P., 2019. Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization. *Sci. Total Environ.* 650, 335–342.
- Young, K.M., Daniels, C.B., Johnston, G., 2007. Species of street tree is important for southern hemisphere bird trophic guilds. *Austral Ecol.* 32 (5), 541–550.
- Zhou, D., Chu, L.M., 2012. How would size, age, human disturbance, and vegetation structure affect bird communities of urban parks in different seasons? *J. Ornithol.* 153 (4), 1101–1112.

**Update**

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## Erratum

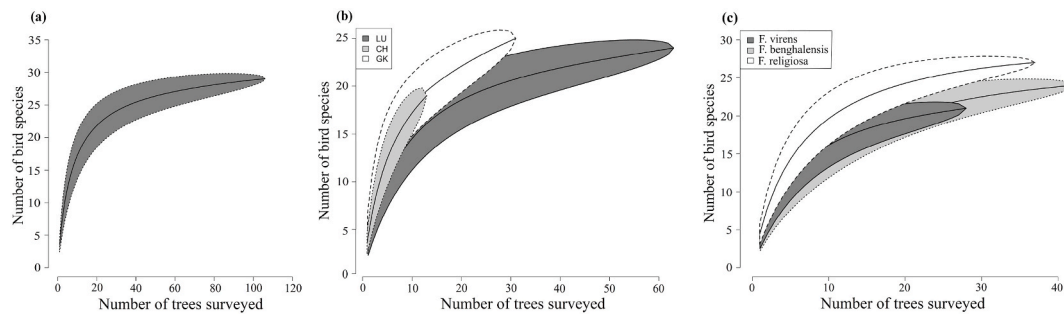
## Corrigendum to 'Micro-scale patterns and drivers of bird visitation on street fig trees in Delhi, India' [Acta Oecol. 118 (2023) 103875]

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**Fig. 3.** Bird species accumulation curves for (a) all the sites combined, (b) the three sites individually, and (c) the three fig species studied.

The authors regret that Fig. 3 presented in the above manuscript is incorrect as we inadvertently uploaded an older version of it. This correction does not affect the results or conclusion presented in the original article. The correct figure is below.

Additionally, in Table S3 of supplementary data, incorrect scientific names have been written for the following species (correct names in

brackets) - Yellow-footed Green Pigeon (*Treron phoenicoptera*), Hume's Warbler (*Phylloscopus humei*), Indian White-eye (*Zosterops palpebrosus*), Coppersmith Barbet (*Megalaima haemacephala*), Oriental Magpie Robin (*Copsychus saularis*), Eurasian Collared Dove (*Streptopelia decaocto*) and Black-rumped Flameback (*Dinopium benghalense*). We regret the same and would like to apologise for any inconvenience caused.

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