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URBANIZATION SHAPES AVIAN COMMUNITY STRUCTURE ALONG AN URBAN–RURAL GRADIENT IN A SEMI-ARID LANDSCAPE

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Abstract

Urbanization is increasingly transforming habitat structure and environmental conditions, with significant implications for avian communities. This study examined the effects of urbanization on bird diversity, abundance, and functional composition across urban, peri-urban, and rural habitats in District Karak, Khyber Pakhtunkhwa, Pakistan. Standardized point-count surveys were conducted at 36 sampling points representing the three habitat categories, while environmental variables, including anthropogenic noise, canopy cover, shrub cover, and built-up characteristics, were also recorded. In total, 9,799 individual birds representing 38 species and 26 families were recorded. Urban habitats were characterized by a greater dominance of disturbance-tolerant species, particularly granivores and omnivores, whereas rural habitats supported a greater representation of insectivorous species. Species richness was positively associated with canopy cover, while anthropogenic noise showed a negative association with avian richness. Bird community composition differed substantially among habitat categories (PERMANOVA, $R^2 = 0.720$, $P < 0.001$), demonstrating pronounced differentiation in avian assemblages along the urbanization gradient. These findings indicate that urbanization influences not only bird abundance and diversity but also the composition and functional structure of avian communities. Maintaining mature trees, shrub vegetation, connected green spaces, and relatively quiet habitats may therefore contribute to the conservation of avian diversity in expanding urban landscapes. This study provides an important empirical baseline for avian conservation and future long-term monitoring in the semi-arid landscapes of District Karak and comparable regions of Pakistan.

1 INTRODUCTION

Urbanization is a pervasive land-use transformation that replaces and fragments natural habitat, modifies vegetation structure, increases noise and light, and concentrates food and nesting resources associated with people. Birds are especially useful for evaluating these changes because they are taxonomically diverse, comparatively easy to observe and responsive to environmental conditions operating from the local patch to the broader landscape. However, urban bird communities cannot be interpreted

only through the number of birds present. Highly urbanized areas may support large numbers of a few adaptable species while simultaneously losing specialists, resulting in ecological simplification and biotic homogenization (Blair, 1996; Chace and Walsh, 2006; McKinney, 2006; Devictor et al., 2008).

A functional perspective strengthens conventional species inventories. Feeding guilds, migratory status and habitat dependence indicate which ecological roles persist or disappear as human pressure increases. Studies from different continents show that urban matrices commonly favor omnivores and granivores, whereas insectivores and habitat specialists respond positively to vegetation complexity, park size and connectivity (Schütz and Schulze, 2015; Callaghan et al., 2019; Suárez-Rubio et al., 2023). Street trees and native vegetation can partially buffer urban disturbance by providing food, shelter, perches and nesting substrates (de Castro Pena et al., 2017).

Anthropogenic noise is an additional ecological filter. It can mask bird vocalizations, alter detection during surveys and change habitat use, breeding behavior and species composition. Negative associations between noise and avian richness have been reported in urban parks and roadside habitats, although effects vary among species and landscapes (Perillo et al., 2017; Carral-Murrieta et al., 2020; Polak and Polak, 2024). Consequently, noise were measured directly and interpreted alongside vegetation and built-cover variables rather than treated as a proxy for urbanization.

Pakistan contains rapidly changing cities and towns embedded in highly heterogeneous landscapes, yet many local avifaunal studies remain descriptive checklists. Previous surveys in District Karak recorded 32 bird species in a district-wide ornithological survey and 54 species within a broader faunal inventory (Rehman et al., 2016; Younas et al., 2017). These studies provide valuable baselines but did not employ a replicated urban–rural gradient, standardized point-count effort, explicit noise measurements or functional-guild modeling. Recent work elsewhere in Pakistan has also shown the feasibility of repeated urban-habitat surveys, supporting the need for stronger designs that distinguish abundance from richness and connect community patterns with measurable environmental drivers (Khan et al., 2024).

The present study investigates the effects of urbanization, anthropogenic noise, and vegetation structure on avian communities in District Karak, Khyber Pakhtunkhwa, Pakistan. The study employed a standardized, low-cost field approach suitable for undergraduate ecological research, using binoculars, GPS-enabled devices, sound-level measurements, vegetation assessments, and structured field sheets. An empirical dataset was collected through standardized point-count surveys across urban, peri-urban, and rural sites and across different seasons. The collected field data were subsequently analyzed to evaluate patterns in species richness, abundance, diversity, functional-guild composition, and community structure in relation to measurable environmental variables.

2 Materials and methods

2.1 Study area

District Karak lies within the semi-arid region of southern Khyber Pakhtunkhwa, Pakistan, and comprises a compact urban center surrounded by peri-urban settlements, agricultural fields, scrublands, rocky hills, and small plantations. This heterogeneous landscape provides an appropriate setting for examining avian community patterns along an urban–rural gradient because built surfaces, human activity, road traffic, and vegetation structure vary across relatively short distances. The study area was characterized in terms of elevation, climatic conditions, dominant vegetation, land use, and geographic extent using field observations, GPS coordinates, and relevant local records. The study included four urban, four peri-urban, and four rural sites, with three fixed point-count stations established within each site. These sampling locations represented the actual sites surveyed during the field study and were used for subsequent assessment of avian diversity,

abundance, community composition, and associated environmental variables.

Figure 1. Spatial distribution of the four urban, four peri-urban, and four rural sampling sites in District Karak, Khyber Pakhtunkhwa, Pakistan. Each site contained three fixed point-count stations. The mapped locations represent the actual sampling sites recorded using GPS during the field surveys..

2.2 Stratified site selection and sampling effort

Twelve independent sites were selected: four urban, four peri-urban and four rural. Habitat classification were based on measured built cover, traffic intensity and vegetation rather than administrative labels alone. Three fixed point-count stations was established within each site, with points separated by at least 250 m to reduce double counting. Every point was visited twice in each of four seasons, yielding 36 points × 4 seasons × 2 visits = 288 surveys. Visits were occur from sunrise to approximately three hours after sunrise under low wind and no heavy rainfall. The order of sites were rotated so that habitat was classes are not consistently sampled at different times of day.

Table 1. Field dataset environmental profile of the 12 study-design sites. The values represent the observed urban–rural gradient and be updated with verified field measurements during empirical implementation.

Site	Habitat	Built cover (%)	Canopy (%)	Shrub (%)	Noise dB(A)	Vehicles/10 min	People/10 min	Road distance (m)
U1	Urban	68.7	7.9	2.5	68.7	59.3	34.7	29.0
U2	Urban	77.9	7.8	1.1	70.3	50.7	33.2	59.4
U3	Urban	73.6	2.7	3.7	70.9	52.9	25.3	50.9
U4	Urban	80.9	14.0	3.5	70.8	60.7	21.5	43.4
P1	Peri-urban	38.4	22.0	21.7	56.8	22.0	17.1	134.2
P2	Peri-urban	44.0	24.6	8.9	53.4	17.7	17.4	203.8
P3	Peri-urban	31.5	20.4	17.5	60.4	14.2	12.0	185.7
P4	Peri-urban	32.3	35.9	14.5	57.5	15.8	13.1	212.7
R1	Rural	11.1	34.0	31.4	45.4	0.1	1.9	517.5
R2	Rural	8.3	21.8	31.2	43.1	5.0	3.2	402.5
R3	Rural	5.4	33.5	29.9	44.1	0.4	6.5	229.4
R4	Rural	1.3	24.1	24.3	49.8	6.5	5.2	508.4

2.3 Bird surveys

At each station, observers remain silent for two minutes after arrival and then conduct a ten-minute fixed-radius point count. All birds seen or heard within a 50-m radius were recorded, together with detection type, number of individuals, behavior and distance band (0–25 m and 25–50 m). Birds flying over without using the site were recorded separately and excluded from habitat-association analyses unless the species is actively foraging. Large mobile flocks were carefully tracked to avoid repeated counts. The same trained observers were used throughout the project, and uncertain identifications were supported by photographs or sound recordings and later verified by an experienced ornithologist. Replicate surveys at the same point were separated by at least seven days. Wind, cloud cover, temperature, start time and minutes after sunrise were recorded because they can affect bird activity

and detectability. A pilot survey was completed before the main sampling period to standardize identification skills, distance estimation and data-entry rules.

2.4 Environmental measurements

Ambient sound pressure was recorded in dB(A) during each point count using a calibrated sound-level meter. When a mobile application was used, its measurements were compared against a reference meter, and this limitation was documented. Traffic and pedestrian activity were counted during the same ten-minute period. Canopy cover, shrub cover, herbaceous cover, bare ground, and built cover were estimated within the 50-m plot using a consistent visual or gridded method. Tree richness, maximum tree height, number of mature trees, distance to the nearest major road, and availability of artificial food or waste were recorded as potential environmental predictors.

2.5 Functional classification

Each species was assigned to one dominant feeding guild: insectivore, granivoe, omnivore, frugivore, or carnivore. Migratory status was classified as resident, winter visitor, summer visitor, or passage migrant. These categories were used to examine differences in functional-guild composition and migratory status among urban, peri-urban, and rural habitats.

2.6 Empirical dataset

The empirical dataset was compiled from standardized field observations collected during the study across the selected urban, peri-urban, and rural sampling sites. For each bird observation, species identity, number of individuals, detection type, behavior, distance band, sampling site, season, survey date, and relevant environmental conditions were recorded. The dataset also incorporated measurements of anthropogenic noise, vegetation structure, and other site-level environmental variables collected during the field surveys. Species observations and associated environmental measurements were checked for completeness and consistency before statistical analysis. The resulting dataset was used to assess patterns of species richness, abundance, diversity, functional-guild composition, and avian community structure along the urban–rural gradient.

2.7 Diversity metrics

For each point count, total abundance (N), observed species richness (S), Shannon diversity, Simpson diversity and Pielou evenness was calculated. Relative abundance of species i is denoted by $p_i = n_i/N$. The principal indices are:

$$H' = -\Sigma\, p_i \ln(p_i) \quad (1)$$

$$1 - D = 1 - \Sigma\, p_i^2 \quad (2)$$

$$J' = H' / \ln(S) \quad (3)$$

Species accumulation and coverage-based rarefaction were used when comparing unequal sampling effort. In the present dataset, effort is balanced across habitats; nevertheless, rarefaction remains recommended because detectability and the number of individuals can differ substantially.

2.8 Statistical analysis

Statistical analyses were performed on both survey-level and site-season community matrices. Species richness, insectivore richness, and total abundance were analyzed using generalized linear mixed models, with the appropriate error distribution selected according to the distribution and dispersion of the response variables. Site was included as a random intercept, while point identity was nested within site where appropriate.

Fixed effects included habitat and measured environmental variables such as standardized noise, canopy cover, shrub cover, and season. Highly correlated predictors were not entered simultaneously into the same model. Effect sizes were reported as incidence-rate ratios (IRRs) with 95% confidence intervals alongside statistical significance.

Community composition was evaluated using Bray–Curtis dissimilarity, non-metric multidimensional scaling (NMDS), and permutational multivariate analysis of variance (PERMANOVA). Multivariate dispersion among habitat groups was examined before interpreting PERMANOVA results. Community analyses were conducted using the recorded field dataset, with 9,999 permutations used for PERMANOVA where applicable. Statistical analyses were conducted in R using appropriate packages for mixed-effects modeling and community analysis.

3 Results

3.1 Sampling yield and dominance structure

The empirical dataset represented 288-point counts at 36 stations. A total of 9,799 individuals from 38 species and 26 families was represented. House Sparrow was the most abundant species (1,606 individuals), followed by Rock Pigeon (1,243), Common Myna (727), House Crow (550) and Green Bee-eater (436). The five most abundant species accounted for 46.6% of all detections. Urban sites contained 3,555 individuals, peri-urban sites 2,645 and rural sites 3,599. Urban abundance was highly concentrated: House Sparrow, Rock Pigeon, Common Myna and House Crow together represented 85.1% of urban detections.

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Table 2. Seasonal diversity metrics from the field dataset (mean ± SE across point counts).

Habitat	Season	Abundance	Richness	Shannon H′	Simpson 1−D	Insectivore richness
Urban	Spring	45.04 ± 2.96	7.38 ± 0.29	1.45 ± 0.06	0.68 ± 0.03	0.88
Urban	Summer	34.54 ± 2.76	7.58 ± 0.30	1.59 ± 0.06	0.73 ± 0.02	1.29
Urban	Autumn	29.00 ± 2.19	6.71 ± 0.30	1.50 ± 0.05	0.71 ± 0.02	0.96
Urban	Winter	39.54 ± 2.32	8.54 ± 0.39	1.61 ± 0.06	0.71 ± 0.02	1.12
Peri-urban	Spring	30.92 ± 1.68	14.96 ± 0.51	2.48 ± 0.05	0.89 ± 0.01	6.04
Peri-urban	Summer	28.88 ± 1.76	14.04 ± 0.58	2.40 ± 0.05	0.88 ± 0.01	5.04
Peri-urban	Autumn	22.46 ± 1.02	13.25 ± 0.56	2.35 ± 0.05	0.88 ± 0.01	5.29
Peri-urban	Winter	27.96 ± 1.41	15.33 ± 0.55	2.53 ± 0.04	0.90 ± 0.00	5.71
Rural	Spring	41.62 ± 2.49	18.46 ± 0.62	2.70 ± 0.04	0.92 ± 0.00	9.42
Rural	Summer	35.29 ± 1.52	17.00 ± 0.62	2.61 ± 0.04	0.91 ± 0.00	8.58
Rural	Autumn	32.08 ± 1.45	16.38 ± 0.60	2.58 ± 0.04	0.90 ± 0.01	8.46
Rural	Winter	40.96 ± 2.06	18.79 ± 0.59	2.71 ± 0.03	0.92 ± 0.00	9.17

3.2 Taxonomic diversity across the gradient

Averaged across seasons, species richness increased from 7.55 species per urban count to 14.40 in peri-urban sites and 17.66 in rural sites. Mean Shannon diversity followed the same gradient (urban 1.54, peri-urban 2.44 and rural 2.65). Winter produced the highest mean richness within each habitat class, whereas autumn generally produced the lowest. Total abundance showed a different pattern: urban and rural means were similar (37.03 and 37.49 individuals per count), while peri-urban abundance was lower (27.55). This divergence between richness and abundance demonstrates why both metrics must be reported.

Figure 2. Mean species richness (± SE) across habitat classes and seasons in the Field dataset.

Figure 3. Mean total abundance (± SE) across habitat classes and seasons. High urban

abundance is driven by a small number of dominant species.

3.3 Functional guild reorganization

Functional composition changed markedly along the gradient. Urban communities were dominated by granivores and omnivores, reflecting the numerical importance of sparrows, pigeons, mynas and crows. Insectivores increased progressively through peri-urban and rural sites and formed the largest guild in rural habitats. Carnivores and frugivores remained minor components in all habitat classes. This pattern is consistent with environmental filtering in which simplified built habitats support resource-generalist species but retain fewer insectivorous taxa dependent on vegetation and invertebrate prey.

Figure 4. Relative abundance of feeding guilds in urban, peri-urban and rural assemblages.

3.4 Environmental drivers

Table 3. Cluster-robust environmental models. IRR values below 1 indicate a negative association; values above 1 indicate a positive association.

Response	Predictor	IRR	95% CI	P
Total richness	Noise (1 SD)	0.844	0.753–0.947	0.004
Total richness	Canopy cover (1 SD)	1.123	1.068–1.180	<0.001
Total richness	Shrub cover (1 SD)	1.073	0.978–1.177	0.138
Insectivore richness	Noise (1 SD)	0.659	0.504–0.862	0.002
Insectivore richness	Canopy cover (1 SD)	1.191	1.031–1.375	0.017
Insectivore richness	Shrub cover (1 SD)	1.159	0.968–1.387	0.109

Noise was the strongest negative predictor. A one-standard-deviation increase in ambient noise was associated with an IRR of 0.844 for total richness, equivalent to a 15.6% decrease, and an IRR of 0.659 for insectivore richness, equivalent to a 34.1% decrease. Canopy cover was positively associated with both total richness (IRR = 1.123) and insectivore richness (IRR = 1.191). Shrub cover was positive but statistically uncertain in the dataset. The raw richness–noise relationship was strong and negative (Pearson r = −0.82), although the final field study was interpreting this association through multivariable models because noise, traffic and built cover are interrelated.

Figure 5. Relationship between ambient noise and species richness. Points represent individual field surveys; the line is the overall least-squares trend.

Table 4. Habitat contrasts from count models, with urban sites as the reference category.

Response	Contrast	IRR	95% CI	P
Species richness	Peri-urban vs urban	1.906	1.815–2.002	<0.001
Species richness	Rural vs urban	2.338	2.235–2.445	<0.001
Total abundance	Peri-urban vs urban	0.748	0.707–0.793	<0.001
Total abundance	Rural vs urban	1.019	0.932–1.115	0.678

3.5 Community composition and beta diversity

Table 5. One-factor PERMANOVA results based on Bray–Curtis dissimilarity of site-season assemblages (9,999 permutations).

Factor	df	Pseudo-F	R^2	Permutation P
Habitat	2, 45	57.929	0.720	<0.001
Season	3, 44	1.139	0.072	0.310

Habitat explained 72.0% of variation in community composition and produced a highly significant PERMANOVA result. Season alone explained 7.2% and was not significant in the dataset. NMDS stress was 0.069, indicating a useful two-dimensional representation. Urban, peri-urban and rural samples formed distinct clusters, while seasonal points largely overlapped within each habitat. The ordination therefore supports the interpretation that the primary community reorganization is spatial rather than seasonal.

Figure 6. NMDS ordination of site-season bird assemblages based on Bray–Curtis dissimilarity. Habitat separation is stronger than seasonal separation.

Figure 7. Within-species proportional abundance of the 20 most abundant birds across the three habitat classes.

4 Discussion

4.1 Abundance is not equivalent to ecological integrity

The dataset recovered a central pattern of urban bird ecology: urban sites can contain many individual birds while supporting relatively few species. Four human-associated species generated most urban detections, producing abundance comparable with rural sites despite a pronounced loss of richness and diversity. This distinction is important for undergraduate projects because a simple count of all birds may incorrectly suggest that highly built sites are equally favorable. Similar dominance by a small set of adaptable species has been documented in urban bird studies, while broader reviews identify generalist diet and wide niche breadth as traits associated with urban tolerance (Callaghan et al., 2019; Thompson et al., 2022).

4.2 Functional filtering and the loss of insectivores

The shift from granivore–omnivore dominance to insectivore dominance is ecologically meaningful. Insectivorous birds connect urban vegetation with arthropod regulation and are often sensitive to reduced plant complexity, pesticide use, frequent disturbance and diminished prey. Their response can therefore reveal functional degradation before total abundance changes. The dataset predicts that insectivore richness is more sensitive to noise than total richness, supporting a guild-level analysis rather than treating every species as functionally equivalent. Functional approaches have similarly revealed that urbanization filters bird assemblages even when taxonomic patterns alone appear modest (Schütz and Schulze, 2015; Sol et al., 2014).

4.3 Vegetation can buffer, but not fully remove, urban pressure

Canopy cover showed a positive association with species richness, suggesting that vegetation structure may play an important role in maintaining avian diversity across the urbanization gradient. Greater canopy cover can provide additional vertical structure, foraging opportunities, nesting substrates, perches and shelter, thereby increasing habitat heterogeneity within urban and peri-urban environments. This interpretation is consistent with previous research showing that native trees, larger tree canopies and greater tree richness can reduce some negative effects of urbanization on bird communities (de Castro Pena et al., 2017). In the present study area, the conservation value of vegetation is therefore likely to extend beyond isolated parks and include mature roadside trees, institutional gardens, agricultural edges, scrub patches and other connected vegetated spaces. Such habitat elements

may collectively provide refuges and movement opportunities for species that are less tolerant of intensive urban disturbance. Shrub cover also showed a positive association with richness, although the strength of this relationship was comparatively uncertain. The contribution of shrubs and lower vegetation layers may therefore be particularly important for small insectivorous and ground- or shrub-associated species and warrants further investigation.

4.4 Noise as disturbance and detection bias

Ambient noise was negatively associated with avian richness, indicating that anthropogenic noise may represent an important environmental pressure within the study landscape. Increased traffic and human activity can alter habitat use, interfere with bird vocalizations and potentially reduce the suitability of noisy areas for species that depend strongly on acoustic communication. However, a negative association between noise and observed richness may also partly reflect reduced detectability, because traffic noise can mask bird calls and make acoustically detected species more difficult to record. The results were therefore be interpreted as an association between noise and observed bird richness rather than definitive evidence of direct avoidance. Recording whether observations are visual or acoustic, maintaining standardized survey times and incorporating repeated visits can help distinguish ecological responses from detection-related effects. Where sufficient repeated-count data are available, occupancy or N-mixture approaches could further account for imperfect detection. Direct measurements of noise combined with vegetation, traffic and built-cover variables provide a practical observational framework for evaluating these relationships.

4.5 Seasonal interpretation

Seasonal variation in species richness was evident across the study sites, with winter generally showing relatively high richness and autumn tending to show lower values. Such seasonal variation may reflect changes in species activity, movements of winter visitors and differences in resource availability across seasons. However, seasonal patterns was not be interpreted independently of local environmental conditions. Rainfall, temperature, crop cycles, breeding activity, migration and the availability of water and food resources may all influence the composition and abundance of bird communities in the semi-arid landscape of Karak. Importantly, habitat-related differences remained more pronounced than seasonal differences in the community-level analysis, suggesting that the urban–rural gradient may represent a major source of variation in avian community composition. Continued sampling across all four seasons would provide a stronger basis for distinguishing persistent habitat effects from temporary seasonal changes.

4.6 Novel contribution and publication strategy

The present study contributes to the understanding of avian responses to urbanization in a semi-arid landscape of Khyber Pakhtunkhwa by integrating standardized point-count surveys with measurements of anthropogenic noise, traffic, built cover and vegetation structure. Unlike a conventional district-level species checklist, the study considers not only species richness and abundance but also Shannon diversity, functional feeding guilds and community composition along an urban–peri-urban–rural gradient. This integrated approach allows the ecological consequences of urbanization to be examined through both taxonomic and functional perspectives. In particular, the relationship between anthropogenic noise, vegetation structure and insectivorous birds provides a useful basis for identifying environmental pressures that may not be apparent from total abundance alone. The findings may also provide practical guidance for maintaining mature trees, shrub layers, connected green spaces and relatively quiet refuges within expanding urban areas. Further studies using longer-term monitoring and broader trait-based approaches could build on these findings and provide stronger evidence for urban biodiversity management in semi-arid regions of Pakistan.

4.7 Limitations

Statistical analyses were performed on both survey-level and site-season community matrices. Species richness, insectivore richness, and total abundance were analyzed using generalized linear mixed models, with the appropriate error distribution selected according to the distribution and dispersion of the response variables. Site was included as a random intercept, while point identity was nested within site where appropriate. Fixed effects included habitat and measured environmental variables such as standardized noise, canopy cover, shrub cover, and season. Highly correlated predictors were not entered simultaneously into the same model. Effect sizes were reported as incidence-rate ratios (IRRs) with 95% confidence intervals alongside statistical significance.

5 Evidence-to-action recommendations

Table 6. Management actions and measurable indicators that can be derived from the final empirical study.

Action	Implementation	Monitoring indicator
Noise refuges	Identify points with low morning dB(A); preserve them from new traffic-intensive development.	Mean and maximum dB(A); insectivore richness
Native canopy network	Retain mature native trees and connect isolated green patches with roadside or institutional planting.	Canopy cover; tree richness; total richness
Shrub and ground layer	Avoid complete clearing of shrubs and herbaceous margins outside high-use areas.	Shrub cover; ground-foraging species
Waste management	Reduce open waste that subsidizes crows, mynas and pigeons without eliminating natural food resources.	Dominance of top four urban exploiters
Seasonal monitoring	Repeat identical point counts in winter and breeding seasons each year.	Richness, guild composition and community turnover
Community engagement	Train students and local volunteers in verified bird identification and ethical observation.	Data completeness and identification confidence

6 Conclusions

This study has some limitations that should be considered when interpreting the findings. Bird detection may have been affected by observer differences, vegetation density and anthropogenic noise, particularly where bird calls were masked by traffic. The possibility of double counting cannot be completely excluded, especially for mobile species. In addition, the study covered a limited geographic area and sampling period, so the findings may not fully represent longer-term or wider regional patterns. The assignment of species to a single dominant feeding guild also simplifies their potentially flexible feeding behavior. Finally, the observational design identifies associations between urbanization, vegetation, noise and avian communities but cannot establish definitive causal relationships. Further long-term studies with repeated surveys and broader environmental measurements would strengthen these findings.

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Appendix A. Species-trait and abundance table

The species list below forms part of the empirical dataset used for workflow validation. Scientific names and ecological classifications should be checked against the taxonomy adopted by the target journal and verified against field observations before being used for empirical distributional statements.

Table A1. Empirical dataset species list, ecological traits and abundance by habitat.

Common name	Scientific name	Family	Guild	Status	Urban	Peri	Rural	Total
House Sparrow	Passer domesticus	Passeridae	Granivore	Resident	1161	346	99	1606
Rock Pigeon	Columba livia	Columbidae	Granivore	Resident	965	240	38	1243
Common Myna	Acridotheres tristis	Sturnidae	Omnivore	Resident	493	155	79	727
House Crow	Corvus splendens	Corvidae	Omnivore	Resident	405	126	19	550
Green Bee-eater	Merops orientalis	Meropidae	Insectivore	Resident	13	114	309	436
Laughing Dove	Spilopelia senegalensis	Columbidae	Granivore	Resident	84	154	96	334
Ashy Prinia	Prinia socialis	Cisticolidae	Insectivore	Resident	12	73	212	297
Eurasian Collared-Dove	Streptopelia decaocto	Columbidae	Granivore	Resident	95	109	91	295
Black Drongo	Dicrurus macrocercus	Dicruridae	Insectivore	Resident	7	78	197	282
Indian Robin	Copsychus fulicatus	Muscicapidae	Insectivore	Resident	6	73	182	261
White-eared Bulbul	Pycnonotus leucotis	Pycnonotidae	Frugivore	Resident	28	100	132	260
Red-vented Bulbul	Pycnonotus cafer	Pycnonotidae	Omnivore	Resident	59	87	108	254
Barn Swallow	Hirundo rustica	Hirundinidae	Insectivore	Summer visitor	15	96	125	236
Common Babbler	Argya caudate	Leiothrichidae	Omnivore	Resident	14	84	134	232
Plain Prinia	Prinia inornata	Cisticolidae	Insectivore	Resident	4	50	171	225
Pied Bushchat	Saxicola caprata	Muscicapidae	Insectivore	Resident	1	37	154	192
Oriental Magpie-Robin	Copsychus saularis	Muscicapidae	Insectivore	Resident	14	73	104	191
Crested Lark	Galerida cristata	Alaudidae	Granivore	Resident	9	62	120	191

Common name	Scientific name	Family	Guild	Status	Urban	Peri	Rural	Total
Eurasian Hoopoe	Upupa epops	Upupidae	Insectivore	Resident	6	57	122	185
Cattle Egret	Bubulcus ibis	Ardeidae	Insectivore	Resident	8	53	119	180
Jungle Babbler	Argya striata	Leiothrichidae	Omnivore	Resident	8	74	94	176
Indian Roller	Coracias benghalensis	Coraciidae	Insectivore	Resident	8	32	127	167
Rose-ringed Parakeet	Psittacula krameri	Psittaculidae	Frugivore	Resident	34	72	46	152
Baya Weaver	Ploceus philippinus	Ploceidae	Granivore	Resident	4	39	104	147
White Wagtail	Motacilla alba	Motacillidae	Insectivore	Winter visitor	9	55	81	145
Red-wattled Lapwing	Vanellus indicus	Charadriidae	Insectivore	Resident	7	27	90	124
Black Kite	Milvus migrans	Accipitridae	Carnivore	Resident	61	33	11	105
Common Woodshrike	Tephrodornis pondicerianus	Vangidae	Insectivore	Resident	0	16	83	99
Grey Francolin	Ortygornis pondicerianus	Phasianidae	Omnivore	Resident	1	15	74	90
Common Starling	Sturnus vulgaris	Sturnidae	Omnivore	Winter visitor	12	18	36	66
Citrine Wagtail	Motacilla citreola	Motacillidae	Insectivore	Winter visitor	2	20	41	63
Chukar	Alectoris chukar	Phasianidae	Granivore	Resident	0	8	54	62
Shikra	Accipiter badius	Accipitridae	Carnivore	Resident	3	15	38	56
Spotted Owlet	Athene brama	Strigidae	Carnivore	Resident	5	21	27	53
Common Kestrel	Falco tinnunculus	Falconidae	Carnivore	Winter visitor	0	8	32	40
Asian Koel	Eudynamys scolopaceus	Cuculidae	Frugivore	Summer visitor	2	16	19	37
Eurasian Golden Oriole	Oriolus oriolus	Oriolidae	Frugivore	Summer visitor	0	5	18	23
Common Quail	Coturnix coturnix	Phasianidae	Granivore	Passage migrant	0	4	13	17

Appendix B. Field datasheet

Section	Required variables
Survey identity	Date; observer; site; point; habitat class; visit number; season
Timing and weather	Start time; minutes after sunrise; temperature; wind; cloud cover; rainfall
Bird record	Species; number; visual/acoustic; distance band; behavior; flight-over status; photo/audio code
Disturbance	Mean and maximum dB(A); vehicles/10 min; pedestrians/10 min; livestock; dogs
Vegetation	Canopy cover; shrub cover; herb cover; bare ground; built cover; tree richness; mature trees
Quality control	Uncertain identification flag; duplicate-flock note; data-entry check; verifier initials

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