Research & Reviews: Journal of
Ecology
ISSN: 2278-2230
Volume 15, Issue 2, 2026
May–August
DOI (Journal): 10.37591/RRJOE
https://journals.stmjournals.com/rrjoe
Research RRJOE

Bird–Tree Associations and Co-Occurrence Patterns in Delhi: Implications for Urban Ecological Restoration and Invasive-Species Management

Anjali Bhardwaj[1], Farid Ahmed[1], Nawin Kumar Tiwary[2], Md Nawazuzzoha[3], Adnan Shakeel[4], Hasan Raja Naqvi[4,*]

Abstract

Urban trees and birds are intertwined indicators of ecological resilience in cities. This study maps citywide bird-tree interactions in Delhi, India, hosting more than 300 avian species. The city was divided into hexagonal grids, and bird–tree data (506 interactions) were collected through field surveys across 131 sites using standardized 1-kilometre transects. Native keystone species, like ficus, supported the greatest bird diversity, while invasive Prosopis juliflora was widely used for perching and vocalization. Native trees contributed significantly to bird richness and behavioral diversity, highlighting their restoration priority. This study is among the first to map bird–tree interaction network and assess its relationship in a megacity, combining bird–bird (mean r = 0.37), plant–plant (mean r = 0.5) and bird–plant (mean r = 0.07) with only 5 pairs exceeding (r = 0.5) co-occurrence analyses with behavior-specific observations. This study offers pertinent facts to inform biodiversity-conscious urban restoration policies in swiftly growing cities. By embedding these patterns within an active Prosopis juliflora canopy-lifting programme, it provides rare, management-ready evidence on how native keystone trees and invasive cover jointly structure urban bird communities.

Keywords: Bird–tree interactions, invasive species, urban ecology, habitat complexity, Delhi city

INTRODUCTION

Bird–tree associations and co-occurrence patterns in Delhi are critical for understanding urban ecological restoration and invasive species management, particularly given the rapid urbanization and its impacts on biodiversity [1, 2]. Research in Delhi highlights how urban green spaces, including street trees and forest fragments, support avian biodiversity, but also face challenges from non-native and invasive plant species [1–3]. Studies have shown that native tree species significantly influence bird communities in urban environments. For instance, Ficus (fig) trees, which are keystone resource providers in tropical landscapes, are a relatively common choice for street trees in Delhi and are associated with bird visitation [2, 4]. The structure of urban green spaces, such as park size and tree canopy cover, also play a crucial role in shaping bird diversity. Larger parks and those with higher mean tree cover generally support greater bird diversity and richness [5, 6]. Moreover, a tree canopy cover exceeding 30% and the presence of native trees are known to enhance bird insectivory and tree biosecurity, supporting ecosystem services like pest control [7, 8]. However, the presence of invasive tree species poses a significant challenge

***Author for Correspondence**
Hasan Raja Naqvi
E-mail: hnaqvi1@jmi.ac.in

[1]Research Scholar, Department of Geography, Faculty of Sciences, Jamia Millia Islamia, New Delhi, Delhi, India
[2]Assistant Professor, Indraprastha College for Women, University of Delhi, New Delhi, Delhi, India
[3]Senior Project Scientist, Centre of Excellence, Climate Change Adaptation, Indian Institute of Technology (IIT), New Delhi, Delhi, India
[4]Assistant Professor, Department of Geography, Faculty of Sciences, Jamia Millia Islamia, New Delhi, Delhi, India

Received Date: May 07, 2026
Accepted Date: July 01, 2026
Published Date: July 01, 2026

Citation: Anjali Bhardwaj, Farid Ahmed, Nawin Kumar Tiwary, Md Nawazuzzoha, Adnan Shakeel, Hasan Raja Naqvi. Bird–Tree Associations and Co-Occurrence Patterns in Delhi: Implications for Urban Ecological Restoration and Invasive-Species Management. Research & Reviews: Journal of Ecology. 2026; 15(2): 1–23p.

to avian biodiversity and ecological restoration efforts in Delhi. *Prosopis juliflora* is a prominent invasive species in the semi-arid regions of India, including Delhi, which has been observed to alternative biodiversity and ecosystem functions [9, 10]. Studies from other regions also emphasize the widespread negative impacts of *Prosopis juliflora* on ecosystems and livelihoods [11–14].

The impact of non-native vegetation on bird communities varies. Some non-native species can provide resources to native fauna, especially in urban areas where native resources are scarce due to biotic homogenization [15]. However, in Delhi, non-native plant forests generally support fewer bird species compared to native forests [3]. The removal of invasive trees has been shown to lead to bird community recovery [16]. For instance, a study examining the removal of *Pittosporum undulatum* in Australia found that bird community composition shifted partially toward reference conditions following removal, although recovery was incomplete and varied among sites [16]. Similarly, controlling invasive species is key to reducing threats to ecosystem viability and can improve the structure of ecological interaction networks [17]. Ecological restoration strategies in urban environments need to consider these complex interactions. Prioritising native tree planting in urban greening initiatives can enhance ecological restoration outcomes by supporting trophic complexity and native bird conservation [18]. This aligns with the concept of urban ecology, which aims to design green infrastructure and manage wildlife to address biodiversity issues in cities [1, 18]. Restoration efforts should focus on recovering historical reference states or at least improving site function, especially in irreversibly altered landscapes [18]. The inclusion of diverse native plant species is crucial for maintaining and enhancing urban bird diversity and ecological health [19, 20].

Furthermore, understanding bird–tree co-occurrence patterns can inform more effective urban forestry practices. Frugivorous birds and fruit trees exhibit strong associations, and analysing these interaction networks in urban parks can reveal structural differences and the role of generalist species [21, 22]. Citizen science data can be valuable in exploring these relationships, helping to identify how species richness and composition of frugivorous birds are linked to fruit tree species in urban settings [21, 22]. The selection of appropriate tree species for urban planting programs is vital. While exotic species might offer ornamental value, their ecological functions and potential invasiveness must be carefully evaluated [15]. High tree species richness and diversity in urban areas, while often associated with increased overall biodiversity, can also increase the availability of suitable hosts for invasive tree pests and pathogens [23]. Therefore, the choice between native and non-native species needs to be balanced, considering both the benefits to native fauna and the risks of introducing or exacerbating invasive species problems [1, 15, 23].

Several pieces of Research show that native plants, especially trees with complex structures, are very important for supporting a wide range of bird groups around the world [24]. Mutualistic networks spanning continents illustrate that keystone tree species directly affect bird diversity and environmental resilience [25]. India is facing more problems on a national level because of urbanization and the proliferation of invasive species. These species are damaging for native bird populations and the quality of their natural habitats. In Delhi, the urban landscape has a unique mix of native and exotic trees that have a direct effect on the birds that live there. There are also efforts to bring back native species and lessen the pressure from invasive species [16]. Our study expands on this nuanced comprehension, concentrating specifically on avian-vegetation interactions within Delhi's urban framework.

Urban ecosystems are important for biodiversity protection, with the interaction between trees and birds acting as a key indicator of ecological health and resilience. Studies show that diverse tree species or polyculture farming practices enhance avian and other biodiversity by offering substantial resources (e.g., food, prey availability, and shelter), thereby improving foraging and nesting opportunities as compared to monoculture plantations [26]. This also applies to urban forest management, as different tree assemblages establish multidimensional habitat niches crucial for sustaining rich bird populations. The structural variety offered by diverse tree species is crucial in urban settings. Polyculture and agroforestry enhance habitat complexity, variety (e.g., tree species diversity), and microclimate regulation, hence improving habitat stand structure due to the stratification of plant layers [26]. This stratification is particularly vital in highly populated metropolitan regions where fragmented green spaces support biodiversity within constrained geographical limits. Individual trees have been extensively researched and are characterized as 'keystone structures' due to their disproportionate impact on the ecosystem relative to the area they occupy [27]. The systematic plantation of trees in urban areas can significantly enhance conservation efforts, especially in fragmented areas.

In 2022, the Delhi government initiated a comprehensive initiative to mitigate the proliferation of the invasive *Prosopis juliflora* (Vilayati Kikar), a prevalent tree on the Delhi Ridge, through "canopy lifting" (pruning the upper canopy) and the introduction of indigenous tree species in its understory [28]. This continuous initiative aims to diminish the dominance of *P. juliflora* without complete eradication, signifying an unparalleled urban habitat management endeavor. In this context, comprehending how Delhi's avifauna employs urban trees, both indigenous and non-native, is particularly relevant. Insight into the use of Vilayati Kikar and other trees as perches, foraging, and calling sites can inform whether such large-scale pruning and replanting efforts will sustain, or disrupt, the city's avifauna.

In Delhi, these ecological questions are inseparable from urban planning and policy. The Ridge and the emerging network of biodiversity parks are being actively redesigned through canopy lifting of *Prosopis juliflora* and under-planting of indigenous trees, while street-tree and park planting schemes are expected to deliver both climate-resilience and biodiversity benefits. Yet planners currently lack city-wide, species-level evidence on which tree assemblages maintain avian diversity, and how invasive structural cover can be removed without creating ecological bottlenecks. By quantifying bird–tree interaction patterns across Delhi and contrasting the roles of native keystone trees and invasive Prosopis, this study provides decision-relevant information for the design of Ridge restoration, biodiversity-park plantings and climate-resilient urban greening strategies.

The objectives of this study are to quantify bird–tree interaction patterns across Delhi's urban landscape, including behavior-specific use (perching, calling, feeding, nesting and fiddling) of each tree species; to identify native and non-native tree species that act as keystone structures for urban birds by comparing the richness and composition of bird assemblages associated with each taxon; and to analyze bird–bird, plant–plant and bird–plant co-occurrence patterns using grid-based Pearson correlation matrices to detect species groups and habitat associations across the city. This study is distinctive in combining fine-scale, citywide bird–tree interaction data with parallel bird–bird, plant–plant, and bird–plant co-occurrence analyses in a highly urbanized megacity. By situating these analyses within Delhi's ongoing canopy-lifting and *Prosopis juliflora* under-planting program, it offers timely, evidence-based insights for invasive-tree management and native-species restoration in dense urban landscapes.

DATA AND METHODS

Study Area

The study was carried out in Delhi, with an area of 1400 km². The city is a part of the central Indo-Gangetic plain, sitting at the junction of strikingly different landscapes. To the west and south, the ancient Delhi Ridge, low hills of hard quartzite, supports dry deciduous woodland dominated by acacias, thorny shrubs and pockets of diverse tree species, offering the city its last vestige of semi-natural forest. Eastward, the land flattens into the Yamuna floodplain, where seasonal inundation creates belts of reed marsh, riparian woodland and a string of recent biodiversity parks that mimic lost wetlands. Scattered among these anchors are irrigated fields on the northern and south-western fringes, plantations of Neem, Sheesham, and Eucalyptus along canals and highways, and long, tree-lined avenues that introduce ornamentals, such as Gulmohar, Amaltas, and royal palm, deep into the urban fabric. Accelerated urban expansion has overlaid Delhi with tightly knit residential enclaves, bustling commercial districts, and an intricate transport network, compressing the landscape into a steep gradient that runs from concrete-dominated city cores to scattered pockets of residual vegetation and peripheral farmland. The city's semi-arid, markedly seasonal climate sharpens this contrast: summer temperatures routinely surpass 45°C, winter nights dip below 5°C, and almost the entire annual rainfall arrives during the brief July–September monsoon. When these climatic swings intersect with persistent air and noise pollution, they create pronounced environmental shifts across surprisingly short distances, making Delhi an interesting setting for studying how biodiversity persists under the pressures of a rapidly growing megacity.

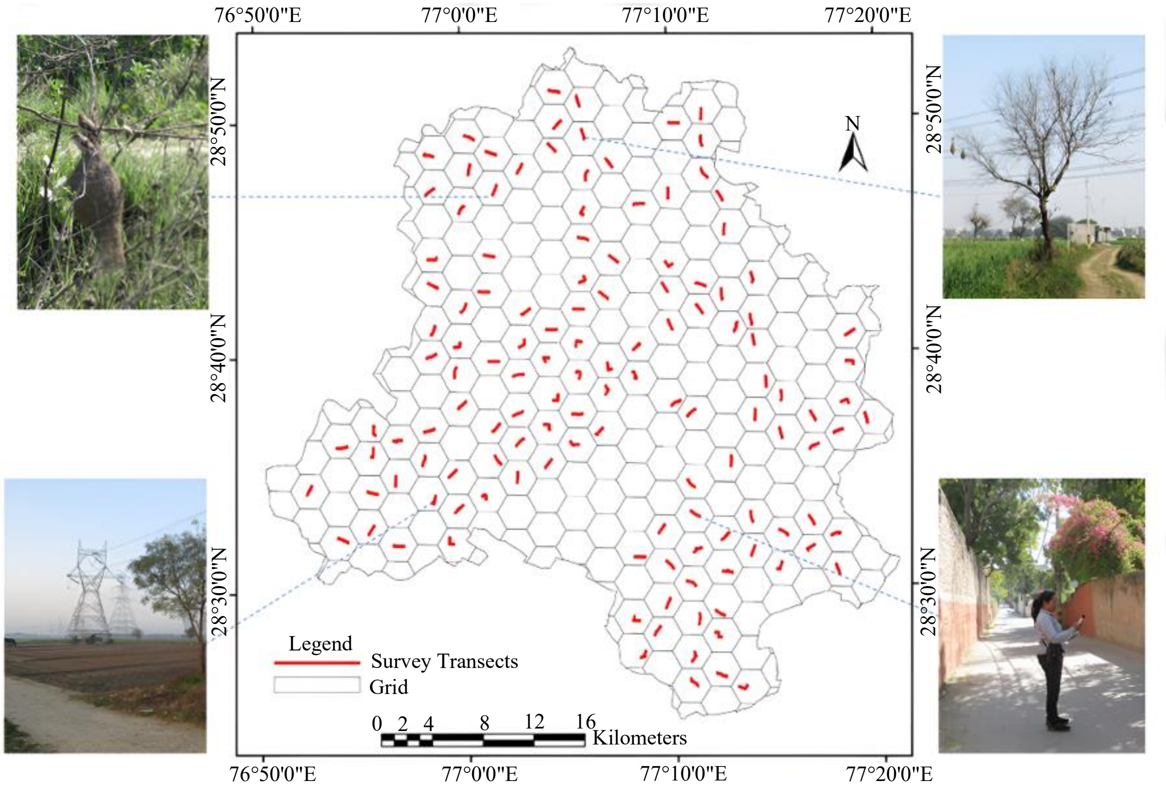


Figure 1. Map of the study area; red lines show the transects walked by the observer to collect the data.

Sampling and Survey

The polylines of transects measuring one km in length were delineated on the Google Earth Android application. Hexagonal grids with an area of 6.25 km² were generated in ArcMap v.10.8 via the Create Tesselation tool. Transects were selected based on logistical feasibility and accessibility, given time and resource constraints. Data collection was conducted on foot by walking the transects within defined grids. The sampling effort involved one individual. The data was collected from early December to mid-March. The designated period for data collection was from sunrise till 11 a.m. Binoculars were used to closely identify bird and plant species, followed by photographic identification of plants using field guides. Each observation encompassed the avian species, the count of individuals, plant species, and the behaviors displayed by the birds over the 131 sampled grids. The data was compiled in Microsoft Excel 2019. The analysis was then carried out using Python from the Anaconda package. The initial step was to clean the information, remove extra space from heads and treat missing information to prepare the set ready for study.

The cleaned data were then transformed into numeric matrices, which represented how often each bird came to each plant, and how often birds and plants occurred at each of multiple locations on grids. These matrices were then used to construct all later analyses of correlation. In an effort to exclude deceptive results due to unusual observations, two filters were applied. The first used only those species which appeared at least three times over all of the data, and the second used an even more stringent threshold of five or more observations. Including these two thresholds, three different levels of analysis were carried out.

Correlation Metrics

Pearson correlation was used on three separate patterns: between bird species, between plant species, and between bird and plant species. For bird–bird correlations, birds were paired together based on which plants they visited. For plant–plant correlations, plants were paired together based on which birds visited them. Separate bird–plant correlations were then calculated for each grid such that comparisons were spatially consistent. Heatmaps were also generated to graphically illustrate the strength of association. Pearson correlation coefficients were calculated using the standard formula, where x_i and y_i represent the abundances of paired species (birds, plants, or bird–plant) in grid i, and $\bar{x}$, and $\bar{y}$ are their respective means across all 131 grids.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where,

- $(x_i - \bar{x})$: How far each x_i is from the average of x (its deviation from the mean).
- $(y_i - \bar{y})$: How far each y_i is from the average of y.
- $(x_i - \bar{x})(y_i - \bar{y})$: Product of deviations; positive if both are above or both below their means, negative if one is above and the other below.
- $\sum(x_i - \bar{x})(y_i - \bar{y})$: Adds up all those products; this is the covariance (up to dividing by $n - 1$).
- The denominator $\sqrt{\sum(x_i - \bar{x})^2}\sqrt{\sum(y_i - \bar{y})^2}$ rescales by the spread (standard deviations) of x and y, so r always lies between -1 and 1.

RESULTS

Descriptive Statistics of Birds Behavior

The dataset contains 506 bird–plant observations spread across six behavioral classes. We distinguished five behavior categories: perching, calling, feeding, nesting and “fiddling”, defined here as within-canopy movement – a bird moving among branches, leaves or twigs inside the tree crown without perching, feeding, calling or nesting. Perching accounts for 293 records (57.9%) and calling for 154 records (30.4%). The remaining behaviors comprise 28 fiddling records (5.5%), 17 feeding records (3.4%), 13 nesting records (2.6%) and 1 mating record (0.2%) (Figure 2).

A small set of bird-behavior pairs explain most of the activity. The single largest pair is House Crow perching, with 89 records (17.6% of all observations), while House Crow calling contributes another 30 records (5.9%). Common Myna shows an almost even split between perching, with 42 records (8.3%), and calling, with 41 records (8.1%), indicating that its preferred perches double as display posts. Additional high-frequency combinations include Red-vented Bulbul perching, with 27 records (5.3%), and calling, with 14 records (2.8%); Black Kite perching, with 45 records (4.9%); and perching by three species: Yellow-footed Green Pigeon, with 16 records (3.2%), Rock Pigeon, with 14 records (2.8%), and Eurasian Collared-Dove, with 13 records (2.6%). Two Jungle Babbler pairs: calling, with 10 records (2.0%), and perching, with 9 records (1.8%), plus calling and perching by Rose-ringed Parakeet and calling by Common Tailorbird, with 7–9 records each (1.4–1.8%), complete the list of fifteen pairs that together account for 70% of all interactions (Figure 2). Behaviors involving direct plant use are infrequent. Feeding events occur mainly in Brown-headed Barbet and House Crow, with 3 records each, and total 17 observations (3.4%). Fiddling, movement among leaves or twigs, peaks in Red-vented Bulbul, with 5 records, but remains marginal overall. Nest-site activity is concentrated in House Crow, with 5 records, and Black Kite, with 3 records, and appears only 13 times in total, while a single mating record (0.2%) involves Brown-headed Barbet (Figure 2).

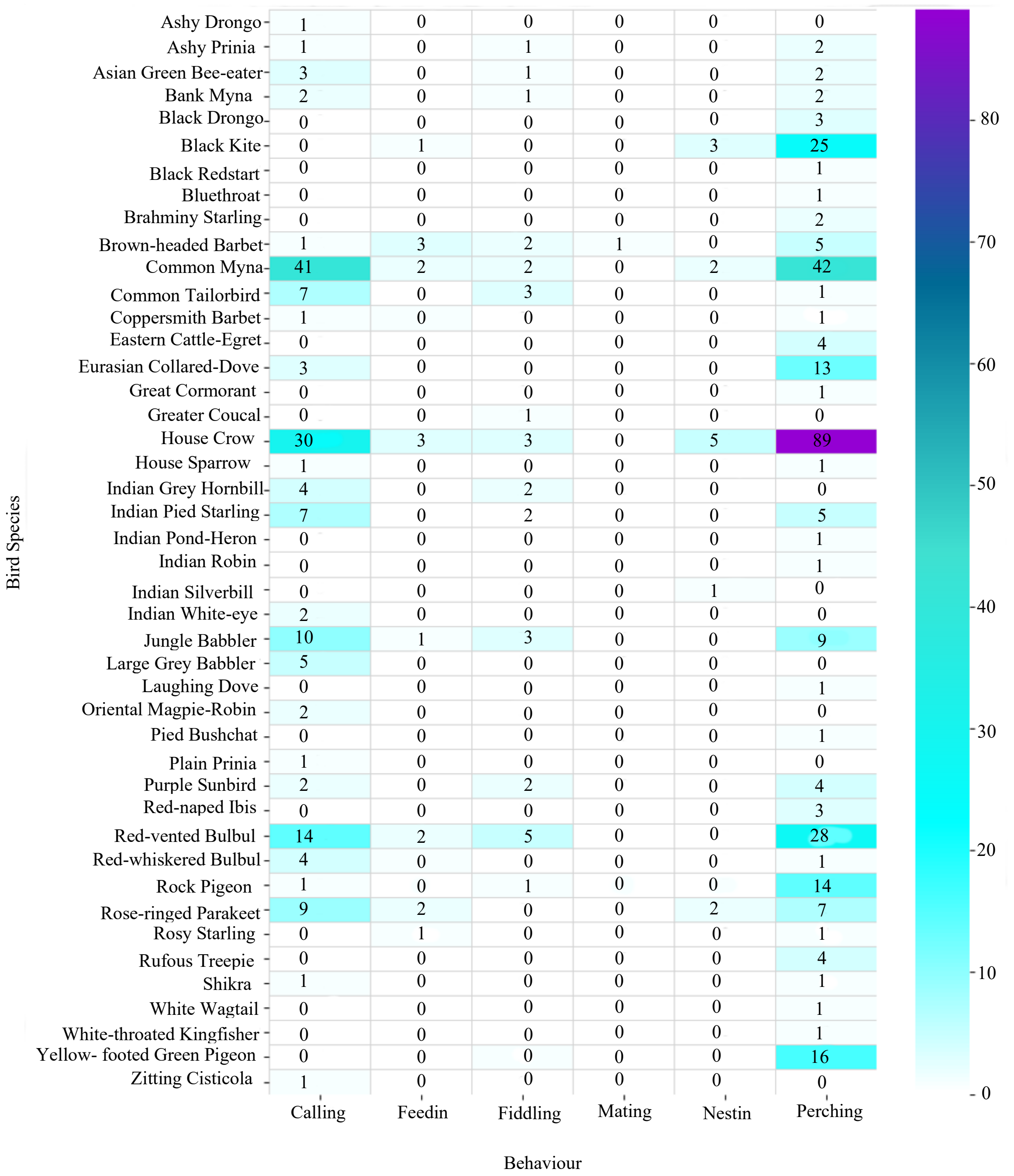


Figure 2. Bird behavior frequency by species in the dataset.

Plant Species Visitor Analysis

Analysis of the plant-centric interaction matrix (n = 34 plant taxa) shows a steep gradient in their attractiveness to birds (n = 44 bird taxa), with a handful of keystone trees supporting disproportionately large avian assemblages and a long tail of sparsely used ornamentals and exotics. At the apex stands Peepal, which provided resources: fruit, foliage or roosting structure, to 23 bird species, making it the single most connected node in the network. Close behind, Neem hosted 20 species, reflecting both its abundant canopy insects and year-round foliage in Delhi's streetscapes. Two functionally similar but primarily exotic taxa: Vilayati Kikar and Eucalyptus spp., shared third position with 19 visitor species each; their high counts testify to the opportunistic exploitation of fast-growing, drought-tolerant cover despite their non-native status. Sheesham hosted 16 species, underscoring the value of riparian hardwoods even where natural riverine corridors have been narrowed or culverted. Semal attracted 11 species, chiefly during its prolific spring flowering. Pilkhan and Banyan supported 8 and 5 species, respectively, confirming the pan-tropical importance of the genus Ficus in sustaining urban wildlife. Other natives in this upper tier included Bakain with 8 species, Saptaparni with 7 and Mulberry with 6, each contributing seasonal fruiting pulses. Widely planted avenue or garden trees, such as Katsagon, Karanj, Gulmohar, and Jamun, each sustained 5–6 bird species, highlighting how diverse planting palettes can broaden foraging options in otherwise built-up grids.

Beyond this point, a substantial drop is evident. Kassod, Subabool, Bougainvillea and Ber each registered 4 visitor species. Ornamental shade trees – such as Silver Oak, Ashoka, and the introduced Sausage Tree – drew 3 species each, suggesting limited but non-negligible ecological utility when woven into mixed plantings. At the lower extreme, Amaltas, Maharukh and Royal Palm supported 2 species each, while ten ornamental or roadside taxa: including Papaya, Kaner, Kadamb, Frangipani, White Frangipani, Chikrassy, Teak, Babool and Weeping Bottlebrush, each recorded only 1 avian associate within the survey window. Although some low counts may reflect seasonal sampling (e.g., off-peak flowering), the consistently sparse use across grids indicates that these ornamentals currently play a minor role in sustaining Delhi's resident bird community (Figure 3).

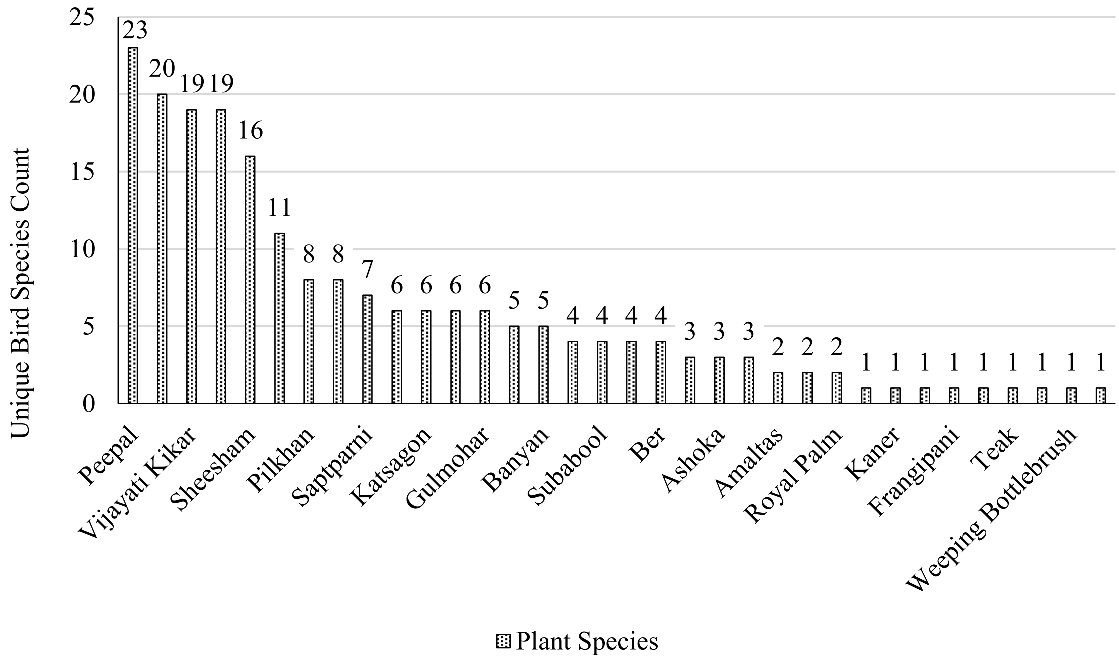


Figure 3. Plant species visited by bird species count.

Strongest Bird–Plant Interactions

The ten strongest bird–plant links, ranked by cumulative bird counts across all grids, illuminate how a small subset of urban-tolerant birds converges on a similarly restricted set of woody hosts, many of them exotic. House Crow foraging or roosting in Eucalyptus groves emerged as the most frequently recorded interaction (57 individuals), underscoring this species' ability to exploit tall, fast-growing exotics that now dominate many avenue plantings. The second-ranked pairing: Rock Pigeon on Vilayati Kikar, with 50 individuals, reveals a comparable synergy between a synanthropic bird and an aggressively invasive tree that offers abundant resting strata in otherwise sparsely vegetated streetscapes. Rock Pigeon also occupied third place in association with Eucalyptus (45 individuals). A more nutritionally driven link appears in the fourth position: Common Myna on Semal, tallying 41 individuals. The profuse spring flowering of Semal furnishes nectar, insects and soft wood, all of which are routinely exploited by mynas. The fifth and sixth pairings returned to the omnipresent House Crow, this time on Neem (37 individuals) and Silver Oak (35 individuals). Rock Pigeon was observed to have a recurrent use of Neem (35 individuals). Asian Green Bee-eater appears twice with Neem (33 individuals) and with Peepal (30) demonstrating how these aerial insectivores track canopy edge habitats rich in flying prey irrespective of the host's native status. House Crow again features in ninth place with Peepal (33), reflecting the fig's year-round fruit and its large boughs suitable for communal roosting (Figure 4).

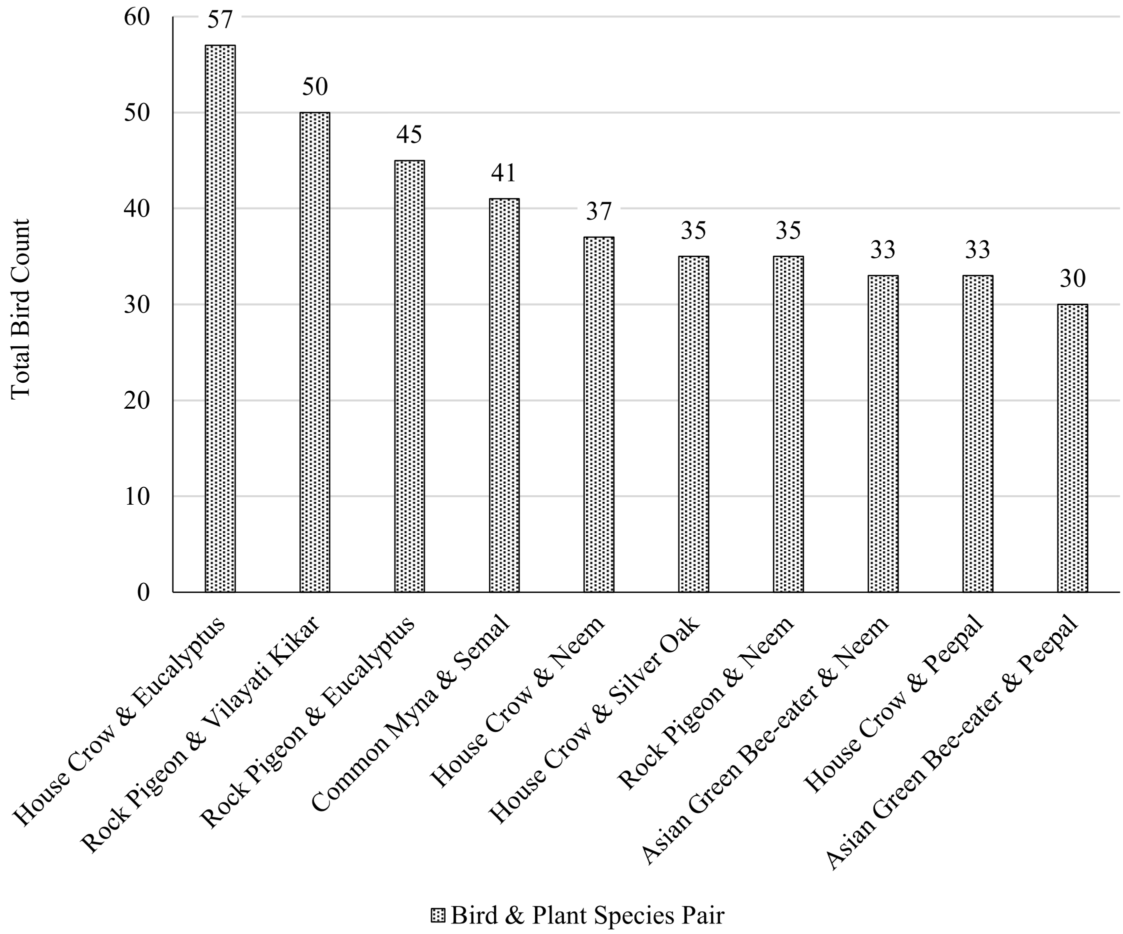


Figure 4. Top 10 strongest bird and plant interaction pairs by total bird count.

Unique Plant Species visited

The interaction matrix revealed pronounced disparities in the breadth of plant use across the 44 bird species recorded. House Crow topped the spectrum, exploiting 26 distinct plant taxa. Common Myna was nearly versatile, associated with 23 taxa. A second tier of broad generalists comprised Red-vented Bulbul (14 taxa), Rose-ringed Parakeet (13) and Jungle Babbler (11); each is a common resident that readily shifts between fruiting avenues, ornamental hedges and native groves, and their double-digit tallies reflect that flexibility. In the mid-range, both Rock Pigeon and Black Kite interacted with 9 taxa. Comparable breadth was recorded for Yellow-footed Green-Pigeon and Common Tailorbird, each linked to 8 taxa, and for Brown-headed Barbet, which visited 7. Three species: Eurasian Collared-Dove, Indian Pied Starling and Purple Sunbird, were observed on 6 taxa apiece. The lower-mid segment, with 4 taxa each, included Rufous Treepie, Red-whiskered Bulbul, Ashy Prinia, Indian Grey Hornbill and Bank Myna. Eastern Cattle-Egret, Large Grey Babbler, Coppersmith Barbet and Asian Green Bee-eater each used 3 taxa, representing an even more circumscribed breadth. Species recorded on only 2 taxa, Shikra, Rosy Starling, Brahminy Starling, Black Drongo and Red-naped Ibis, occupied a transitional position between moderate plasticity and single-resource dependence (Figure 5).

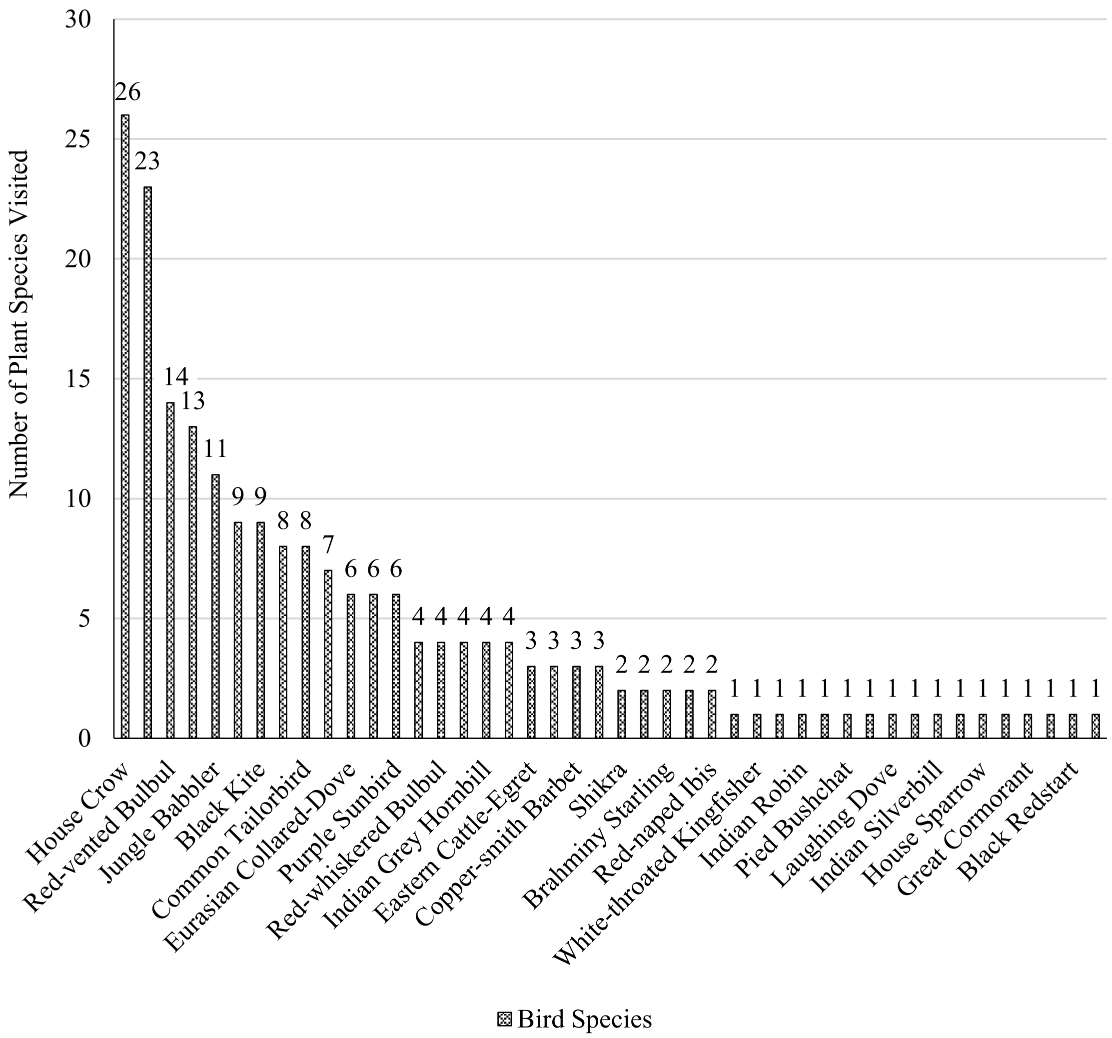


Figure 5. Number of unique plant species visited by each bird species.

Taken together, the data depict a strongly right-skewed distribution of plant use: a small cadre of highly adaptable generalists shoulders most interactions, while fully half of the assemblage exhibits markedly limited plant associations. Such asymmetry is typical of urbanized landscapes where a few winner species capitalize on heterogeneous, human mediated food supplies, whereas many others persist only where preferred plant resources remain intact (Figure 6).

Pearson Correlation Analyses

Pairwise Pearson correlation coefficients were calculated for bird and plant species abundances across the survey grids to quantify the degree of linear co-variation in their spatial distributions. This metric is widely used in community-ecology studies because it (i) enables symmetric, scale-independent comparison of interaction strength among taxa with disparate absolute counts, (ii) captures both positive and negative associations, thereby discriminating potential facilitative links from putative competitive or habitat-segregation patterns, and (iii) remains computationally straightforward, facilitating transparent replication of results. Implementing a minimum-record threshold prior to coefficient estimation further mitigated small-sample bias, ensuring that the derived correlations reflect ecologically substantive patterns rather than artifacts of sparse observations. Collectively, this analytical framework provides a statistically robust and conceptually tractable basis for identifying the most consequential bird–plant pairings and for guiding subsequent multivariate or mechanistic investigations. The python code used for all analyses is provided as a Jupyter notebook in the supplementary material.

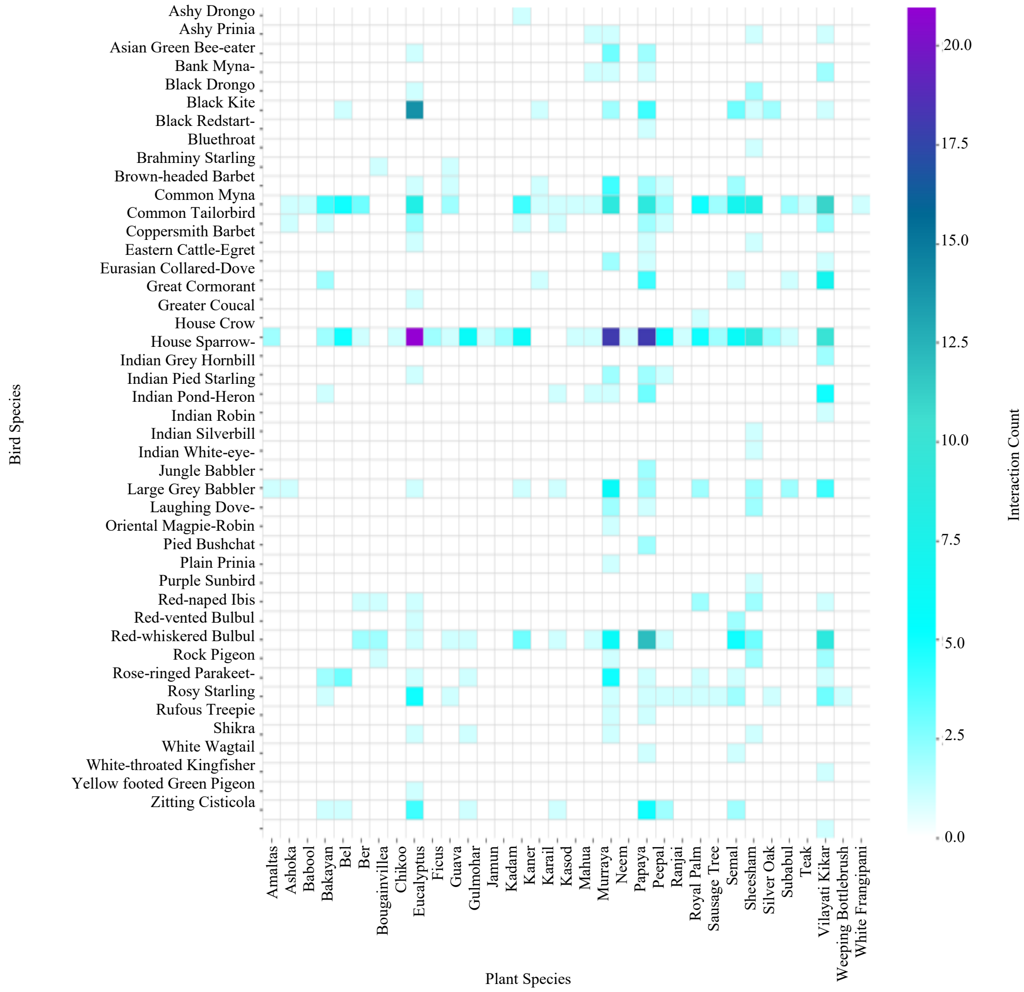


Figure 6. Bird and plant species interaction with heat map.

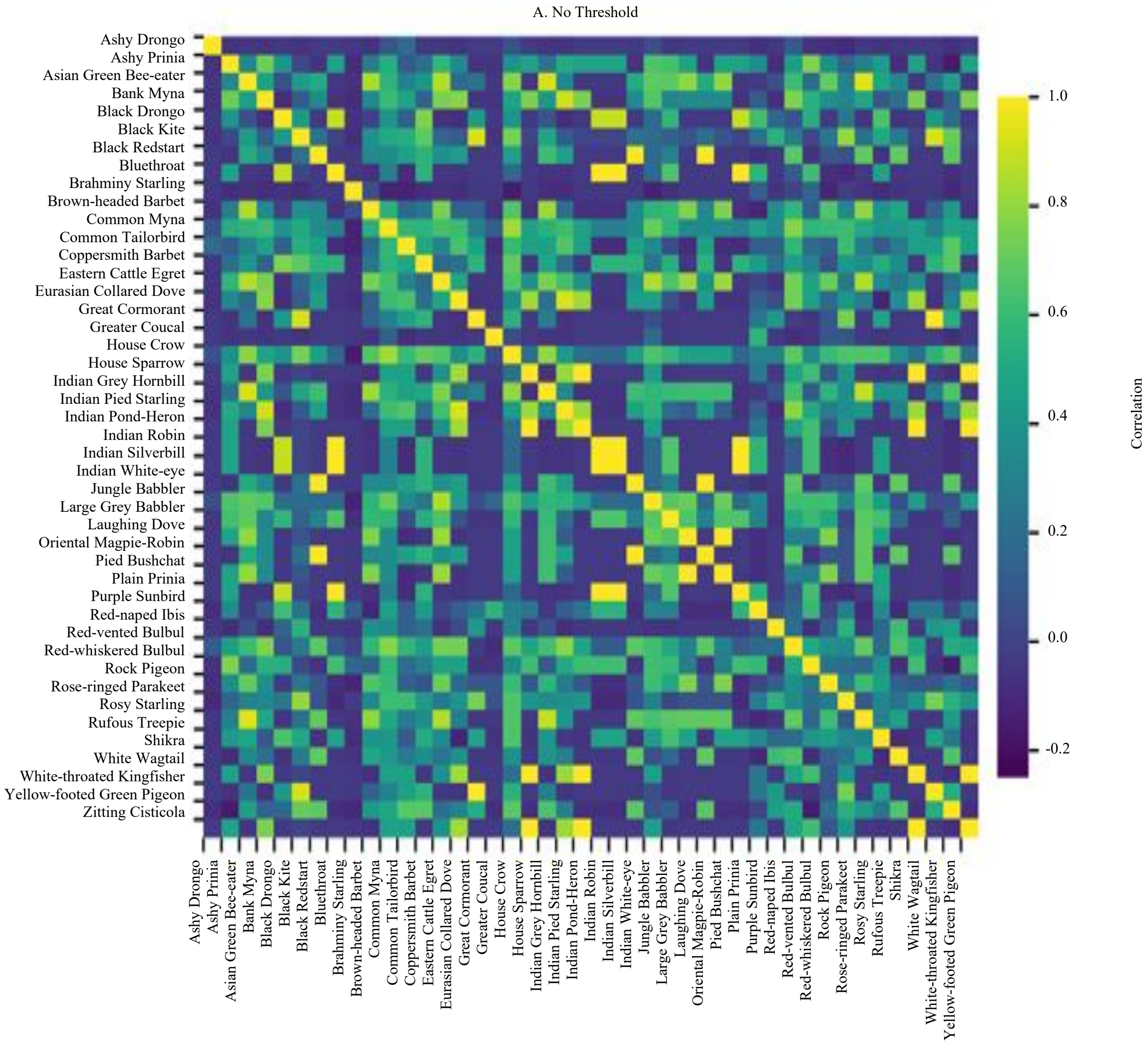
Bird–Bird Pearson Correlation

No Threshold

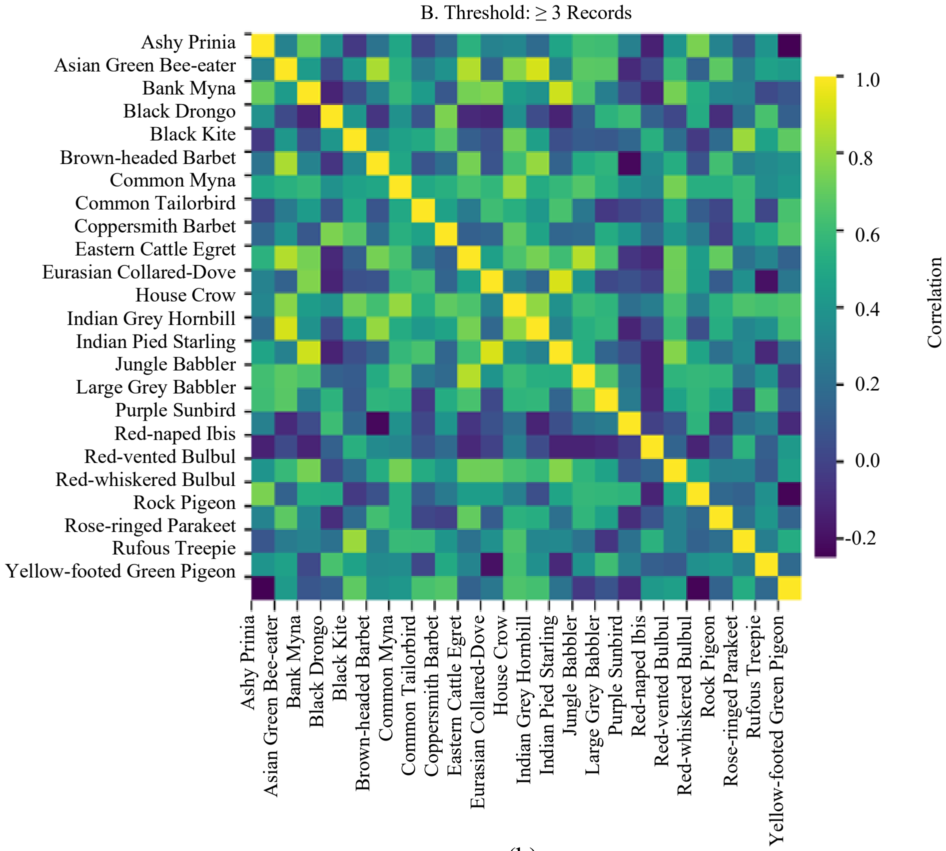
The 44*44 Pearson matrixes divide naturally into four strength classes. Strong positive associations ($r \geq 0.70$) are limited to 79 species pairs: 8% of the 946 unique combinations, but they convey nearly all the biologically meaningful structure in the data. Within this group, exactly fifteen pairs achieve a perfect correlation of $r = 1.00$: for example, House Sparrow with Indian Pond-Heron, Black Redstart with Indian White-eye, and Bluethroat with Indian Robin. Beyond the perfect set, the upper tail includes Asian Green Bee-eater and Rosy Starling ($r = 0.94$), Eurasian Collared-Dove and Indian Pied Starling (0.93), and Black Kite matched at 0.92 with both Great Cormorant and White-throated Kingfisher. Moderate positive correlations ($0.30 \leq r < 0.70$) encompass 138 pairs, about 15% of the matrix. These coefficients capture looser but still appreciable habitat overlap: Black Kite with Common Myna ($r \approx 0.55$), Ashy Prinia with Purple Sunbird (≈ 0.46), and Bank Myna with Plain Prinia (≈ 0.41). The matrix is dominated by weak or near-zero associations ($–0.29 \leq r < 0.30$), totaling 567 pairs (60%). The mean coefficient in this band is essentially zero (0.02 ± 0.11 SD (Figure 7(a)).

Threshold: ≥3

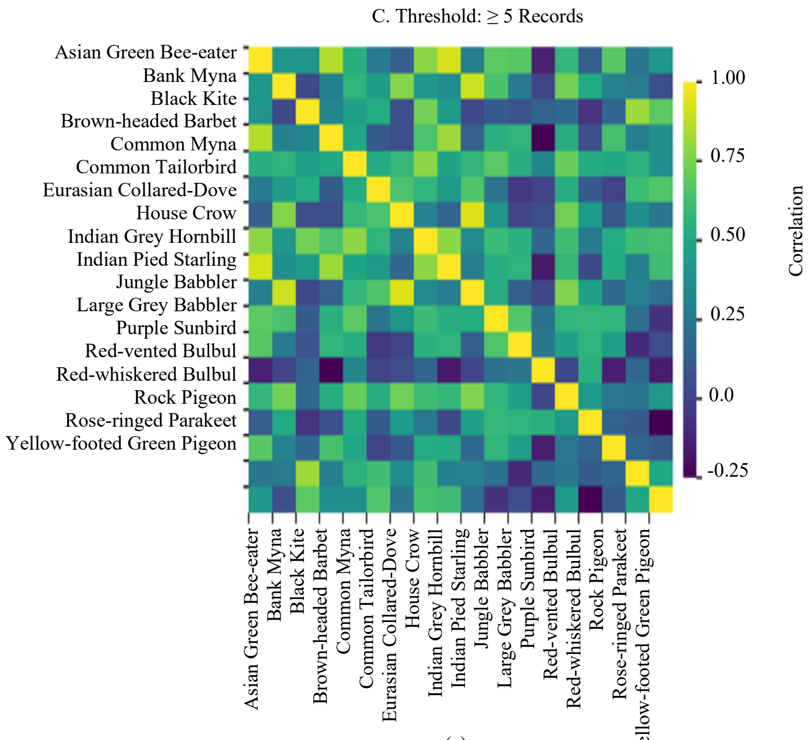
Applying the three-records threshold retained 24 bird species, those that occurred in at least three observations, produced 276 pairwise Pearson coefficients. The coefficients span 0.26 to +0.92 and are strongly skewed toward positive values (mean = 0.31, median = 0.30, SD = 0.24). No pair falls below –0.30, confirming that statistically meaningful spatial avoidance is absent at this spatial grain once very rare species are removed.24 pairs (9% of the matrix) meet or exceed the 0.70 threshold. The highest correlation is observed between Eurasian Collared-Dove and Indian Pied Starling (r = 0.92). Other notable dyads include Asian Green Bee-eater with Indian Grey Hornbill (0.92), Bank Myna with Indian Pied Starling (0.90), Eastern Cattle-Egret with Jungle Babbler (0.86), Asian Green Bee-eater with Brown-headed Barbet (0.84), and Black Kite with Rose-ringed Parakeet (0.81). Several corvid-passerine pairs also register as strong: Common Myna with House Crow (0.80) and House Crow with Indian Grey Hornbill (0.79). A further 129 pairs (47%) fall in the moderate band. Mid-range coefficients (0.55–0.68) repeatedly tie canopy-nesting or cavity-nesting specialists such as Indian Grey Hornbill, Brown-headed Barbet and Red-vented Bulbul to structurally similar companions: Sausage Tree, Bakain and other large, crowned trees. Lower-moderate values (0.30–0.55) link generalists (Plain Prinia, Ashy Prinia) to urban-edge associates like Bank Myna and Rosy Starling. The remaining 123 pairs (44%) cluster tightly around zero, with a mean coefficient of 0.05 ± 0.09 SD. Typical examples include Purple Sunbird versus House Crow (r ≈ 0.07) and Black Drongo versus Rock Pigeon (≈ 0.04). Because these values are small and evenly distributed, they indicate that most retained species vary independently once extremely infrequent co-occurrences are excluded. The lowest coefficient, Ashy Prinia versus Black Kite (–0.26), remains far above the –0.50 threshold usually interpreted as evidence of active segregation (Figure 7(b)).



(a)



(b)



(c)

Figure 7. Bird–Bird correlation for all three thresholds.

Threshold: ≥5

After limiting the analysis to species recorded in at least five observations, the bird–bird matrix contains 18 species and all 153 pairwise Pearson coefficients. Values extend from –0.29 to 0.93, with a mean of 0.37 and a median of 0.41, showing a clear tilt toward positive co-occurrence. Standard deviation is 0.27, so most coefficients cluster within roughly a quarter-unit of the mean and only a small fraction approach the extremes. Fifteen pairs exceed the strong-association threshold of 0.70.

The tightest link joins Eurasian Collared-Dove and Indian Pied Starling with a coefficient of 0.93, indicating that these two species occupy almost the same habitats. Asian Green Bee-eater and Indian Grey Hornbill follow at 0.92, Bank Myna and Indian Pied Starling at 0.90, and Asian Green Bee-eater with Brown-headed Barbet at 0.86. A value of 0.82 couples Brown-headed Barbet with Indian Grey Hornbill, while Black Kite pairs with Rose-ringed Parakeet at 0.82. Common Myna aligns with House Crow at 0.79, House Crow with Indian Grey Hornbill at 0.79, and Asian Green Bee-eater with House Crow at 0.78. Remaining strong links include Bank Myna with Eurasian Collared-Dove at 0.77, Indian Pied Starling with Red-vented Bulbul at 0.76, Black Kite with House Crow at 0.73, Bank Myna with Red-vented Bulbul at 0.73 and Eurasian Collared-Dove with Red-vented Bulbul at 0.73.73 coefficients fall in the moderate band between 0.30 and 0.69.

The upper part of this range includes Black Kite with Yellow-footed Green Pigeon at 0.69, Common Myna with Jungle Babbler at 0.69, Asian Green Bee-eater with Jungle Babbler at 0.68 and Asian Green Bee-eater with Rock Pigeon at 0.68. Coefficients near 0.65 link Common Tailorbird with Yellow-footed Green Pigeon, Jungle Babbler with Large Grey Babbler and Brown-headed Barbet with House Crow.65 pairs are weak or near-zero, lying between minus 0.29 and plus 0.29. The average within this band is 0.05 with a spread of 0.09, indicating that once rare species are excluded, most birds vary independently across the grids. No coefficient breaches that negative threshold, so meaningful avoidance is absent at this scale (Figure 7(c)).

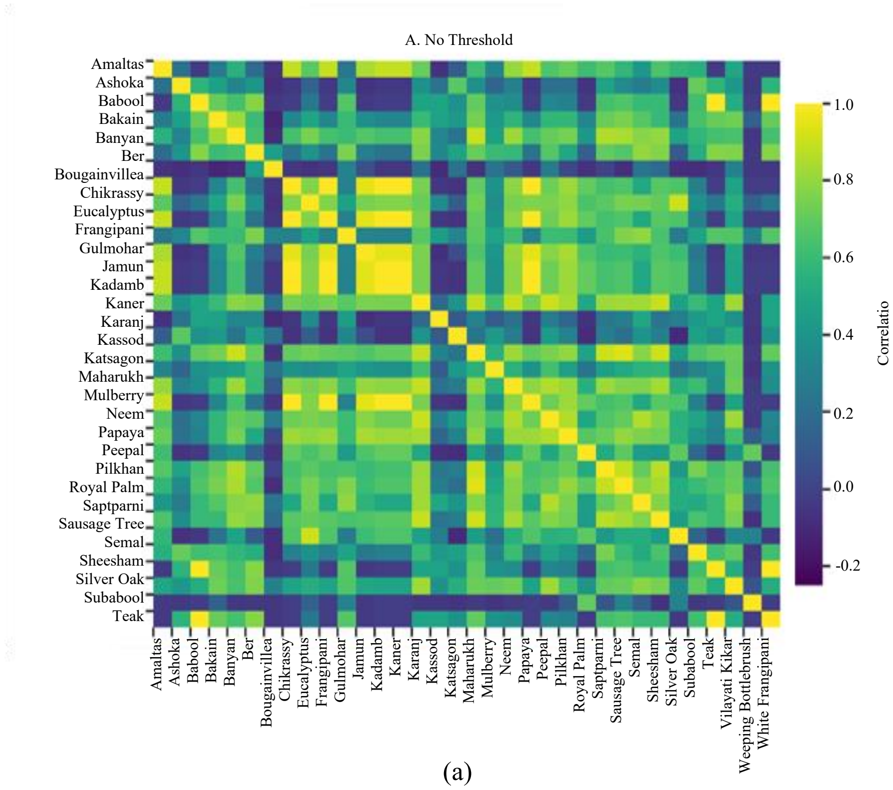
Plant–Plant Pearson Correlation

No Threshold

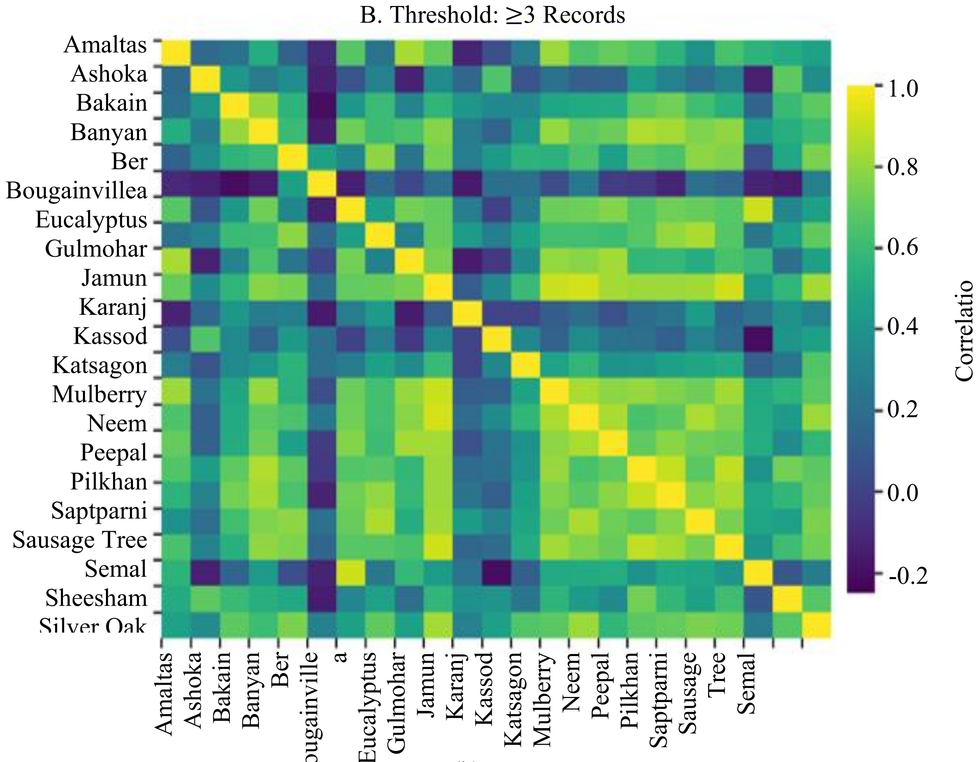
The plant–plant correlation matrix, calculated for 34 species, contains 561 unique Pearson coefficients ranging from –0.12 to +1.00. The distribution is markedly skewed to the positive side (mean = 0.46, median = 0.51, SD = 0.31), indicating that most species tend to co-occur rather than segregate at this spatial grain. A small but ecologically revealing upper tail comprises 18 strongly positive pairs ($r \geq 0.95$; 3.2% of all combinations). Thirteen of these are perfect ($r = 1.00$). The first clique links Babool, Teak, and White Frangipani. The second larger clique joins the ornamentals Chikrassy, Frangipani, Kadamb, Kaner and Papaya. Five additional very high coefficients ($r \approx 0.95$) bridge this ornamental cluster to Jamun.Below this threshold lie 266 moderate positive correlations ($0.50 \leq r < 0.95$; 47% of the matrix). Coefficients in the 0.70–0.90 range typically connect Banyan with Bakain, and Bougainvillea and Kaner with Babool. Values between 0.50 and 0.70 links Eucalyptus and Jamun to several less common companions. The bulk of the matrix: 275 pairs (49%), falls in a weak or near-zero band ($–0.10 < r < 0.50$). Here, coefficients cluster tightly around zero. Only two pairs show even modest negative association (Bakain versus Bougainvillea and Katsagon versus Silver Oak, $r \approx –0.12$), far from the conventional 0.50 threshold that would signal competitive exclusion; negative structure is, therefore, negligible at the grid scale (Figure 8(a)).

Threshold: ≥3

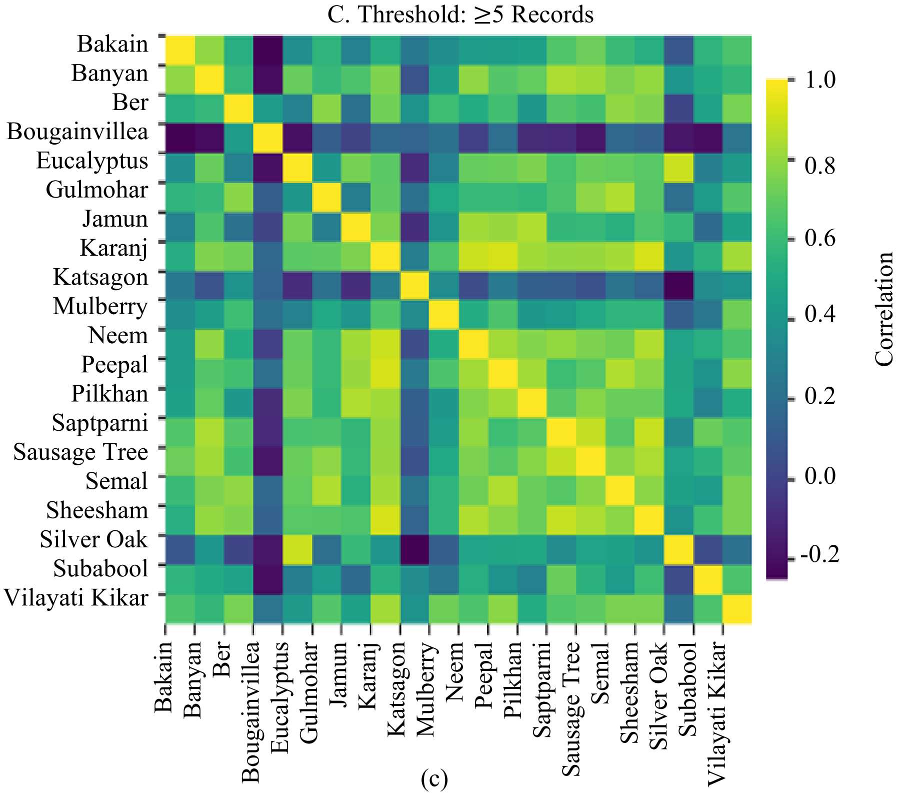
After imposing the ≥ 3 records filter, the plant dataset is reduced to 23 species occurring in at least three observations each. Their pair wise matrix now contains 253 Pearson coefficients, spanning –0.21 to +0.92 and strongly biased toward positive values (mean = 0.47, median = 0.51, SD = 0.28). No perfect ($r = 1.00$) matches remain, confirming that the threshold successfully removed results driven by single-site coincidences. Strong co-occurrence ($r \geq 0.70$) is still prominent: 63 pairs, or one quarter of the matrix, exceed this cut-off. Karanj aligns almost perfectly with Peepal ($r = 0.92$), Sheesham (0.91) and Neem (0.90). Exotic avenue trees also cluster tightly: Eucalyptus with Silver Oak (0.90), while mature shade assemblages link Saptparni simultaneously to Sausage Tree (0.89), Sheesham (0.88) and Banyan (0.85). Moderate positive associations ($0.30 \leq r < 0.70$) account for 116 pairs (46%). Jamun pairs at $r \approx 0.63$ with Peepal and Neem, and Bougainvillea groups at 0.50–0.65 with Subabool and Vilayati Kikar. Weak or near-zero correlations ($–0.10 < r < 0.30$) make up 74 pairs (29%). Here, species co-occur too erratically for any pattern to emerge once rarity is discounted; for instance, Ashoka and Sheesham register r ≈ 0.04. Negative links are both scarce and mild, only 20 coefficients fall below zero, the lowest being Katsagon (Pterocarpus marsupium) against Silver Oak at r ≈ –0.21. Even these negative tails remain far above the –0.50 threshold for meaningful spatial segregation, underscoring that competitive exclusion among tree species is negligible at the 6.25 km² grid scale (Figure 8(b)).



(a)



(b)



(c)

Figure 8. Plant–plant Pearson correlation heatmap for all three thresholds.

Threshold: ≥5

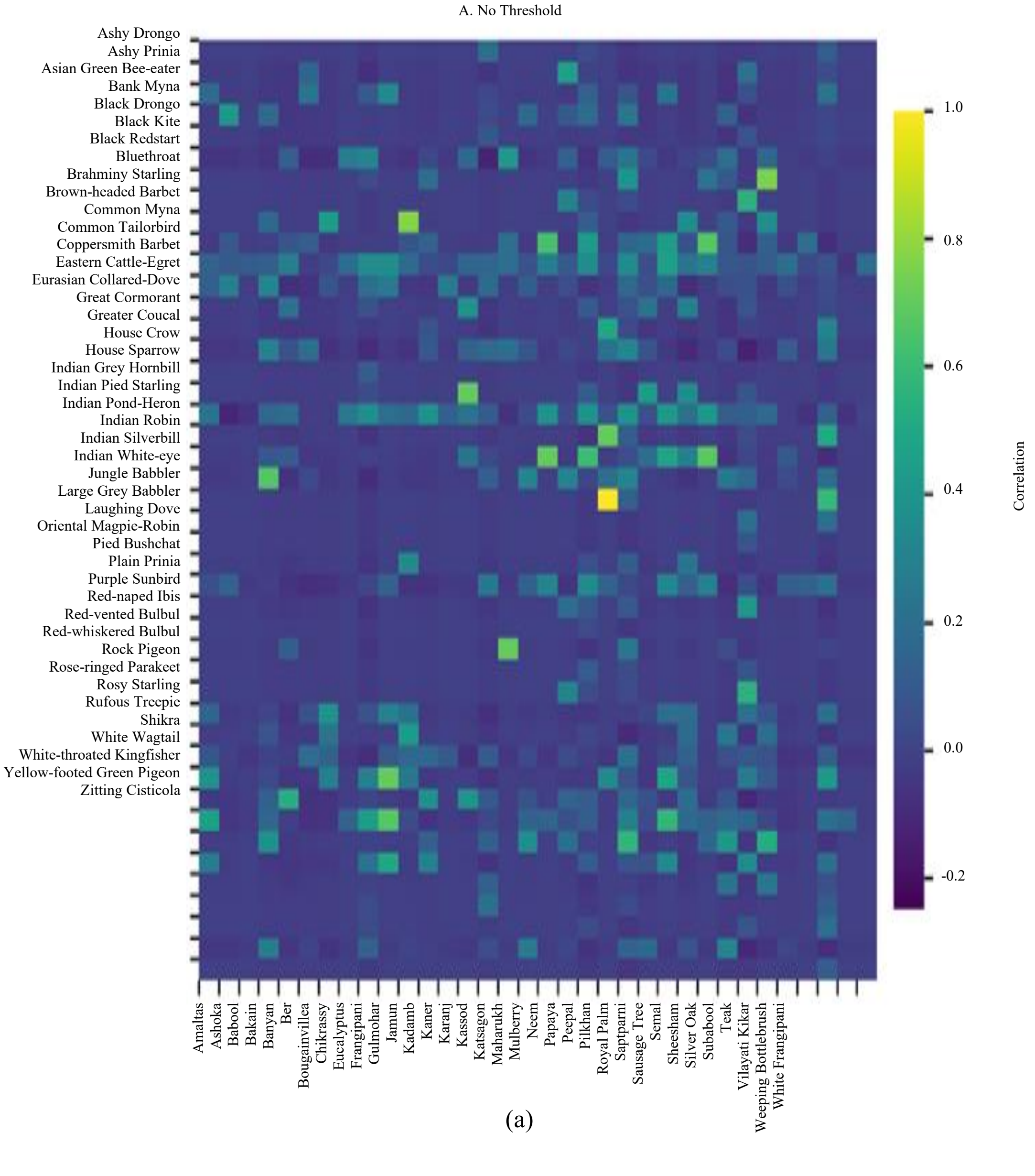
Imposing the five-record threshold retains 20 tree species and generates 190 Pearson coefficients. The coefficients extend from –0.302 to 0.920, average 0.503 with a standard deviation of 0.284, and the median is 0.570, confirming a strong overall tendency for the species to co-occur rather than segregate at the scale. Positive structure is especially pronounced: fifty-six pairs, just under thirty per cent of the matrix, reach or exceed the strong-association benchmark of 0.70, whereas only a single pair: Katsagon with Silver Oak at minus 0.302 falls into the negative domain. The tightest link couples Karanj with Peepal at 0.920 and is matched almost exactly by Karanj with Sheesham at 0.919. Eucalyptus aligns with Silver Oak at 0.900, Karanj matches Neem at 0.899, and Saptparni pairs with Sheesham at 0.891 and with Sausage Tree at 0.887. Old-growth shade trees contribute several further high values: Peepal relates with Semal at 0.850, Jamun joins Pilkhan at 0.850, Neem again joins Sheesham at 0.850, and Gulmohar joins Semal at 0.850. Moderate positive associations, defined here as coefficients from 0.30 up to 0.69, account for 87 additional pairs. Typical examples are Jamun with Neem at 0.622, Pilkhan with Banyan at 0.605, and Bougainvillea with Neem at 0.566.46 pairs lie in the weak or near-zero band between –0.30 and 0.30. The average within this class is roughly 0.070. Bakain with Bougainvillea illustrates the low end at minus 0.300, whereas Ashoka with Sheesham registers 0.040 near the centre of the distribution. The dataset, therefore, contains a distinct, management-driven stratum of 56 strongly co-occurring pairs, a broader but weaker layer of moderately positive links, and virtually no evidence of competitive exclusion (Figure 8(c)).

Bird–Plant Pearson Correlation

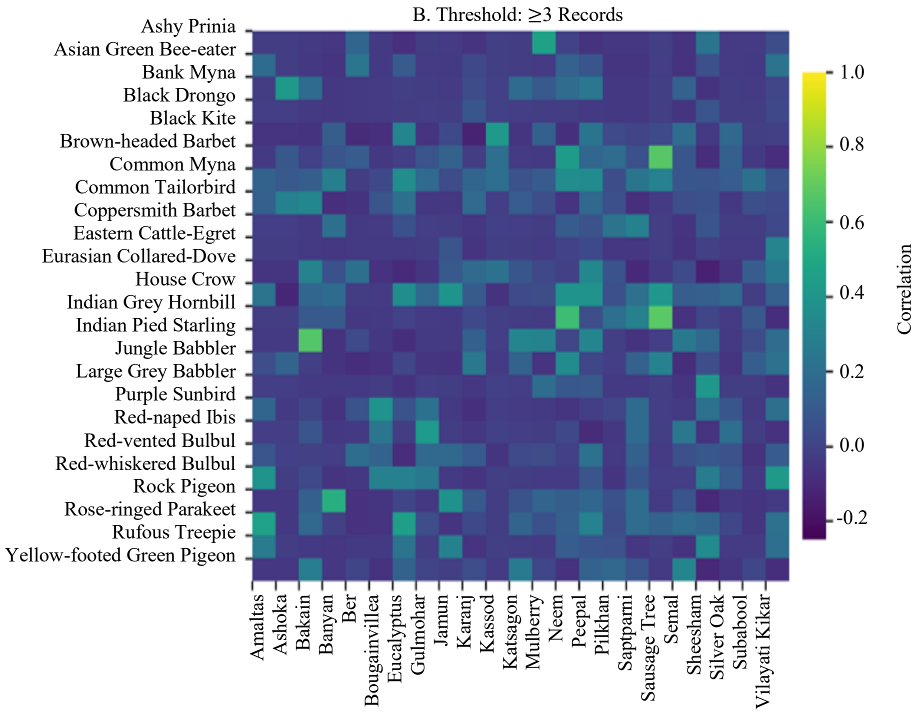
No Threshold

The bird–plant cross-correlation matrix links 44 bird species with 34 plant taxa, yielding 1496 Pearson coefficients that range from –0.14 to +1.00 (mean = 0.03, median ≈ –0.02, SD = 0.13). The distribution is sharply peaked around zero, but a narrow positive tail contains the few biologically interpretable links. Eight pairs (0.5% of all combinations) reach $r \geq 0.70$. One is perfect: Indian Pond-Heron and Papaya ($r = 1.00$). The remaining high-end links span $r = 0.70$–0.78. Brahminy Starling with

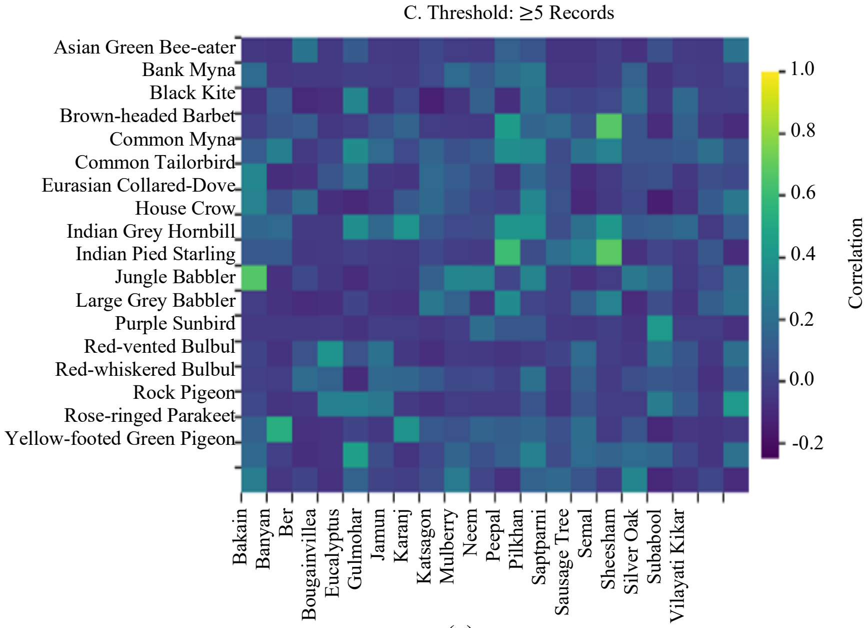
Gulmohar (0.77), Black Redstart with Silver Oak (0.75), Red-whiskered Bulbul with Frangipani (0.71), Indian Grey Hornbill with Maharukh (0.71), Greater Coucal with Kaner (0.70), Oriental Magpie-Robin with Kassod (0.70) and House Sparrow once more with Papaya (0.70). All involve fleshy fruit, sheltered understorey, or rich arthropod prey, suggesting shared micro-habitat rather than direct facilitation. Seventy-five additional pairs fall in the moderate positive band ($0.30 \leq r < 0.70$). The strongest of these links canopy-nesting or cavity-nesting birds to large, architecturally complex trees: Indian Grey Hornbill (0.68) and Brown-headed Barbet (0.67) both peak with the Sausage Tree, while Indian Pied Starling matches Bakain at 0.67. Mid-range coefficients (0.55–0.60) bind species such as Indian Pond-Heron and House Sparrow to Vilayati Kikar, and passerines: Rosy Starling, Plain Prinia, Bluethroat, to Sheesham and Silver Oak. Slightly lower but still notable links pair Rose-ringed Parakeet with both Royal Palm (0.58) and Frangipani (0.67). Weak or near-zero correlations ($-0.30 < r < 0.30$) dominate the matrix, accounting for 1413 pairs (94%) (Figure 9(a)).



(a)



(b)



(c)

Figure 9. Bird–Plant Pearson correlation heatmap for all three thresholds.

Threshold: ≥3

Applying the three-record filter yields a bird–plant matrix with 552 coefficients for 24 bird species and 23 tree taxa. Values run from –0.14 to 0.68, cluster tightly around zero (average 0.053, standard deviation 0.14) and show no evidence of strong negative association. Although no pair reaches the strong-link threshold of 0.70, thirty-seven combinations sit in the moderate zone between 0.30 and 0.68 and, therefore, merit attention. The single highest coefficient, 0.68, ties Indian Grey Hornbill to Sausage Tree, a cavity-rich species whose large pods and broad canopy evidently attract repeated use by this specialized frugivore. Brown-headed Barbet shows a nearly equal affinity for the same tree, registering 0.67, and Indian Pied Starling aligns most closely with Bakain at 0.67. Other notably high pairs include Indian Grey Hornbill with Neem at 0.61 and Rock Pigeon with Banyan at 0.54, pointing to tall, old-growth trees that provide both shelter and food resources. Two Rose-ringed Parakeet links stand out: Amaltas scores 0.47 and Eucalyptus 0.45. Ashy Prinia joins Mulberry at 0.46, while Red-naped Ibis pairs with Gulmohar at 0.43. Black Kite and Kassod yield 0.43 and Red-whiskered Bulbul reaches 0.43 with Vilayati Kikar. The remaining moderate coefficients fall between 0.30 and 0.42. Examples include Bank Myna with Ashoka at 0.42, Large Grey Babbler with Sheesham at 0.42, and House Crow with Eucalyptus at 0.36; Common Myna shows a consistent but weaker signal with Neem at 0.36, Eucalyptus at 0.36 and Peepal at 0.35. Eurasian Collared-Dove matches Peepal at 0.33, while Common Tailorbird aligns with Bakain at 0.32. All other bird–plant pair's exhibit coefficients below 0.30 in absolute magnitude, indicating statistical independence at the 6 km^2 grid scale. The lowest value, –0.14, links Eurasian Collared-Dove to Sheesham and is far removed from the –0.50 benchmark for meaningful spatial segregation (Figure 9(b)).

Threshold: ≥5

Filtering the cross-taxon matrix to species recorded in at least five observations leaves 18 birds, 20 tree species, and 360 bird–plant pairs. Pearson coefficients extend from –0.14 to 0.68, cluster tightly around zero (mean 0.07, median 0.03, standard deviation 0.14) and show no evidence of strong negative association. Only five links exceed the mid-level mark of 0.50: Indian Grey Hornbill with Sausage Tree scores 0.68, Brown-headed Barbet with the same tree 0.67, Indian Pied Starling with Bakain 0.67, Indian Grey Hornbill with Neem 0.61 and Rock Pigeon with Banyan 0.54. 24 additional pairs lie in the softer positive band between 0.30 and 0.49; the upper edge of this group includes Rose-ringed Parakeet with Eucalyptus at 0.45, Brown-headed Barbet with Neem at 0.44, Red-whiskered Bulbul with Vilayati Kikar at 0.42, Large Grey Babbler with Sheesham at 0.42 and House Crow with Sausage Tree also at 0.42. The remaining 331 coefficients fall between –0.14 and 0.29, confirming statistical independence for most bird–tree combinations. The weakest value, –0.14, links Eurasian Collared-Dove to Sheesham and is far above the conventional –0.50 threshold used to flag spatial segregation (Figure 9(c)).

DISCUSSION

The ongoing removal and pruning of Vilayati Kikar (*Prosopis juliflora*) in Delhi's urban forests is driven by evidence that invasive-dominated stands can depress overall biodiversity. For instance, areas with very high Vilayati Kikar density in semi-arid India support lower bird richness and lose many sensitive species, retaining mostly generalist birds like pigeons and sparrows. Our study confirms that the tree currently provides important structural habitat for several urban birds – we recorded synanthropic species, such as the Rock Pigeon, extensively using Vilayati Kikar for roosting and territorial calls [29–31]. House Sparrows and Indian Pond-Herons also showed strong positive associations with this invasive tree in our surveys [32, 33]. These observations raise concerns that aggressive canopy pruning of Vilayati Kikar, if not carefully managed, could temporarily diminish perching and calling opportunities for these birds. In the absence of equally functional native replacements, birds may be forced to shift their ranging and behavior, potentially vacating pruned areas until alternative foliage matures [34]. To mitigate such impacts, we recommend a staggered pruning schedule and adaptive management approach. Restoration programs should be phased in space and time so that some stands of Vilayati Kikar (or their canopy structure) are retained while new native saplings establish, thereby providing continuous habitat for birds during the transition [16].

Concurrently, behavior-based monitoring should be integrated into the project: birds are rapid indicators of habitat change [16] and tracking their perch use, calling behavior, and site fidelity can reveal if the pruned areas continue to meet their ecological needs. If significant declines in bird activity are observed post-pruning, management should adjust by, for example, slowing the removal rate or enhancing habitat structure (e.g., installing perching poles or conserving select old trees as "framework" species) [35].

However, without lush crowns, those pruned trees offer only limited bird support until native saplings grow tall. In summary, urban forest restoration must balance invasive species control with wildlife habitat preservation. Delhi's Vilayati Kikar initiative provides a test case for bird-friendly invasive management in cities. Our evidence suggests that maintaining a patchwork of old and new growth - rather than indiscriminate clearance – would allow urban bird communities to adjust gradually. By adopting staggered canopy reduction, rigorous avian monitoring, and expedited native replantation, city planners can ensure that the ecological functions of urban trees as perches, song posts, and refuges remain intact.

For urban planners, our results translate into three concrete design principles. First, restoration of the Central Ridge and biodiversity parks should prioritize structurally complex native keystone trees, such as Ficus spp., Neem, and Sheesham, which support the richest and most behaviorally diverse bird assemblages across the city. Second, street-tree and park planting schemes should avoid monotonous rows of low-value ornamentals and instead use mixed palettes that combine drought-tolerant natives with a limited number of non-native but structurally useful species, thereby spreading foraging and roosting opportunities through the urban fabric. Third, invasive-tree removal plans need to be scheduled in space and time so that at any point along the Ridge and in major green corridors, birds can shift between overlapping patches of old crowns and maturing native plantings rather than facing abrupt structural gaps. Such measures will help safeguard Delhi's rich bird life through the current transition, validating the principle that urban biodiversity conservation should proceed hand-in-hand with greening initiatives.

A small set of ecologically versatile natives (notably Neem) and hardy exotics (Eucalyptus) forms the structural backbone of bird–plant interactions in the metropolis, whereas many ornamentals contribute little beyond aesthetic value. Prioritizing the retention and strategic planting of high-value keystone trees, alongside diversifying mid-tier native species, should, therefore, be central to any habitat-enhancement scheme aimed at bolstering avian functional diversity in rapidly urbanizing landscapes. Structurally or tropically important trees: Sausage Tree, Bakain, Neem, Banyan, Amaltas, Eucalyptus, Mulberry, Gulmohar, Kassod, Ashoka, Sheesham and Peepal, consistently elevate local occupancy for hornbills, barbets, starlings, pigeons, parakeets, prinias, ibises and several urban generalists [36, 37]. For Rufous Treepie, Ashy Prinia, Indian Grey Hornbill, and Bank Myna, plant associations appear broad enough to permit diet switching yet sufficiently bounded to suggest preferential targeting of certain fruiting or flowering phonologies [37, 38]. House Crow and Common Myna are two of Delhi's most behaviorally plastic inhabitants, due to their abundance and association with many tree species [38, 39]. Taken together, just three bird species: House Crow, Rock Pigeon, Asian Green Bee-eater and four tree taxa: Eucalyptus, Vilayati Kikar, Neem and Peepal, account for eight of the ten highest-volume interactions. This clustering highlights an urban network in which ecological generalists repeatedly capitalize on fast-growing exotics and a handful of native keystone trees. Such redundancy may buffer these birds against habitat change, yet it simultaneously signals a functional bottleneck: if management reduces the prevalence of these particular hosts, a large fraction of observed bird activity could be displaced, with uncertain consequences for less plastic species that share the same sites.

Thresholding at three records removes spurious perfect correlations generated by single-grid coincidences and sharpens the ecological signal: strong positive links now involve common, behaviorally compatible species rather than rare outliers. The high-r pairs provide a concise set of guild indicators: open-field insectivores (Asian Green Bee-eater-Brown-headed Barbet), wetland scavengers (Black Kite-Rose-ringed Parakeet) [40, 41], and peri-urban granivores (Eurasian Collared-Dove-Indian Pied Starling), that can anchor joint-species occupancy or network analyses. Finally, the prevalence of weak correlations ensures that multicollinearity remains low when species are modelled individually, reinforcing the inference that habitat structure, rather than inter-specific competition, dominates bird assemblage patterns in Delhi's urban landscape once a minimal co-occurrence criterion is imposed [42].

The observed patterns of bird–tree interactions in Delhi align closely with global research emphasizing the importance of habitat complexity and structural diversity for urban avian communities [34, 42–44]. The dominance of perching and calling behaviors reflects how urban trees primarily function as three-dimensional habitat structures that expand vertical space availability, supporting the principle that polyculture and agroforestry farming improve habitat complexity, habitat heterogeneity (e.g., tree species richness), and microclimate regulation [26].

The concentration of feeding activities among frugivorous species, like Brown-headed Barbet, supports research demonstrating that multiple tree species or polyculture farming practice can benefit birds and other biodiversity by providing considerable resources (e.g., food, prey availability, and shelter), therefore, improving foraging and nesting opportunities compared to monoculture plantations [26, 45]. This pattern validates the importance of maintaining diverse native tree assemblages that provide complementary resources across different seasons and ecological requirements [34]. The preference for larger, more structurally complex trees reflects their function as "keystone structures" because of their disproportionate role in the ecosystem relative to the area occupied [27, 46]. This principle applies directly to urban conservation strategies, where protecting large, mature trees can yield conservation benefits far exceeding their spatial footprint [37].

The relationship between tree characteristics and bird utilization patterns supports research indicating that increasing tree girth, cover, and crown size may enhance seedling recruitment [47]. The trees most valuable for bird habitats also contribute to long-term ecosystem regeneration through seed dispersal and recruitment facilitation, creating positive feedback loops essential for urban biodiversity persistence [36, 48, 49], However, the data also reflect the complex trade-offs inherent in urban tree–bird relationships [50]. Research acknowledges that trees may increase predation risk for some species while benefiting others [51] reminds us that urban forest management must consider diverse species requirements and potential ecological conflicts. The correlation patterns observed in Delhi, showing management-driven rather than purely ecological associations between birds and trees, highlight how human landscape design decisions mediate urban biodiversity patterns [32]. This finding underscores the critical importance of evidence-based urban forestry that incorporates ecological principles into planning decisions [42].

For Delhi and similar megacities, the evidence supports prioritizing diverse native tree plantings that provide the habitat complexity, habitat heterogeneity (e.g., tree species richness), and microclimate regulation [26] essential for supporting urban bird communities. The research validates strategies that protect existing large trees while establishing new plantings that create the structural stratification and resource diversity necessary for sustaining avian biodiversity in rapidly urbanizing landscapes [34, 46]. These findings contribute to growing recognition that urban areas can serve as critical refugia for biodiversity when properly designed and managed, with tree–bird interactions serving as both indicators of ecosystem health and drivers of ecological resilience in urban environments [32, 52].

CONCLUSION

Urban tree–bird interaction networks play a critical role in maintaining ecological resilience in megacities. This study shows that habitat complexity offered by trees, particularly native keystone species, is essential for sustaining urban avifauna. While invasive trees – such as *Prosopis juliflora* – currently provide important structural habitat for several bird species, their control must be implemented through adaptive, phased management that maintains functional habitat continuity. Preserving a diverse array of tree species, both native and exotic, while prioritizing structurally complex native keystones will best support urban bird communities during large-scale restoration initiatives. Taken together, these findings situate Delhi's bird–tree interaction network at the nexus of biodiversity conservation, invasive species control and climate resilient urban greening. By demonstrating how a small set of native keystone trees and structurally dominant invasive underpin the city's avifauna, the study highlights both the risks of uncoordinated canopy removal and the opportunities for informed restoration design. Embedding such species level ecological information into Ridge restoration plans, biodiversity park layouts, and street tree policies can help Delhi reconcile invasive tree management with the long-term maintenance of urban biodiversity and associated ecosystem services.

Declaration of Conflict of Interest
The authors declare that they have no known conflict of interests.

Declaration of Funding
Authors have not received any financial support for conducting this research.

REFERENCES

1. Chauhan S, Yadav G, Babu S. Ecological networks in urban forest fragments reveal species associations between native and invasive plant communities. Plants (Basel). 2022;11(4):541. doi: 10.3390/plants11040541.
2. Rawal P, Chatrath D, Shahabuddin G. The Role of Street Fig Trees as Avian Resource Providers in a Tropical Megacity: Study of Patterns and Drivers. 2022 May 17;. Available from: https://web.archive.org/web/20220523231431id_/https://assets.researchsquare.com/files/rs-1657686/v1/8f7c0a62-c981-4803-bfc9-cea321de32df.pdf?c=1652816335
3. Barhadiya G, Sultana A, Khudsar FA, Hussain MS. Is there any impact of non-native vegetation on bird communities in Delhi, India? Trop Ecol. 2022;63(1):49–60. doi: 10.1007/s42965-021-00181-2.
4. Rawal P, Chatrath D, Shahabuddin G. Micro-scale patterns and drivers of bird visitation on street fig trees in Delhi, India. Acta Oecol. 2023;118:103875. doi: 10.1016/j.actao.2022.103875.
5. Kumari D, Srivastava A, Hore U. Park size as a key factor in urban bird diversity: Insights from a study in Delhi, India. Ornithol Res. 2024;32(4):336–346. doi: 10.1007/s43388-024-00193-1.
6. La Sorte FA, Aronson MF, Lepczyk CA, Horton KG. Area is the primary correlate of annual and seasonal patterns of avian species richness in urban green spaces. Landscape and urban planning. 2020 Nov 1;203:103892.
7. Basile M, Augustinus BA, Brockerhoff EG. Tree cover and geographic origin of tree species drive bird functional groups in urban environments. Wildlife Biology. 2025 Jul:e01446.
8. Basile M, Augustinus BA, Brockerhoff EG. Urban tree canopy cover over 30% and native trees enhance bird insectivory and tree biosecurity. Biological Conservation. 2025 Oct 1;310:111387.
9. Subedi DR, Liu Q, Bhuju DR, Vaidya S, KC YB, Pradhan P. Diverse perceptions of ecosystem (dis) services in a Himalayan protected area. Environmental and Sustainability Indicators. 2026 Jan 10:101130.
10. R J, SL D, A S, BN P. Study of the impact of Prosopis juliflora on soil moisture and humidity. Environ Ecol. 2024;42(1A):220–228. doi: 10.60151/envec/OTWB2845.
11. Eschen R, Kaaya OE, Kilawe CJ, Malila BP, Mbwambo JR, Mwihomeke MS, Nunda W. Adoption of a sustainable land management practice for invasive Prosopis juliflora in East Africa. CABI Agriculture and Bioscience. 2024 Dec;5(1):113.
12. Kamiri HW, Choge SK, Becker M. Management strategies of Prosopis juliflora in Eastern Africa: What works where? Diversity (Basel). 2024;16(4):251. doi: 10.3390/d16040251.
13. Kishoin V, Tumwesigye W, Turyasingura B, Wilber W, Chavula P, Gweyi-Onyango JP, et al. The negative and positive impacts of Prosopis juliflora on the Kenyan and Ethiopian ecosystems: A review study. Not Sci Biol. 2024;16(1):11832. doi: 10.55779/nsb16111832.
14. Shiferaw H, Alamirew T, Dzikiti S, Bewket W, Zeleke G, Teketay D, Schaffner U. Water abstraction of invasive Prosopis juliflora and native Senegalia senegal trees: A comparative study in the Great Rift Valley Area, Ethiopia. Science of the Total Environment. 2023 Mar 1;862:160833.
15. Deshpande P, Sharma R, Lehikoinen A, Thorogood R. Native fauna interact differently with native and alien trees in a tropical megacity. Science of the Total Environment. 2023 Apr 10;868:161683.
16. O'Leary BA, Burd M, Venn SE, Gleadow RM. Bird community recovery following removal of an invasive tree. Ecol Solut Evid. 2021;2(2):e12080. doi: 10.1002/2688-8319.12080.
17. Marciniak B, Peroni N, Traveset A, De Sá Dechoum M. Effects of the control of an invasive tree on the structure of a plant-frugivore network. Ecol Appl. 2024;34(8):e3037. doi: 10.1002/eap.3037.

18. Klaus VH, Kiehl K. A conceptual framework for urban ecological restoration and rehabilitation. Basic and Applied Ecology. 2021 May 1;52:82-94.
19. Elliot Noe E, Innes J, Barnes AD, Joshi C, Clarkson BD. Habitat provision is a major driver of native bird communities in restored urban forests. J Anim Ecol. 2022;91(7):1444–1457. doi: 10.1111/1365-2656.13700.
20. Schillé L, Paquette A, Marcotte G, Ouellet H, Cobus S, Barbaro L, Castagneyrol B. Urban tree diversity fosters bird insectivory despite a loss in bird diversity with urbanization. Landscape and Urban Planning. 2025 Apr 1;256:105274.
21. Liu X, Yang X, Li X, Yang J. Exploring the relationship between frugivorous birds and fruit trees in urban parks using citizen science data. Urban Ecosyst. 2025;28(1):51. doi: 10.1007/s11252-024-01625-y.
22. Liu X, Yang X, Zhou J, Li X, Yang J. Intra-urban variability in frugivorous bird and fruit tree interaction networks. Ecol Front. 2026;46(2):771-778. doi:10.1016/j.ecofro.2025.12.010.
23. Augustinus BA, Abegg M, Queloz V, Brockerhoff EG. Higher tree species richness and diversity in urban areas than in forests: Implications for host availability for invasive tree pests and pathogens. Landscape and Urban Planning. 2024 Oct 1;250:105144.
24. García D. Birds in ecological networks: Insights from bird-plant mutualistic interactions. Ardeola. 2016;63(1):151–180. doi: 10.13157/arla.63.1.2016.rp7.
25. Poisot T, Bergeron G, Cazelles K, Dallas T, Gravel D, MacDonald A, et al. Global knowledge gaps in species interaction networks data. J Biogeogr. 2021;48(7):1552–1563. doi: 10.1111/jbi.14127.
26. Yahya MS, Atikah SN, Mukri I, Sanusi R, Norhisham AR, Azhar B. Agroforestry orchards support greater avian biodiversity than monoculture oil palm and rubber tree plantations. Forest Ecology and Management. 2022 Jun 1;513:120177.
27. Pustkowiak S, Kwieciński Z, Lenda M, Żmihorski M, Rosin ZM, Tryjanowski P, et al. Small things are important: The value of singular point elements for birds in agricultural landscapes. Biol Rev. 2021;96(4):1386–1403. doi: 10.1111/brv.12707.
28. Six-member panel to monitor Ridge's restoration, says Rai. Times of India. 2021 Mar 23. Available from: https://timesofindia.indiatimes.com/city/delhi/six-member-panel-to-monitor-ridges-restoration-says-rai/articleshow/81639353.cms
29. Choudhary NL, Chishty N. Effect of Prosopis juliflora on avifauna in Udaipur district, Rajasthan, India. Uttar Pradesh J Zool. 2020;41(9):128–139.
30. Johnston R. Evolution in the rock dove: Skeletal morphology. Auk. 2024;109(3). Available from: https://digitalcommons.usf.edu/auk/vol109/iss3/12
31. Khera N, Mehta V, Sabata BC. Interrelationship of birds and habitat features in urban greenspaces in Delhi, India. Urban For Urban Green. 2009;8(3):187–196. doi: 10.1016/j.ufug.2009.05.001.
32. Rawal P, Kittur S, Chatakonda MK, Sundar KSG. Winter bird abundance, species richness and functional guild composition at Delhi's ponds: Does time of day and wetland extent matter? J Urban Ecol. 2021;7(1): Juab001. doi: 10.1093/jue/juab001.
33. Skórka P, Sierpowska K, Haidt A, Myczko Ł, Ekner-Grzyb A, Rosin ZM, et al. Habitat preferences of two sparrow species are modified by abundances of other birds in an urban environment. Curr Zool. 2016;62(4):357–368. doi: 10.1093/cz/zow069.
34. Hanle J, Duguid MC, Ashton MS. Legacy forest structure increases bird diversity and abundance in aging young forests. Ecol Evol. 2020;10(3):1193–1208. doi: 10.1002/ece3.5967.
35. Cavallero L, Raffaele E, Aizen MA. Birds as mediators of passive restoration during early post-fire recovery. Biol Conserv. 2013;158:342–350. doi: 10.1016/j.biocon.2012.10.004.
36. Kitamura S. Frugivory and seed dispersal by hornbills (Bucerotidae) in tropical forests. Acta Oecol. 2011;37(6):531–541. doi: 10.1016/j.actao.2011.01.015.
37. Wagh G, Borode N, Chaudhari P, Kasambe R, Wadatkar J. Nesting sites and dietary choices of Indian grey hornbills (Ocyceros birostris) in urban area, Amravati City, Maharashtra, India. Int J Fauna Biol Stud. 2025;12(4):60–68. doi: 10.22271/23940522.2025.v12.i4a.1112.
38. Patel PK, SND. Selection of nesting sites and nesting material in common myna (Acridotheres tristis) in an urban area. Int J Pharm Life Sci. 2012;3(8):1897–1904.

39. Kaur M. Nesting preferences of birds in relation to exotic trees in Ludhiana, Punjab. J Anim Res. 2020;10(1). doi: 10.30954/2277-940X.01.2020.14.
40. Kumar N, Mohan D, Jhala YV, Qureshi Q, Sergio F. Density, laying date, breeding success and diet of black kites Milvus migrans govinda in the city of Delhi (India). Bird Study. 2014;61(1):1–8. doi: 10.1080/00063657.2013.876972.
41. Shiels AB, Kalodimos NP. Biology and impacts of Pacific Island invasive species. 15. Psittacula krameri, the rose-ringed parakeet (Psittaciformes: Psittacidae). Pac Sci. 2019;73(4):421. doi: 10.2984/73.4.1.
42. Shaw T, Scherer-Lorenzen M, Müller S. Forest structural heterogeneity positively affects bird richness and acoustic diversity in a temperate, central European forest. Frontiers in ecology and evolution. 2024 Aug 20;12:1387879.
43. Carrasco L, Giam X, Papeş M, Sheldon K. Metrics of LiDAR-derived 3D vegetation structure reveal contrasting effects of horizontal and vertical forest heterogeneity on bird species richness. Remote Sens. 2019;11(7):743. doi: 10.3390/rs11070743.
44. Goetz S, Steinberg D, Dubayah R, Blair B. Laser remote sensing of canopy habitat heterogeneity as a predictor of bird species richness in an eastern temperate forest, USA. Remote Sens Environ. 2007;108(3):254–263. doi: 10.1016/j.rse.2006.11.016.
45. Ragusa-Netto J. Fruiting phenology and consumption by birds in Ficus calyptroceras (Miq.) Miq. (Moraceae). Braz J Biol. 2002;62(2):339–346. doi: 10.1590/S1519-69842002000200018.
46. Rottenborn S. Nest-site selection and reproductive success of urban red-shouldered hawks in Central California. J Raptor Res. 2024;34(1). Available from: https://digitalcommons.usf.edu/jrr/vol34/iss1/3
47. Wang Z, Gao S, Huang X, Zhang S, Li N. Functional importance of bird-dispersed habitat for the early recruitment of Taxus chinensis in a fragmented forest. Acta Oecologica. 2022 May 1;114:103819.
48. Coates-Estrada R, Estrada A. Fruiting and frugivores at a strangler fig in the tropical rain forest of Los Tuxtlas, Mexico. J Trop Ecol. 1986;2(4):349–357. doi: 10.1017/S0266467400000985.
49. Kinnaird M, O’Brien T, Suryadi S. Population fluctuation in Sulawesi red-knobbed hornbills: Tracking figs in space and time. Auk. 2024;113(2). Available from: https://digitalcommons.usf.edu/auk/vol113/iss2/16
50. Vincze E, Papp S, Preiszner B, Seress G, Bókony V, Liker A. Habituation to human disturbance is faster in urban than rural house sparrows. Behav Ecol. 2016;27(5):1304–1313. doi: 10.1093/beheco/arw047.
51. Depalma DM, Mermoz ME. Ground nesting birds in roadside borders of the Argentine Pampas: Habitat use and predation risk of artificial nests. Rev Bras Ornitol. 2019;27(4):261–274. doi: 10.1007/BF03546072.
52. Gonji AI, Chauhan S, Babu S. Coexistence of wild fauna in the city: A case study of the golden jackal (Canis aureus Linn.) in Central Ridge, Delhi. Ecol Econ Soc. 2024;7(2). doi: 10.37773/ees.v7i2.1192.

