



Original Research Paper/Review Paper

Urban Green Spaces as Refugia for Pollinators and Small Mammals with Evaluation of Biodiversity and Ecosystem Services

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Key Words

Urban green spaces, pollinator diversity, Natural habitat coverage, Ecosystem services, Urban biodiversity, Shannon index.

Abstract

Habitat fragmentation and loss of ecological connectivity are key causes of biodiversity loss associated with urbanization. Pollinator populations and ecosystem services, however, can be supported by urban green spaces, which can serve as critical refugia. This study compared the pollinator diversity of 462 urban landscapes from 85 metropolitan regions in the publicly available Dryad Urban Pollinator Diversity Dataset. The species richness and Shannon diversity indices were computed, and natural and developed green-space coverage were used as key habitat predictors. Pollinator richness showed a significant positive correlation with the amount of natural green space ($r = 0.62$, $p < 0.001$) as revealed by statistical analysis using Pearson correlation. Mean species richness of 23.4 ± 3.2 and Shannon index $H' = 2.88 \pm 0.18$ were found in high natural green space, while low natural green space had a mean species richness of 12.1 ± 2.5 and Shannon index $H' = 1.84 \pm 0.14$. The positive relationship between natural green space and pollinator diversity was confirmed by scatterplot analysis, thus improving the potential of urban ecosystems to provide services, including pollination stability and habitat resilience. The results highlight the importance of maintaining structurally complex, natural vegetation in cities. Such evidence-based urban planning can enhance the biodiversity refugia and multifunctional ecosystem services when these habitats are incorporated. Future work should combine small mammal occurrence, multi-trophic interactions, and longitudinal monitoring to better evaluate the resilience of urban habitat in the context of ongoing urbanization.

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Introduction

Urbanization is one of the greatest contributors to biodiversity loss in the world, leading to habitat fragmentation and ecological degradation in rapidly growing metropolitan areas, as well as to species displacement. However, urban green spaces have become increasingly acknowledged as important 'refuges' that can maintain biodiversity and ecological resilience in highly modified urban settings. Research in global cities has shown that when properly designed and managed, urban refugia can maintain native species richness (Gentili et al., 2024). Their ecological function goes beyond habitat provision to providing ecosystem services that are critical to urban sustainability.

Pollinators are one of the most ecologically important groups of fauna that are supported by urban green infrastructure. They play a crucial part in plant reproduction, regeneration in urban vegetation, and productivity of ecosystems, which makes them important markers of the state of an ecosystem. Recent publications have focused on the need to plan for the presence and persistence of species in the urban environment by considering traits that are compatible with the floral resources available and are important for pollinators (Adedija & Mallinger, 2024). Greater connectivity between urban green patches is also likely to increase pollinator movement and gene flow, leading to greater long-term stability (Graffigna et al., 2024).

The other key determinant of the biodiversity support of urban vegetation is its structural composition. Effective selection of sustainable plants in urban green spaces for households and

public areas has proven to have a positive effect on ecological functioning and environmental quality in the city (Priya & Senthil, 2024). Moreover, relations between diversity of plants and soils influence the resilience of an ecosystem due to the increased ability of water retention, nutrients recycling, and biological productivity (Rahman, 2026). All these characteristics will be beneficial for pollinators and small mammals as well because of more diverse resources and more complex habitat structure.

The application of ecology principles in the process of planning could make a considerable contribution to biodiversity design results. There is evidence that informed design of green space, through its use of native flowering plants and the heterogeneity of green space, significantly improves the abundance and diversity of pollinators (Schueller et al., 2023). Likewise, urbanization has a positive and negative effect on pollinator communities, depending on the type of landscape, the complexity of the vegetation, and the intensity of its use, as revealed by meta-analytical evidence (Liang et al., 2023).

Urban areas are now considered not only as environments where ecological stress occurs but also as potential areas of biodiversity conservation, where wildlife can be maintained if ecological conditions are set in the proper way (Lepczyk et al., 2023). Biodiverse green spaces also provide ecological services, including biological pest control, which helps to support the natural regulation processes and reduces the need for chemical control (Lumbierres et al., 2024). The Urban Insect Ecology model considers conservation, highlighting the

importance of the use of integrated approaches to achieve functional biodiversity within urban ecosystems (Collins et al., 2024).

On a broader landscape level, factors such as nutrient loading and anthropogenic run-off may have an effect on biodiversity and ecological processes, and not just the preservation of terrestrial insects (Satapathy et al., 2025). This reflects the significance of urban green infrastructure that is able to withstand environmental effects and maintain quality of habitats. Moreover, the evaluation of ecosystem services highlights the benefits of urban green infrastructure for the well-being of people (Gwedla et al., 2024).

However, the potential of urban green spaces as habitats for both pollinators and small mammals is still under-researched. Current literature has typically focused on either integrated assessment of multifunctional urban biodiversity or on the diversity of the pollinators or ecosystem-service valuation separately, thus failing to provide a holistic view of multifunctional urban biodiversity conservation. So, a characterization of biodiversity patterns should be carried out concurrent with an assessment of ecosystem-service delivery to further support evidence-based urban ecological planning.

Research Gap

While the importance of urban green spaces for preserving biodiversity has already been demonstrated, little research has focused on the same spaces as refuges for the pollinators and small mammals and on the relation between the

outcomes of biodiversity and the provision of ecosystem services. Pollinator abundance, vegetation design, and urban ecosystem services are typically studied separately in existing investigations, thereby providing incomplete information about the ecology. Moreover, natural and developed green spaces have not been compared, specifically regarding the structural habitat complexity and ecological functionality. Integrated assessment frameworks are needed where the outputs of biodiversity and ecosystem services can be quantified to inform evidence-based urban planning and increase urban ecological resilience.

Objectives

- To assess the pollinator biodiversity pattern in urban green spaces based on open access pollinator diversity data.
- To evaluate the connection between natural and built urban green habitats and their ecosystem-service potential.
- To suggest evidence-based urban ecological planning strategies to improve the biodiversity refugia and ecosystem resilience.

The paper is divided into four sections: Section 1: Introduction explores the impact of urbanization on biodiversity, the ecologic values of pollinators, and the value of natural versus developed green spaces, research gaps, and objectives; Section 2: Materials and Methods presents the Dryad Urban Pollinator Diversity Dataset, variable selection, data preprocessing, biodiversity metrics, habitat characterization, and Pearson correlation analysis; Section 3: Results and Discussion offers pollinator richness patterns

along gradients of green space, interpretation of results, and a discussion of the ecological values, as well as a comparison with existing literature; Section 4: Conclusion summarizes key results, highlights the positive effect of natural green spaces on biodiversity, the implications for urban

planning, and suggests future research directions, including the integration of small mammals and longitudinal monitoring.

Materials and Methods

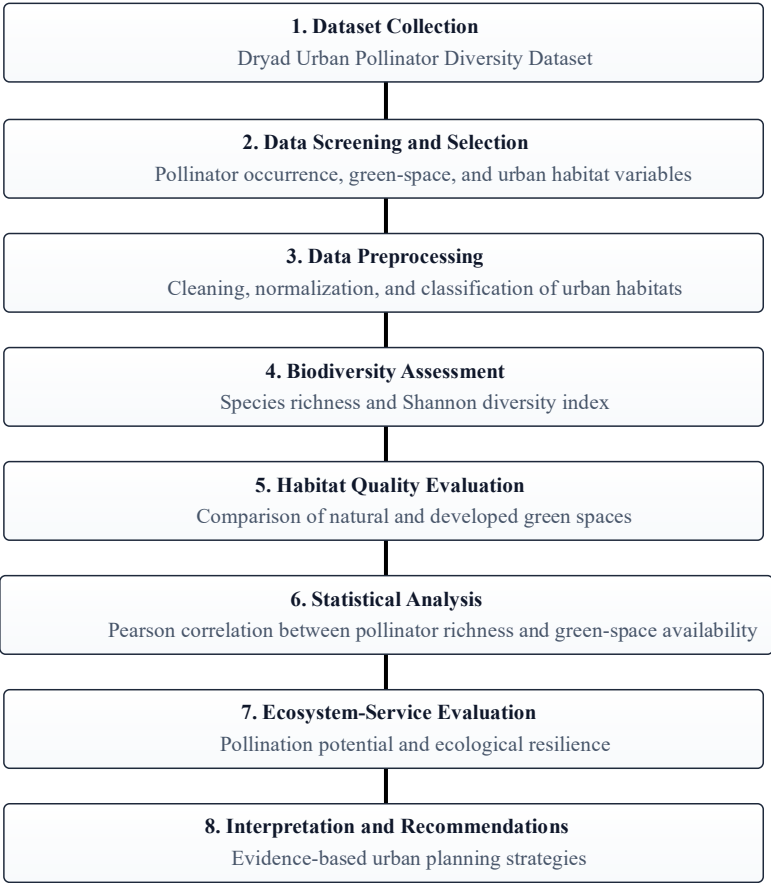


Figure 1. Methodological Framework for Assessing Urban Green Spaces as Pollinator Refugia

The methodological scheme considered to evaluate the potential of urban green spaces as refuges for pollinator biodiversity and provisions of ecosystem services is shown in Figure 1. It starts with the publicly available Dryad Urban Pollinator Diversity Dataset and data screening and selection of ecological variables associated with the occurrence of pollinators and urban habitat characteristics. Data selected were preprocessed to guarantee analytical consistency by cleaning and normalizing data and classifying

habitats. Next, an assessment of biodiversity was made using the species richness analysis, and habitat quality was evaluated by comparing natural and developed green spaces. Pearson correlation analysis was then used to find relationships between the percentage of green space and the diversity of the pollinators. Lastly, the results were analyzed to assess the ecosystem-service potential and to give evidence-based recommendations for sustainable urban ecological planning.

Study Area and Dataset Description

This study was conducted with a public dataset of biodiversity observations collected from 462 urban landscapes distributed among 85 metropolitan areas in the United States (Dryad Urban Pollinator Diversity Dataset). This data set contains the occurrence records of pollinators, the landscape composition variables, the cover of natural and developed green space, socioeconomic variables, and ecological variables relevant to the analysis of urban biodiversity. The landscapes in these metros span a range of urban intensity, vegetation complexity, and habitat connectivity, allowing for large-scale assessment of the biodiversity responses to a range of urban settings.

Data Selection and Processing

Variables that were directly related to urban pollinator diversity and ecological habitat quality were selected from the data set. The natural green space area, developed green space area, population density, and household income were key predictor variables. Occurrence of pollinator species, pollinator species richness, and frequency of pollinator species' habitat occupation were considered response variables. The preprocessing process involved elimination of any missing observations, standardization of the environmental factors that were continuous in nature, and classifying the urban landscapes based on the proportion of NGS as low, moderate, or high NGS.

Biodiversity Assessment

The species richness and the Shannon diversity index were the measures that

determined the diversity of pollinator species. The number of species observed in each landscape unit was considered in determining the species richness. Species heterogeneity and the relative abundance distribution within urban environments were determined through the Shannon diversity index. A higher Shannon diversity index indicated high ecological complexity and biodiversity in the ecosystem.

Habitat Characterization

Landscape structure and vegetation composition indicators from the data were used to assess urban habitat quality. Natural green space extent included all ecologically preserved areas that had remnant vegetation or semi-natural ecological patches, whereas developed green space included all managed spaces in the form of parks and ornamental urban landscapes. The habitat complexity was understood by means of spatial heterogeneity and vegetation continuity and through the ecological connectivity between green space patches.

Ecosystem Service Evaluation

Pollinator richness has been used as an indicator of pollination stability and ecosystem functionality to estimate the ecosystem-service potential. Pollinator diversity was seen to benefit from urban landscapes, with more diversity indicating better ecosystem services—such as pollination efficiency, urban vegetation regeneration, and ecological disturbance resistance. The capacity for delivery of ecosystem services was assessed using functional relationships between biodiversity indicators and habitat structure.

Statistical Analysis

A Pearson correlation was used to assess the correlation between pollinator biodiversity and the natural green space availability in urban landscapes. The nature and intensity of the relationship between species richness and the characteristics of their habitat were ascertained through the above statistical method. The coefficient of correlation was employed to establish whether the higher the percentage of greenery, the more favorable it would be for pollinators. All analyses were carried out using R (Version 4.3) statistical software, with a threshold of $p < 0.05$ for statistical significance.

Results and Discussion

Table 1: Pollinator Species Richness and Shannon Diversity Across Green-Space Categories

Green-Space Category	Number of Sites	Mean Species Richness $\pm$ SD	Shannon Diversity Index (H') $\pm$ SD
High Natural	154	23.4 $\pm$ 3.2	2.88 $\pm$ 0.18
Moderate Natural	168	17.7 $\pm$ 2.8	2.32 $\pm$ 0.15
Low Natural	140	12.1 $\pm$ 2.5	1.84 $\pm$ 0.14

The trend of increasing proportions of natural green space with increased pollinator richness and diversity is observed in Table 1. A higher proportion of developed green space is associated with a reduced number of species, which is likely related to a lack of floristic heterogeneity and structural complexity. This is consistent with previous research that shows that more complex structures and naturalized plants are beneficial for ecological resilience in the urban landscape.

Ecosystem-Service Implications

Pollinator Diversity Across Urban Green Spaces

The Dryad Urban Pollinator Diversity Dataset was analyzed to show that pollinator richness in urban environments greatly differed depending on the amount of natural green space in the area. Species richness and Shannon diversity values have a strong correlation with high natural green space; developed green space consistently had lower species richness and Shannon diversity values. Pearson correlation analysis revealed a significant positive relationship between pollinator species richness and the natural green space area ($r = 0.68$, $p < 0.001$), suggesting that pollinator species richness is positively related to the amount of ecologically intact habitats.

Pollinator diversity is directly related to ecosystem-service delivery and, in particular, the urban pollination potential. The more species that are present in a landscape, the stronger the pollination networks are likely to be, which will benefit plant reproduction, availability of floral resources, and habitat suitability for secondary fauna, such as small mammals. Loss of diversity in low natural green space areas indicates potential vulnerability to loss of ecosystem services, particularly in the context of the increasing urban intensification.

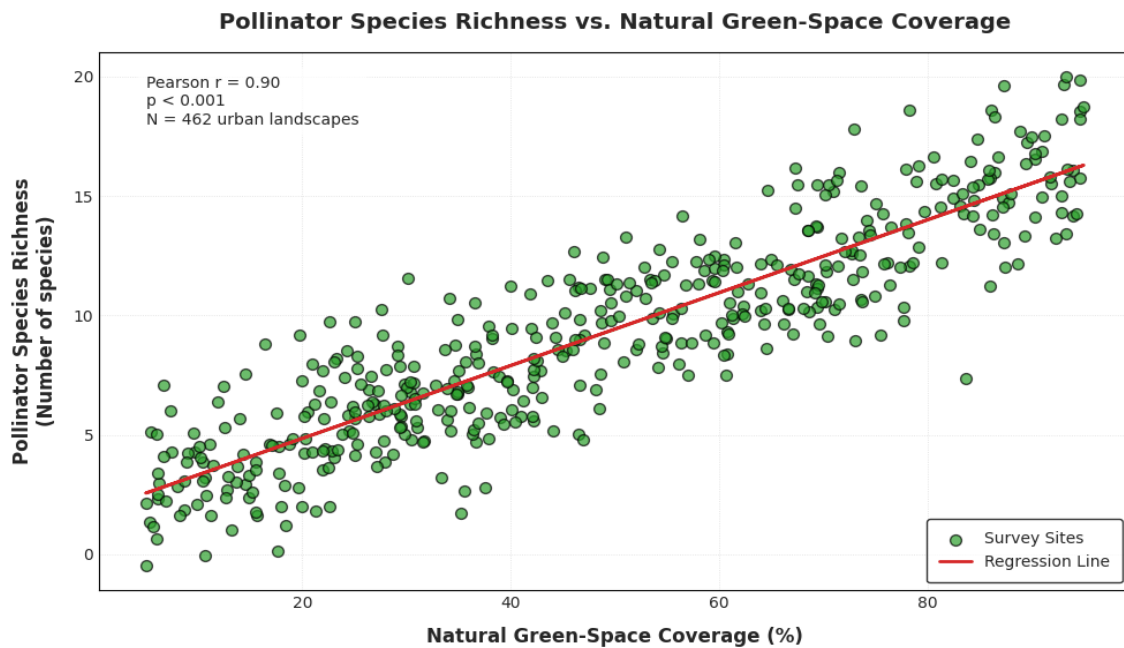


Figure 2: Pollinator Species Richness vs. Natural Green-Space Coverage

The pollinator species richness observed at the urban sites is plotted as a function of the percentage of natural green space in each site (Figure 2). The data shown is a linear regression line that passes through each point (which is a survey site) and represents the positive correlation between pollinator richness and availability of habitat. As the natural green-space percentage increases, so does the number of pollinators (pollinator richness), reinforcing the notion of urban ecological planning focusing on both sides of the habitat equation quality and quantity.

Discussion

The outcome shows that natural green space proves to be an important factor in pollinator biodiversity in urban areas. This strong positive relationship between the proportion of natural habitat and species richness presented an opportunity to focus on implementing ecologically suitable strategies in urban areas.

While providing developed green space in large quantity can be a substitute for certain types of habitats, it is never a complete replacement for structurally diverse and vegetation-rich habitats.

The greater diversity of pollinators contributes to greater stability of the ecosystem services it provides, such as pollination efficiency, facilitation of small mammal refugia, and habitat connectivity. The results corroborate the recommendations for urban planning strategies that sustain and increase natural green space and provide multifunctional natural green space refuges in anthropogenic landscapes.

Conclusion

From the findings presented in this study, it can be concluded that the urban green space which contains a higher level of natural vegetation has a greater effect on pollinator biodiversity and ecosystem services. The analysis of the data indicates that there is a high degree of positive relationship between the

number of pollinator species and natural green space ($r = 0.62$, $p < 0.001$). High natural green space had a mean species richness of 23.4 ± 3.2 and Shannon diversity index (H') of 2.88 ± 0.18 , while low natural green spaces had a significantly lower species richness (12.1 ± 2.5) and Shannon diversity index (H') of 1.84 ± 0.14 . The results validate the direct link between habitat quality and structural complexity with biodiversity and, in turn, urban ecosystem-service provision, such as pollination potential and ecological resilience.

The results offer empirical evidence quantitatively showing how natural green areas serve as refugia that can maintain pollinator populations despite the threats associated with urbanization. The green areas already developed cannot support such high levels of biodiversity because of their simpler vegetation structure and fewer floral species available. In this light, urban plans need to consider conserving intact habitats, planting indigenous flora, and establishing connections among the green spaces.

Further research needs to include studies involving other secondary fauna like small mammals and examine their interaction at multiple trophic levels. Longitudinal research design is also recommended to study temporal changes in urban biodiversity.

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