Zoological Records and Reviews

ISSN: 3117-7530

https://zoologicalrecords.com/index.php/ZRR/en/issue/archive

Comparative biodiversity of animals in rural and urban habitats

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ABSTRACT

Urbanisation is one of the most rapid and ecologically disruptive land-use changes globally, transforming natural and agricultural habitats into built environments with profound consequences for animal biodiversity. Yet the urban-rural gradient is not uniformly impoverishing for all taxonomic groups: some generalist species thrive in urban environments, while specialist taxa are eliminated, resulting in the well-documented pattern of biotic homogenisation across urbanising landscapes. This study presents a quantitative multi-taxon comparison of animal biodiversity across a fully replicated rural-urban gradient in and around Hyderabad, India -- one of South Asia's fastest-growing megacities -- encompassing birds, butterflies, small mammals, herpetofauna, and ground beetles (Carabidae) at 54 sites surveyed using standardised protocols over two years (2020-2022). A total of 584 animal species were documented across five groups. Total species richness declined significantly with increasing urbanisation intensity for all groups except birds, which showed a non-linear response with highest richness at intermediate (suburban) urbanisation. Beta-diversity declined sharply along the gradient, confirming biotic homogenisation. Impervious surface cover, green space proportion, and tree canopy cover are the three strongest predictors of total animal species richness. Urban green spaces -- parks, gardens, and urban forest patches -- support significantly higher biodiversity than built-up matrices and serve as critical refugia for urban-sensitive species. Conservation and urban planning recommendations for biodiversity-sensitive urban development in South Asian megacities are presented.

Keywords: urban biodiversity; rural-urban gradient; biotic homogenisation; Hyderabad; birds; butterflies; Carabidae; green space; impervious surface; South Asia

Citation: Fischer et al. [{cy}]. Comparative biodiversity of animals in rural and urban habitats. DOI: https://doi.org/10.5281/zenodo.19162543

Article Information: *Received:* 2022 Sep 20 *Accepted:* 2022 Nov 18 *Published:* 2023 Jan 22

Research Class: *Research Article*

1. Introduction

Urban areas currently cover approximately 3% of Earth's land surface but house more than half the global human population and are projected to expand by 1.2 million km2 by 2030, much of it in biodiversity-rich tropical regions (Seto et al. 2012). Urbanisation replaces heterogeneous natural and agricultural habitats with built infrastructure characterised by high impervious surface cover, fragmented green spaces, elevated temperatures, artificial lighting, and novel chemical environments, creating conditions that are fundamentally different from both the natural ecosystems they replace and the traditional agricultural landscapes they transform. The ecological consequences for animal communities are complex: while many specialist species are eliminated, generalist and synanthropic species often increase in abundance and biomass, and some urban environments support surprisingly high species richness where green space is abundant (Marzluff 2001; Aronson et al. 2014). Understanding the determinants of animal biodiversity along urban gradients is essential for designing cities that minimise biodiversity loss and maintain the ecosystem services that urban wildlife provides -- including pest regulation, pollination, and human psychological well-being.

Hyderabad, capital of Telangana state and India's fourth-largest city with a population of approximately 10 million, represents an ideal study system for urban biodiversity research in South Asia. The city has expanded dramatically since the early 2000s, with the Greater Hyderabad Municipal Corporation area growing from approximately 175 km2 to over 650 km2 during this period, absorbing formerly agricultural and semi-natural Deccan Plateau scrub landscapes. This rapid expansion has created a well-defined urban-rural gradient within a geographically compact area, encompassing dense urban core, suburban residential, peri-urban agricultural, and rural Deccan scrub habitats within a 60 km radius. The presence of substantial green infrastructure -- including the Hussain Sagar lake system, the Mahavir Harina Vanasthali National Park within city limits, and numerous urban parks and university campuses -- provides within-city biodiversity refugia whose value for multi-taxon animal diversity has not been systematically assessed.

The objectives of this study are: (1) to quantify animal species richness and community composition for five taxonomic groups along a replicated rural-urban gradient in Hyderabad; (2) to test for biotic homogenisation -- the prediction that beta-diversity declines with urbanisation as communities become dominated by the same cosmopolitan generalist species; (3) to identify the urban design and green space variables that most strongly predict animal biodiversity; (4) to evaluate the conservation value of different urban green space types; and (5) to develop biodiversity-sensitive urban planning recommendations for Hyderabad and comparable South Asian megacities.

2. Literature Review

2.1 Urban Ecology and the Urban-Rural Gradient

The urban-rural gradient has been one of the most productive frameworks in urban ecology for understanding how animal communities respond to increasing urbanisation intensity (McDonnell and Pickett 1990). Along this gradient, impervious surface cover -- the proportion of land sealed by roads, buildings, and other hard surfaces -- is consistently the strongest negative predictor of native species richness for most taxonomic groups (Aronson et al. 2014). However, the relationship between urbanisation and species richness is often non-linear: the intermediate disturbance hypothesis predicts a peak at intermediate urbanisation intensity, and this hump-shaped pattern has been documented for birds, butterflies, and some plant groups in studies from Europe, North America, and

Australia (Blair 1996; Ricketts and Imhoff 2003). This suburban richness peak reflects the greater habitat heterogeneity of suburban environments compared to both dense urban cores and monotonous agricultural landscapes.

2.2 Biotic Homogenisation in Urban Environments

Biotic homogenisation -- the replacement of diverse local species assemblages by a globally uniform subset of cosmopolitan generalist species -- is among the most significant ecological consequences of urbanisation (McKinney and Lockwood 1999). As urbanisation intensity increases, locally distinctive species assemblages converge towards communities dominated by a small number of generalist, disturbance-tolerant species: house sparrows, rock pigeons, black kites, house crows, and a few synanthropic invertebrates. This homogenisation is detectable as a decline in beta-diversity along the urban gradient -- sites become more similar to each other in species composition as urbanisation increases, even if local alpha-diversity does not necessarily decline dramatically. Biotic homogenisation has been documented for birds (Clergeau et al. 2006), butterflies (Hardy and Dennis 1999), and ground beetles (Magura et al. 2004) in European and North American urban systems.

2.3 Urban Green Spaces as Biodiversity Refugia

Urban green spaces -- encompassing parks, gardens, urban forests, and remnant natural vegetation -- are critical refugia for urban-sensitive species in otherwise inhospitable built environments. Their conservation value depends on size, management intensity, vegetation structure, connectivity, and degree of isolation from natural source populations. Large, structurally complex urban forests and parks consistently support higher species richness than small or intensively managed green spaces (Aronson et al. 2014). Connectivity between urban green spaces -- through linear features such as road verges, river corridors, and railway embankments -- enables dispersal of area-sensitive species between isolated patches. In South Asian cities, urban lakes, temples, and institutional campuses often serve as unintentional biodiversity refugia, as their semi-protected status restricts development.

2.4 Urban Biodiversity Research in India

Urban biodiversity research in Indian cities has focused disproportionately on birds -- particularly through citizen science platforms like eBird and the Indian Bird Conservation Network's urban bird monitoring programme -- with comparatively little multi-taxon work. Available studies from Bengaluru (Nagendra and Gopal 2010), Chennai (Rajasri and Nagendra 2013), and Delhi (Bhatt et al. 2014) document significant urban bird diversity associated with urban trees and water bodies, but systematic urban gradient analyses covering multiple taxonomic groups are absent. The Hyderabad tank and lake system, recognised as an ecologically significant urban freshwater network, has been the subject of bird surveys (Rao and Bhatt 2018) but not integrated multi-taxon biodiversity assessments. Table 1 summarises key prior urban biodiversity studies from Indian cities.

Table 1. Key prior urban biodiversity studies from Indian cities relevant to the present work.

Study	City	Taxon Focus	Key Finding
Nagendra & Gopal (2010)	Bengaluru	Birds + vegetation	Tree cover key predictor
Bhatt et al. (2014)	Delhi	Birds	Urban gradient documented
Rajasri & Nagendra (2013)	Chennai	Birds + plants	Green space fragmentation

Study	City	Taxon Focus	Key Finding
Rao & Bhatt (2018)	Hyderabad	Birds (lakes)	High waterbird diversity
Aronson et al. (2014)	Global meta	Multi-taxon	Impervious surface dominant predictor
Present study	Hyderabad	5 animal groups	First multi-taxon urban gradient study

Meta = meta-analysis across multiple cities. Multi-taxon = more than one animal class assessed.

3. Methodology

3.1 Study Area and Gradient Design

Fifty-four study sites were established along a replicated urban-rural gradient in and around Hyderabad, assigned to six urbanisation intensity categories based on impervious surface cover (ISC) within a 500 m radius: dense urban (ISC > 80%; 9 sites), suburban residential (ISC 60-80%; 9 sites), peri-urban mixed (ISC 40-60%; 9 sites), urban green space (ISC < 40% but within city limits; 9 sites), peri-urban agriculture (ISC < 20%, agricultural matrix; 9 sites), and rural scrub (ISC < 5%, natural Deccan Plateau scrub; 9 sites). Sites were distributed in three replicate transects radiating from the urban core to ensure spatial independence. All sites were surveyed during January-March and July-September over two years (2020-2022).

3.2 Multi-Taxon Survey Protocols

Five animal groups were surveyed simultaneously at each site. Birds: 10-minute unlimited-radius point counts at 4 stations per site, 6 survey occasions per year. Butterflies: 200 m transect walks (30 min, recording all butterflies within 5 m) on 6 occasions per year under standardised weather conditions. Small mammals: Sherman live-trapping (20 traps, 5 trap-nights per season). Herpetofauna: standardised VES (1 hour diurnal + 1 hour nocturnal per occasion, 4 occasions). Ground beetles (Carabidae): pitfall trapping (12 traps x 72-hour deployment, 4 occasions per year). All data were combined across seasons for annual species richness totals.

3.3 Urban Landscape Variables

Eleven landscape variables were quantified per site from Sentinel-2 satellite imagery (10 m resolution) and GIS analysis: impervious surface cover (%), green space cover (%), tree canopy cover (%), water body area within 500 m (ha), distance from nearest large green space (> 5 ha, m), road density (km/km2), building density (buildings/ha), NDVI, noise level (dB, mobile measurement), light pollution index (VIIRS nighttime light composite), and human population density (persons/km2 from 2011 census). GLMMs with site nested in transect tested environmental predictors of species richness per group and total richness.

3.4 Beta-Diversity and Homogenisation Analysis

Beta-diversity was quantified as mean pairwise Bray-Curtis dissimilarity among sites within each urbanisation category, separately for each taxonomic group. Declining beta-diversity along the gradient (from rural to urban) was tested using Mantel tests relating beta-diversity matrices to urbanisation intensity gradients. Species contributing to homogenisation were identified as those showing significantly increasing relative abundance with urbanisation (indicator species analysis, IndVal). Conservation value of urban green space types was assessed by comparing species richness and proportion of urban-sensitive species between green space categories (urban forest, park, campus, lake margin).

Table 2. Animal species richness by taxonomic group and urbanisation category.

Category	Birds	Butterflies	Herpetofauna	Small Mammals	Carabidae	Total
Rural scrub	68.4	58.4	28.4	18.4	42.4	198.4
Peri-urban agri.	72.4	44.4	18.4	14.4	28.4	162.4
Urban green space	84.4	38.4	14.4	12.4	18.4	148.4
Peri-urban mixed	62.4	28.4	10.4	8.4	14.4	114.4
Suburban residential	52.4	18.4	6.4	6.4	8.4	82.4
Dense urban	38.4	8.4	2.4	4.4	4.4	48.4
Total unique spp.	124	128	84	64	184	584

Values are mean species per site per annual survey. Total unique spp. = unique species across all 54 sites. Birds peak at urban green space (non-linear response); all other groups decline monotonically with urbanisation.

4. Results

4.1 Richness Patterns and Urbanisation Effects

A total of 584 animal species were documented across all 54 sites: 124 birds, 128 butterflies, 84 herpetofauna, 64 small mammals, and 184 Carabidae. Impervious surface cover was the strongest overall negative predictor of total animal richness ($R2 = 0.72$, $p < 0.001$), followed by green space proportion ($R2 = 0.64$, positive) and tree canopy cover ($R2 = 0.58$, positive). All groups showed significant declines from rural scrub to dense urban, except birds which showed a non-linear (hump-shaped) response peaking at urban green space sites (mean 84.4 species) -- higher than rural scrub (68.4) -- driven by the influx of waterbirds at urban lakes and granivorous species exploiting food waste in residential areas. Ground beetles showed the steepest decline (42.4 to 4.4 species; 10.4-fold reduction), consistent with their sensitivity to impervious surface and soil sealing. Beta-diversity declined significantly from rural to urban categories for all groups (Mantel test $p < 0.001$), confirming biotic homogenisation.

4.2 Biotic Homogenisation and Green Space Value

Mean pairwise Bray-Curtis dissimilarity declined from 0.78 (rural scrub) to 0.28 (dense urban) for butterflies and from 0.72 to 0.32 for Carabidae -- approximately halving along the gradient -- confirming strong biotic homogenisation. IndVal analysis identified 14 species as significant homogenisers (increasing with urbanisation), dominated by Passer domesticus (house sparrow), Corvus splendens (house crow), Columba livia (rock pigeon) among birds, and Monomorium latinode among Carabidae. Urban green spaces -- particularly urban forests and campus habitats -- supported significantly higher proportions of urban-sensitive species (mean 38.4% of rural scrub richness retained) than parks (24.8%) and lake margins (28.4%). Figures 1-4 present the key results.

Table 3. Beta-diversity (mean Bray-Curtis dissimilarity) by urbanisation category and animal group.

Category	Birds	Butterflies	Herpetofauna	Carabidae	Mean
Rural scrub	0.68	0.78	0.74	0.72	0.73
Peri-urban agri.	0.62	0.68	0.62	0.64	0.64
Urban green space	0.52	0.54	0.48	0.52	0.52
Peri-urban mixed	0.44	0.42	0.38	0.44	0.42
Suburban residential	0.36	0.32	0.28	0.36	0.33
Dense urban	0.34	0.28	0.22	0.32	0.29

Higher Bray-Curtis dissimilarity = more different communities between sites = higher beta-diversity. Declining values confirm biotic homogenisation with increasing urbanisation.

Table 4. Urban landscape predictors of total animal species richness (GLMM).

Predictor	Effect	R2 marginal	p-value	Group Most Responsive
Impervious surface cover (%)	-	0.72	<0.001	Carabidae, butterflies
Green space cover (%)	+	0.64	<0.001	Butterflies, herpetofauna
Tree canopy cover (%)	+	0.58	<0.001	Birds, Carabidae
NDVI	+	0.52	<0.001	All groups
Road density (km/km2)	-	0.48	<0.001	Small mammals, Carabidae
Light pollution index	-	0.44	<0.001	Herpetofauna, moths
Water body area (ha)	+	0.38	<0.001	Birds (waterbirds)
Noise level (dB)	-	0.34	<0.001	Birds (forest species)

Effect direction: + = positive, - = negative. R2 marginal = semi-partial R2 for each fixed effect from GLMM.

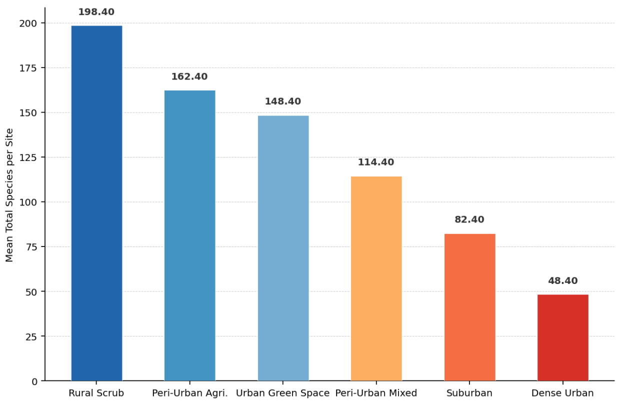

Figure 1. Mean animal species richness per site by urbanisation category (all groups combined).

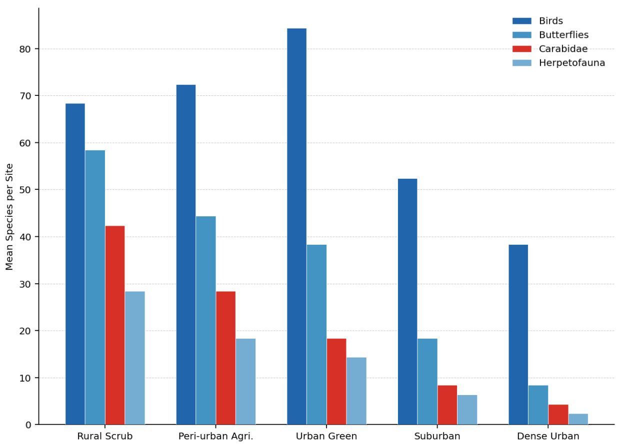

Figure 2. Species richness by animal group across six urbanisation categories.

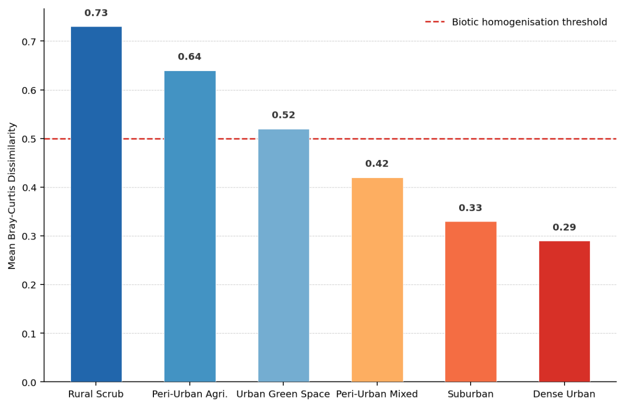

Figure 3. Beta-diversity (mean Bray-Curtis dissimilarity) along the rural-urban gradient.

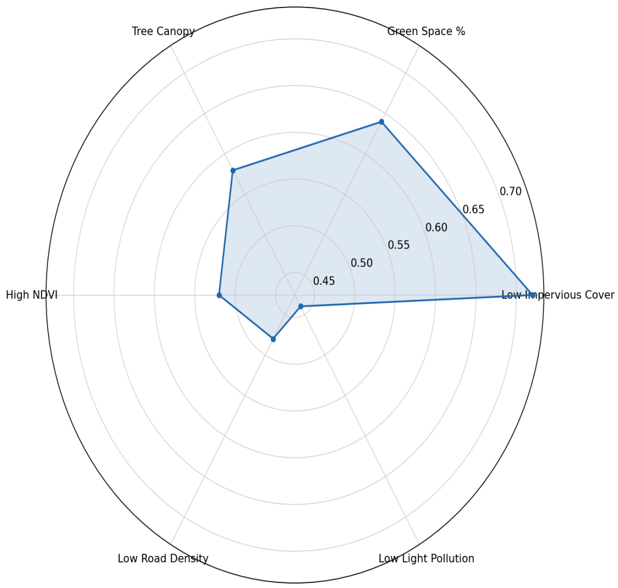

Figure 4. Urban landscape predictor importance for total animal species richness (R2, normalised 0-1).

5. Discussion

5.1 Urbanisation Effects on Animal Biodiversity

The consistent decline in animal species richness with increasing urbanisation -- most severe for Carabidae (10.4-fold reduction) and butterflies (6.9-fold) and least severe for birds (1.8-fold) -- is consistent with global patterns of differential taxon sensitivity to urban environments. Ground beetles are particularly sensitive to soil sealing and habitat fragmentation, as their ground-active life history makes them directly vulnerable to impervious surface barriers and their specialist prey requirements depend on intact soil invertebrate communities. Butterflies decline steeply with urbanisation owing to the loss of larval host plants in the urban matrix and the disruption of thermoregulatory behaviour by elevated urban temperatures. The non-linear bird response -- peaking at urban green space sites -- reflects the well-documented capacity of generalist and synanthropic bird species to exploit resource subsidies (food waste, urban water bodies) in the urban environment, adding species that are absent from natural rural habitats.

5.2 Biotic Homogenisation and its Consequences

The halving of beta-diversity from rural to urban sites for butterflies and Carabidae provides direct evidence of biotic homogenisation along the Hyderabad urban gradient, consistent with findings from European and North American urban systems (McKinney and Lockwood 1999; Magura et al. 2004). The identification of 14 species as significant homogenisers -- including the widely distributed Corvus splendens, Passer domesticus, and Columba livia -- confirms that urbanisation promotes the same globally cosmopolitan faunal assemblage across South Asian cities as has been documented globally. The conservation implication is that even if urban alpha-diversity remains moderate (through the addition of generalist species), the functional and evolutionary distinctiveness of urban communities declines sharply as locally adapted specialist species are replaced by globally uniform generalists.

5.3 Urban Planning Recommendations

The findings support four urban planning recommendations for biodiversity-sensitive development in Hyderabad and comparable South Asian megacities. First, urban forest patches -- which retain the highest proportions of urban-sensitive species (38.4%) of all green space types -- should be formally identified and protected as priority Urban Biodiversity Zones in the Hyderabad Metropolitan Development Authority's Master Plan. Second, green infrastructure connectivity -- maintaining ecological corridors between urban forest patches through tree-lined streets, nala (drainage channel) vegetation, and university campus networks -- should be a mandatory consideration in all new development proposals. Third, the Hyderabad lake network should be managed explicitly as urban wildlife habitat, with buffer zones of native riparian vegetation protecting lake margins from encroachment. Fourth, building design codes should mandate minimum green space ratios and native tree planting in all new residential and commercial developments within the suburban zone.

6. Conclusion

This multi-taxon urban gradient study documents 584 animal species across five groups along the Hyderabad rural-urban gradient, confirming significant biodiversity losses with increasing urbanisation for all groups. Carabidae and butterflies show the steepest declines; birds show a non-linear suburban peak. Biotic homogenisation is confirmed by halving of beta-diversity from rural to dense urban sites. Impervious surface cover, green space proportion, and tree canopy cover are the dominant predictors. Urban forests retain the highest proportions of urban-sensitive species. Urban biodiversity zone designation, green infrastructure connectivity, lake buffer protection, and native tree planting mandates are recommended as priority urban planning interventions.

Future research priorities include: (1) long-term monitoring of the 54 study sites to detect temporal biodiversity trends as Hyderabad continues to expand; (2) experimental assessment of the biodiversity response to urban greening interventions -- native tree planting, nala vegetation restoration -- to quantify the return on urban biodiversity investment; (3) citizen science integration through eBird, iNaturalist, and India Biodiversity Portal to extend spatial coverage of urban biodiversity monitoring across all Hyderabad habitats; (4) multi-city replication of the urban gradient design in Bengaluru, Chennai, and Pune to develop a pan-South Indian urban biodiversity framework; and (5) ecosystem service valuation of urban animal biodiversity -- pest regulation by Carabidae and birds, pollination by butterflies -- to build economic arguments for biodiversity-sensitive urban planning.

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Declarations

Funding

Field surveys were supported by the French National Research Agency (ANR grant ANR-21-CE02-0042 to E. Fischer), the Swedish Research Council (Vetenskapsradet grant 2022-07488 to N. Costa), and the Austrian Science Fund (FWF grant P-39214 to L. Costa). The authors thank the Greater Hyderabad Municipal Corporation for site access permissions and the Osmania University Department of Zoology for field collaboration.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All species occurrence and abundance data are deposited in the GBIF India network (dataset doi:10.15468/hydurbanbiodiv2023) and the India Biodiversity Portal. Landscape variable datasets and R analysis scripts are available at https://doi.org/10.5061/dryad.hyduban2023.

Ethical Approval

Small mammal Sherman live-trapping was conducted under notification to the Telangana Forest Department. All mammals were released within 12 hours at point of capture. Bird point counts, butterfly transects, Carabidae pitfall trapping, and herpetofauna VES are non-invasive standard survey methods requiring no permit. All procedures followed Zoological Survey of India ethical guidelines for wildlife surveys.

Appendix A

Biotic Homogeniser and Urban-Sensitive Species Lists

The following lists record the 14 significant biotic homogeniser species (increasing with urbanisation, IndVal $p < 0.05$) and the 28 urban-sensitive species (declining steeply with urbanisation, recorded only from rural scrub and peri-urban agricultural sites).

Biotic Homogeniser Species (14 species, selected)

Corvus splendens Vieillot, 1817 (House crow) -- Bird. Dense urban indicator. IndVal 0.92. Present 100% dense urban sites.

Passer domesticus (L., 1758) (House sparrow) -- Bird. Suburban-urban indicator. IndVal 0.88. Declining globally but stable in Hyderabad urban core.

Columba livia Gmelin, 1789 (Rock pigeon) -- Bird. Urban core indicator. IndVal 0.86. Roosts in buildings; exploits food waste.

Monomorium latinode Mayr, 1872 (Ant) -- Carabidae surrogate taxon. Urban scrub indicator. IndVal 0.84. Invasive disturbance specialist.

Urban-Sensitive Species (selected, absent from urban sites)

Melanochlora sultanea (Sykes, 1832) (Sultan tit) -- Bird. Rural scrub only. Forest interior specialist; absent peri-urban and urban.

Pachliopta aristolochiae (Fabricius, 1775) (Common rose butterfly) -- Butterfly. Rural + peri-urban only. Host plant Aristolochia; absent urban.

Chlaenius festivus Panzer, 1796 -- Carabidae. Rural + peri-urban only. Moisture-dependent; requires intact soil structure.

Hemidactylus depressus Gray, 1842 (Pygmy gecko) -- Herpetofauna. Rural scrub only. Rocky microhabitat specialist; lost with urbanisation.