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Ecological Responses of Three Bird Species to the Urban Landscape: Habitat Suitability and Connectivity in DKI Jakarta

Ady Kristanto[1], Tatang Mitra Setia[2], Nurul L. Winarni[3]

[1] *Postgraduate Student, Biology Study Program, Universitas Nasional*
[2] *Center for Urban Biodiversity Studies, Universitas Nasional*
[3] *Research Center for Climate Change, Universitas Indonesia*

*Correspondence Author: ady.kristanto@gmail.com

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Abstract

Urbanization alters habitat structure and the ecological connectivity of urban wildlife. This study evaluated habitat suitability and connectivity for three bird species with contrasting ecological strategies—the Red-breasted Parakeet (Psittacula alexandri), Brown-throated Sunbird (Anthreptes malacensis), and Olive-backed Tailorbird (Orthotomus sepium)—in DKI Jakarta. Habitat suitability was modeled using MaxEnt with six environmental variables, while connectivity was analyzed using a circuit-theory approach in Circuitscape. The MaxEnt models yielded AUC values of 0.755–0.791, indicating fair predictive performance. The principal determinants differed among species: population density dominated the Red-breasted Parakeet model (52.7%), NDVI dominated the Brown-throated Sunbird model (40.6%), and land use dominated the Olive-backed Tailorbird model (41.0%). NDVI was consistently the most important variable according to permutation importance. Highly suitable habitat covered 9.6–19.5% of the study area. Connectivity analysis revealed contrasting patterns: the Red-breasted Parakeet exhibited centralized connectivity through narrow pinch points, whereas the Brown-throated Sunbird and Olive-backed Tailorbird displayed more diffuse corridor networks. Monas and Gelora Bung Karno consistently functioned as both habitat and connectivity hubs for all three species, making them priority areas for urban bird conservation in Jakarta.

Keywords: urban birds; Circuitscape; habitat connectivity; MaxEnt; green open

INTRODUCTION

Urbanization is one of the principal drivers of landscape transformation and biodiversity loss worldwide. The conversion of natural land into built-up areas alters habitat structure, reduces vegetation cover, and fragments wildlife habitat into patches separated by an inhospitable urban matrix. For avifauna, these changes affect food availability, nesting sites, and movement among habitats, all of which are essential for long-term population persistence.

DKI Jakarta, one of the world's most densely populated metropolitan regions, retains only limited and dispersed green open spaces, including the National Monument (Monas), Gelora Bung Karno (GBK), Srengseng Urban Forest, and several urban parks and forests. These

green spaces may serve as refugia for urban birds, but their connectivity within the densely settled urban matrix has rarely been quantified. Understanding how species with different ecological requirements respond to the urban landscape is therefore essential for effective urban conservation planning.

Maximum entropy-based species distribution modeling (MaxEnt) has been widely used to predict habitat suitability from occurrence records and environmental variables. To complement this representation of habitat function, the circuit-theory approach implemented in Circuitscape enables connectivity modeling by treating movement across a resistance surface as analogous to electrical current flow. Integrating the two approaches provides a comprehensive picture of where suitable habitats occur and how they are connected.

This study aimed to: (1) model habitat suitability for three bird species with contrasting ecological strategies—the urban-tolerant Red-breasted Parakeet (*Psittacula alexandri*), the nectarivorous Brown-throated Sunbird (*Anthreptes malacensis*), and the shrub-dwelling insectivorous Olive-backed Tailorbird (*Orthotomus sepium*)—in DKI Jakarta; (2) analyze habitat connectivity for the three species; and (3) compare their ecological responses to identify priorities for urban bird biodiversity conservation.

METHOD

Study Area and Research Objects

The study was conducted in DKI Jakarta, covering the central part of the city from the Monas area in the northeast to Gelora Bung Karno in the central-southern area, together with the surrounding residential districts. The research objects were three bird species: the Red-breasted Parakeet *(Psittacula alexandri*), Brown-throated Sunbird (*Anthreptes malacensis*), and Olive-backed Tailorbird (*Orthotomus sepium*). These species were selected because they represent different feeding guilds—frugivore-granivore, nectarivore, and insectivore—and were therefore expected to show contrasting responses to the urban landscape.

Occurrence Data and Environmental Variables

Species occurrence data were compiled from field observations and occurrence databases, with 68 training points for the Red-breasted Parakeet, 91 for the Brown-throated Sunbird, and 59 for the Olive-backed Tailorbird. Six environmental variables were used as predictors: population density, infrastructure, land use (categorical), NDVI (vegetation greenness index), water bodies, and distance from noise sources. All variables were standardized to the same spatial resolution and coordinate reference system.

Habitat Suitability Modeling

Habitat suitability was modeled using MaxEnt version 3.4.4 with cloglog output. Model performance was evaluated using the Area Under the Curve (AUC) and training gain, while variable contributions were assessed using percent contribution and permutation importance.

The Maximum Training Sensitivity Plus Specificity threshold was used to distinguish suitable from unsuitable habitat. Suitability maps were classified into four equal-interval classes.

Connectivity Analysis

Habitat connectivity was analyzed in Circuitscape using a circuit-theory approach. The MaxEnt habitat-suitability maps were converted into resistance surfaces, after which cumulative current-flow maps were calculated. High current-flow values indicate important movement routes or critical pinch points for population connectivity. The area of each suitability class and the intensity of current flow were calculated from raster-cell counts and converted to square kilometers.

RESULT AND DISCUSSION

Model Performance and Key Habitat Determinants

All three MaxEnt models showed fair predictive performance, with training AUC values of 0.761 for the Red-breasted Parakeet, 0.755 for the Brown-throated Sunbird, and 0.791 for the Olive-backed Tailorbird. The Olive-backed Tailorbird had the highest AUC and regularized training gain (0.619), indicating the most specific habitat association. The principal determinants of habitat suitability differed markedly among species (Table 1). Population density dominated the Red-breasted Parakeet model (52.7%), reflecting its synanthropic characteristics; NDVI dominated the Brown-throated Sunbird model (40.6%), consistent with its nectarivorous ecology; and land use dominated the Olive-backed Tailorbird model (41.0%). Notably, NDVI consistently ranked first or second in permutation importance for all species, emphasizing the central role of vegetation cover.

Table 1. Contributions of the dominant environmental variables to habitat-suitability models for three bird species (percent contribution; permutation importance in parentheses)

Variable	Red-breasted Parakeet	Brown-throated Sunbird	Olive-backed Tailorbird
Population density	52,7 (41,2)	7,9 (5,5)	18,2 (16,0)
Infrastructure	18,8 (30,3)	13,6 (28,2)	3,5 (16,2)
Land use	12,6 (1,8)	31,2 (7,0)	41,0 (14,0)
NDVI	11,0 (19,2)	40,6 (47,9)	27,2 (43,1)
Water bodies	2,7 (3,8)	4,5 (10,5)	8,4 (10,6)
Distance from noise sources	2,2 (3,8)	2,2 (0,9)	1,7 (0,0)

These differences in key determinants reflect contrasting ecological strategies. The Red-breasted Parakeet can use residential landscapes containing shade trees and fruit-bearing plants, allowing its distribution to follow gradients of human settlement. By contrast, the

Brown-throated Sunbird depends on flowering vegetation as a source of nectar, whereas the Olive-backed Tailorbird requires dense understory structure as its characteristic habitat. Differences between percent contribution and permutation importance for several variables indicate correlations among predictors; therefore, individual variable contributions should be interpreted cautiously.

The modeling results also revealed differences in the ecological responses of the three species to urban landscape structure. The Red-breasted Parakeet (*Psittacula alexandri*) can use residential mosaics that retain large trees, shade trees, and fruit-bearing trees. Research in Lapangan Banteng Park, Jakarta, recorded the Red-breasted Parakeet as a frugivorous bird that directly used park vegetation as a food source. This finding shows that artificial green spaces within built-up areas can still provide resources for the species when suitable food plants are present (Hakamashe et al., 2022). In addition to food, large trees are important nesting resources. Rumblat et al. (2021) recorded the Red-breasted Parakeet in the Situ Gintung area, where large trees with trunk cavities remained available as nesting sites. Therefore, habitat suitability for the Red-breasted Parakeet in residential areas does not merely reflect tolerance of humans; rather, it indicates that portions of the residential landscape retain a combination of food resources, canopy cover, shade trees, and large-diameter trees. Under these conditions, the species can follow gradients of human settlement as long as these key vegetation elements remain available. This interpretation is also consistent with research on tropical urban bird communities, which shows that bird richness and diversity tend to increase in habitats with more advanced vegetation succession and better vegetation cover (Wong et al., 2023).

By contrast, habitat suitability for the Brown-throated Sunbird (*Anthreptes malacensis*) is more closely related to the availability of floral resources. Afidah et al. (2024) recorded the species in agroforestry habitat containing nectar-producing plants, including Calliandra (*Calliandra calothyrsus*), and noted that flowering plants supported the occurrence of Nectariniidae. These findings reinforce the interpretation that the distribution of the Brown-throated Sunbird is influenced not only by the extent of green cover, but also by vegetation composition, continuity of flowering periods, and the availability of nectar-producing flowers. Consequently, green open spaces or gardens dominated by non-flowering trees or nectar-poor ornamental vegetation may not provide optimal habitat. More broadly, recent studies of urbanization and pollination indicate that local flowering-plant richness can reduce the negative effects of urbanization on pollinator communities and maintain floral resources in urban environments (Liang et al., 2023). Although that study did not specifically examine the Brown-throated Sunbird, it supports the ecological mechanism underlying the relationship between nectarivorous birds and flowering vegetation.

The Olive-backed Tailorbird (*Orthotomus sepium*) has different habitat requirements because it is a small insectivorous bird that is highly active in low vegetation, shrubs, and the lower strata of stands. The species was recorded in Pesanggrahan Forest, Malang, in habitat with high shrub and forest-floor plant diversity—104 species, representing a high level of diversity. These conditions indicate that the Olive-backed Tailorbird is associated with habitats that retain vertical vegetation complexity, particularly shrub and ground-vegetation layers that provide shelter, foraging sites, and substrates for its insect prey (Rohman et al., 2023). The modeled distribution can therefore be interpreted as a response to dense and continuous understory vegetation, rather than merely to general greenness or canopy cover.

Spatial Distribution of Habitat Suitability

Habitat-suitability maps for the three species are presented in Figure 1. In general, highly suitable areas were concentrated in the principal green open spaces, particularly Monas and Gelora Bung Karno. The proportion of highly suitable habitat varied among species (Table 2): the Brown-throated Sunbird had the largest extent (19.5%; 121.7 km²), followed by the Red-breasted Parakeet (12.2%; 75.8 km²), while the Olive-backed Tailorbird had the smallest extent (9.6%; 59.8 km²). The restricted and concentrated distribution of highly suitable habitat for the Olive-backed Tailorbird is consistent with its specialized habitat requirements, whereas the Brown-throated Sunbird can use a more dispersed mosaic of urban vegetation.

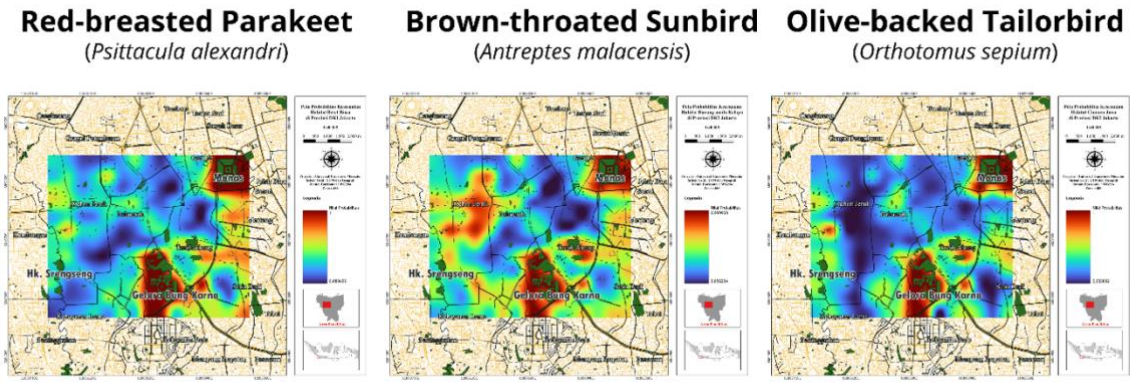


Figure 1. MaxEnt habitat-suitability probability maps for three bird species in DKI Jakarta. Warm colors indicate higher suitability

Figure 1 shows that the three species have different potential distribution patterns across DKI Jakarta. These differences reflect variation in each species' response to land-cover composition, the intensity of development, the presence of green open space, and urban vegetation structure. In general, areas with high habitat-suitability probabilities were not evenly distributed, but formed habitat pockets in locations that retained relatively good vegetation cover.

Table 2. Proportions of habitat-suitability classes (%) and the extent of suitable habitat for three bird species

Suitability class	Red-breasted Parakeet	Brown-throated Sunbird	Olive-backed Tailorbird
Unsuitable (0–0.2)	23,6	24,2	34,1
Low (0.2–0.4)	40,6	30,5	32,4
Moderate (0.4–0.6)	23,6	25,8	23,9
High (0.6–1.0)	12,2	19,5	9,6
Suitable habitat (MaxSS threshold)	27,1	24,0	20,3

According to Table 2, the Brown-throated Sunbird had the largest proportion of highly suitable habitat, at 19.5% or approximately 121.7 km². The Red-breasted Parakeet ranked second, with 12.2% or approximately 75.8 km², while the Olive-backed Tailorbird had the smallest proportion, at 9.6% or approximately 59.8 km². These values indicate that highly suitable environments for the Brown-throated Sunbird are more widely distributed than those for the Red-breasted Parakeet and Olive-backed Tailorbird.

The Red-breasted Parakeet (*Psittacula alexandri*) showed a relatively broad potential habitat distribution, although most of the modeled area fell within the low-suitability class. Low suitability accounted for 40.6%, the largest proportion among all classes. Unsuitable and moderately suitable areas each accounted for 23.6%, while highly suitable habitat represented only 12.2%. This pattern indicates that the species can reach a broad urban mosaic, but only a small proportion provides an optimal combination of habitat conditions. The distribution is consistent with the species' ability to use urban green spaces where food trees, canopy cover, and sufficiently large trees remain available. The results also demonstrate that urban parks can function as foraging sites when their vegetation composition provides appropriate resources (Hakamashe et al., 2022).

The Brown-throated Sunbird (*Anthreptes malacensis*) had a highly suitable habitat proportion of 19.5%, the largest among the three species. Low suitability covered 30.5%, moderate suitability 25.8%, and unsuitable areas 24.2%. This composition was relatively more balanced than those of the Red-breasted Parakeet and Olive-backed Tailorbird. The combined moderate- and high-suitability classes, totaling 45.3%, indicate that the Brown-throated Sunbird can potentially use a relatively broad mosaic of urban vegetation.

This pattern can be associated with the ability of sunbirds to exploit flowering plants in urban parks, gardens, greenways, orchards, office complexes, and other open spaces. Urban ecological literature indicates that local flowering-plant richness can reduce the negative effects of urbanization on organisms that depend on floral resources. Green spaces that provide flowers continuously can sustain nectar availability within the urban landscape (Liang

et al., 2023). Studies of plant–pollinator interactions in cities also emphasize that urban green spaces can maintain ecological interactions when they contain adequate plant diversity and floral resources (Silva et al., 2021).

The Olive-backed Tailorbird (*Orthotomus sepium*) had the most restricted distribution of highly suitable habitat. Unsuitable areas accounted for 34.1%, low suitability 32.4%, moderate suitability 23.9%, and high suitability only 9.6%. Thus, approximately two-thirds of the study area was unsuitable or of low suitability for this species. Based on the MaxSS threshold, suitable habitat for the Olive-backed Tailorbird was also the smallest, at 20.3%. This pattern suggests that the species has more specific microhabitat requirements. As a small insectivore, it frequently uses shrubs, low vegetation, thickets, and the understory for foraging, shelter, and movement. Habitat limitation in Jakarta may be associated with green-space management that tends to simplify the understory. Many urban parks and gardens contain shade trees, but their ground surfaces are dominated by closely mown grass, paving, or open areas.

Habitat Connectivity

The Circuitscape analysis (Figure 2) revealed different connectivity patterns among species (Table 3). The Red-breasted Parakeet showed the most centralized connectivity, with the highest maximum current-flow value (43.51) but the smallest high-current area (8.3%). This pattern indicates dependence on narrow, critical, and vulnerable pinch points. By contrast, the Brown-throated Sunbird (20.9%) and Olive-backed Tailorbird (21.1%) had larger high-current areas with branching and dispersed corridor networks, making their connectivity more resilient because it did not depend on only a few routes.

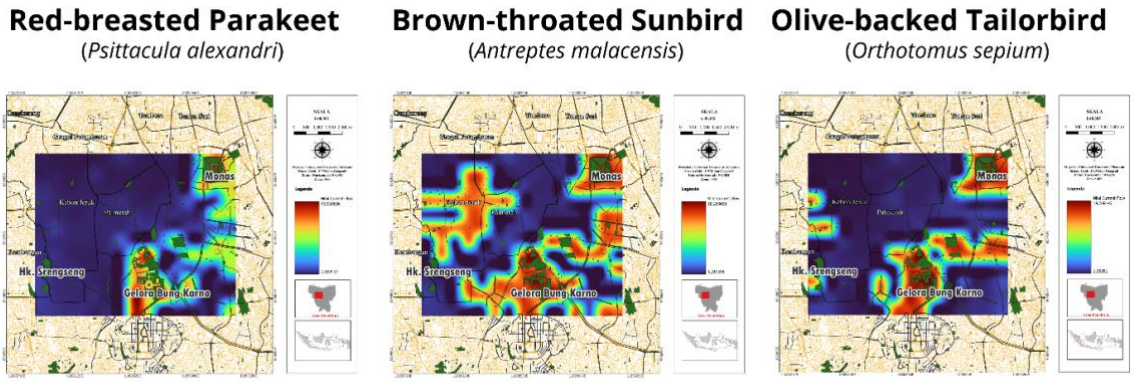


Figure 2. Cumulative current-flow maps (Circuitscape) for three bird species. Warm colors indicate higher current flow and therefore important movement routes or corridors

Table 3. Summary of connectivity parameters (current flow) for three bird species

Parameter	Red-breasted Parakeet	Brown-throated Sunbird	Olive-backed Tailorbird
Maximum current flow	43,51	18,27	20,08
High-current area (%)	8,3	20,9	21,1
Main connectivity pathways (%)	61,3	58,5	77,2
Connectivity pattern	Centralized	Dispersed	Broadly diffuse

The high proportion of connectivity pathways for the Olive-backed Tailorbird (77.2%) appears paradoxical given its very limited core habitat. This can be explained as a consequence of fragmentation: because optimal habitat pockets are dispersed and isolated, the connectivity model channels current through numerous diffuse routes linking those pockets. Thus, the extensive corridor network reflects connectivity challenges rather than ease of movement.

The contrasting patterns among the three species demonstrate that the extent of green open space alone is insufficient to guarantee habitat suitability for bird communities. The Red-breasted Parakeet benefits primarily from large trees, fruit trees, and canopy continuity. The Brown-throated Sunbird requires flowering plants with sustained nectar availability, while the Olive-backed Tailorbird is more strongly associated with shrubs, understory vegetation, and dense habitat structure. Therefore, bird-habitat development in Jakarta should increase vegetation heterogeneity both vertically and horizontally.

Comparative Synthesis and Conservation Implications

A comprehensive comparison of the three species (Table 4) revealed three ecological-response patterns in the urban landscape. The Red-breasted Parakeet represents a synanthropic species that benefits from residential areas but is vulnerable in terms of connectivity; the Brown-throated Sunbird represents a flowering-vegetation-dependent species with the most resilient connectivity; and the Olive-backed Tailorbird represents a shrub specialist with the most accurate model but the most restricted and fragmented core habitat. Despite these differences, all three species shared one important feature: the central role of vegetation cover (NDVI) and the concentration of both suitable habitat and connectivity in Monas and Gelora Bung Karno.

Table 4. Comprehensive comparison of modeling results for three bird species

Parameter	Red-breasted Parakeet	Brown-throated Sunbird	Olive-backed Tailorbird
Scientific name	*P. alexandri*	*A. malacensis*	*O. sepium*
Feeding guild	Frugivore-granivore	Nectarivore	Insectivore
Occurrence points	68	91	59
Training AUC	0,761	0,755	0,791
Dominant variable	Population density	NDVI	Land use
Ecological type	Urban-tolerant	Vegetation-dependent	Shrub specialist
Highly suitable habitat (%)	12,2	19,5	9,6
Connectivity	Centralized, vulnerable	Dispersed, resilient	Diffuse, restricted core

These findings have complementary conservation implications. First, Monas and Gelora Bung Karno should be prioritized as core areas functioning as both habitat and multi-species connectivity hubs. Second, improving vegetation quality and diversity—including flowering vegetation for the Brown-throated Sunbird and dense shrub structure for the Olive-backed Tailorbird—will increase habitat carrying capacity. Third, strengthening connecting green corridors, particularly along the GBK–Monas axis, will enhance the overall resilience of urban ecological connectivity and support the persistence of all three species under continuing urbanization pressure.

CONCLUSION

Habitat-suitability and connectivity modeling for three bird species in DKI Jakarta revealed contrasting ecological responses to the urban landscape: the Red-breasted Parakeet is synanthropic and strongly associated with population density, the Brown-throated Sunbird depends on flowering vegetation cover, and the Olive-backed Tailorbird is a shrub specialist with the most restricted core habitat. AUC values of 0.755–0.791 indicate fair model performance, with NDVI consistently emerging as the most important variable. Connectivity patterns ranged from centralized and vulnerable for the Red-breasted Parakeet to dispersed and resilient for the Brown-throated Sunbird and Olive-backed Tailorbird. Monas park and Gelora Bung Karno consistently functioned as habitat and connectivity hubs for all three species and should therefore be prioritized for urban bird biodiversity conservation in Jakarta. Strengthening vegetation cover and connecting green corridors is recommended as a cross-species management strategy.

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