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River proximity and urban park attributes influence bird diversity in Arequipa, Peru

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Abstract. *Rivero-Mamani M, Villegas-Paredes L, Villasante-Benavides J, Luque-Fernandez CR. 2025. River proximity and urban park attributes influence bird diversity in Arequipa, Peru. Biodiversitas 26: 5838-5847.* Urban green spaces are critical for sustaining biodiversity in rapidly expanding cities, yet their ecological function in arid landscapes remains poorly understood. This study examines how park attributes and river proximity influence bird diversity across 12 urban parks in Arequipa, southern Peru. Bird surveys were conducted using standardized point counts from January to June 2020. For each park, habitat structure, vegetation cover, noise level, and distance to the Chili River were quantified, and their effects on species richness and abundance were evaluated using model selection based on Akaike's Information Criterion. A total of 28 species were recorded in the urban parks, with Passeriformes and Columbiformes being well represented. The most frequent and abundant species were *Turdus chiguanco* and *Zenaida meloda*. Variation in species richness and abundance showed significant differences among the parks and sampling months. Parks located closer to the river exhibited higher diversity during the study period. In the analysis of structural characteristics and bird diversity, the models indicated that although distance to the river was not a relevant predictor, bird richness responded significantly to certain attributes, such as the proportion of green area, park size, and distance to the nearest agricultural zone. In contrast, abundance and Shannon-Wiener diversity did not show significant responses. These findings underscore the ecological importance of riparian connectivity and vegetation structure in enhancing avian diversity within arid urban settings. Integrating green space design with river corridor conservation could improve habitat quality, strengthen urban ecological networks, and support long-term biodiversity resilience in Andean cities.

Keywords: Biodiversity, habitat diversity, river effect, urban forests, urbanization

INTRODUCTION

In cities, birds play essential ecological roles, such as bioindicators of environmental quality, seed dispersers, pollinators, and biological control agents (Vides-Hernández et al. 2017). However, they are heavily impacted by habitat modification. Urbanization is a key driver of habitat loss and biotic homogenization, as natural ecosystems are replaced by built environments that simplify vegetation and generate fragmentation (Juri and Chani 2009; Nolazco, 2012; Aronson et al. 2014; Sidemo-Holm et al. 2022; Santos et al. 2024). These disturbances alter bird community composition and ecological roles, causing birds to move towards less urbanized areas, adapt their foraging, and adjust behavioral strategies (Faggi and Perepelizin 2006; Pollack et al. 2018). This dynamic is particularly pronounced in arid Andean cities where water scarcity and limited vegetation intensify challenges for bird diversity. Integrated green and blue infrastructures, such as parks and riparian corridors, serve as biodiversity refugia, enhancing habitat availability in these largely xeric environments (Ortega-Álvarez and MacGregor-Fors 2011; Beninde et al. 2015). Despite high regional endemism and steep elevational gradients in high-Andean cities, most urban bird studies in the Neotropics have focused on lowland or temperate areas (Ortega-Álvarez and MacGregor-Fors 2011; Garizábal-Carmona et al. 2024). Urban expansion in the tropical Andes has led to the erosion of native forests remnants and a lack of understanding regarding how green-blue networks support native bird species (Garizábal-Carmona et al. 2024). Evidence suggests that both proximity to rivers and park attributes influence urban bird diversity. Riparian corridors provide water, cooler microclimates, and gallery vegetation, supporting more diverse and less homogenized bird communities than adjacent urban areas (McClure et al. 2015; Sun et al. 2022). Larger parks tend to harbor more species due to the species-area relationship, while greater tree canopy and vertical complexity support native species and increase overall richness (Beninde et al. 2015; Yang et al. 2020; Xie et al. 2022; La Sorte et al. 2023; Rahman et al. 2025). However, urban ornithology in Latin America remains underrepresented, particularly in arid Andean cities, limiting our understanding of how water availability and urban infrastructure shape bird diversity (Ortega-Álvarez and MacGregor-Fors 2011).

Urban bird research in Peru has mainly focused on a few cities, such as Lima, Trujillo, Arequipa, and Cajamarca, and has primarily been limited to species lists and broad urban gradients. Few studies explore the mechanisms linking habitat configuration to diversity patterns, with the roles of riparian corridors or park structure often studied separately (Takano-Goshima and Castro-Izaguirre 2007; Nolazco 2012; Silva-Guzmán et al.

2012; Castillo-Palacios et al. 2014; Luque et al. 2018; Pollack et al. 2018; Roncal-Rabanal et al. 2020; Leveau et al. 2022). As a result, there is a lack of evaluations explicitly comparing the relative importance of river proximity and park structural attributes in shaping avian α-diversity and community structure in arid Andean cities like Arequipa, limiting the development of evidence-based green-blue management plans. Arequipa, Peru's second-largest city, is rapidly expanding in the arid mesotropical belt (de Mera et al. 2010). The Chili River crosses the city and provides water for agriculture, industry, human consumption, and urban green spaces. Its riparian zone supports a floristically rich assemblage with native and endemic species, embedded in an irrigated agricultural landscape known as the "campiña," which likely offers several ecosystem services that remain unevaluated (Montesinos-Tubée et al. 2019). However, it is unclear to what extent this river-campiña-park mosaic supports native and riparian bird assemblages in the metropolitan core or benefits mainly urban-tolerant species. In arid Andean cities, riparian corridors may act as dispersal pathways and microclimatic refuges, while park structure mediates local habitat quality in an otherwise xeric environment. This study tests the hypotheses that bird α-diversity decreases with distance from the Chili River and that park area and structural attributes are positively associated with α-diversity. The objective was to determine how bird richness, abundance, and community composition in urban parks of metropolitan Arequipa vary as a function of distance to the Chili River, and to assess the relative importance of park structural attributes in explaining these spatial and temporal patterns. The results are intended to provide useful recommendations for the conservation of this type of urban biodiversity.

MATERIALS AND METHODS

Study area

The study was conducted in Arequipa City (16°23'56"S, 71°32'6"W), located in southwestern Peru at an average altitude of 2,350 m asl, characterized by rugged topography dominated by the Volcanic Cordillera and marked aridity. Temperatures typically range from 9°C to 23°C, rarely falling below 7°C or exceeding 25°C throughout the year. The metropolitan area of Arequipa comprises 21 districts covering approximately 50,246 ha (PDLC 2016), with the Chili River as the only permanent watercourse traversing the city, along which a large proportion of cultivated areas are established. For this study, 12 urban parks were selected, these parks ranged in altitude from 2,286 to 2,411 m asl (Figure 1, Table 1) and grouped into three categories according to their straight-line distance from the Chili River (near: <0.6 km; intermediate: 0.6-1.4 km; distant: 1.4-2.4 km).

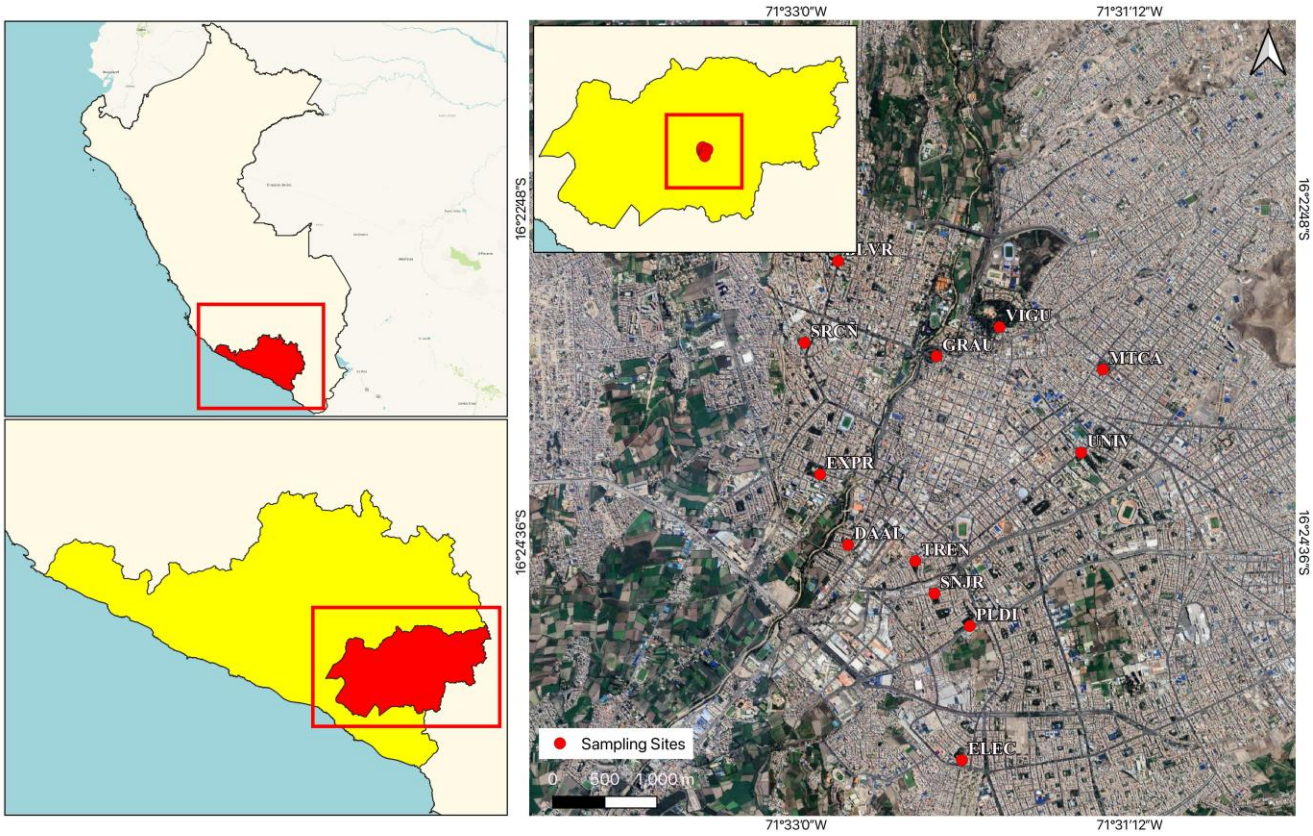

Figure 1. Location of the 12 urban parks studied in the metropolitan area of Arequipa, Peru. The circles indicate the centroids of the parks evaluated

Table 1. Geographical location and altitude of the parks evaluated in this study

Code	Park name	Latitude	Longitude	Elevation (m)
GRAU	Grau	16° 23' 35.67" S	71° 32' 14.60" W	2334
DAAL	Dante Alighieri	16° 24' 36.72" S	71° 32' 43.29" W	2286
VIGU	Vizcardo Y Guzman	16° 23' 26.20" S	71° 31' 54.20" W	2372
EXPR	Libertad De Expresion	16° 24' 13.91" S	71° 32' 52.33" W	2312
SRCÑ	Señor De La Caña	16° 23' 31.26" S	71° 32' 57.36" W	2350
TREN	Del Tren	16° 24' 41.99" S	71° 32' 21.46" W	2305
BLVR	Simon Bolivar	16° 23' 04.85" S	71° 32' 46.47" W	2388
SNJR	San Jerónimo	16° 24' 52.50" S	71° 32' 15.30" W	2310
MTCA	Mayta Capac	16° 23' 39.97" S	71° 31' 20.73" W	2411
PLDI	Palardeli	16° 25' 02.98" S	71° 32' 03.78" W	2317
UNIV	Universitario	16° 24' 06.84" S	71° 31' 27.78" W	2373
ELEC	Villa Electrica	16° 25' 46.43" S	71° 32' 06.39" W	2312

Characterization of urban parks

Each park was characterized using structural variables of potential and usable bird habitat, including vertical structure and ground cover, as well as anthropogenic pressure related to vehicular traffic and noise. Additional metrics included distances to the river, distances to other parks (Isolation 1) and to the nearest agricultural area (Isolation 2), and the number of parks within a 200 m radius, due to their potential "source" effect on species richness (Fernández-Juricic 2000; Wang et al. 2013). Structural habitat characterization was conducted through standardized visual inspection, recording bird space-use preferences, and assigning each park to 13 structural habitat categories (modified from Yang et al. 2020). These categories included tree type and size, shrub structure, presence of aquatic areas, clearings (bare soil/grass), and built structures (chapels, pavilions). The proportion of paved versus green area was also estimated, with green area further disaggregated into vegetation strata (trees, shrubs, herbaceous plants, bare soil) (Romero et al. 2014). Vehicular traffic and noise were classified into three standardized levels (low, medium, high) based on vehicle flow per minute in the park's immediate surroundings (modified from Romero et al. 2014). Ambient noise (dB) was measured using Sound Meter Pro v2.6.2a on a calibrated smartphone. Before fieldwork, the device was calibrated with a class 2 sound level meter in a range of 40 to 80 dB (with an accuracy of ±1.5 dB). During each visit to the park, measurements were taken for 120 seconds, for a total of four measurements per park. This assessment was carried out from the central part of each park.

Bird sampling: Richness and abundance

The parks were randomly surveyed during the last 12 days of each month (January-May 2020), with one park censused per day under comparable weather conditions (Morelli et al. 2018). This evaluation period was established because the vegetation in the parks is more vigorous and in better condition as a result of the rainy season. In each park, two fixed-radius point counts (20 m radius, 15 min duration each) were established (Ralph et al. 1996; Garitano-Zavala and Gismondi 2003; Perepelizin and Faggi 2009; Arteaga-Chávez 2017; Chávez-Villavicencio 2017; Chaiyarat et al. 2018; Echevarría et al. 2023). Prior to each count, a rapid 10-minute species checklist was conducted by direct observation to maximize detection of richness. Surveys were carried out between 06:00 and 08:00 h. Each recorded species was classified by origin (Soto-Saravia 2014) and feeding guild (carnivore, frugivore, granivore, insectivore, nectarivore, omnivore), based on observed foraging behavior (Strewe et al. 2009). Species use of the park (feeding, resting, nesting) and foraging stratum (ground, arboreal, aerial) were also recorded. Complementary records collected outside formal point counts were used solely to complete cumulative park species lists; they were excluded from inferential analyses of variation in richness and abundance to avoid effort-related bias.

Data processing and analysis

We evaluated bird inventory completeness with species accumulation curve (Colwell et al. 2004). We used the common nonparametric estimator Chao 1 to estimate the expected true number of bird species (S_{exp}) in each park (Chao et al. 2005). The sampling adequacy analyses were performed using the "vegan" package (Oksanen et al. 2025). Species richness and abundance data were tested for normality (Shapiro-Wilk test). After normality assessment, ANOVA was applied to evaluate differences among distances, parks, and months, with Tukey's post hoc test for multiple comparisons (α: 0.05). Additionally, the Shannon-Wiener Index (H′) was calculated per park and month, as well as by park groups according to distance from the Chili River, for spatial and temporal comparisons. To assess the influence of park characteristics and distance from the river on bird diversity, Pearson correlation tests were applied to predictor variables, excluding those with correlation values >0.7. Subsequently, a candidate model set was built by combining non-correlated variables. Model selection was based on the corrected Akaike Information Criterion (AICc), with models presenting ΔAICc <2 considered to have substantial support (Burnham and Anderson 2002). We adopted an information-theoretic approach using AICc, given the modest sample size relative to the number of candidate predictors. ΔAICc values quantify the distance to the best model, and Akaike weights (wi) approximate the probability that a model is the best within the candidate set.

Analyses were performed using the MuMIn package (Bartoń 2025) in the R 4.4.1 environment (R Core Team 2024).

RESULTS AND DISCUSSION

Characterization of the selected urban parks

Park area sizes ranged from 0.29 to 3.67 ha, with a mean of 0.96 ha. The average green-area proportion across parks was 73.08% (63-88%), while paved surface averaged 26.91% (12-37%). The park with the highest proportion of green area was VIGU, and the lowest was SRCN. Regarding vegetation strata, tree cover varied from 30% (SRCN) to 57% (ELEC), with frequent species including *Fraxinus americana*, *Casuarina equisetifolia*, *Morus* sp., *Jacaranda mimosifolia*, and *Pinus radiata*. Herbaceous cover ranged from 26% (ELEC) to 53% (DAAL), dominated by species such as *Chrysanthemum* sp., *Plantago major*, *Taraxacum officinale*, *Oxalis corniculata*, and *Gazania* sp.. Shrub cover varied from 3% (UNIV) to 28% (MTCA), represented primarily by *Rosa canina*, *Lantana camara*, *Nerium oleander*, and *Hydrangea macrophylla*. About structural habitat features available to birds, between 6 and 11 habitat types were recorded. Parks EXPR, VIGU, and MTCA exhibited the greatest number of habitat types, whereas GRAU and UNIV had the fewest; both of the latter also experienced high vehicular traffic. In contrast, DAAL and ELEC were classified as having low traffic levels (Table 2).

Temporal variation in bird diversity in the selected parks

A total of 28 bird species were recorded, belonging to nine orders, 17 families, and 25 genera. According to the expected true species richness (S_{exp}), the average survey completeness for the 12 parks was 97%, ranging from 82 to 100% (Table 2). Meanwhile, the species accumulation curve approached an asymptote (Figure 2), indicating a high level of bird inventory completeness for the 12 study parks. In terms of species richness, the most represented order was Passeriformes, while the best-represented family was Columbidae (Table 3). All recorded species are currently categorized as Least Concern (LC), with the exception of *Psittacara erythrogenys*, which is categorized as Near Threatened (NT). During the study period, 6116 individuals were recorded. The most abundant species was *Turdus chiguanco* with 1190 individuals (19.5%), followed by *Columba livia* with 893 individuals (14.6%) and *Zenaida meloda* with 876 individuals (14.4%). The least abundant species were *Dives warszewiczi*, *Falco femoralis*, *Geranoaetus polyosoma*, *Myrtis fanny*, *Molothrus bonariensis*, and *Setophaga ruticilla* (Table 3), which were recorded only occasionally within the parks.

Across parks, bird richness spanned a modest range and averaged roughly ten species per park, while abundance averaged about seventy individuals. Richness was not detectably different among months, but it did very strongly among parks (one-way ANOVA: F(11,36): 8.83, p<0.001, η^2: 0.73). The highest values occurred consistently in EXPR and VIGU, whereas BLVR, GRAU, and TREN occupied the lower end of the gradient. Although June showed the highest monthly mean richness, pairwise contrasts were not significant, confirming that spatial rather than monthly variation structured richness (F(3, 36): 1.78, p: 0.168, η^2: 0.11).

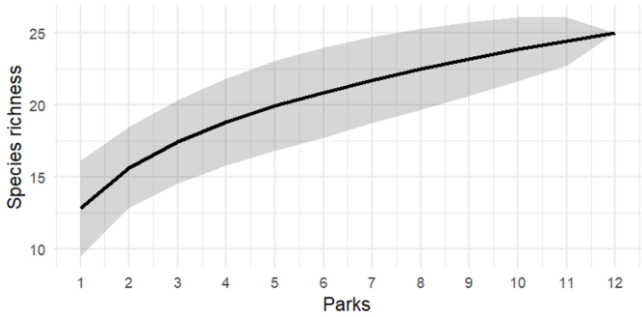

Figure 2. Species-accumulation curve for birds in the 12 urban parks of Arequipa, Peru

Table 2. Characteristics of the 12 study parks in Arequipa, Peru, Isolation 1 is given as distance to the nearest larger park, Isolation 2 is given as distance to the nearest agricultural area, river distance represents the distance of the park to the Chili River

Park code	Area (ha)	River distance (km)	Isolation 1 (km)	Isolation 2 (km)	Habitat diversity	Shape index	Noise(dB)+SD	S_{obs} (n)	S_{exp} (n)	S_{com}	Ab±SD
GRAU	0.46	0.12	0.02	0.23	6	1.13	86.34±1.96	10	10	1.00	49.75±3.86
DAAL	0.36	0.17	0.07	0.2	9	1.32	67.59±6.19	14	17	0.82	66.75±6.99
EXPR	1.67	0.4	0.13	0.35	11	1.13	80.12±4.21	15	15.5	0.97	115±24.59
VIGU	3.67	0.55	0.04	0.35	11	1.08	81.98±4.84	15	16	0.94	91.75±10.21
TREN	0.47	0.89	0.08	0.84	7	1.36	80.83±5.86	13	13	1.00	45±9.49
SRCN	0.35	1.1	0.09	0.3	8	1.18	74.46±4.88	11	11	1.00	79.75±9.29
BLVR	0.29	1.23	0.06	0.71	7	1.36	81.24±3.99	12	12	1.00	53.5±16.36
SNJR	0.7	1.28	0.1	0.46	10	1.17	72.49±5.3	14	14	1.00	64.5±7.72
MTCA	0.96	1.59	0.09	1.52	11	1.14	82.57±3.51	11	12	0.92	66.75±14.86
PLDI	0.9	1.63	0.02	0.1	10	1.45	73.03±5.24	14	14	1.00	66.75±14.5
UNIV	0.86	1.95	0.02	1.16	6	1.65	82.84±3.99	11	11	1.00	75.25±8.66
ELEC	0.84	2.39	0.06	0.8	9	1.14	70.99±4.63	14	14.5	0.97	88±9.49

Note: S_{obs}: Observed species richness, S_{exp}: Expected species richness (Chao 1), S_{com}: Survey completeness (Chao 1), Ab: Average abundance and standard deviation

Table 3. List of bird diversity in urban parks of Arequipa (Peru) and characteristics of use and frequency

Species	English common name	Origin	Trophic guild	Foraging stratum	Habitat use	Relative frequency (%)
Geranoaetus polyosoma	Variable Hawk		Carnivore	-	Resting	<4
Parabuteo unicinctus	Harris's Hawk	Native	Carnivore	-	Resting	<4
Cathartes aura	Turkey Vulture	Native	Carnivore	-	Resting	10
Myrtis fanny	Purple-collared Woodstar	Native	Nectarivore	Aerial	Feeding	<4
Rhodopis vesper	Oasis Hummingbird	Native	Nectarivore	Aerial	Feeding, Resting	83
Thaumastura cora	Peruvian Sheartail	Native	Nectarivore	Aerial	Feeding, Resting	25
Columba livia	Rock Pigeon	Introduced	Omnivore	Ground	Feeding, Resting, Nesting	94
Columbina cruziana	Croaking Ground Dove	Native	Granivore	Ground	Feeding, Resting, Nesting	88
Patagioenas maculosa	Spot-winged Pigeon	Native	Granivore	Ground	Feeding, Resting, Nesting	21
Zenaida auriculata	Eared Dove	Native	Granivore	Ground	Feeding, Resting, Nesting	67
Zenaida meloda	West Peruvian Dove	Native	Granivore	Ground	Feeding, Resting, Nesting	100
*Crotophaga sulcirostris**	Groove-billed Ani	Native	Insectivore	Aerial	Feeding, Resting	<4
Falco femoralis	Aplomado Falcon	Native	Carnivore	Arboreal	Feeding, Resting	<4
Falco sparverius	American Kestrel	Native	Carnivore	Arboreal	Feeding, Resting	19
Conirostrum cinereum	Cinereous Conebill	Native	Frugivore	Arboreal	Feeding	65
Dives warszewiczi	Scrub Blackbird	Native	Frugivore	-	Resting	<4
Molothrus bonariensis	Shiny Cowbird	Native	Omnivore	Ground	Feeding, Resting	<4
Passer domesticus	House Sparrow	Introduced	Omnivore	Ground	Feeding, Resting	6
Pygochelidon cyanoleuca	Blue-and-white Swallow	Native	Insectivore	Aerial	Feeding	65
Setophaga ruticilla	American Redstart	Migrant	Insectivore	Arboreal	Resting	<4
*Spinus atratus**	Black Siskin	Native	Granivore	Arboreal	Feeding, Resting	<4
Spinus magellanicus	Hooded Siskin	Native	Granivore	Arboreal	Feeding, Resting	63
Turdus chiguanco	Chiguanco Thrush	Native	Omnivore	Ground, Arboreal	Feeding, Resting, Nesting	100
Zonotrichia capensis	Rufous-collared Sparrow	Native	Omnivore	Ground	Feeding, Resting, Nesting	94
Nycticorax nycticorax	Black-crowned Night-Heron	Native	Carnivore	-	Resting	44
Psittacara erythrogenys	Red-masked Parakeet	Introduced	Frugivore	Arboreal	Feeding, Resting	13
Thectocercus acuticaudatus	Blue-crowned Parakeet	Introduced	Frugivore	Arboreal	Feeding, Resting	<4
*Athene cunicularia**	Burrowing Owl	Native	Carnivore	-	Resting	<4

Note: *: Occasional record (outside the evaluation period)

Abundance, in contrast, was shaped by both park identity and month (type II ANOVA). The park effect was very large ($F(11, 36)$: 60.47, $p<0.001$, partial η^2: 0.881): parks leading in richness (notably EXPR and VIGU) also concentrated more individuals, while TREN and GRAU consistently had fewer. The month effect was also strong ($F(3, 36)$: 35.55, $p<0.001$, partial η^2: 0.745): June exhibited a clear abundance peak relative to January, February, and May (Tukey, $p<0.001$), with no differences among those three months (Tukey, $p>0.60$).

Distance to the Chili River further clarified these patterns. Richness was higher in parks closest to the river and declined at intermediate and far distances (one-way ANOVA: $F(2, 45)$: 6.43, p: 0.0035, η^2: 0.22). Practically, parks within 0.6 km of the river supported roughly one to two more species than parks farther away; the two more distant groups did not differ (Tukey, p: 0.70). Abundance mirrored this trend: distance groups differed overall (Kruskal-Wallis: $\chi^2(2)$: 6.78, p: 0.0338, ε^2: 0.144), with near-river parks holding more individuals than the intermediate and far groups, which were indistinguishable in pairwise tests. Consistently, Shannon-Wiener diversity was higher near the river ($F(2, 93)$: 5.25, $p<0.05$) and showed no contrast between the two farther-distance categories (Tukey, p: 0.81).

Influence of park characteristics on bird diversity

Based on the AICc model selection, the best multivariable model incorporated three attributes: the proportion of total green area in the park (green_area), park size (size), and distance to the nearest agricultural zone (Isolation 2). This model best explained species richness (ΔAICc: 0.00; w_i: 0.908) (Table 4). In this model, richness increased with the proportion of green area (β: 0.36±0.15, p: 0.019) and park size (β: 0.38±0.13, p: 0.005), but decreased with greater distance to agricultural areas (β: -0.34±0.14, p: 0.022). Thus, parks with larger green areas, greater size, and closer proximity to agricultural zones tended to support higher bird richness (Figure 3). For abundance, model selection was not conclusive (Σw_i for models with ΔAICc ≤2: 0.446). Although model averaging showed positive effects, they were not statistically significant for the proportion of green area (β: 11.59±13.96, p: 0.408; w^+: 0.44), park size (β: 11.39±15.29, p: 0.474; w^+: 0.30), or habitat diversity (hd; β: 5.35±6.83, p: 0.431; w^+: 0.27), even though these attributes would be expected to increase abundance (Table 4). Finally, diversity, as measured by the Shannon-Wiener Index, averaged coefficients identified the proportion of green area as the most important predictor (w^+: 1.00), with a positive and significant effect (β: 0.22±0.07, p: 0.003). Herbaceous cover (herb) showed a positive but non-significant effect (β: 0.08±0.06, p: 0.196; w^+: 0.71) (Table 4).

Discussion

Arequipa's urban parks showed considerable variation in size, shape, and vegetation structure, with green cover ranging approximately from 63% to 88% of each park's area. This variability is comparable to what has been observed in other South American cities spanning a broad urbanization gradient, such as La Paz-El Alto, where green cover ranges from 10% to 90% depending on urban density, and highly consolidated centers like Buenos Aires, where the green fraction in public space is often much lower, frequently below 10% (Garitano-Zavala and Gismondi 2003; Perepelizin and Faggi 2009). Within that regional context, Arequipa's parks, with relatively high proportions of green space, and with tree canopy cover in the surveyed parks ranging from sparse at about 30% to dense at around 57%, reflect differences in planting density and stand age. Although few studies explicitly quantify vegetation structure as a direct predictor of urban bird diversity, the literature consistently shows that parks with greater structural complexity a mix of tall trees, shrub layers, and ground-layer cover support higher richness and diversity by providing more niches, trophic resources, and nesting sites (Díaz and Armesto 2003; Garitano-Zavala and Gismondi 2003; González 2004; Germain et al. 2008; Romero et al. 2014; Muñoz et al. 2018). Our results agree with this general principle: parks with well-developed vertical structure harbored more diverse bird species. This is consistent with studies in large metropolitan areas showing positive effects of vegetation complexity and park-level green cover on urban bird diversity, reinforcing the broad applicability of this ecological pattern (Callaghan et al. 2018; Yang et al. 2020).

Table 4. Candidate model selection (ΔAICc ≤2) relating bird species richness and abundance to predictor variables of urban parks

Variable	Model	k	logLik	AIC_c	delta	w_i
Richness	y ~ green_area + iso 2 + size	4	-2.14	24.28	0	0.908
Abundance	y ~ green_area	2	-49.37	107.74	0	0.195
Abundance	y ~ size	2	-49.76	108.51	0.77	0.133
Abundance	y ~ hd	2	-49.87	108.74	1	0.118
Shannon-Wiener Index	y ~ green_area + herb	3	19.73	-25.74	0	0.444
Shannon-Wiener Index	y ~ green_area	2	16.46	-23.92	1.82	0.179

Note: k: Number of parameters, logLik: log-likelihood, AICc: Akaike Information Criterion, ΔAICc: Difference from the best model and w_i: Akaike weight

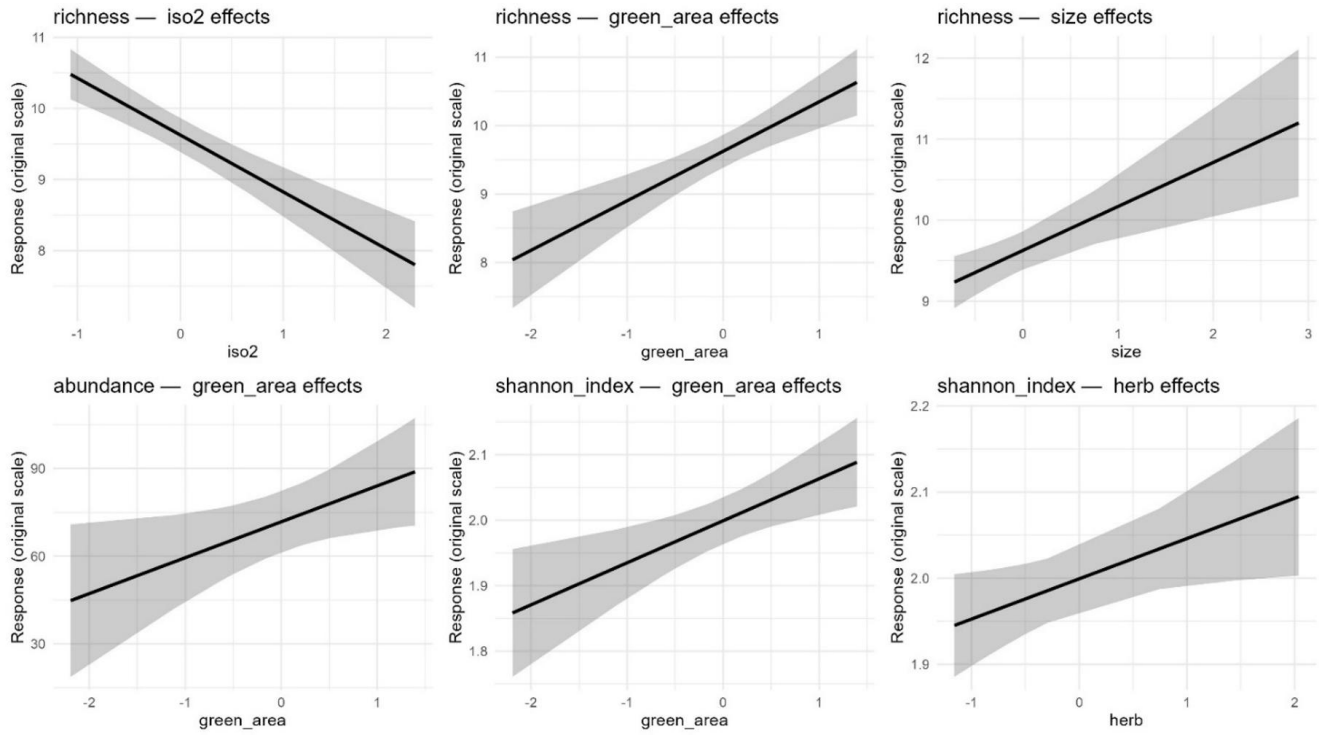

Figure 3. Marginal effects of park attributes on species richness, abundance, and Shannon-Wiener diversity. Lines show model-averaged predictions with 95% CIs (predictors standardized: green area: proportion of total green area; size: park area; iso2: distance to nearest agricultural zone; herb: herbaceous cover)

Habitat diversity was another important factor. We recorded up to 13 microhabitat types across Arequipa's parks, with 6 to 11 per park, including groupings of tall trees such as conifers, scattered shrublands, and areas of bare soil. Parks offering a mosaic of these types showed higher bird richness, presumably because they facilitate niche partitioning and resource complementarity among species. Similar positive effects of habitat diversity have been documented in urban parks elsewhere, and recent assessments indicate that parks with a greater number of habitat types and stratified vegetation sustain more diverse assemblages (Chaiyarat et al. 2018; Yang et al. 2020; Zhang and Huang 2020).

Richness and abundance

Surveys in this study recorded 28 bird species, including several not previously reported for the urban area of Arequipa (Luque-Fernández et al. 2018), among them *D. warszewiczi*, *F. femoralis*, *G. polyosoma*, *P. domesticus*, and *C. atratus*. These additions likely reflect broader spatiotemporal coverage, the inclusion of varied habitats, and recent distributional dynamics. A particularly notable finding was the observation of *S. ruticilla*, a boreal migratory warbler, foraging in a surveyed park. This species is a rare migrant in Peru, and there had been no records near Arequipa since 1996, so this sighting represents the second regional record and the first documented within the city's urban area (eBird 2021). *Setophaga ruticilla* typically uses dense shrublands during migration (Lemon et al. 1996; Sterling 2011), although in our case, it was observed actively foraging in introduced trees taller than 3 m, *Populus deltoides* and *C. equisetifolia*, consistent with its insectivorous foliage-gleaning behavior (Rivera-Gutiérrez 2006). The species' ability to use an urban green space underscores the potential of city parks to serve as occasional refuges or stopover sites for migratory and rare species (Pacheco-Muñoz et al. 2025). Such occurrences have relevant conservation implications: even infrequent visitors can benefit from complex vegetation structure in parks, which favors both residents and migrants. Indeed, recent research shows that cities with abundant tree cover can function as "simplified forests" that support surprisingly complex assemblages of migratory birds when suitable habitat is available (Pacheco-Muñoz et al. 2025).

The overall composition in Arequipa's parks was dominated by a few urban-tolerant species, with *T. chiguanco* and *Z. meloda* among the most frequent, a pattern consistent with their strong synanthropy reported for other Andean cities (Garitano-Zavala and Gismondi 2003; Muñoz et al. 2008; Romero et al. 2014). The dominance of *T. chiguanco* in high Andean cities can be explained by a set of traits favorable to urban environments: greater boldness, less neophobia, and behavioral innovation in urban populations compared to extra-urban populations (Garitano-Zavala et al. 2022). In addition, its omnivorous diet (invertebrates and fruits) and flexible use of strata (ground-tree) may facilitate the exploitation of resources in parks and gardens, contributing to its prevalence in xeric urban matrices. Notably, *C. livia*, often abundant in urban centers, was not particularly numerous in our surveys (Garitano-Zavala and Gismondi 2003; Nolazco 2012), which could be due to local factors such as park management, food availability, or higher tree cover that reduces open foraging areas. It is worth noting that although about 88 species have been reported for the greater urban area of Arequipa (Sullivan et al. 2009), many of those records come from the Chili River riparian corridor, for example, *Merganetta armata* or *Cinclus leucocephalus*, or from adjacent peri-urban habitats. By focusing strictly on interior parks, the species pool is smaller and better reflects park habitats than direct river influence.

Richness differed significantly among parks, with the largest and greenest in particular, EXPR and VIGU, supporting, on average, more species. In contrast, no temporal variation in richness was detected across the survey periods, a pattern consistent with managed urban parks in other cities (González 2004; Leveau and Leveau 2012; Yapura et al. 2022). The stability of richness likely reflects that these maintained systems exhibit relatively constant vegetation structure and resources throughout the year (Leveau and Leveau 2004; Juri and Chani 2009). Ornamental plantings and irrigated areas buffer what would otherwise be seasonal entries or departures of species, so richness tends toward an equilibrium dominated by residents. In contrast, total abundance did show marked temporal and spatial variation. Some parks showed higher counts in specific months, which may be linked to phenological cycles, flowering or fruiting that increase resources, climatic factors that affect insect availability, and variable levels of human disturbance, for example, lower recreational use or maintenance in certain periods (Leveau and Leveau 2012; Leveau et al. 2019). We observed that parks with the highest abundances tended to be those with more green areas and well-developed canopies, attributes associated with greater carrying capacity for birds in cities (Benito et al. 2019).

Effect of distance and park characteristics on bird diversity

Parks closer to the Chili River had higher richness and abundance than those farther away, a pattern consistent with the idea that urban water bodies and their vegetation act as biodiversity nodes that support nearby communities (Xie et al. 2022; Li et al. 2024). The Chili River likely functions as a source of species dispersing into the city, and its riparian strip, together with the traditional agricultural matrix "campiña," maintains a diverse fauna that can contribute individuals to the urban core (Montesinos-Tubée et al. 2019). However, the models showed that distance alone ceased to be a significant predictor once internal park variables were included. Likewise, the apparent effect of distance is better explained by differences in park quality, size, proportion of green area, habitat diversity, and vegetation structure. This finding is consistent with comparative evidence showing that local habitat attributes can outweigh landscape context in urban ecosystems. For example, green space area emerged as the strongest predictor of urban bird diversity in an analysis

encompassing 51 cities (Callaghan et al. 2018), while within-park habitat complexity can mitigate isolation effects (Shwartz et al. 2008). In Arequipa, we interpret that park quality, considering sufficient size, high vegetation cover, and diverse structure, can compensate for isolation from natural corridors. This implies that interior parks or those far from the river can support rich communities if designed and managed with biodiversity criteria, and that a park adjacent to the river will not reach its potential if it lacks sufficient green area or structural complexity. From a management perspective, our results suggest that park design in arid Andean cities should prioritize sufficient area, high vegetation cover, and vertically stratified canopies. Increasing the cover and structural complexity of trees and shrubs, while reducing impervious surfaces, has been shown to be one of the most effective strategies for enhancing urban bird richness and diversity (Fontana et al. 2011). In practice, this implies conserving and planting native large trees, maintaining a mixture of native tree and shrub species, allowing patches of dense vegetation, and avoiding excessive pruning that simplifies the canopy.

Among the evaluated attributes, the proportion of green area and park size were decisive for explaining variation in richness and diversity. This pattern reinforces findings that larger parks with greater vegetation cover harbor more species because they offer larger core areas, greater niche variety, and reduced edge effects (Fernández-Juricic 2004; Yang et al. 2020). In Mexico City, structural heterogeneity combinations of trees, shrubs, and open areas are associated with higher taxonomic, functional, and phylogenetic diversity in urban green spaces (Nava-Díaz et al. 2022), a result consistent with our findings on the importance of vertical complexity and the presence of multiple microhabitats. Additionally, herbaceous cover showed a positive, although not significant, effect on richness, which is plausible given the predominance of ground granivores that benefit from herbaceous strata (Nava-Díaz et al. 2022). Long-term studies also document that increasing the extent and quality of urban green space produces sustained gains in diversity (Cheng et al. 2023). In contrast, no park attribute consistently explained total abundance, probably because this metric responds more strongly to resource pulses, climate, and anthropogenic disturbance, and may exhibit nonlinear dynamics (Felgentreff et al. 2024; Leveau et al. 2024; Li et al. 2024; Ventura et al. 2025).

This study demonstrates that both river proximity and internal habitat structure are key drivers of bird diversity within the urban parks of Arequipa. Parks adjacent to the Chili River and those with greater vegetation cover and vertical complexity harbor richer and more balanced bird communities, whereas smaller, isolated parks tend to support fewer and more urban-tolerant species. These results highlight the crucial role of riparian corridors as biodiversity reservoirs in arid urban ecosystems. In the case of the Chili River, this highlights the need to conserve and restore riparian strips with continuous tree cover and native gallery vegetation, as these features enhance habitat quality, support plant-bird interactions, and increase bird richness in restored urban riparian areas (Carvalho et al. 2025). Evidence from other cities shows that maintaining or widening vegetated buffers, avoiding the removal of riparian trees, and improving structural complexity along river margins can substantially benefit urban bird communities and facilitate dispersal from riparian corridors into adjacent green spaces (Keten et al. 2020). Urban planning strategies that maintain ecological connectivity and promote diverse vegetation types can enhance habitat suitability for native and migratory species alike. Incorporating these ecological principles into local park management and citywide green infrastructure design would not only benefit urban biodiversity but also improve the environmental quality and well-being of Arequipa's residents. Moreover, citizen science programs offer an opportunity to translate these findings into long term monitoring and adaptive management of Arequipa's parks. Large-scale initiatives based on eBird data have shown that volunteer observations can provide reliable estimates of bird diversity in urban greenspaces and inform management decisions (Callaghan et al. 2017). Implementing local bird monitoring schemes in collaboration, would allow tracking temporal changes in park communities and evaluating the effectiveness of management and with these data streams can be integrated into decision-making by park managers and urban planners (Callaghan et al. 2020). Likewise, future similar studies should include data based on functional diversity attributes, as well as temporal assessments throughout the day of the accompanying fauna community, mainly invertebrates associated with these parks, which could provide a better explanation for some of the results found.

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