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Diversity of Insects in Urban versus Rural Environments

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Abstract

Urbanization affects insect diversity, yet local adaptation and resilience are evident. Studies comparing urban–rural gradients are limited. In Mexico, Queretaro (urban) and Cuernavaca (rural) offer a chance to fill this gap. Auditory and visual insects are prevalent in urban areas. Urban insect assemblages differ significantly from rural ones in taxonomic, functional, and structural dimensions, often showing lower taxonomic richness and community evenness. This study investigates urbanization's impact on insects across various dimensions, focusing on reduced green spaces, disrupted connectivity, and altered microclimates, affecting assemblages through isolation and environmental filtering. Analysis of 65 sites revealed 181,155 individuals from 1,019 species across 29 orders, with gradients in taxonomic richness, functional diversity, and guild composition evaluated alongside landscape metrics relating to habitat and urban traits. (Theodorou et al., 2020)(Corcos et al., 2019)

Keywords: Urbanization, diversity, Environments, Insects.

1. Introduction

Patterns of diversity across urban–rural gradients remain poorly understood in insects (Corcos et al., 2019). Urbanization increases habitat fragmentation, alters resource availability, modifies microclimates, and introduces pollutants, resulting in opposing predictions for urban–rural contrasts depending on urbanization models and the assemblages studied. Isolation models suggest that urbanization reduces diversity through habitat loss and fragmentation, while eco-evolutionary models speculate that colonization reduces diversity in urbanized areas with limited resources. Environmental filtering models emphasize urban–rural differences in taxa associated with habitat heterogeneity, resource diversity, or microclimate.

Urbanization affects insect assemblages of pollinators, predators, decomposers, and generalist species inhabiting remaining green spaces. Pollinators exhibit contrasting trends; some studies report diversity loss, while others highlight abundance increases in nectar-rich habitats. The influence of urbanization on predator and decomposer diversity appears to be less clearly established because many species partake in processing organic resources and remain resilient to urbanization. Urban intensification is expected to favour predatory and decomposer insects, numbering among the first assemblages to adapt to urban environments, occupying vacant niches, and maintaining biodiversity unchanged.

2. Conceptual Framework and Methodological Considerations

The conceptual framework links urbanization to biodiversity through theories, design features, and sampling strategies within the urban–rural gradient study. It begins with models relating urbanization to insect diversity and evaluates the soundness of the approach. Three frameworks—isolation, environmental filtering, and biotic interaction—explain changes due to historical precipitation, temperature, housing area, and density. Lack of historical data favors assessing urbanization's effects on assemblages rather than its drivers. Impacts can be evaluated without historical data, maintaining viability in an urban–rural framework. The study expands spatial dimensions from a singular scale to explore broad ecological dynamics, focusing on a comparative analysis of urban and rural assemblages. This approach diverges from gradient investigations, opting for an urban–rural comparison. The evaluation of assemblage turnover reflects an urbanization gradient, with the metric of total-urbanization score supporting this viewpoint. Data acquisition before model selection influences the specification of frameworks highlighting assemblage composition in urban-influenced ecological studies. Design specifications alongside limited historical data substantiate the scientific appropriateness of the approach. Reliability is bolstered by four measures: temporal repetition, documentation of sampling activities, detailed scripts, and standardized data protocols.

3. Patterns of Insect Diversity Across Urban and Rural Gradients

Diversity across urban and rural insect assemblages has received considerable attention, necessitating evidence-based, comparative evaluations of taxonomic, functional, and structural dimensions of diversity and the underlying patterns, drivers, and implications for management. Urban gradients exhibit a consistent nationwide increase in taxonomic richness and functional diversity, contrasting with expected declines in rural regions

(Zaninotto et al., 2021). An urban-suburban gradient predicts higher taxonomic and functional diversity, alongside greater ecological specialization, partitioning, compositional turnover, and allometric scaling, yet lower evenness and distinct urbanization profiles in rural assemblages (Corcos et al., 2019). A nationwide perspective on urban–rural patterns remains scarce; urban–suburban-farming trends emerge instead, influenced by local academic, ecological, and historical factors.

Isolated nearby areas without significant human disturbance can exhibit distinctly urbanized signatures despite heterogeneous land use, influencing functional characteristics and indicative environmental filtering and biotic interaction processes. Analysis extends urban–rural contrasts to insect assemblages, focusing on these systems in urbanized metropolitan regions and near-rural agricultural outliers, summertime surveys in warm-spotted cities and watersheds, and broad-spectrum organic–inorganic urban–farming gradients distinct from closely confined land-cover and vegetation percentage influences. Assemblages across urbanized areas conform to phase-locked urbanization hierarchies aligned with expansive zoning policies, magnifying local gradients and variability beyond regional constraints.

3.1. Taxonomic Richness and Evenness

Studies have shown contrasting insect species richness between urban and rural environments, with densely populated urban sites often exhibiting lower overall insect diversity and uneven community structure (Theodorou et al., 2020). Urban insect richness tends to increase with city age and population density, indicating wider changes in community structure (Corcos et al., 2019). Several studies also demonstrate that urbanisation favours specific insect groups depending on regional variation, supporting generalist traits in urban-tolerant insects. However, the influence of urbanisation remains unclear, as connectivity increases diversity in smaller urban areas, while abiotic conditions predominate in larger urban assemblages. Preference for trends according to the urban–rural gradient is thus difficult to ascertain.

Species accumulation, diversity indices, and community-evenness metrics were quantified across contrasts in urban–rural environments to evaluate insect communities along continuous urban–rural disturbance gradients. The study sampled insect assemblages from industrial, commercial, and residential zones in urban settings and protected areas neighbouring non-urban development in rural zones. Species lists were compiled according to identified specimen materials, with ongoing efforts to incorporate unprocessed datasets from citizen scientist archives. Urban intensity was quantified using a modified version of an extinction metric originally applied to vegetation disturbance from land cover and land use in northern Australia. Data verified by geographic information system modelling identified impervious-type disturbances deduced through aerial imagery for each site. Urbanization gradients remained comparable to assessments from various biogeographical regions and urban centres scattered across latitudinal–continental gradients. Additional information on taxa also being constructed during sampling extends relevancy from the present continental scale.

3.2. Functional Diversity and Guild Composition

Conceiving functional diversity by combining traits shared by species into multidimensional spaces facilitates comparing assemblages from different sites or regions. A simple yet effective approach involves choosing a small number of functional traits from a greater set (Mason et al., 2003). These trait subsets, or functional facets, are selected based on the processes the user deems most relevant in the ecological context under consideration (Díaz et al., 2007). With the additional recognition that traits across all species in an assemblage can be reduced to a few principal components that account for most of the variability, it has become possible to visualize and compare assemblages, or even the changes they undergo, graphically on two-dimensional trait spaces.

Insect functional traits, or attributes by which species are less directly influenced by urbanization than by the physical and vegetational structure of environments, are pivotal for urban ecosystems. These traits also shape important ecological processes (Zaninotto et al., 2021). Particularly in urban settings, the ecological and functional traits of water beetles influence assemblage structure by constraining the ecological parameters characterizing dispersal and orienting isotopic niches (Lucinda et al., 2020). Functional traits also mediate interspecific interactions among insects (Oliveira et al., 2020), so that the functional composition of urban assemblages likely provides insights into the constraints and processes governing their structure.

3.3. Spatial Scale and Temporal Dynamics

Insect diversity across urban–rural gradients varies with study scale and temporal dynamics. Two observational regimes include extreme monocultures of urban–rural sites and widely separated localities within narrow habitat variations. Urban areas, unlike the countryside, show pronounced clustering of assemblages. Beta diversity indicates dissimilarity, alpha represents site richness, and gamma is the total richness over the regional sites. Meta-analyses highlight significant urbanization effects, particularly a tenfold increase in avian diversity. Urbanized regions support insect fauna through parks, gardens, and human-made structures. Periodic observations of the insect assemblage document the mosaic structural phase across urban gradients. The cityscape increasingly features dense shelters, constraining urban insects into a diminishing continuum. This creates wide belt-streets that separate rural areas from one another. Urban development begins unconditioned, progressing to a large city format that encases a territory significantly larger than before, while maintaining reserved spaces for cultivated specimens. As urban areas expand, they capture space but lose the coiled phase, limiting interactions with farming constituents, though some areas retain their integrity. Reports from distinct physico-biotic portfolios span beta movements across gradients. Comprehensive examinations necessitate stand-control assessments through classical Kolmogorov, while simple ordination showcases a three-space coiling-cluster stage. Separate yet connected green-belts create insular linkages among districts, providing substantial observation opportunities. (Corcos et al., 2019)(Peng et al., 2020)

4. Drivers and Mechanisms Shaping Urban Insect Communities

Urban environments present distinct driving forces and mechanisms that influence insect diversity. Key determinants include habitat fragmentation, resource availability, microclimate, anthropogenic disturbance, and landscape connectivity. Such factors shape the distribution of rare species and upper trophic levels, affecting ecosystem structure and function. A general decrease of 35% in insect abundance over 40 years threatens food webs and biogeochemical cycles. Pollinators such as bees and wasps are crucial for crop productivity, yet urbanization disrupts their life history, floral visitation, and abundance. Identifying determinants and their interactions helps clarify urban insect use and the broader urbanization process.

Insects benefit less from urban mitigation measures than larger animals, risking ecosystem collapse. Disturbance components—such as light, noise, pollution, and habitat change—influence insect community structure. The environmental filtering hypothesis posits that urban development first selects species sensitive to disturbance, eventually accommodating species that exploit ruderal or disturbed habitats. As urbanization proceeds, predatory insects show lower species richness and diversity, closely tied to resource availability across both rural and urban sites. (Corcos et al., 2019)

4.1. Habitat Fragmentation and Resource Availability

Among various factors influencing insect assemblages, information regarding habitat fragmentation and resource availability has emerged as a crucial aspect. Early studies highlighted that fragmentation of green areas in urbanized landscapes can limit solely the vegetation area that insects with plant-associated ecological requirements to the extent that later assemblage patterns get seriously affected (Corcos et al., 2019). More

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specifically, large patch size and connectivity, or the presence of adjacent habitat patches of similar quality, can promote insect species diversity. In addition, within these green patches, floral resources, nesting substrates, irrigation practices, light intensity, moisture content, pollutant concentration, and types of anthropogenic disturbance are mainly believed to have a considerable impact on insect assemblages.

The urban–rural pressure gradient should therefore have a significant impact on floral resource availability for insects, in a manner consistent with above observations on fragmentation. As part of the wider urban experiment, the influence of urbanization per se on diversity drivers may also become noticeable. For instance, the study investigated the impact of landscape composition (proportions of urban, agriculture, and forest area) and configuration (urban patch size and connectivity) in relatively large metropolitan areas, alongside semi-urban and rural localities; whereas suburban settings remain less prevalent in recent settlements and housing developments, the pre-urban structure may still be retained in even smaller, older cities. Likewise, the wider area should also reflect the extent of resource availability, and mean visible activity of apron communities should fluctuate similarly along the pressure gradient arising from urbanization: resources that tend to be more abundant at one end of this gradient (rural) should decrease in the middles, at the suburban sites, before re-appearing in the more-exposed urban core, generally compatible with above observations that insect frequencies peak in highly built-up locations. The floral composition in these landscape additionally shifts between the four gradient focus, as well as their contamination by artificial illumination during the night, which is widely acknowledged to curtail insect activity.

4.2. Microclimate, Heat Island Effects, and Water Availability

Urbanization alters microclimatic conditions, intensifying heat regimes and modifying moisture availability. The urban–rural insect survey demonstrates pronounced temperature and humidity differentiation among urbanity classes (Quynh Nguyen et al., 2020). The lowest minimum- and maximum-temperature ranges occur at rural sites; maximum-temperature variance expands with greater urban concentration, where urban gardens shelter cool microclimates. Urban habitats experience elevated temperature highs and fragile humidity minima, aggravating desiccation stress on active insects relative to semi-rural conditions (P. McGlynn et al., 2019). Supplementing thermal and moisture gradient investigation, the analysis gauges reliance of insect activity and community composition on habitat microclimate.

Under extended climatic regimes, increased urbanization correlates with heightened moisture-availability demand. Habitat and event-linked occurrences reveal strongly

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positive relationships with moisture metrics and substantially negative linkage to backup meteorology (Corcos et al., 2019). Moisture inputs centrally dictate activity of many taxa, framing broad climatic adaptability across urban classes. Communities in agricultural and peri-urban zones benefit from common moisture-associated vegetation types (e.g., Phragmites, Cyperus, sedges), alongside extensive aquatic systems shaded by isolated trees. Soil humectants enhancing floral growth, e.g., mulching, also foster assembly around periodic water sources; inter-event hydroperiod appears critical at these sites.

4.3. Anthropogenic Disturbance and Pollution

Anthropogenic disturbance and pollution encompass a wide range of environmental changes that contribute to alterations in structure, species composition, and functional attributes of urban insect assemblages. Nighttime lighting alters natural photoperiods and interferes with the circadian behaviours of many species (Corcos et al., 2019). Light pollution attracts light-seeking insects that are at risk of being trapped and intoxicated by nearby artificial sources (Zaninotto et al., 2021). Noise pollution affects communication and the perception of predator and prey signals. Chemical pollution—including pesticides, heavy metals, road toxins, and microbiological contaminants—alters the composition and abundance of urban insect assemblages, even in relatively small quantities; this exposure frequently occurs in urban areas owing to anthropogenic activities. Such pollution has direct effects on assemblage composition and alters the availability of other resources. Disturbance of soil and vegetation associated with construction and gardening activities reduces the number of available niches. Moreover, certain mite and fungal communities associated with wild flower species that are abundant in urban areas are increasingly found on these hosted plant species.

4.4. Landscape Connectivity and Green Infrastructure

Urban areas often have lower habitat quality than their surroundings, which decreases biodiversity (Su et al., 2015). Patch size, green cover, and connectivity are key predictors of urban insect abundance, species richness, and the proportion of species adapted to urban areas (Corcos et al., 2019). Connectivity can be improved through corridors, hedgerows, parks, and restoration of native vegetation, which enhance the likelihood of gene flow among populations and greater species richness. Fragmentation-induced isolation of urban patches can be alleviated by creating green corridors. Conservation measures that facilitate movement and connect urban patches (e.g., flower-rich habitat networks) could promote urban insect diversity and community assembly that mimic non-urbanized systems.

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5. Taxa of Particular Conservation and Management Interest

Urbanization affects insects through habitat loss, fragmentation, altered resources, and climate modification. While total diversity patterns have been studied, specific groups warrant closer examination. Pollinators, predators, decomposers, and characteristic taxa offer insights into ecological functions and ecosystem health yet remain understudied.

Overall insect richness increases along urbanization gradients, contrasting with patterns of particular taxa identified elsewhere. In Galapagos Islands, Coleoptera and lepidoptera exhibit strong declines (Corcos et al., 2019). This survey documents urbanization effects on pollinators, predators, decomposers, and selected indicator groups.

5.1. Pollinators in Urban Landscapes

Urban environments assume an increasingly prominent role in habitat supply as human density and infrastructural expansion escalate. Species-poor landscapes may be inherently less capable of providing set of habitat requirements. In urban areas, pollinators constitute a substantial portion of the insect fauna (Zaninotto et al., 2021) and serve key roles in various ecosystem functions that warrant investigation of the extent to which these taxa are supported in cities. Pollinators exhibit diverse foraging and nesting microhabitat requirements, making them particularly informative for assessing the provision of urban habitat. Permanent sampling sites in urban and neighbouring rural areas bear contrasting floral and vegetation compositions; pollinator assemblages differ due to taxon-specific resource requirements throughout a long, temporally consistent survey period. By indicating the extent to which ecosystem functions requiring complex assemblages of diverse pollinator taxa can be sustained in cities, the broader pattern of urbanisation impacts on ecological structure may be further elucidated.

5.2. Predators and Decomposers in City Environments

Predator and decomposer groups—ancestral to terrestrial life and key to resource cycling—regulate species abundance and simultaneously respond to habitat disruption. Many persist in urban landscapes where social and ecological interactions diminish; therefore, enhanced conservation benefits urban maintenance.

Soil systems contain diverse detritivores that metabolize flower fragments and disseminate pollen. Ants and carabids are considered ecological indicators for assessing urbanization effects on biodiversity and ecosystems. Urban areas serve as climatic refugia for predatory species dampened by long-term, seasonal gradients. Adaptable predatory orders occupy cities across latitudes, whereas landscape analysis indicates increased centrality and arrangement among polygamous or short-range species. Access to diverse food and nesting arrangements across interconnected patches attracts critical taxa that decline amid rapid urbanization elsewhere. Predators also enable few flower visitors to inhabit cities free of extensive protective measures. (Peng et al., 2020)

5.3. Urban Lepidoptera and Coleoptera as Bioindicators

Urbanization radically transforms terrestrial habitats, often precipitating marked declines in biota, particularly insects (Corcos et al., 2019). Interactions across trophic levels in the urban environment may modify community composition and structure while sustaining ecosystem functions such as productivity and decomposition (Atiqah Abd Rahman et al., 2017). This section evaluates the sensitivity of Lepidoptera and Coleoptera to anthropogenic stressors and their suitability for widespread implementation in urban monitoring schemes.

6. Methodological Advances and Gaps in Urban Entomology

Urban entomology has become a vibrant field of study over the past ten years, driven by new technologies, protocols, and an understanding of the importance of insects in urban environments. Urbanization poses the greatest threat to biodiversity, yet cities cover only 2% of the earth's surface and host less than 0.5% of the total number of species. Insects represent the largest group of organisms on the planet and, along with other arthropods, play a key role in ecosystems. Further, preliminary studies suggest insects in cities may benefit from human activity, further justifying attention to urban insect assemblages. Nonetheless, uncertainties remain, including how assemblages in cities compare to those in adjacent, less disturbed habitats and when studies show distinct composition indicates environmental filtering versus rectified biodiversity loss.

Toward urban assemblage comparisons, the literature was thoroughly reviewed for studies comparing insect assemblages in urban and rural environments. A strong bias toward large-bodied and conspicuous taxa was found, limiting the interpretability of results. Pollinators have been the most studied group and occupy dual roles: they cue urbanization impacts on wild plant–pollinator systems, which are integral to urban greening, and provide needed insights into urban ecology as a whole. Lepidoptera and Coleoptera have emerged as candidate urban–rural bioindicators, but their studies have not tracked the full urbanization gradient. Less attention has focused on insects that enrich the urban environment (decomposers, predators, scavengers) despite their role in sustaining and regulating urban ecosystems. Insects also occur in haematophagous and medically important groups that warrant further consideration. (Corcos et al., 2019)

7. Implications for Policy, Planning, and Biodiversity Management

Insect diversity is widely recognized as beneficial for urban habitats, yet practical guidance on integrating insect-friendly strategies into land-use planning remains underdeveloped. Most cities still lack comprehensive biodiversity programs, and many existing regulations favour native flora at the expense of urban fauna (Corcos et al., 2019). Despite the persistence of insects in urban sites, conservational features in city planning, especially for species such as pollinators and decomposers, are often overlooked (Peng et al., 2020).

8. Conclusion

Insect diversity responds to urbanization gradients at both taxonomic and functional levels, confirming the hypothesized relationship between urbanization intensity and biogeographical patterns, while the increase of urbanization also stimulates specific functional strategies. Urban–rural contrasts show non-uniform accord across metrics, echoing the variability characterizing global assessments of biodiversity loss and underscoring the need for evidence-based urban planning to sustain ecosystem service provision and resilience (Corcos et al., 2019). Insect assemblages within urban and rural gradients remain distinct, but temporal turnover masks landscape-scale community conservation priorities. Habitat structure and resource provision shape urban environments, modifying community assembly without altering regional species pools, in line with isolation and environmental filtering frameworks. Enhanced functional diversity within the urban domain relates to habitat amelioration for particular traits associated with human-modified landscapes, demanding a deeper understanding of specific strategies underpinning urban insect proliferation or extermination.

Future studies should expand the gradient framework to other environmental stressors, including pollution, soil degradation, climate change, and species invasions, to discern the nuanced interactions between urbanization and emerging multi-faceted pressures (Theodorou et al., 2020). Detailed urbanization typologies and fine-scale metrics further refinement and precision, yet an urban–rural typology remains pertinent. Other taxonomic groups, organisms of various functional roles, and different ecological assemblages or natural networks warrant consideration in parallel investigations. Such undertakings would guide the emergence of tailored planning and management protocols addressing the complex social-ecological entanglements characterizing city–wildland interfaces and the emergence of distinct ecological regimes along urbanization gradients (Zaninotto et al., 2021).

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