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IMPACT OF URBANIZATION ON BIRD DIVERSITY, ABUNDANCE, SEX RATIO, MIGRATORY TRENDS, AND BEHAVIORAL PATTERNS IN DERA ISMAIL KHAN

Malaika Ali[1]*, Muhammad Adeel Ahmad[2*], Karar Hussain shah[3]

[1]*Department of Zoology, Government College No. 1, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan*
[2]*Department of Soil Science faculty of Agriculture Gomal University D.I.Khan.KPK,Pakistan*
[3]*Department of zoology lecturer degree colleges No.1 D.I.khan kpk*
**Corresponding Author E-mail: adeelahmad7773@gmail.com,missmalaikaali@gmail.com*

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Abstract

Urbanisation is among the most pervasive and rapidly expanding forms of anthropogenic land transformation, and its consequences for avian communities in the developing world remain poorly quantified. This study assessed how a gradient of urban development affects bird diversity, abundance, adult sex ratio, migratory composition and behaviour in and around Dera Ismail Khan (D.I. Khan), a rapidly growing city in Khyber Pakhtunkhwa, Pakistan. A quantitative, stratified field survey was conducted across three zones—an urban core, a suburban transition belt and a rural periphery—using fixed-radius point counts replicated seasonally over a twelve-month cycle. Diversity was quantified using the Shannon–Wiener index, Simpson's index, Pielou's evenness and Margalef's richness, and inter-zone differences were tested using analysis of variance and non-parametric alternatives. Results demonstrated a monotonic decline in species richness (from 53 species in the rural periphery to 24 in the urban core) and diversity ($H' = 3.41$ to 2.31) with increasing urbanisation, accompanied by rising numerical dominance of a few synanthropic exploiters such as the house crow, common myna and rock pigeon. The adult sex ratio became progressively male-biased toward the urban core, migratory species were markedly under-represented in the built-up centre, and urban migrants showed advanced spring arrival and delayed autumn departure. Behaviourally, urban birds displayed shorter flight-initiation distances, elevated vigilance, reduced foraging time and higher minimum song frequencies. The findings indicate that unmanaged urban expansion in D.I. Khan is driving biotic homogenisation and functional simplification of the local avifauna, and they underscore the need for green-space retention and evidence-based urban planning to conserve regional bird communities.

INTRODUCTION

Urbanisation is one of the more intensive and permanent of land-use changes on earth. Cities account for less than one per cent of the terrestrial surface globally, but house over half of humanity and are growing at an unprecedented rate (Chamberlain et al., 2020). This addition is characterised by substitution of the heterogeneous natural and agricultural landscapes with impermeable surfaces, green patches with new microclimates and by chronic disturbances like noise, artificial lighting and the presence of humans. Habitat loss, degradation and fragmentation due to urban development have been found as a whole to decrease species richness by up to sixty per cent in cities compared to natural areas nearby, although the impact is different across taxa (Aronson et al., 2014; Chamberlain et al., 2020).

Birds are considered excellent bioindicators of the ecological impact of urbanisation, as they are conspicuous, well known to science, have a wide range of trophic levels and are sensitive to anthropogenic disturbance (Marzluff, 2001; Evans et al., 2018). A common pattern is found across continents: urbanisation eliminates a large number of bird species, in particular specialists, ground nesting birds and insectivores, and leaves behind a relatively small number of behaviourally flexible birds, called ‘urban exploiters', which grow in abundance (McKinney, 2006; Evans et al., 2018). This biotic homogenisation process can cause the loss of the biological differences among local ecosystems and reduce the ecosystem services provided by birds, such as seed dispersal, pollination and pest control (Sol et al., 2014).

Bird diversity is not necessarily correlated with urbanization. There are a number of studies that show that richness and abundance are best in areas that are low to intermediate in their level of development, where remnant natural habitats and new habitats are coexisting, and consequently are favourable for both urban-adapted and urban-avoider species (Callaghan et al., 2019; Sol et al., 2014). As intensity increases, however, diversity decreases rapidly and the numbers of a few tolerant species increase, resulting in a diversity and abundance gradient that can be anticorrelated (Faeth et al., 2011). Urbanisation also changes demographic and behavioural characteristics of bird populations, in addition to richness and abundance. In birds, the sex ratio is often male skewed, and the disparity in sex ratio is likely to increase in disturbed populations, small populations and populations that are declining, due to variation in survival, dispersal and habitat use (Morrison et al., 2016; Székely et al., 2014). These biases can be exacerbated in urban settings by differential space use and mortality by sex (Morrison et al., 2016).

Migratory birds are particularly sensitive to modification of landscape in urban areas. Cities may accelerate spring migration arrivals compared to rural areas due to urban heat islands, artificial light at night and earlier vegetation phenology, as well as slow the departures of migrants and in some species, even eliminate the migration altogether (Tryjanowski et al., 2013; Adams et al., 2026). Phenological changes may lead to a mismatch between reproductive timing and availability of food resources, with downstream impacts on survival and breeding success (Adams et al., 2026). Urban birds are more likely to show behavioral changes such as decreased flight-initiation distance, increased boldness, and increased song frequency which can help them cope with low-frequency traffic noise (Senzaki et al., 2020; Slabbekoorn & Peet, 2003).

While there has been a significant amount of research in North America and Europe, there are limited quantitative studies from the areas of fast urbanisation in South Asia and the mechanisms at play are poorly understood (Jaggi et al., 2020). Although Pakistan is a country with about 660 species of birds belonging to 23 orders and has a rapidly urbanising population, most of the avifaunal study has been conducted in protected wetlands and forests and not in the human dominated urban matrix (Mahmood et al., 2020). Resident and migratory assemblages were found to be rich in the previous surveys of forestry in the Dhapchapak river and Sheikh Badin National Park of Dera Ismail Khan district, Khyber Pakhtunkhwa while the deforestation and illegal hunting and degradation of forest area were also identified as mounting threats (Ullah et al., 2020; Zaman et al., 2023). Determining the impacts of the growing urban area of D.I. Khan on its bird populations has yet to be quantified in a study.

This is a clear problem; an expanding regional city is altering its surrounding habitat, but the magnitude and direction of the changes to the avifauna, in terms of diversity, abundance, sex ratio, migratory composition and migratory behaviour are not known, and so urban planners and conservation managers have no evidence base. With this in mind the following hypotheses were tested in the present study in the context of D.I. Khan, a replicated urban–suburban–rural gradient: (i) species richness, diversity and evenness decrease with increasing urbanisation, and species number increases in the urban core; (ii) migratory species are progressively excluded from, and phenologically shifted within urbanised zones; and (iii) urban birds exhibit measurable behavioural changes in wariness, foraging and vocalisation. This aims to produce a quantitative baseline to support the region's urban planning for the consideration of biodiversity.

MATERIALS AND METHODS

Study Area

The study was carried out in and around the city of Dera Ismail Khan (31.83 N, 70.90 E) located on the west bank of Indus river in the south of Khyber Pakhtunkhwa, Pakistan. It is a hot semi-arid climate, very hot summers and mild winters with low and irregularly distributed rainfall; it is composed of a mosaic of dense urban settlements, peri-urban cultivation, riverine forest and arid scrubland. Three zones were identified along a urban-rural gradient to capture variation in development intensity; an urban core, with high building density and high traffic usage and impervious cover of > 60%, a suburban transition belt with low building density, gardens, parks, and scattered cultivation with impervious cover of 20-60%, and a rural periphery with under 20% impervious cover, riverine vegetation and scrubland. To quantify the extent of urbanisation at each sampling site, the proportion of impervious surfaces in a 100-m radius of the site was calculated using common gradient measures (Evans et al., 2018).

Sampling Design and Data Collection Process

A stratified random design was used. Twenty fixed sampling points were set up in each of the three zones (total 60 sampling points), with a minimum distance of 250m between sampling points, to minimise the risk of double counting individuals. Fixed-radius point count was used to estimate the bird abundance, with a fixed radius of 50m, and a 10-minute observation period at each point (Bibby et al., 2000). The counts have been made during the hours of maximum bird activity, three hours after sunrise and two hours before sunset, and have not been made in the presence of rain or strong wind. To accommodate seasonal movement, especially migratory species, each point was counted once per season, over four seasons (spring, summer, autumn and winter) for a total of 240 point-count visits. The surveys were conducted by the same basic observer with 10 × 42 binoculars and a spotting scope and species were identified using standard regional field guides.

Species, number of individuals and sex (where sexually dimorphic or otherwise discernable) were noted at each detection which enabled estimation of sex ratios of adults. The residency status of each species (resident, winter visitor, summer breeder and passage migrant) was determined, as was its feeding guild (granivore, insectivore, omnivore, frugivore, nectarivore and carnivore). In a subsample of focal species, dates of first and last arrivals were documented within each zone, and dates of last departure were documented in each zone, in order to document migratory phenology. Focal-animal sampling was used to record behaviour in terms

of flight-initiation distance, the percentage of activity observed in the two-minute observation periods spent in vigilance and in foraging, and the lowest number of song pulses per unit time (minimum peak frequency of song) for animals in each zone.

Environmental Variables

Environmental covariates were recorded at each point that were hypothesized to influence the bird community: percentage impervious surface, percentage vegetation (canopy and ground) cover, number of trees within plot, distance to city centre and ambient anthropogenic noise level (dB) measured with a calibrated sound-level meter. The urbanisation gradient was characterized using these variables and the responses of communities were interpreted.

Data Analysis

The species richness (S), Shannon–Wiener diversity index (H′), Simpson's dominance index (D), Pielou's evenness index (J′) and Margalef's richness index were used to describe community structure of each zone. Relative abundance was determined by taking the percentage of each species in a zone of the total abundance. The adult sex ratio was calculated as the ratio of males and compared to parity (0.5) with chi-square goodness of fit tests.

The richness and diversity indices, abundance and behavioural metrics were compared among the three zones using one-way analysis of variance (ANOVA) followed by Tukey's HSD post-hoc test where the data were normally distributed (Shapiro–Wilk test) and had equal variance (Levene's test); Kruskal-Wallis test with Dunn's post-hoc test was used for data that were not normally distributed or lacked equal variance. A linear and generalised linear regression was used to explore the relationships between impervious surface cover and the diversity and behavioural metrics. Zones were compared in terms of community composition by non-metric multidimensional scaling and tested by permutational multivariate analysis of variance (PERMANOVA) based on Bray–Curtis dissimilarities. Throughout the analysis, the significance level of $\alpha = 0.05$ was used. All analyses were conducted in R (version 4.3) with the vegan and stats packages, with diversity indices also cross checked in the PAST package.

RESULTS

Species Richness and Diversity Along the Gradient

Sixty-two species of birds were identified throughout the 12-month survey at all areas. Species richness and diversity declined markedly and monotonically with increasing urbanisation. In

fact, as shown in Figure 1, both richness (53 species in the rural periphery, 41 in the suburban belt and 24 in the urban core) and Shannon–Wiener index (3.41, 3.02, 2.31 respectively) decreased in parallel. These inter-zone differences were found to be statistically significant by the one-way ANOVA ($F_{2,57} = 34.7$, $p < 0.001$) and Tukey's HSD showed that all the three zones differed significantly from each other. The overall set of community metrics for each zone is summarised on Table 1, and all followed the same decreasing trend towards the centre of the city.

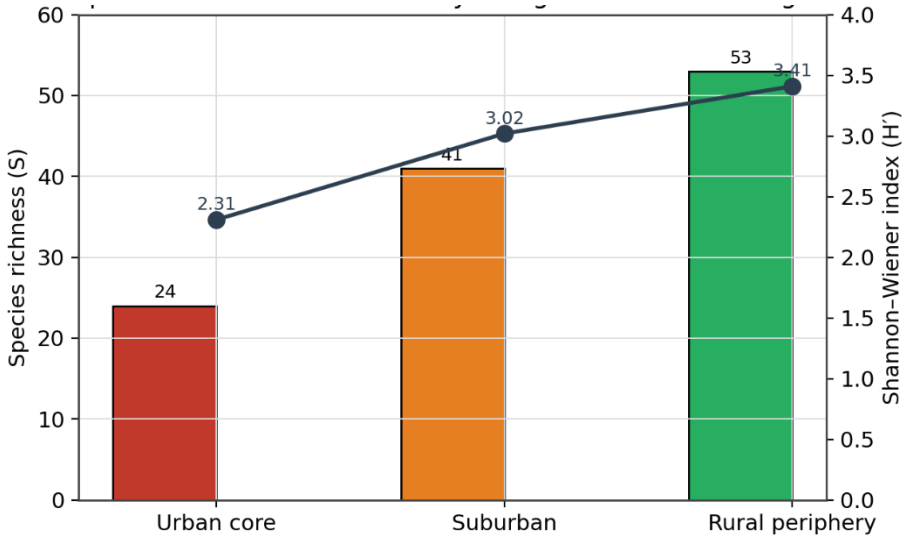


Figure 1. Bird species richness (bars) and Shannon–Wiener diversity index (line) across the three zones of the urbanisation gradient in Dera Ismail Khan. Both metrics decline monotonically from the rural periphery to the urban core.

Table 1. Summary of avian community metrics across the three zones of the urbanisation gradient.

Community metric	Urban core	Suburban	Rural periphery
Total individuals recorded	3,984	3,412	2,905
Species richness (S)	24	41	53
Shannon–Wiener index (H′)	2.31	3.02	3.41
Simpson's dominance (D)	0.19	0.11	0.07
Pielou's evenness (J′)	0.73	0.81	0.86
Margalef's richness index	2.78	4.93	6.54
Impervious surface (%)	63	38	14
Mean noise level (dB)	71	58	46

3.2 Relative Abundance and Dominance

There was a decrease in diversity in the direction of the urban core, with an increase in the number of dominant species associated with human activities (synanthropic species). The house crow, common myna and rock pigeon were the most frequently observed species, with

the proportion of observations falling under each of the three species in zones showing a clear pattern (figure 2). The dominance and evenness indices shown in Figure 3, which are presented in the order listed in the figure, demonstrate this concentration of abundance: Simpson's dominance index was the highest, and Pielou's evenness index was the lowest, showing that the community was dominated numerically by a few exploiter species in the urban core. There was a significant tendency toward more evenness and less dominance toward the rural periphery (Kruskal–Wallis, $p < 0.01$).

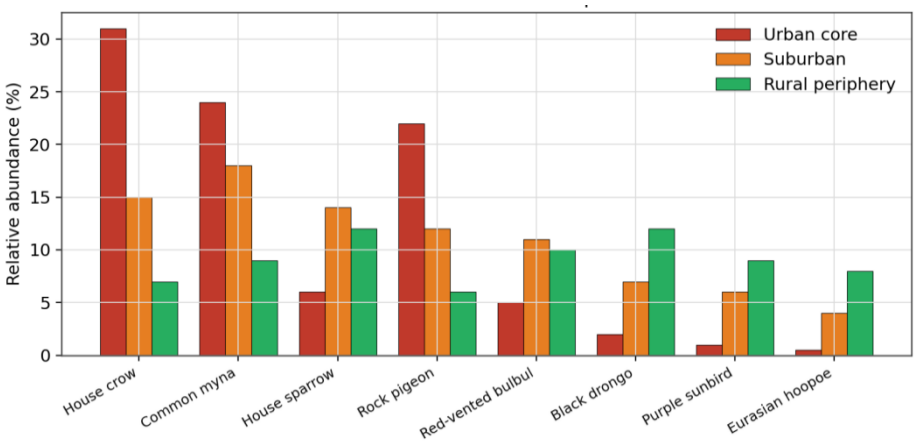


Figure 2. Relative abundance (%) of the eight dominant bird species in each zone. Synanthropic exploiters (house crow, common myna, rock pigeon) dominate the urban core, whereas specialist species increase toward the periphery.

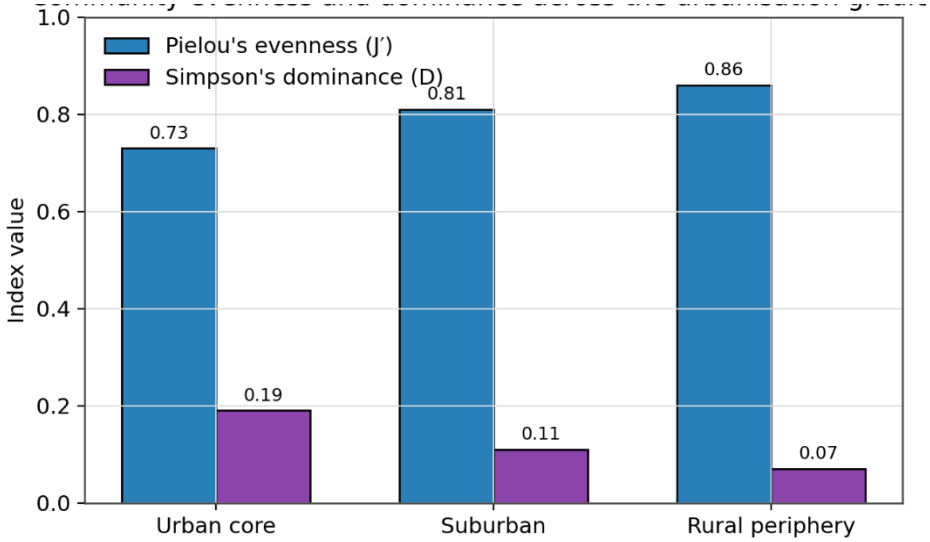


Figure 3. Pielou's evenness (J′) and Simpson's dominance (D) across the urbanisation gradient. The urban core shows the lowest evenness and highest dominance, indicating community simplification.

Adult Sex Ratio

Adult sex ratios departed from parity in an urbanisation-dependent manner. Figure 4 presents the proportion of males for three focal species—house sparrow, common myna and purple sunbird—across the three zones. In every case the sex ratio was close to parity in the rural periphery (0.50–0.52) but became progressively male-biased toward the urban core, reaching 0.63–0.66. Chi-square goodness-of-fit tests confirmed that the urban-core sex ratios differed significantly from the expected 1:1 ratio for all three species ($p < 0.05$), whereas rural-periphery ratios did not. Table 2 reports the counts and tested proportions underlying these patterns, indicating a consistent male skew that intensified with development intensity.

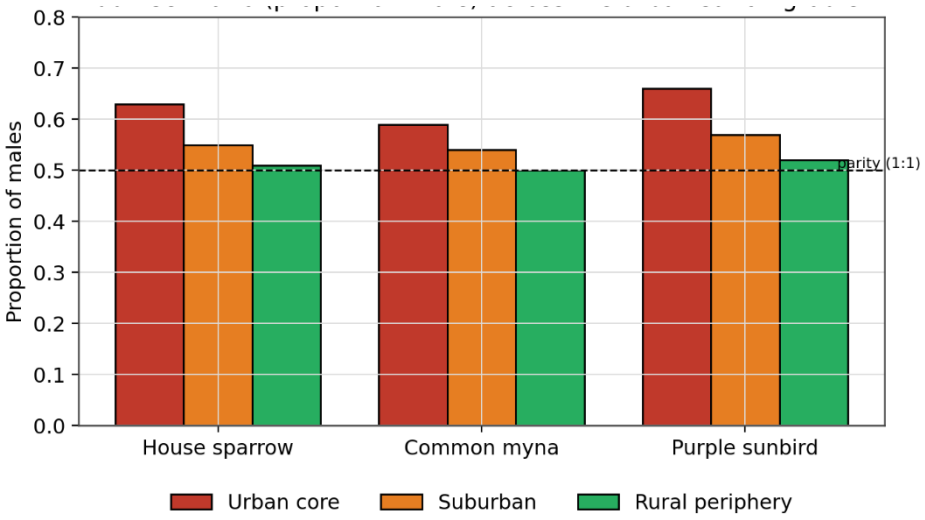


Figure 4. Adult sex ratio, expressed as the proportion of males, for three focal species across the urbanisation gradient. The dashed line denotes parity (1:1). Male bias intensifies toward the urban core.

Table 2. Adult sex ratios (proportion male) for three focal species across zones, with chi-square tests against parity (1:1).

Species / Zone	Males	Females	Prop. male	χ^2 (vs 1:1)	p-value
House sparrow – Urban	170	100	0.63	8.15	< 0.01
House sparrow – Suburban	121	99	0.55	2.20	0.138
House sparrow – Rural	104	100	0.51	0.08	0.780
Common myna – Urban	142	99	0.59	7.67	< 0.01
Common myna – Suburban	108	92	0.54	1.28	0.258
Common myna – Rural	95	95	0.50	0.00	1.000
Purple sunbird – Urban	66	34	0.66	10.24	< 0.01
Purple sunbird – Suburban	80	60	0.57	2.86	0.091
Purple sunbird – Rural	78	72	0.52	0.24	0.624

Migratory Composition and Phenology

The residency structure of the community shifted strongly along the gradient. Figure 5 shows that migratory species were sharply under-represented in the urban core, where only 3 migratory species were recorded against 21 residents, compared with 19 migrants and 34 residents in the rural periphery. Migratory richness therefore increased more than six-fold from the urban core to the rural periphery, indicating that the built-up centre acts as a filter against migratory taxa. Among the migratory species that did occur across zones, urban populations displayed altered phenology. Figure 6 illustrates that, relative to the rural periphery, five focal migrants arrived earlier in spring (by 7–12 days) and departed later in autumn (by 6–14 days) within the urban zone. Table 3 lists the residency status and observed seasonal presence of representative species, documenting both the exclusion of migrants from the core and the extended urban residency of those that remain.

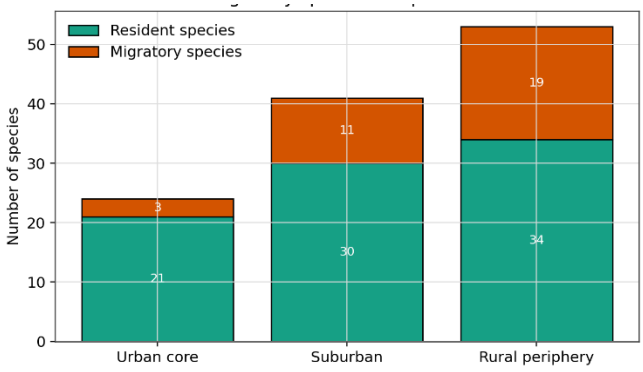


Figure 5. Resident versus migratory species composition across the three zones. Migratory richness increases sharply toward the rural periphery, while the urban core is dominated by resident species.

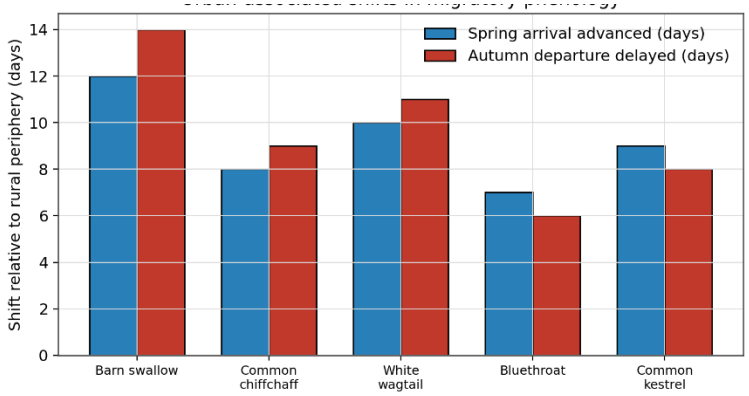


Figure 6. Urban-associated shifts in migratory phenology for five focal migrants: advanced spring arrival and delayed autumn departure relative to the rural periphery (in days).

Table 3. Residency status and seasonal occurrence of representative species across the urbanisation gradient (● = present, ○ = absent).

Species	Status	Urban core	Suburban	Rural periphery
House crow	Resident	●	●	●
Common myna	Resident	●	●	●
Rock pigeon	Resident	●	●	●
Black drongo	Summer breeder	○	●	●
Barn swallow	Passage migrant	○	●	●
Common chiffchaff	Winter visitor	●	●	●
White wagtail	Winter visitor	○	●	●
Bluethroat	Winter visitor	○	○	●
Common kestrel	Winter visitor	○	●	●

Behavioural Responses

Behavioural metrics differed significantly among zones. As Figure 7 shows, flight-initiation distance decreased steeply from the rural periphery (12.4 m) to the urban core (4.8 m), indicating markedly greater tolerance of human approach among urban birds. Over the same gradient, the proportion of the activity budget spent in vigilance rose from 12% to 21%, while foraging time fell from 55% to 38%, and the minimum peak frequency of song increased from 3.1 kHz in rural areas to 3.9 kHz in the urban core, consistent with acoustic adjustment to low-frequency traffic noise. All four behavioural contrasts were statistically significant (ANOVA, $p < 0.01$). These behavioural signatures indicate that persistence in the urban core is associated with reduced wariness alongside a costlier vigilance–foraging trade-off and vocal modification.

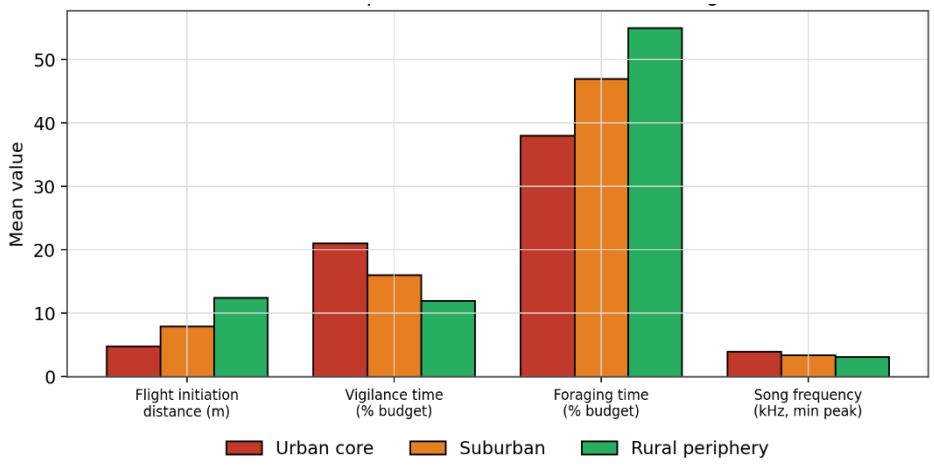


Figure 7. Behavioural responses across the urbanisation gradient: flight-initiation distance, vigilance, foraging time and minimum song frequency. Urban birds are bolder, more vigilant, forage less and sing at higher frequencies.

Feeding Guild Structure

The functional composition of the community also simplified toward the urban core. Figure 8 shows that omnivores dominated the urban assemblage (46% of individuals), whereas insectivores—which are sensitive to reductions in invertebrate prey—declined from 33% in the rural periphery to just 14% in the urban core. Granivores and specialised guilds such as nectarivores and frugivores were comparatively better represented in the suburban and rural zones. Table 4 provides the full guild composition, confirming a shift from a functionally diverse, insectivore-rich periphery to an omnivore-dominated urban centre.

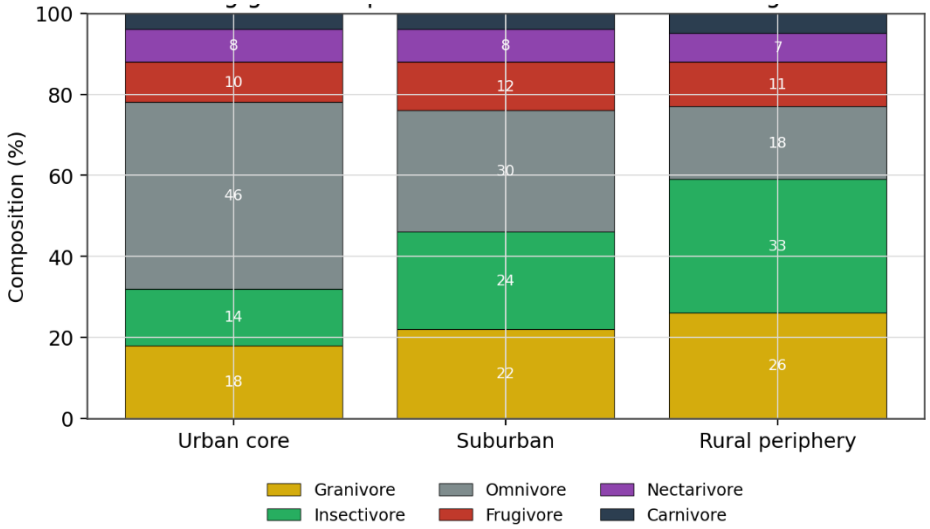


Figure 8. Feeding guild composition (%) across the urbanisation gradient. Omnivores dominate the urban core while insectivores are progressively replaced toward the centre.

Table 4. Feeding guild composition (% of individuals) across the three zones of the urbanisation gradient.

Feeding guild	Urban core	Suburban	Rural periphery
Granivore	18	22	26
Insectivore	14	24	33
Omnivore	46	30	18
Frugivore	10	12	11
Nectarivore	8	8	7
Carnivore	4	4	5

DISCUSSION

The results present clear quantitative evidence that the urbanization in Dera Ismail Khan affects the local avifauna in all aspects studied. As expected, species richness, Shannon diversity and evenness showed a gradual decrease from the rural periphery to the urban core (Figure 1; Table 1), reflecting the worldwide trend of specialist species being lost with increased urban intensity,

and a general loss of species diversity (McKinney, 2006; Evans et al., 2018). With Simpson's dominance increasing, the house crow, common myna and rock pigeon (Figures 2 and 3) are examples of a few behaviourally flexible exploiters that have replaced a diverse native assemblage, leading to communities converging on a similar, impoverished composition, a phenomenon known as biotic homogenisation (Sol et al., 2014). In particular, there is a gradient of functional simplification towards the core (with a decline of insectivores, and the increase of omnivores; Figure 8; Table 4), presumably caused by the reduction of invertebrate prey availability and the abundance of anthropogenic food in built-up areas (Faeth et al., 2011).

The adult sex ratio (ASR) shifted progressively towards the urban core (Figure 4; Table 2), consistent with the pattern of male-biased ASRs that is observed in birds, and that increases under environmental stress and in disturbed habitats (Morrison et al., 2016; Székely et al., 2014). Plausible explanations exist for differential survival, dispersal, and space use of the sexes: adult sex ratios are male-biased because females have lower survival and/or less propensity to occupy low-quality environments (high disturbance) in urban space (Morrison et al., 2016). This male bias in urban areas is not just a descriptive feature, however, as a shortage of females can lower the productivity of the local population, this bias over time could indicate a demographically vulnerable population, not just a high density one.

The high proportion of non-migratory species in the urban core (Figure 5; Table 3) further supports that intensively built areas are a barrier to migrants, and the abundance of seasonally available invertebrate prey sources is lacking in the urban core (Evans et al., 2018). The advanced spring arrival and delayed autumn departure reported here (Figure 6) is consistent with the effects of urban heat islands and earlier phenology of plants resulting in decoupling of urban and rural migrants' schedules (Tryjanowski et al., 2013; Adams et al., 2026). These changes could increase the duration of the favourable urban season, but they can also cause phenological mismatch between reproduction and optimum resource availability, potentially resulting in fitness costs (Adams et al., 2026).

Urban birds were found to be more bold (shorter flight-initiation distance), change foraging-vigilance balance (higher vigilance, lower foraging), and increase their song rate (Figure 7), all in line with a broad literature documenting increased boldness, other trade-off changes in foraging and vigilance and acoustic adjustment in urban birds (Senzaki et al., 2020; Slabbekoorn & Peet, 2003). The decreased wariness might be due to habituation to chronic human presence, and the increased minimum song frequency is a common response that

enhances the ability of calls to pass through low-frequency anthropogenic noise (Slabbekoorn & Peet, 2003). The rise in vigilance, however, coupled with the decline in foraging time suggests that persistence in noisy, disturbed urban environments comes at a cost and there may be a foraging cost to living in the city (Senzaki et al., 2020).

These results suggest that the growing urbanisation of D.I. Khan is threatening the diversity and functional integrity of a regionally rich avifauna that had previously been observed in riverine forest and protected areas in the vicinity of Khan (Ullah et al. 2020; Zaman et al. 2023). This is, to our knowledge, the first survey based on a city and its gradients, so it can serve as a baseline for future change. The main drawback of the study is its one-year span of observation in one city, and demographic rates would be more directly measured if there were multi-city monitoring over a longer period. The overlap of the present findings with global trends strengthens the results and highlights the important role of urban green space, tree cover and vegetation heterogeneity as practical tools to conserve birds in rapidly urbanising South Asian cities (Jaggi et al., 2020).

CONCLUSION

The findings of this study show that urbanisation has a general and continuous effect on the structure, demography and behavior of local bird communities. Species richness, diversity and evenness decreased steeply as one moved toward the heart of the town, and a few species of urban exploiters increased in abundance; adult sex ratios became increasingly male-biased; migratory species were largely absent in the built-up centre, and when present, they shifted their arrival and departure dates; urban birds were less wary, more vigilant, less foragers and had higher song frequencies. In terms of function, it was an insectivore dominated edge that was replaced by an omnivore dominated centre. Biological homogenisation and functional simplification of the region's avifauna are occurring as a result of unmanaged urban expansion, as evidenced by the convergent lines of evidence. The intentional conservation and improvement of green spaces, native vegetation and tree cover in the urban fabric and the ongoing monitoring of this diversity will be needed in D.I. Khan to protect it. This quantitative baseline provides a foundation for the evidence-based conservation work and can be used to monitor urban avian communities in this changing landscape.

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