

# Influence of Green Open Spaces (GOS) on bird composition and abundance in Kendari City, Southeast Sulawesi, Indonesia

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**Abstract.** Ahmad SW, Erif LOM, Mukhsar, Adcu AS, Isnawati R, Indarwani Z, Fadilah, Karya A. 2025. Influence of Green Open Spaces (GOS) on bird composition and abundance in Kendari City, Southeast Sulawesi, Indonesia. *Biodiversitas* 26: 5814-5823. One of the negative impacts of shrinking Green Open Spaces (GOS) and urban landscape change is the decline in biodiversity. GOS play a key role in maintaining biodiversity within rapidly expanding cities. In urban areas, GOS such as urban parks serve as habitats for birds despite high human density and altered land cover. Complex and diverse vegetation structures provide better habitat quality, and larger GOS connected to natural habitats tend to support higher bird diversity. This study examined the influence of GOS characteristics, area, vegetation quality, water availability, and connectivity with natural habitats on bird composition and abundance in Kendari City, Southeast Sulawesi, Indonesia. Eight GOS sites were surveyed, recording a total of 48 bird species, including 14 Sulawesi endemics, with total abundance ranging from 208 to 580 individuals per site. Canonical Correspondence Analysis (CCA) indicated that these habitat variables explained 12.33% of the variation in bird community composition, suggesting a weak but ecologically meaningful influence. While generalist species dominated smaller ornamental parks, larger, forest-like sites supported higher species richness and endemic representation. These findings highlight the importance of retaining native vegetation and ensuring water availability in urban planning to enhance bird diversity and support biodiversity-based management strategies.

**Keywords:** Bird abundance, biodiversity, canonical correspondence analysis, green open spaces, Kendari City

## INTRODUCTION

Kendari City, the capital city of Southeast Sulawesi Province in Indonesia, has experienced rapid growth in recent decades. Statistics Indonesia (2024) show that the population of Kendari City in 2023 increased by 1.8% from 364,220 people in 2022 to 370,760 people in 2024. The development includes infrastructure, settlements, and industries, which often leads to a reduction of natural habitats (Jurumai et al. 2023). One of the negative impacts of shrinking Green Open Spaces (GOS) and urban landscape change is the decline in biodiversity (Sushinsky et al. 2013). This occurs across various taxa such as insects (Su et al. 2015; Wastian et al. 2016; Turo and Gardiner 2021), mammals (Villaseñor et al. 2016), amphibians (Puglis and Boone 2012; Mester et al. 2020), reptiles (Guiller et al. 2022), and birds (Donnelly and Marzluff 2006; Leveau 2019; Prihandi and Nurvianto 2022; Melo and Piratelli 2023). In urban areas, GOS such as urban parks serve as habitats for birds despite high human density and altered land cover (Vasquez and Wood 2022). Complex and diverse vegetation structures provide better habitat quality, and larger GOS connected to natural habitats tend to support higher bird diversity (Donnelly and Marzluff 2006). Dong et al. (2023) added that the availability

of water sources effectively increases species diversity, while Yang et al. (2020) found that the distance between parks and city centers can predict bird diversity.

Urban ecological studies show that green open spaces function not only as recreational areas but also as ecological refuges that maintain biodiversity and ecosystem services, in tropical regions like Kendari, where urban expansion often borders forests and coastal ecosystems. Maintaining GOS is crucial to reducing biodiversity loss and sustaining endemic species. The vegetation composition and presence of native trees strongly influence the capacity of GOS to support various bird species (de Groot et al. 2021). The management of GOS affects ecological balance and bird populations (Hughes et al. 2022; Melo et al. 2022). The quality of GOS, including green infrastructure and vegetation arrangement, directly impacts bird diversity and abundance (Davis et al. 2012). High-quality GOS characterized by native vegetation, canopy layering, and water sources offer diverse food and nesting resources. Conversely, GOS dominated by ornamental plants and subjected to frequent human disturbance tend to support only a few generalists or synanthropic species.

Kendari City features various Green Open Spaces (GOS) like urban parks, forests, greenways, and riverbanks, each differing in vegetation structure, size, and

human impact. However, limited information exists on how these factors affect bird composition and abundance. Kendari is home to several Sulawesi endemic birds (Karya et al. 2017) and threatened species (Martin et al. 2018), highlighting the need to study urban bird diversity for regional conservation. As Sulawesi is a biodiversity hotspot, understanding the ecological roles of urban GOS can inform how cities can coexist with native fauna. Bird diversity is a valuable bioindicator for assessing urban ecosystem health, as variations in bird richness and abundance reflect habitat quality, vegetation diversity, and disturbance levels, aiding in biodiversity-focused urban planning and conservation.

This study aimed to assess bird diversity across different types of green open spaces in Kendari City and to analyze how their characteristics influence community composition and abundance based on the Shannon–Wiener diversity index ( $H'$ ) using Canonical Correspondence Analysis (CCA). Understanding these relationships is essential to protect biodiversity and maintain ecological balance in urban ecosystems. The results are expected to support the development of evidence-based conservation policies and sustainable spatial planning for the management of GOS in Kendari City.

## MATERIALS AND METHODS

### Study area

Kendari City is located in the southern part of the equator line between  $3^{\circ}54'40''$  and  $4^{\circ}5'05''$  South Latitude and stretching from west to east between  $122^{\circ}26'33''$  and  $122^{\circ}39'14''$  East Longitude (Statistics Indonesia 2024). As the capital of Southeast Sulawesi Province, Indonesia, it has an area of 271.76 km<sup>2</sup>, with 25.03 km<sup>2</sup> (9.21%) covering GOS (<https://sipsn.menlhk.go.id/sipsn/public/rth>). The observation sites are GOS, consisting of city parks and botanical gardens (Figure 1). In this study, data collection was performed from May to June 2022 in seven city parks and also obtained from Kendari Botanical Garden between May and June 2021, and the observed GOS varied in size from 1.8–7.5 ha (Table 4). Site 1 is Kendari Botanical Gardens (Near GOS of Universitas Halu Oleo, Figure 1);

Site 2 is GOS of Universitas Halu Oleo; Site 3 is Kendari Urban Park; Site 4 is Puuwatu Landfill Park; Site 5 is Retention Pond Park; Site 6 is Kendari Beach Lotus Park; Site 7 is Ranomeeto Border City Park; and Site 8 is Governor Roundabout Park.

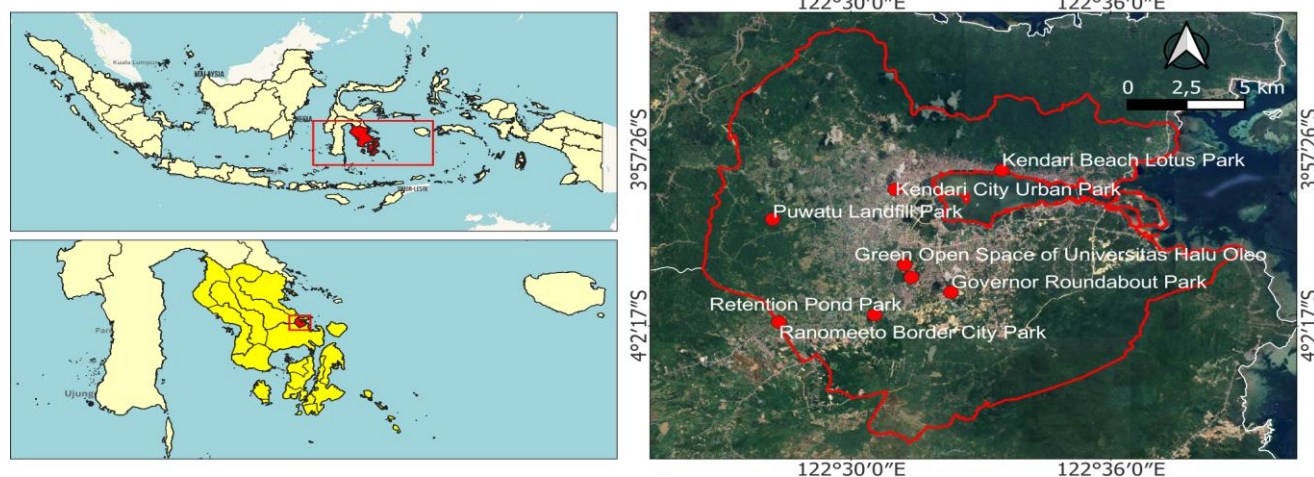
### Procedures

#### *Environmental data collection*

To determine the influence of the environment on birds, data were obtained on GOS area, population density in each sub-district, using statistical data for Kendari City (Statistics Indonesia 2024). The presence of water sources in GOS was identified through direct observation. Connectivity with natural habitats, interpreted using Google Earth 7.3.3, and the types of plants forming GOS vegetation were also analyzed. In this parameter, plants were grouped into four, namely wild, street shade trees, palms, and ornamental. According to Kershaw (1964), species with relative abundances exceeding 75%, 51–75%, 26–50%, 11–25%, and 1–20% were categorized as dominant, abundant, frequent, occasional, and rare, respectively.

#### *Bird data collection*

A bird survey was carried out using the line transect method (Bibby et al. 2000), where each area consisted of a single transect with a length ranging from 750 meters to 1,000 meters. Observations were replicated twice, conducted in the morning and in the afternoon, to ensure temporal consistency and data reliability. The survey started at 06:00 to 08:00 Central Indonesian Time (UTC+8) and continued at 15:30 to 17:30 UTC+8. Bird identification was performed directly through visual observation and sound in a radius of 25 meters on both sides of the transect (Dong et al. 2023). The procedures for identification followed the method by Coates et al. (1997), but passing birds were not recorded. Birds flying in the observation area for feeding activity were included in the observation data (Leveau and Leveau 2016), with six surveys conducted at each GOS area, totaling 48. Bird species richness was calculated based on the number of bird species found in GOS. Individual abundance was calculated based on the number of individuals of each species.



**Figure 1.** The observation sites of city parks and botanical gardens in Kendari City, Southeast Sulawesi, Indonesia

### Data analysis

In a study examining the influence of GOS characteristics on bird composition and abundance in Kendari City, Canonical Correspondence Analysis (CCA) was used to assess responses to environmental factors (Dray et al. 2003). The CCA method has shown excellent performance using data from complex collection designs (McGarigal et al. 2000). Furthermore, cluster analysis was used to determine the grouping of GOS based on the attributes. All statistical analyses were performed using R, a free open-source software environment (R Core Team 2006). A species abundance matrix was constructed with rows representing observation sites and columns indicating species.

A matrix of GOS characteristics was constructed with rows representing observation sites and columns indicating measured GOS variables. CCA analysis calculated canonical axes, which were linear combinations of GOS characteristic variables explaining most of the variation in bird species abundance and composition. The results were visualized in the form of biplot diagrams, which showed the position of bird species and observation sites as well as the vector of GOS characteristics. The length of the characteristics vector indicated the strength of the relationship between the variable and the canonical axis. Meanwhile, the angle between GOS characteristics vector and the canonical axis showed the correlation between the variable and the canonical axis. The position of bird species and observation sites on the biplot could be interpreted as influential GOS

characteristics. The relationship between species abundance and composition was tested using Monte Carlo permutation tests. CCA analysis helped identify which GOS characteristics most influence bird community composition and abundance in Kendari City, as well as to understand the distribution patterns of bird species based on these characteristics. The results provide valuable insight for better planning and management of GOS in the study area.

## RESULTS AND DISCUSSION

### Bird abundance and composition

Based on observations across the eight GOS (Table 1), Site 1 supported the highest species richness, with 31 recorded species, followed by Site 3 (23 species) and Site 2 (17 species). Sites 6 and 8 each had 14 species, Site 7 had 12 species, and Sites 4 and 5 each had 10 species. In terms of individual abundance (Table 3), Site 4 exhibited the highest count (580 individuals), followed by Site 7 (499 individuals), Site 8 (469 individuals), and Site 5 (334 individuals). Site 6 (322 individuals), Site 3 (284 individuals), Site 1 (281 individuals), and Site 2 (208 individuals) represented moderately abundant yet highly diverse assemblages. Species with total abundances exceeding 100 individuals are summarized in Table 2.

**Table 1.** Bird species listed in GOS of Kendari City, Southeast Sulawesi, Indonesia

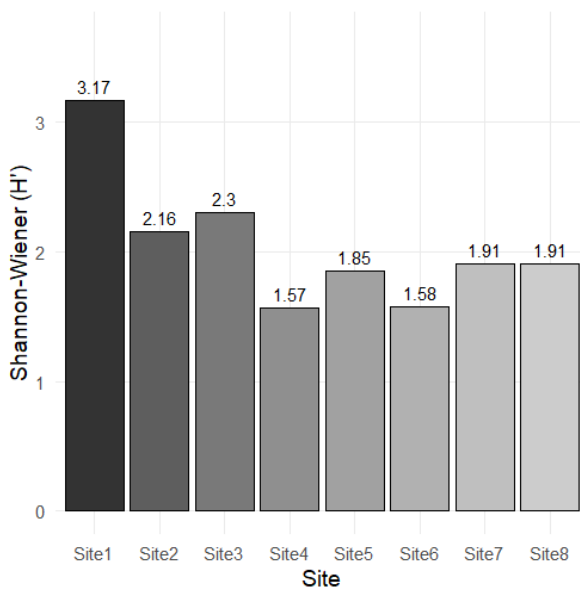
Family	Common name	Scientific name	GOS								IUCN	
			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8		
Accipitridae	Dwarf Sparrowhawk	<i>Accipiter nanus</i> (W.Blasius, 1897)* ‡	-	+	-	-	-	-	-	-	-	LC
Accipitridae	Sulawesi Serpent Eagle	<i>Spilornis rufipectus</i> (Gould, 1858)* ‡	+	-	-	-	-	-	-	-	-	LC
Accipitridae	Sulawesi Hawk-Eagle	<i>Nisaetus lanceolatus</i> (Temminck & Schlegel, 1844)* ‡	+	-	-	-	-	-	-	-	-	LC
Psittaculidae	Golden-mantled Racket-tail	<i>Prioniturus platurus</i> (Vieillot, 1818)* ‡	+	-	-	-	-	-	-	-	-	LC
Psittaculidae	Great Hanging Parrot	<i>Loriculus stigmatus</i> (S.Muller, 1843)* ‡	+	-	-	-	-	-	-	-	-	LC
Picidae	Ashy Woodpecker	<i>Mulleripicus fulvus</i> (Quoy & Gaimard, 1832)* ‡	+	-	-	-	-	-	-	-	-	LC
Strigidae	Sulawesi Scops Owl	<i>Otus manadensis</i> (Quoy & Gaimard, 1832)* ‡	+	-	-	-	-	-	-	-	-	LC
Tytonidae	Sulawesi Masked Owl	<i>Tyto rosenbergii</i> (Schlegel, 1866) ‡	+	-	-	-	-	-	-	-	-	LC
Rallidae	Barred Rail	<i>Gallirallus torquatus</i> (Linnaeus, 1766)	+	-	-	-	-	-	-	-	-	LC
Phasianidae	Blue-breasted Quail	<i>Coturnix chinensis</i> (Linnaeus, 1766)	+	-	-	-	-	-	-	-	-	LC
Columbidae	Asian Emerald Dove	<i>Chalcophaps indica</i> (Linnaeus, 1758)	+	-	-	-	-	-	-	-	-	LC
Columbidae	Rock Dove	<i>Columba livia</i> (J.F.Gmelin, 1789)	-	-	+	+	-	-	+	+	LC	
Columbidae	White-faced Cuckoo-Dove	<i>Turacoena manadensis</i> (Quoy & Gaimard, 1832) ‡	+	-	-	-	-	-	-	-	-	LC
Columbidae	Green Imperial Pigeon	<i>Ducula aenea</i> (Linnaeus, 1766)	+	-	-	-	-	-	-	-	-	NT
Columbidae	Zebra Dove	<i>Geopelia striata</i> (Linnaeus, 1766)	-	-	+	-	-	-	-	-	-	LC

Columbidae	Grey-cheeked Green Pigeon	<i>Treron griseicauda</i> (Bonaparte, 1855)	+	-	-	-	-	-	-	-	LC
Columbidae	Spotted Dove	<i>Spilopelia chinensis</i> (Scopoli, 1786)	-	-	+	-	-	-	-	-	LC
Columbidae	Sultan's Cuckoo-Dove	<i>Macropygia doreya</i> (Bonaparte, 1854)	+	-	-	-	-	-	-	-	LC
Columbidae	Black-naped Fruit Dove	<i>Ptilinopus melanospilus</i> (Salvadori, 1875)	+	-	-	-	-	-	-	-	LC
Cuculidae	Yellow-billed Malkoha	<i>Rhamphococcyx calyborhynchus</i> (Temminck, 1825)‡	+	-	-	-	-	-	-	-	LC
Cuculidae	Bay Coucal	<i>Centropus celebensis</i> (Quoy & Gaimard, 1830)‡	+	-	-	-	-	-	-	-	LC
Cuculidae	Rusty-breasted Cuckoo	<i>Cacomantis sepulcralis</i> (S.Muller, 1843)	+	-	-	-	-	+	-	-	LC
Cuculidae	Little Bronze Cuckoo	<i>Chrysococcyx minutillus</i> (Gould, 1859)	+	+	+	+	+	+	+	+	LC
Cuculidae	Moluccan Drongo-Cuckoo	<i>Surniculus musschenbroeki</i> (A.B.Meyer, 1878)	+	-	-	-	-	-	-	-	LC
Alcedinidae	White-collared Kingfisher	<i>Halcyon chloris</i> (Boddaert, 1783)	+	+	+	+	+	+	+	+	LC
Dicruridae	Hair-crested Drongo	<i>Dicrurus hottentottus</i> (Linnaeus, 1766)	+	-	-	-	-	-	-	-	LC
Corvidae	Slender-billed Crow	<i>Corvus enca</i> (Horsfield, 1821)	-	-	+	-	-	-	-	-	LC
Sturnidae	Javan Myna	<i>Acridotheres javanicus</i> (Cabanis, 1851)	-	-	+	-	-	-	-	+	VU
Sturnidae	Short-tailed Starling	<i>Aplonis minor</i> (Bonaparte, 1850)	-	-	+	+	+	+	+	+	LC
Campephagidae	White-shouldered Triller	<i>Lalage sueurii</i> (Vieillot, 1818)	-	+	+	-	+	+	-	-	LC
Oriolidae	Black-naped Oriole	<i>Oriolus chinensis</i> (Linnaeus, 1766)	+	-	-	-	-	-	-	-	LC
Monarchidae	Black-naped Monarch	<i>Hypothymis azurea</i> (Boddaert, 1783)	+	-	-	-	-	-	-	-	LC
Pycnonotidae	Sooty-headed Bulbul	<i>Pycnonotus aurigaster</i> (Vieillot, 1818)	-	+	+	+	+	+	+	+	LC
Pycnonotidae	Yellow-vented Bulbul	<i>Pycnonotus goiavier</i> (Scopoli, 1786)	-	+	+	+	-	+	-	+	LC
Artamidae	White-breasted Wood- Swallow	<i>Artamus leucorhynchus</i> (Linnaeus, 1771)	-	+	+	-	-	-	-	-	LC
Hirundinidae	Pacific Swallow	<i>Hirundo tahitica</i> (Gmelin, 1789)	-	+	+	+	+	+	+	+	LC
Hemiprocnidae	Grey-rumped Treeswift	<i>Hemiprogne longipennis</i> (Rafinesque, 1802)	+	+	+	-	-	+	+	+	LC
Apodidae	Glossy Swiftlet	<i>Collocalia esculenta</i> (Linnaeus, 1758)	+	+	+	-	-	-	-	-	LC
Timaliidae	Sulawesi Babbler	<i>Trichastoma celebense</i> (Strickland, 1850)‡	+	-	-	-	-	+	-	-	LC
Acanthizidae	Golden-bellied Gerygone	<i>Gerygone sulphurea</i> (Wallace, 1864)	-	+	+	+	-	+	+	+	LC
Zosteropidae	Lemon-bellied White-eye	<i>Zosterops chloris</i> (Bonaparte, 1850)	+	+	+	+	+	+	+	+	LC
Nectariniidae	Olive-backed Sunbird	<i>Cinnyris jugularis</i> (Linnaeus, 1766)	-	+	+	-	+	-	+	+	LC
Nectariniidae	Black Sunbird	<i>Leptocoma sericea</i> (Lesson, 1827)	+	-	-	-	-	-	-	-	LC
Dicaeidae	Gray-sided Flowerpecker	<i>Dicaeum celebicum</i> (S.Muller, 1843)‡	+	+	+	-	+	+	+	+	LC
Dicaeidae	Yellow-sided Flowerpecker	<i>Dicaeum aureolimbatum</i> (Wallace, 1865)‡	+	-	+	-	-	-	-	-	LC
Passeridae	Eurasian Sparrow	<i>Passer montanus</i> (Linnaeus, 1758)	-	+	+	+	+	+	+	+	LC
Estrildidae	Chestnut Munia	<i>Lonchura atricapilla</i> (Vieillot, 1807)	-	+	+	-	+	-	-	-	LC
Estrildidae	Black-faced Munia	<i>Lonchura molucca</i> (Linnaeus, 1766)	-	+	+	-	-	-	-	-	LC

Note: \*: Protected by the Indonesian government under Ministerial Regulation No. P.106/2018 on Protected Plant and Animal Species, ‡: Endemic to the Sulawesi region, including adjacent small islands, IUCN: International Union for Conservation of Nature, LC: Least Concern, NT: Near Threatened, VU: Vulnerable. IUCN Red List data from: IUCN (2025). The IUCN Red List of Threatened Species. Version 2025-2. Available at: <https://www.iucnredlist.org>

**Table 2.** List of dominant bird species (with >100 individuals) recorded in GOS, Kendari City, Southeast Sulawesi, Indonesia

Common name	Scientific name	Total individuals	Relative abundance (%)	Dominant site(s)	Habitat association
Eurasian Sparrow	<i>Passer montanus</i> (Linnaeus, 1758)	410	14.8	4, 7, 8	Urban open area, ornamental vegetation
Yellow-vented Bulbul	<i>Pycnonotus goiavier</i> (Scopoli, 1786)	372	13.4	1, 2, 3	Mixed vegetation, shade trees
Pacific Swallow	<i>Hirundo tahitica</i> (Gmelin, 1789)	351	12.6	4, 5, 8	Open space near water and buildings
White-collared Kingfisher	<i>Halcyon chloris</i> (Boddaert, 1783)	295	10.6	1, 2, 6	Riparian zones, forest edge
Olive-backed Sunbird	<i>Cinnyris jugularis</i> (Linnaeus, 1766)	230	8.3	1, 3, 6	Flowering shrubs, ornamental plants
Sooty-headed Bulbul	<i>Pycnonotus aurigaster</i> (Vieillot, 1818)	221	8.0	3, 4, 5	Shrubland, semi-open forest
Zebra Dove	<i>Geopelia striata</i> (Linnaeus, 1766)	190	6.9	5, 7, 8	Grassland, disturbed urban edge
Black-naped Oriole	<i>Oriolus chinensis</i> (Linnaeus, 1766)	165	6.0	1, 2	Forest canopy, mature trees
Black Sunbird	<i>Leptocoma sericea</i> (Lesson, 1827)	143	5.2	1, 3	Native vegetation, flowering trees
Spotted Dove	<i>Spilopelia chinensis</i> (Scopoli, 1786)	121	4.4	4, 7	Roadside and semi-open vegetation

**Figure 2.** Species richness in eight GOS, Kendari City, Southeast Sulawesi, Indonesia**Table 3.** Diversity indices (Shannon–Wiener  $H'$ , Simpson  $1-D$ , Evenness  $E$ , and total abundance) for bird assemblages across eight GOS sites in Kendari City, Southeast Sulawesi, Indonesia. Diversity values correspond to the ten dominant species

Site	$H'$	$1-D$	$E$	Species richness	Total abundance
Site 1	3.17	0.95	0.92	31	281
Site 2	2.16	0.83	0.76	17	208
Site 3	2.30	0.83	0.73	23	284
Site 4	1.57	0.71	0.68	10	580
Site 5	1.85	0.81	0.76	10	334
Site 6	1.58	0.76	0.63	14	322
Site 7	1.91	0.82	0.77	12	499
Site 8	1.91	0.80	0.72	14	469

Biodiversity analysis across the eight sampling sites revealed significant variation in community structure and ecological conditions. Site 1 ( $H' = 3.17$ ) had the highest Shannon diversity, indicating a stable, diverse community, while Site 4 ( $H' = 1.57$ ) had the lowest diversity, suggesting species dominance or habitat disturbance. The diversity gradient, from highest to lowest, was Site 1 > Site 3 > Site 2 > Site 7 = Site 8 > Site 5 > Site 6 > Site 4 (See Figure 2).

According to Simpson's diversity index ( $1-D$ ), which represents the probability that two randomly selected individuals belong to different species, Site 1 ( $1-D = 0.95$ ) again demonstrated a highly diverse and evenly structured community, whereas Site 4 ( $1-D = 0.71$ ) reflected strong dominance by one or a few species. Site 1 had the most species (31), which suggests that it was a complex habitat with little disturbance. Site 4 and Site 5 had the fewest species (10), which suggests that it was a more homogeneous or stressed environment (Table 3).

Total bird abundance varied significantly, with Site 4 having the highest number (580) but low diversity, indicating species dominance. In contrast, Site 1 had moderate abundance (281) and high diversity, suggesting a stable community. Species evenness ranged from high in Site 1 ( $E = 0.92$ ) to low in Site 6 ( $E = 0.63$ ), where a few species dominated. Site 1 supported the healthiest bird community, while Site 4 showed signs of ecological stress. Sites 2, 3, 5, 7, and 8 had moderate to high diversity and stable conditions, while Site 6 had low evenness despite moderate richness. The sequence of sites by total abundance, from the lowest to highest, was Site 2 < Site 1 < Site 3 < Site 6 < Site 5 < Site 8 < Site 7 < Site 4, indicating that sites with higher habitat carrying capacity supported greater bird abundance.

#### Characteristics of GOS on bird composition and abundance in Kendari City

CCA was conducted to evaluate the relationship between bird species community composition across eight sampling

sites and  $H'$  as an environmental explanatory variable. The total inertia, representing the overall variance in species composition, was 0.30. Approximately 0.04 (12.33%) of the total variation was attributed to the environmental variable  $H'$ , while the remaining 0.26 (87.67%) represented unconstrained variance. This suggested that the factor did not explain the majority of the variation in species composition. Ecologically, the results suggested that  $H'$  exerted an influence on community structure, but the influence was relatively weak and accounted for only a small fraction of the total variance. Therefore, species composition across sites was influenced by diversity levels and additional environmental factors such as habitat conditions, vegetation cover, food availability, and anthropogenic disturbances.

The model obtained a single constrained axis (CCA1), corresponding to the included environmental variable. The eigenvalue of CCA1 was 0.04, representing 100% of the variation explained by  $H'$ , which captured the primary gradient of habitat diversity affecting species distribution among sites. Species and sites related to the direction of  $H'$  vector in CCA biplot were more strongly associated with areas, showing higher diversity. Those positioned in the opposite direction were related to sites with lower diversity, suggesting specific species' ecological responses to diversity gradients. Some species may tolerate more homogeneous environments, while others prefer structurally complex and diverse habitats.

The permutation test (999 permutations) showed no significant relationship between  $H'$  and species composition ( $F = 0.84$ ,  $p = 0.38$ ), and CCA1 was not statistically significant ( $p = 0.38$ ). This indicated that the environmental gradient represented by  $H'$  did not significantly influence species distribution patterns. The cumulative proportion of variance explained by CCA1 remained at 12.33%, while the first two unconstrained axes (CA1 and CA2) accounted for 51.49% and 32.73% of the residual variation, respectively. These results showed that key drivers of bird community composition extended beyond the diversity index and included unmeasured environmental variables.

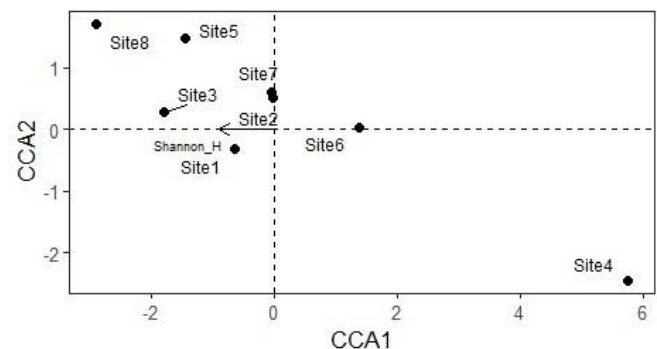
From an ecological perspective, sites with high  $H'$  values (Site 1 and Site 3) tended to support more stable, diverse, and evenly distributed communities, indicating favorable habitat conditions with balanced resource availability and minimal disturbance. In comparison, sites with low  $H'$  values (Site 4 and Site 6) showed high total abundance but low diversity, suggesting dominance by a few species and potential ecological stress such as habitat degradation or anthropogenic pressure. The limited explanatory power of  $H'$  underscored that diversity was not the primary determinant of species distribution patterns. Therefore, incorporating additional environmental variables, such as elevation, vegetation density, microclimate, precipitation, or proximity to human activity, could improve the explanatory strength of the model. As shown in Figure 3, CCA results indicated that  $H'$  exerted a measurable but limited influence on bird community variation among sites. The primary constrained axis captured the main ecological gradient associated with community diversity, although the structure of bird

assemblages remained complex and multidimensional, with other environmental drivers likely playing dominant roles. Despite the lack of statistical significance, the analysis provided valuable exploratory insights and a foundation for further multivariate modeling.

## Discussion

CCA aims to study the relationship between various characteristics of GOS as well as bird abundance and diversity, including species richness and total individuals. The results obtained were in line with previous studies on bird diversity in urban areas. The larger size of GOS tended to support more species and a greater number of individuals. Similarly, MacArthur and Wilson (2001) and Nielsen et al. (2014) reported established species-area relationships in ecology, where larger habitats could sustain more diverse and abundant populations. The availability of water sources around GOS was positively associated with higher diversity. This result supported previous studies emphasizing the crucial role of water resources in urban bird communities, providing essential opportunities for drinking, bathing, and foraging (Lerman and Warren 2011; Helden et al. 2012). Overall, CCA analysis reinforced the importance of preserving and maintaining native plant diversity, larger GOS, and ensuring the availability of water resources in the urban landscape. Numerous studies consistently identified these factors as important determinants of urban bird diversity (Lepczyk et al. 2017; Narango et al. 2017). By considering and incorporating these results into urban planning and biodiversity conservation efforts, cities can increase biodiversity and support a more sustainable and ecologically balanced environment (Table 4).

Based on the results, Sites 1, 2, and 3 form a cluster, indicating a high level of similarity in environmental characteristics. This similarity can be attributed to the dominance of shade plants in vegetation composition. Common protective trees found in Site 3 include *Samanea saman* (Jacq.) Merr., *Swietenia mahagoni* (L.) Jacq., and *Senna siamea* (Lam.) H.S. Irwin & Barneby. Shade plants, typically large trees or plants that provide significant canopy cover, can create similar environmental conditions across sites by modifying the microclimate (De Silva et al. 2020).



**Figure 3.** CCA biplot between total individual birds, bird species richness, and characteristics of GOS sites in Kendari City, Southeast Sulawesi, Indonesia

**Table 4.** Habitat characteristics of eight GOS sites in Kendari City, Southeast Sulawesi, Indonesia

Site	Area (ha)	Vegetation complexity (rank 1-3)	Canopy cover (%)	Presence of wild/natural vegetation	Water source	Notes
Site 1	7.5	3 (high)	85	Yes (natural & planted)	Pond + drainage	Botanical garden-type habitat
Site 2	5.0	2 (moderate)	65	Yes (mainly planted)	Small pond	Medium-sized urban park
Site 3	4.8	2 (moderate)	60	Low (native shrubs)	Drainage	Supports ~50 % of total species
Site 4	2.0	1 (low)	40	Low (ornamental only)	None	Waste-affected vegetation.
Site 5	1.8	1 (low)	30	Low (ornamental)	None	Small open park
Site 6	3.6	2 (moderate)	55	Low (native grasses)	Stream nearby	Intermediate structure
Site 7	2.9	1 (low)	35	Low (ornamental)	Drainage	Compact urban site
Site 8	3.2	2 (moderate)	50	Moderate (native shrubs)	Pond	Medium connectivity

Note: D: Dominance, A: Abundance, F: Frequently, O: Occasionally, R: Rare, +/-: Presence/absence

The presence of mature trees and shade plants has been observed to influence microclimatic conditions, such as temperature and humidity, which influence biodiversity in GOS (Teshnehdel et al. 2020; Ambarwati et al. 2023). Additionally, Site 5 and Site 6 were found near each other, indicating a high level of similarity in terms of water availability. The presence of water sources, such as ponds, lakes, or proximity, is another common characteristic between these sites. Water availability significantly influences diversity and abundance in urban areas (Lerman and Warren 2011; Helden et al. 2012), as wetlands and water bodies provide important resources for birds, including drinking water, foraging, and nesting (Tremblay and St. Clair 2011). Furthermore, Sites 5 and 8 show similarities in terms of shade trees and smaller vegetation types. Both sites are characterized by vegetation mostly found along road medians or smaller GOS, which can be trees and shrubs or herbaceous plants. The presence of these smaller GOS and roadside vegetation contributes to urban biodiversity, particularly for mobile species such as birds (Lepczyk et al. 2017). However, the biodiversity value is affected by vegetation structure, connectivity, and disturbance levels (Nielsen et al. 2014).

The results are different from the widely accepted view that connectivity with natural habitats is a major driver of species richness and total abundance of birds in urban landscapes. Compared to previous reports emphasizing the importance of habitat connectivity for sustaining avian diversity (Shanahan et al. 2011a; Egerer et al. 2024). This study shows no significant correlation between connectivity and bird diversity across GOS in Kendari City. This discrepancy suggests that the relationship between connectivity and bird diversity is context-dependent and strongly influenced by the specific characteristics of urban GOS, the configuration of the surrounding landscape, and the spatial scale (Donnelly and Marzluff 2006; Beninde et al. 2015). In dense urban matrices, isolated patches with favorable internal habitat structures can still support a diverse avian community, indicating that intra-patch quality may offset limited connectivity. Among the key internal habitat attributes, the presence of wild and native plants, including

shrubs, fruiting trees, and flowering species, was positively associated with both species richness and total abundance. This result confirmed that native vegetation supported higher bird diversity in urban environments by providing essential ecological resources such as food (fruits, nectar, and insects), nesting materials, and shelter (Threlfall et al. 2016; Lepczyk et al. 2017; Narango et al. 2017; Berthon et al. 2021). In comparison, shade trees and ornamental species showed little to no relationship with diversity, indicating that ecological contribution was limited compared to native flora. These patterns were consistent with previous studies showing that native plant communities were significantly more effective at supporting assemblages than ornamental or non-native plantings, failing to sustain insect prey populations necessary for insectivorous birds (Dyson 2021; Smallwood and Wood 2023).

A particularly important ecological component of avifauna in Kendari City is the assemblage of endemic bird species, whose distribution shows a strong dependence on habitat size and quality. Site 1 (7.5 ha) hosts 13 endemic species out of 31 total (41.9%). These include forest insectivores and raptors such as the ashy woodpecker (*Mulleripicus fulvus* (Quoy & Gaimard, 1832)), Sulawesi serpent eagle (*Spilornis rufipectus* Gould, 1858), Sulawesi hawk-eagle (*Nisaetus lanceolatus* (Temminck & Schlegel, 1844)), Sulawesi scops owl (*Otus manadensis* (Quoy & Gaimard, 1832)), and Sulawesi masked owl (*Tyto rosenbergii* (Schlegel, 1866)), as well as frugivores and nectarivores such as White-faced cuckoo-dove (*Turacoena manadensis* (Quoy & Gaimard, 1832)), Yellow-billed malkoha (*Rhamphococcyx calyborhynchus* (Temminck, 1825)), Bay coucal (*Centropus celebensis* Quoy & Gaimard, 1830), and endemic flowerpeckers (*Dicaeum celebicum* S.Muller, 1843, *Dicaeum aureolimbatus* (Wallace, 1865)). The species are recognized by BirdLife International as forest-dependent taxa, restricted primarily to lowland and montane forests in Sulawesi and adjacent islands (BirdLife International 2023a, b, c). In comparison, medium and small GOS, Site 2 (5.0 ha; 2 endemics), Site 3 (4.8 ha; 2 endemics), and Sites 4, 5, 7, 8 (0-2 endemics) are dominated by urban generalists such as *Passer montanus* (Linnaeus, 1758), *Pycnonotus aurigaster* (Vieillot, 1818),

and *Hirundo tahitica* (Gmelin, 1789). This suggests that patch size and forest-like structural complexity (mature canopy, multilayered vegetation, and cavity-bearing trees) are the primary determinants of endemic species occurrence. The patterns correlate with the classic species-area relationship (MacArthur and Wilson 2001) and empirical results, showing that larger, structurally complex habitats support richer communities and more specialized guilds (Nielsen et al. 2014; Lepczyk et al. 2017; Narango et al. 2017).

Ecologically, large, forested GOS are essential for endemic birds, as raptors, woodpeckers, and owls require extensive territories, mature tree stands, and low levels of disturbance conditions best provided by Kendari Botanical Garden. BirdLife species accounts emphasize these reliance species on intact forests and sensitivity to fragmentation (BirdLife International 2023a, b). Some smaller endemic passerines, such as *D. celebicum*, *D. aureolimbatum*, can persist in smaller GOS when native fruiting or nectar-producing plants and dense shrub layers are present. However, long-term persistence improves significantly with larger patch sizes, higher vegetation complexity, and low human pressure (Threlfall et al. 2015; Mata et al. 2021). Broader urban ecological study consistently identifies area, native plant richness, and canopy cover as primary drivers of avian diversity. Meanwhile, ornamental and exotic vegetation often reduces habitat quality by limiting invertebrate prey for insectivores (Lepczyk et al. 2017; Berthon et al. 2021; Tartaglia and Aronson 2024).

This study shows that the capacity of GOS to support endemic birds is significantly dependent on size and habitat quality, with Site 1 providing the most suitable conditions. The survival of endemic birds in smaller GOS is restricted to several generalist or tolerant species capable of exploiting available resources. Meanwhile, forest-dependent specialists such as endemic raptors, owls, and woodpeckers are unlikely to form stable populations in small, ornamental, and highly fragmented environments. CCA results show that the Shannon–Wiener index explained only 12.33% of the variation in community composition. This suggests that key habitat characteristics are not adequately represented in the model. Various factors, such as patch size, interior forest structure, availability of nesting cavities, native plant diversity, and disturbance levels, likely play a more significant role in influencing the distribution of endemic birds. Therefore, conservation strategies should prioritize the protection and expansion of large, forest-like patches, enhancement of native vegetation, and mitigation of anthropogenic pressures to strengthen the ecological integrity and biodiversity value of urban GOS for Sulawesi endemic avifauna (Shanahan et al. 2011b; Beninde et al. 2015; Lu et al. 2024; Egerer et al. 2024; Irsan et al. 2024; Oropeza-Sánchez et al. 2025).

Based on the landscape of Kendari City, GOS serve as essential refuges for avian biodiversity, playing an essential role in sustaining and protecting birds. The detection of several protected and threatened species in these parks underscores ecological importance in an increasingly urbanized environment. During the study, seven protected and one vulnerable species were documented, including

Javan Myna (*Acridotheres javanicus* Cabanis, 1851), which is listed as Vulnerable by the International Union for Conservation of Nature (IUCN) (BirdLife International 2020). Although originally native to Java and Bali (MacKinnon et al. 2010), the Javan myna has extended to other Indonesian islands, including Sulawesi, due to the bird trade (Tasirin and Fitzsimons 2014).

Conclusion, this study shows that the size of the habitat, the quality of the vegetation, and the availability of water are the main factors that affect the number and variety of birds in GOS Kendari City. Larger, forest-like habitats such as the Kendari Botanical Garden supported higher species richness and a greater proportion of Sulawesi endemics, whereas generalist species dominated smaller ornamental parks. The Shannon–Wiener index accounted for only 12.33% of the variation in community composition, suggesting that other factors such as vegetation layering, nesting cavity availability, and anthropogenic disturbance play more significant roles in structuring avian assemblages.

The single-season sampling design, lack of microclimatic and elevation variables, and dependence on short-term observational data constrain the study's interpretation. These limitations may have restricted the detection of temporal and fine-scale habitat variations. Future research should therefore employ multi-seasonal and multi-year monitoring, integrate remote-sensing and landscape connectivity analyses, and examine nesting ecology or trophic interactions to elucidate long-term drivers of urban avian diversity better.

Maintaining and expanding GOS is crucial for sustaining avian populations and enhancing biodiversity resilience in tropical urban ecosystems. Strengthening native vegetation management and ensuring water availability can further increase the conservation value of these habitats. Moreover, prioritizing GOS around culturally or spiritually significant sites where bird diversity tends to be higher can foster local community engagement and strengthen conservation through traditional and religious values. Collectively, these findings provide an evidence-based foundation for developing effective urban conservation policies and sustainable planning strategies to preserve bird diversity and ecological integrity in Kendari City.

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