Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Patch area and spatial position shape the distribution of acoustically active Orthoptera in urban green spaces

Hideyuki Niwa
niwa.hideyuki@kuas.ac.jp

Kyoto University of Advanced Science
Daisuke Iwai
Ecosystem Conservation Society-Japan

Research Article

Keywords: urban biodiversity, biological indicator, green infrastructure, soundscape

Posted Date: June 9th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9780944/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Urban green spaces provide important habitats for insects, but their value for biodiversity conservation depends on both local habitat characteristics and spatial configuration. Acoustically active Orthoptera, including crickets and katydids, are widely distributed in urban environments and can be efficiently surveyed through their species-specific calling songs. However, how patch area and spatial position jointly influence their distribution in urban green spaces remains poorly understood. We surveyed acoustically active Orthoptera across 126 urban green space sites in Kyoto, Japan, and examined how species richness was related to green space type, patch area, and network distance from the Katsura River riverbed, a major riparian habitat. Species were identified primarily by acoustic characteristics during nocturnal surveys, and patch area was quantified using GIS. A total of 18 species were recorded. Species richness varied among green space types and was higher in larger patches such as riverine habitats, parks, and corporate green spaces. Generalized linear models showed that patch area had a positive association with species richness. The negative relationship between species richness and distance from the riverbed became weaker after accounting for patch area, suggesting that patch size partly explained the apparent spatial gradient in species richness. These results indicate that patch area is a key factor shaping the distribution of acoustically active Orthoptera in urban green spaces. While spatial position relative to large riverine habitats may also influence species occurrence, the findings highlight the importance of conserving and managing sufficiently large vegetated patches within urban landscapes. Acoustic surveys of Orthoptera may provide a practical approach for monitoring insect diversity in urban green spaces.

1. Introduction

Urban expansion frequently leads to fragmentation and isolation of green spaces within cities. Such landscape fragmentation reduces habitat availability and disrupts ecological processes that support biodiversity in urban ecosystems (Haila 2002; Wei et al. 2018). As a consequence, maintaining connectivity among urban green spaces has become an important objective in urban biodiversity conservation and sustainable city planning (Parker et al. 2008; Dai et al. 2021). Networks of interconnected green spaces are often referred to as urban ecological networks and are considered a key component of urban green infrastructure (Jongman & Pungetti 2004; Mell et al. 2017).

Urban ecological networks are commonly evaluated using spatial analyses of green space configuration derived from land-use maps or remote sensing data. Various spatial indices have been developed to quantify structural connectivity among green spaces, including distance-based metrics and graph-based network analyses (Yeo et al. 2024). However, structural connectivity derived from spatial data does not necessarily reflect how organisms actually use urban landscapes. Therefore, evaluating connectivity from the perspective of species distribution is essential for understanding the ecological functioning of urban green spaces.

Biological indicators provide a practical approach for assessing habitat conditions and ecosystem changes. Biological indicators are species or assemblages that reflect environmental conditions and ecological processes in an ecosystem (Chowdhury et al. 2023). Among potential indicator taxa, insects are particularly useful because they are abundant, respond rapidly to environmental changes, and can be surveyed efficiently (Kremen et al. 1993; Schowalter et al. 2003). Due to their sensitivity to habitat structure and land-use intensity, insect communities have been widely used to evaluate ecosystem health and environmental change (Mahanta et al. 2023).

Orthoptera (grasshoppers, crickets, and katydids) are known to respond strongly to vegetation structure and habitat management, and their community composition has been used as an indicator of habitat quality in various ecosystems (Ramola et al. 2024). In particular, many orthopteran species depend on herbaceous vegetation and are sensitive to mowing, land-use intensity, and vegetation structure. These characteristics make them potentially useful organisms for evaluating the ecological conditions of urban green spaces.

Within orthoptera, acoustically active species—here referred to as sounding orthoptera—may offer additional advantages as biological indicators. Many orthopteran species produce species-specific calling songs that allow reliable identification without capture. Acoustic surveys can therefore enable efficient monitoring of orthopteran communities across relatively large areas. In addition, sounding orthoptera are familiar insects in Japan and hold cultural significance, making them particularly suitable for environmental education and public engagement (Kano 2011).

Despite these advantages, the spatial distribution of sounding orthoptera in urban green spaces and their potential usefulness as indicators of spatial connectivity remain poorly understood. Most previous studies on urban ecological networks have relied primarily on spatial analyses of land cover rather than on biological data. As a result, the relationship between urban green space configuration and the distribution of insect communities remains insufficiently explored.

To address this knowledge gap, this study investigates the spatial distribution of sounding orthoptera in urban green spaces within a typical urban landscape in Kyoto, Japan. Specifically, this study addresses the following research questions:

1. How does species richness of sounding orthoptera vary among different types of urban green spaces?

2. How does spatial proximity to a potential source habitat influence species richness?

3. Can spatial patterns in sounding orthoptera distribution provide useful information for understanding connectivity among urban green spaces?

By examining these questions, this study aims to clarify the spatial patterns of sounding orthoptera in urban landscapes and explore their potential as biological indicators for evaluating habitat conditions and spatial connectivity in urban green spaces.

2. Methods

2.1. Study Area

The study area covering approximately 110 ha was defined as the urban region comprising Umezu, Ukyo Ward, and Kyoto City in Kyoto Prefecture, Japan (135°42'21"E 35°0'7"N; Fig. 1). Kyoto has a humid subtropical climate with a mean annual temperature of approximately 16°C and annual precipitation of about 1,500 mm. The study area is located in a densely populated urban district with a population density of approximately 11,668 people per square kilometer. The landscape includes a mosaic of residential areas, corporate premises, parks, schools, temples, agricultural land, and the Katsura River riverbed. The Katsura River riverbed contains extensive grassland habitats and is known to support high diversity of sounding orthoptera species, making it a potential source habitat for surrounding urban areas.

2.2. Survey of Sounding Orthoptera

The survey targeted sounding orthoptera species that are primarily active during autumn nights. Field surveys were conducted in September 2025 during the peak calling season. Three types of survey zones were defined based on land use and accessibility (Fig. 1):

a) corporate grounds
b) urban areas
c) river zones
Survey methods differed slightly among these zones due to access constraints.

In corporate grounds, surveys were conducted after obtaining permission from the companies. Green spaces within the premises were walked while listening for insect calls. Surveys were conducted on September 2 and 3, 2025. In urban areas, surveys were conducted by walking along roads within the study area (Fig. 1). When insect calls were heard, the location of the green space was recorded using a handheld GNSS device (Garmin GPSMAP 66i). Surveys were conducted on September 8, 18, and 24, 2025. River zones were divided into riverbed and riverbank habitats. Surveys were conducted by walking these areas on September 19, 2025.

All surveys were conducted within two hours after sunset when acoustic activity of orthoptera is high. The walking speed was kept relatively constant to standardize detection effort. Species were identified primarily based on acoustic characteristics using standard references. All surveys were conducted by the same observer with extensive experience in identifying orthopteran sounds in the field.

2.3. Classification of Green Spaces

To classify green spaces containing sounding orthoptera, an orthomosaic image (4 cm/pixel) was created from images captured by an unmanned aerial vehicle (DJI Mavic 3T) on September 26, 2025. The locations where sounding orthoptera were identified were imported into GIS, visually corrected, and point data was created. This point data was overlaid with orthomosaic imagery, and the green spaces where sounding orthoptera were present were classified into 11 categories (Fig. 2). Classification considered the importance of green space management entities regarding planning of quality improvements or creation of ecological networks.

2.4. Data Analysis

Species richness among green space types was compared based on the number of sounding orthoptera identified at each survey site. Species counts were calculated using presence/absence data at each site. Differences in species richness between green space types were visualized using box plots.

Indicator species analysis was conducted to evaluate the relationship between sounding orthoptera and green space types. Indicator species analysis can extract ecologically meaningful indicators (indicator species) for any type of classification (Dufrnc and Lcgendrc l997). The analysis used the IndVal.g method (group equalized indicator values), implemented via the multipatt function in the R package indicspecies. First, fidelity and specificity were calculated. Fidelity is defined as the occurrence rate of a species at survey sites within the same green space type, while specificity is defined as the proportion of occurrence sites within a green space type relative to the total number of occurrence sites (Dufrnc and Lcgendrc l997). The index value was calculated as the product of specificity and fidelity (IndVal = A × B) (Dufrnc and Lcgendrc l997). The statistical significance of indicator values was assessed using a permutation test with 999 permutations. However analysis was not limited to statistically significant indicator species; specificity, fidelity, and index values were calculated for all species.

Spatial connectivity between sites was evaluated using network distances constructed from geographic coordinates. Pairwise geographic distances (m) were calculated from the latitude and longitude of survey sites, and a k-nearest neighbor network (k = 6) was constructed to ensure connectivity between sites. Two sites on the Katsura River riverbed were treated as source sites. For each survey site, the minimum distance from the two source sites was used as the network distance to the source site. To quantify the relationship between spatial proximity and species richness, a negative binomial generalized linear model was fitted with species richness as a function of the base network distance from source sites. Deviation residuals from a model were calculated to represent variation in species richness not explained by distance alone. Residuals were compared between green space types using box plots. Statistical differences in residuals between green space types were verified using the Kruskal-Wallis test, with post-hoc tests performed using Dunn's multiple comparison method with Benjamin-Hochberg correction.

3. Results

3.1. Species composition and distribution

Eighteen species of sounding orthoptera were identified. The species observed at the most sites was *Ornebius kanetataki*, while the species identified in the most green space type was *Velarifictorus micado* (Table 1). Of the 18 species, two— *O. kanetataki* and *Truljalia hibinonis* —are arboreal, while the others are grassland species. The 128 green space sites where sounding orthoptera were identified were classified into 11 types (Fig. 3).

The number of sounding orthoptera identified at each survey site varied by green space type (Figs. 4 and 5). Riverbed had the highest number of identified species at 13. While riverbed, riverbank, parks, and corporation included sites with high species richness, other green space types showed low medians and limited variation. In addition to differences in median species richness between green space types, the variation in species richness between sites within the same green space type also differed across green space types. While differences in survey area at each sites likely influenced species richness, this study prioritized the managing entity of the green space and therefore did not adjust for area.

3.2. Indicator species analysis

Analysis of specificity and fidelity revealed the indicator characteristics of sounding orthoptera within each green space type (Fig. 6). No species showed statistically significant indicator values based on the replacement test ($p < 0.05$). However, many species exhibited relatively high specificity or high fidelity for specific green space types. Some species exhibited high fidelity within specific green space types despite relatively low specificity. High fidelity suggests that these species occur stably within that specific green space type. In contrast, species exhibiting high specificity and low fidelity also existed. High specificity suggests that these species are restricted to specific green space types.

3.3. Effects of network distance and patch area

Species richness tended to decrease with increasing network distance from the Katsura River riverbed (Fig. 7). In contrast, species richness increased with increasing patch area (Fig. 8). Generalized linear modeling indicated that patch area had a positive association with species richness (Table 2). The effect of network distance became weaker after accounting for patch area (Fig. 9), suggesting that some of the apparent distance effect was associated with variation in patch size among sites. The partial effect plots derived from the generalized linear model demonstrated a strong positive effect of patch area on predicted species richness (Fig. 9A), whereas the negative effect of network distance was comparatively weaker after controlling for patch area (Fig. 9B).

3.4. Residual variation among green space types

Deviance residuals from the generalized linear model varied among green space types (Fig. 10). A Kruskal–Wallis test indicated significant differences among green space types (Table 3). Positive residuals indicate sites with higher species richness than predicted by patch area and network distance alone, suggesting that additional unmeasured habitat factors may influence Orthopteran assemblages.

Table 1
Number of sites where sounding orthoptera identified by green space type. n indicates the number of survey sites for each green space type; other figures show the number of sites where sounding orthoptera identified.

Scientific name	Classification of green spaces											
	Riverbed	River bank	Park	Corporation	School	Temples and shrines	Farmland	Garden (Detached House)	Garden (Others)	Vacant lot	Parking lot	Total
n	8	5	5	2	2	2	11	72	14	2	3	
Ornebius kanetataki	3	1	5	2	1	2	2	55	5	□	□	76
Loxoblemmus campestris	5	2	4	2	1	2	3	7	7	□	□	33
Velarifictorus micado	5	2	4	2	1	1	4	10	1	□	2	32
Teleogryllus emma	6	3	3	2	1	□	7	2	1	1	□	26
Dianemobius nigrofasciatus	5	2	3	2	□	□	2	2	2	1	2	21
Loxoblemmus doenitzi	2	1	2	2	□	□	□	5	1	□	□	13
Truljalia hibinonis	2	□	1	2	1	2	2	□	2	□	□	12
Polionemobius mikado	3	2	2	2	□	□	□	□	1	□	□	10
Oecanthus euryelytra	3	3	1	1	□	□	□	□	□	1	□	9
Xenogryllus marmoratus	2	3	1	1	1	□	□	1	□	□	□	9
Meloimorpha japonica	2	3	1	□	□	□	□	□	□	□	□	4
Ruspolia lineosa	2	1	1	□	□	□	□	□	□	□	□	4
Conocephalus exemptus	2	1	□	□	□	□	□	□	□	□	□	3
Mitius minor	2	1	□	□	□	□	□	□	□	□	□	3
Modicogryllus siamensis	1	□	□	1	□	□	1	□	□	□	□	3
Mecopoda niponensis	1	1	□	□	□	□	□	□	□	□	□	2
Screlogryllus punctatus	2	□	□	□	□	□	□	□	□	□	□	2
Oecanthus longicauda	1	□	□	□	□	□	□	□	□	□	□	1

4. Discussion

4.1. Spatial patterns of sounding orthoptera in urban green spaces

This study revealed clear spatial patterns in the distribution of sounding orthoptera within an urban landscape. Species richness tended to decrease with increasing network distance from the Katsura River riverbed, suggesting that proximity to a potential source habitat influences the occurrence of sounding orthoptera in surrounding urban green spaces. Such spatial gradients are consistent with ecological theory predicting that species richness in fragmented landscapes often declines with increasing distance from major habitat patches. However, considerable variation in species richness was observed among sites within the same green space types. This pattern indicates that spatial proximity alone cannot explain the distribution of sounding orthoptera. Local habitat conditions, such as vegetation structure, habitat area, and management practices, likely play important roles in determining habitat suitability. Orthopteran assemblages are known to respond strongly to vegetation height, plant species composition, and disturbance intensity (Ramola et al. 2024), suggesting that these factors may influence species occurrence even within similar green space categories.

4.2. Species-specific distribution patterns

The species composition observed in this study reflects the ecological characteristics of sounding orthoptera. Among the recorded species, the tree-dwelling cricket *Ornebius kanetataki* was detected at the largest number of sites. This species is commonly associated with shrubs and trees and is known to occur widely in urban environments. Its frequent occurrence in residential gardens and other small green spaces suggests that arboreal species may tolerate relatively small habitat patches in urban areas. In contrast, many of the other species detected in this study are grassland-associated orthoptera. These species generally depend on herbaceous vegetation and are therefore more strongly influenced by the availability of grassland habitats. For example, *Velarifictorus micado*, which was observed across the largest number of green space types, is known to inhabit open grassland habitats and appears to be relatively tolerant of moderate disturbance. This ecological flexibility may explain its widespread distribution across different urban green spaces. Some species, such as *Teleogryllus emma*, were recorded primarily in specific green space types. This species often inhabits open herbaceous environments and may therefore depend on relatively well-developed grassland vegetation. The restricted occurrence of such species suggests that the presence of suitable herbaceous vegetation within urban green spaces may be important for maintaining orthopteran diversity. These species-specific patterns highlight the importance of vegetation structure in shaping orthopteran assemblages. Urban green spaces that include both herbaceous vegetation and woody plants may provide a wider range of microhabitats and therefore support higher species richness.

4.3. Patch area as a major driver of species richness

The inclusion of patch area substantially improved the ecological interpretation of the observed distribution patterns. Species richness increased with increasing patch area, consistent with the species–area relationship commonly observed in fragmented landscapes. Larger green spaces may support more Orthopteran species because they contain a greater variety of microhabitats, including herbaceous vegetation, shrubs, trees, and less disturbed interior areas.

Importantly, the relationship between species richness and distance from the Katsura River riverbed became weaker after accounting for patch area. This suggests that some of the apparent spatial gradient in species richness may have reflected differences in patch size rather than distance from the source habitat alone. Therefore, the results should not be interpreted as direct evidence of functional connectivity. Instead, they indicate that patch area and spatial position jointly shape the distribution of sounding Orthoptera in urban green spaces.

This finding directly addresses one of the main limitations of the earlier analysis. Because patch area is a fundamental determinant of species richness in landscape ecology, its inclusion provides a more rigorous basis for interpreting differences among green space types. Corporate green spaces, parks, and riverine habitats tended to have larger vegetated areas and supported higher species richness, whereas residential gardens and small vacant lots generally had smaller patch areas and lower species richness. However, because vegetation structure and management intensity were not directly quantified, these mechanisms should be interpreted cautiously.

4.4. Influence of green space types

Corporate green spaces and parks exhibited relatively high species richness compared with other green space types. These areas typically include relatively large and continuous vegetated patches and often contain heterogeneous habitat structures, such as combinations of grasslands, shrubs, and trees. Such structural heterogeneity is known to increase habitat availability for orthopteran species by providing a wider range of microhabitats, including calling sites, shelter, and oviposition substrates (Ramola et al. 2024). In particular, grassland-associated species are likely to benefit from the presence of well-developed herbaceous vegetation, while arboreal species can utilize shrubs and trees. Therefore, the coexistence of multiple vegetation layers in these green spaces may contribute to the observed higher species richness. In addition, the relatively large area of corporate green spaces and parks may also play an important role. Larger habitat patches generally support more species due to increased habitat diversity and reduced local extinction risk. Although habitat area was not explicitly quantified in this study, the consistently higher species richness observed in these green space types suggests that patch size may be an important factor influencing orthopteran assemblages in urban environments.

In contrast, residential gardens, vacant lots, and parking areas generally showed lower species richness. These green space types are typically characterized by small patch size, simplified vegetation structure, and relatively high levels of disturbance, such as frequent mowing or human activity. Such conditions may reduce habitat suitability for many orthopteran species, particularly those dependent on stable herbaceous vegetation. As a result, these environments are more likely to support a limited number of generalist species that can tolerate disturbance (White & Ker 2007).

Agricultural land also exhibited relatively low species richness in this study. This pattern may be associated with intensive management practices, including mowing, pesticide use, and fertilization, which can reduce vegetation complexity and negatively affect insect communities (Sanchez-Bayo and Wyckhuys 2019). However, some sites showed higher species richness than expected, suggesting that less intensively managed farmland may still provide suitable habitats for certain orthopteran species.

Temples and shrines, as well as school grounds, showed intermediate levels of species richness. These sites often contain woody vegetation but may have limited herbaceous layers due to management practices such as mowing or landscaping. This combination of habitat features may support a subset of orthopteran species but may not provide optimal conditions for maintaining high species diversity.

Overall, these patterns suggest that vegetation structure, habitat area, and management intensity are likely key factors influencing the distribution of sounding orthoptera across urban green spaces. However, because these variables were not explicitly quantified in this study, the interpretations presented here should be considered as hypotheses that require further investigation.

4.5. Implications for urban green space management

Although the present study focused primarily on spatial patterns in species richness, the results suggest that both spatial configuration and habitat characteristics influence orthopteran assemblages in urban landscapes. Maintaining diverse vegetation structures, including herbaceous vegetation and shrubs, may help support a wider range of orthopteran species within urban green spaces. At the landscape scale, the presence of large habitat areas such as river corridors may also contribute to maintaining insect diversity in surrounding urban environments. However, because this study did not directly measure dispersal processes or ecological network dynamics, management implications should be interpreted cautiously.

4.6. Limitations and future research

Several limitations of this study should be acknowledged. First, environmental variables such as vegetation structure, habitat area, and management intensity were not explicitly incorporated into the statistical analyses. Including these variables would likely improve understanding of the drivers of species richness patterns. Second, surveys were conducted during a limited period within the peak calling season. Although this timing maximizes detection probability, repeated surveys across seasons would provide a more comprehensive understanding of temporal dynamics. Third, spatial autocorrelation among sites was not explicitly modeled. Future studies incorporating environmental variables, repeated surveys, and multiple urban regions would help clarify the ecological processes shaping orthopteran distribution and further evaluate their usefulness as biological indicators of urban biodiversity.

Declarations

Competing Interests

No funding was received to assist with the preparation of this manuscript.

Acknowledgments

This research was inspired by the activities of the “Katsura River Basin Ecosystem Network Council: Connecting Through the Sounding Insects.”

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Disclosure of potential conflicts of interest

No, I declare that the authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

The authors have no relevant financial or non-financial interests to disclose.

Funding

This research received no external funding.

Author Contributions Statement

All authors contributed to the study conception and design. Data collection was performed by Hideyuki Niwa and Daisuke Iwai. Material preparation, and analysis were performed by Hideyuki Niwa. The first draft of the manuscript was written by Hideyuki Niwa and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

1. Chowdhury S, Dubey VK, Choudhury S et al (2023) Insects as bioindicator: A hidden gem for environmental monitoring. Front Environ Sci 11
2. Dai L, Liu Y, Luo X (2021) Integrating the MCR and DOI models to construct an ecological security network for the urban agglomeration around Poyang Lake, China. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.141868. 754:
3. Haila Y (2002) A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. Ecol Appl 12:321–334. https://doi.org/https:// doi.org/10.1890/1051-0761(2002)012[0321:ACGOFR]2.0.CO;2
4. Jongman RHG, Pungetti G (2004) Ecological Networks and Greenways: Concept, Design and Implementation. Cambridge University Press
5. Kano Y (2011) Nakumushi-bunkashi [Cultural History of Cricket]. HSK books
6. Kremen C, Colwell RK, Erwin TL et al (1993) Terrestrial arthropod assemblages: their use in conservation planning. Conserv Biol 7:796–808. https://doi.org/https://doi.org/10.1046/j.1523-1739.1993.740796.x
7. Lindenmayer D, Hobbs RJ, Montague-Drake R et al (2008) A checklist for ecological management of landscapes for conservation. Ecol Lett 11:78–91. https://doi.org/10.1111/j.1461-0248.2007.01114.x
8. Mahanta DK, Samal I, Komal J, Bhoi TK, Majhi PK, Ahmad MA Understanding anthropogenic climate change, its consequences on insect pests, and techniques in forecasting and monitoring pest dynamics: a contemporary scenario. In Climate change and insect biodiversity (pp. 44–67).CRC, Press.Mell I, Allin S, Reimer M, Wilker J (2023) (2017) Strategic green infrastructure planning in Germany and the UK: a transnational evaluation of the evolution of urban greening policy and practice. Int Plan Stud 22:333–349. https://doi.org/10.1080/13563475.2017.1291334

9. Parker K, Head L, Chisholm LA, Feneley N (2008) A conceptual model of ecological connectivity in the Shellharbour Local Government Area, New South Wales, Australia. Landsc Urban Plan 86:47–59. https://doi.org/10.1016/j.landurbplan.2007.12.007
10. Ramola GC, Rawat N, Singh R et al (2024) Insects as Ecological Indicators: A Review. Int J Environ Clim Change 14:260–279. https://doi.org/10.9734/ijecc/2024/v14i124623
11. Sánchez-Bayo F, Wyckhuys KAG (2019) Worldwide decline of the entomofauna: A review of its drivers. Biol Conserv 232:8–27
12. Schowalter TD, Zhang YL, Rykken JJ (2003) Litter Invertebrate Responses to Variable Density Thinning in Western Washington Forest. Ecol Appl 13:1204–1211
13. Wei J, Qian J, Tao Y et al (2018) Evaluating spatial priority of urban green infrastructure for urban sustainability in areas of rapid urbanization: A case study of Pukou in China. Sustain (Switzerland) 10. https://doi.org/10.3390/su10020327
14. White PJT, Kerr JT (2007) Human impacts on environment–diversity relationships: evidence for biotic homogenization from butterfly species richness patterns. Glob Ecol Biogeogr 16:290–299. https://doi.org/https://doi.org/10.1111/j.1466-8238.2007.00298.x
15. Yeo OTS, Mohd Yusof MJ, Maruthaveeran S, Saito K, FRAMEWORKS OF ECOLOGICAL CONNECTIVITY: SYSTEMATIC REVIEW ON GREEN INFRASTRUCTURE'S CASE STUDIES (2024) New Des Ideas 8:372–388. https://doi.org/10.62476/ndi82372
16. Dufrene M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monogr 67(3):345–366. https://doi.org/10.2307/2963459

Tables

Tables 2 and 3 are not available with this version.

Figures

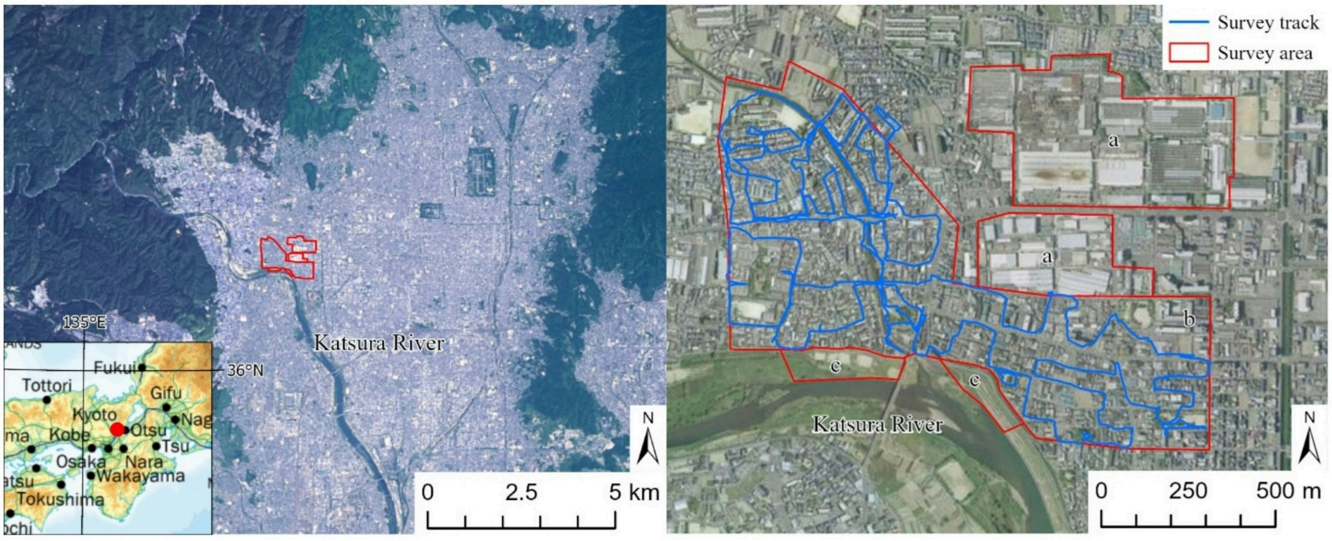


Figure 1

Study area. The red frame indicates the survey area. a is corporate grounds, b is urban area, c is river zones. Survey methods differ slightly between areas a–c. Map source: Geospatial Information Authority of Japan.



Figure 2

Eleven type of green spaces.

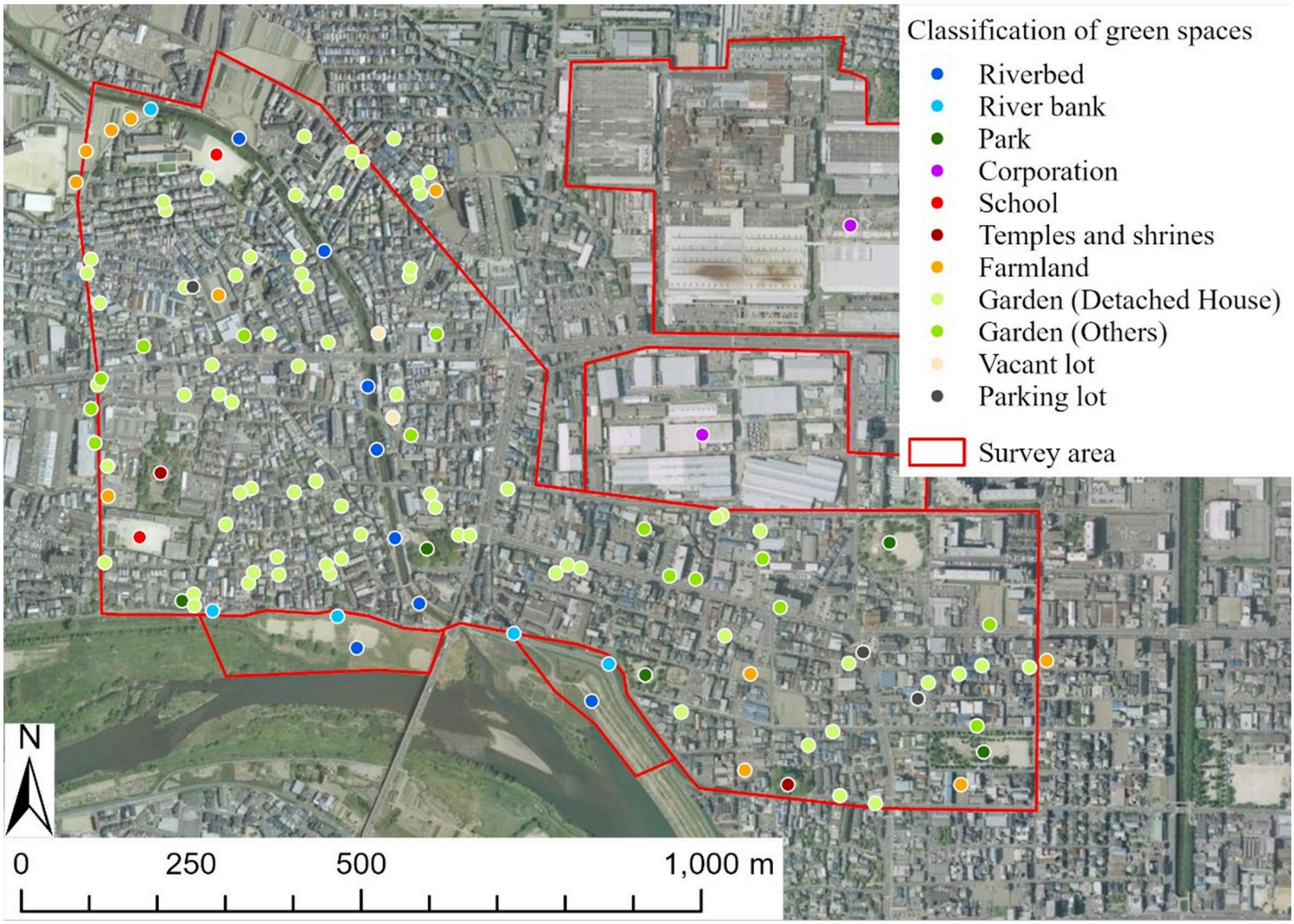


Figure 3

Elevn green space type at 128 sites where sounding orthoptera were identified

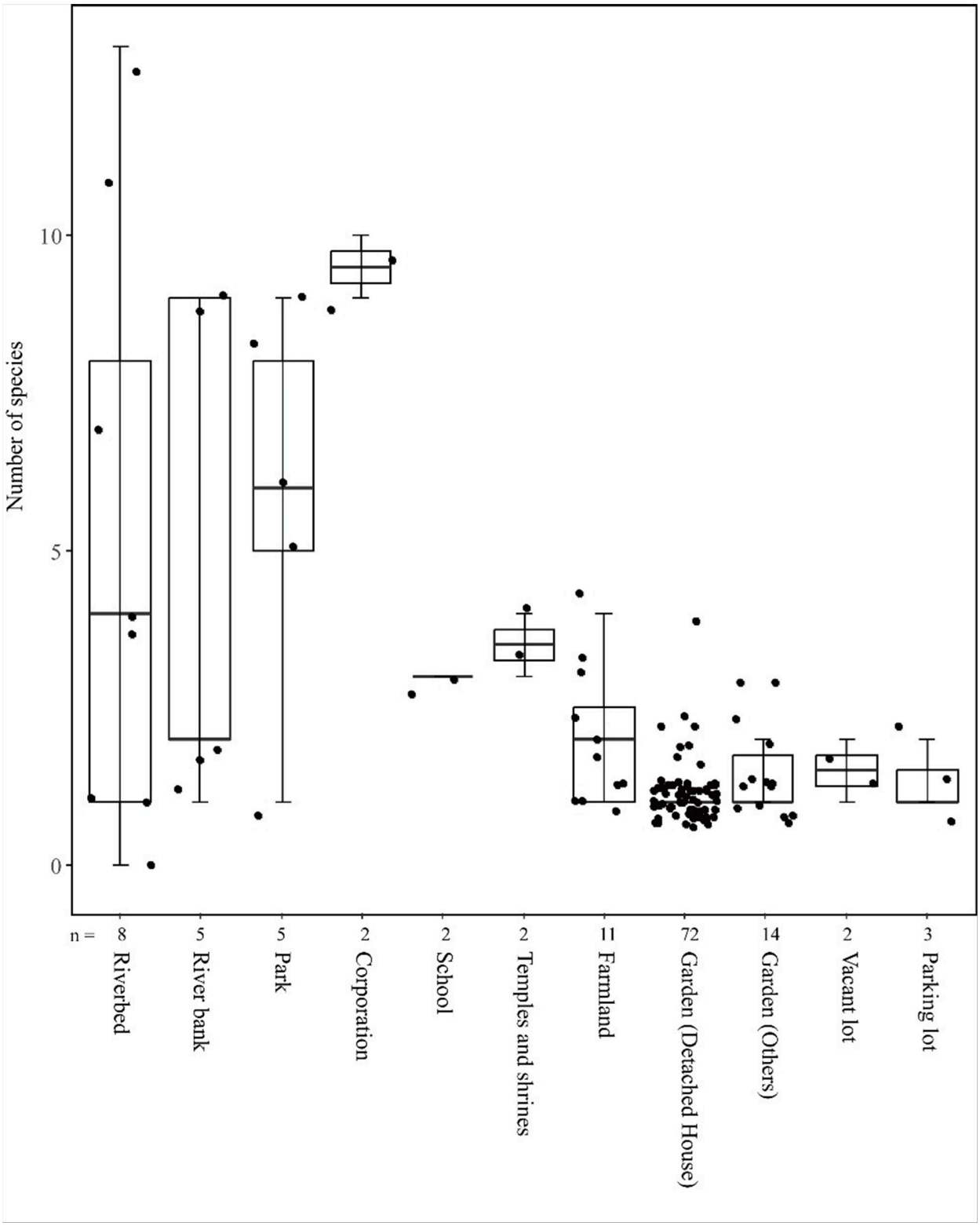


Figure 4

Species richness of sounding orthoptera across green space types. Boxes represent medians and interquartile ranges, whiskers indicate ranges excluding outliers, and points represent individual survey sites. Species richness varied among green space types, although statistical comparisons were not conducted due to differences in survey area and sampling conditions.

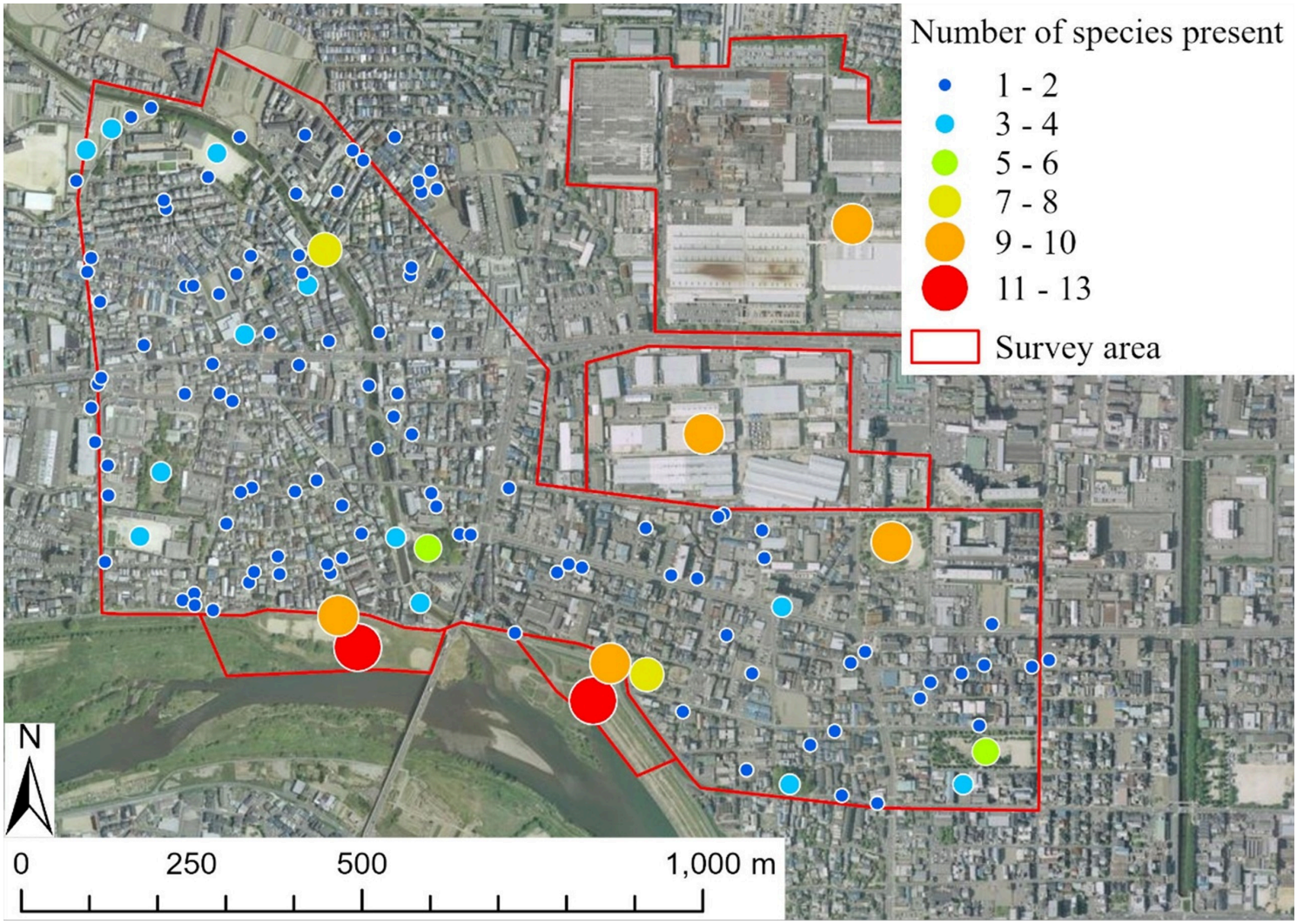


Figure 5

Spatial distribution of species richness of sounding orthoptera identified at each survey site

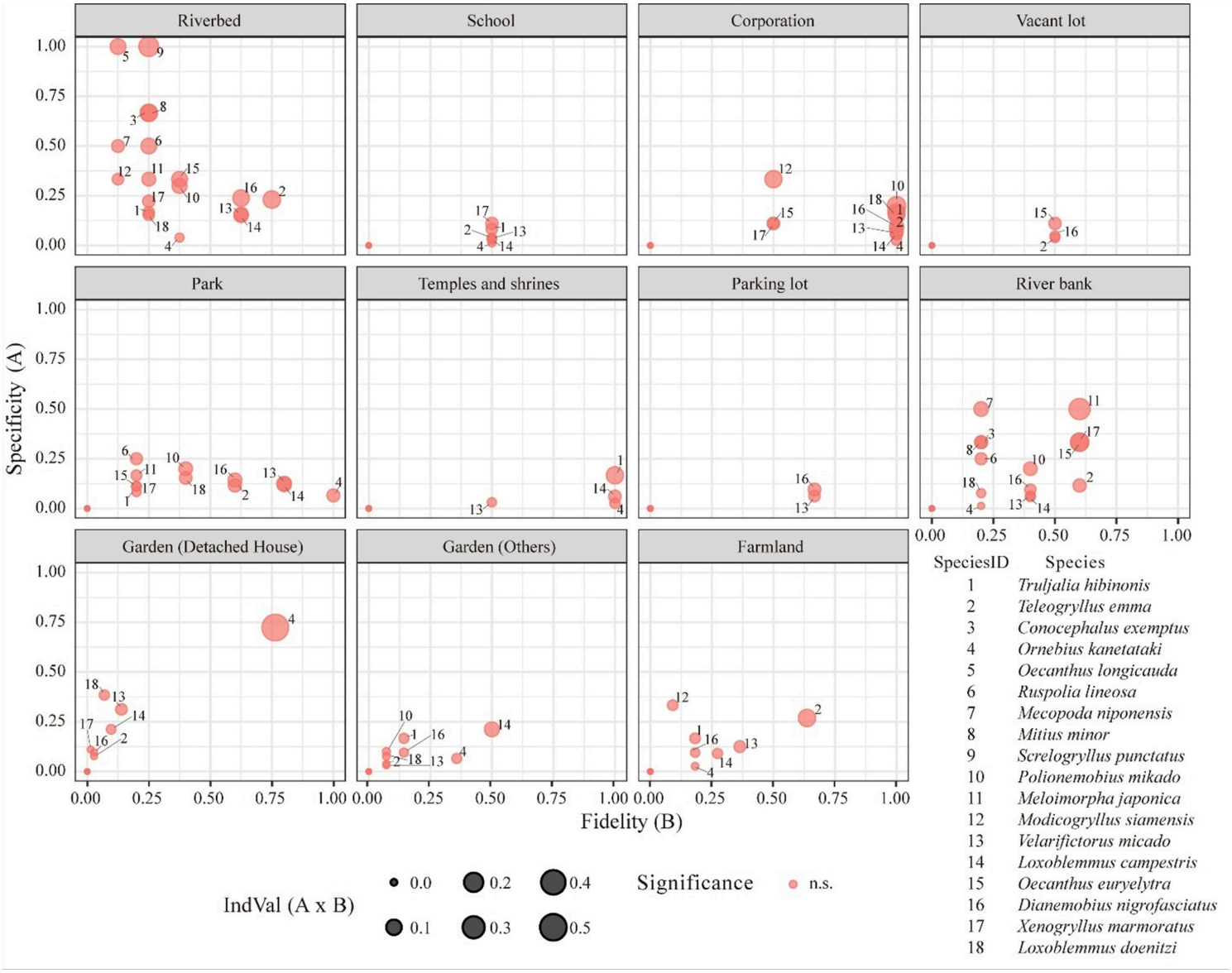


Figure 6

Specificity (A) and fidelity (B) of sounding orthoptera across green space types. Each point represents a species, with point size indicating the indicator value (IndVal = A × B). No significant index values were found ($p < 0.05$, permutation test using 999 permutations). Non-significant species are shown to indicate continuous variation in the index characteristics. Species IDs were displayed for all species except those with IndVal = 0.

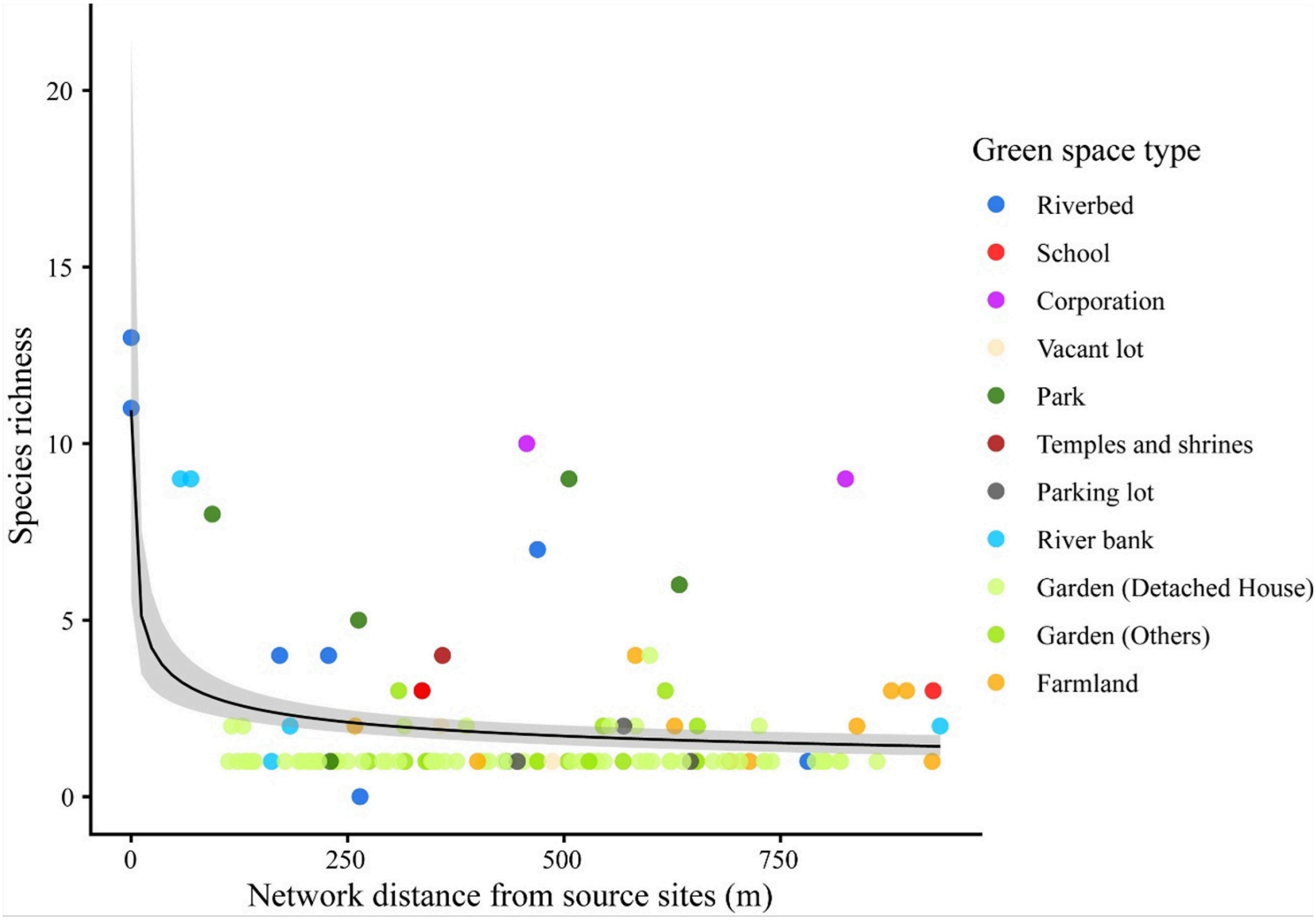


Figure 7

Relationship between species richness and network distance from the Katsura River riverbed. Species richness tended to decrease with increasing network distance from the riverbed.

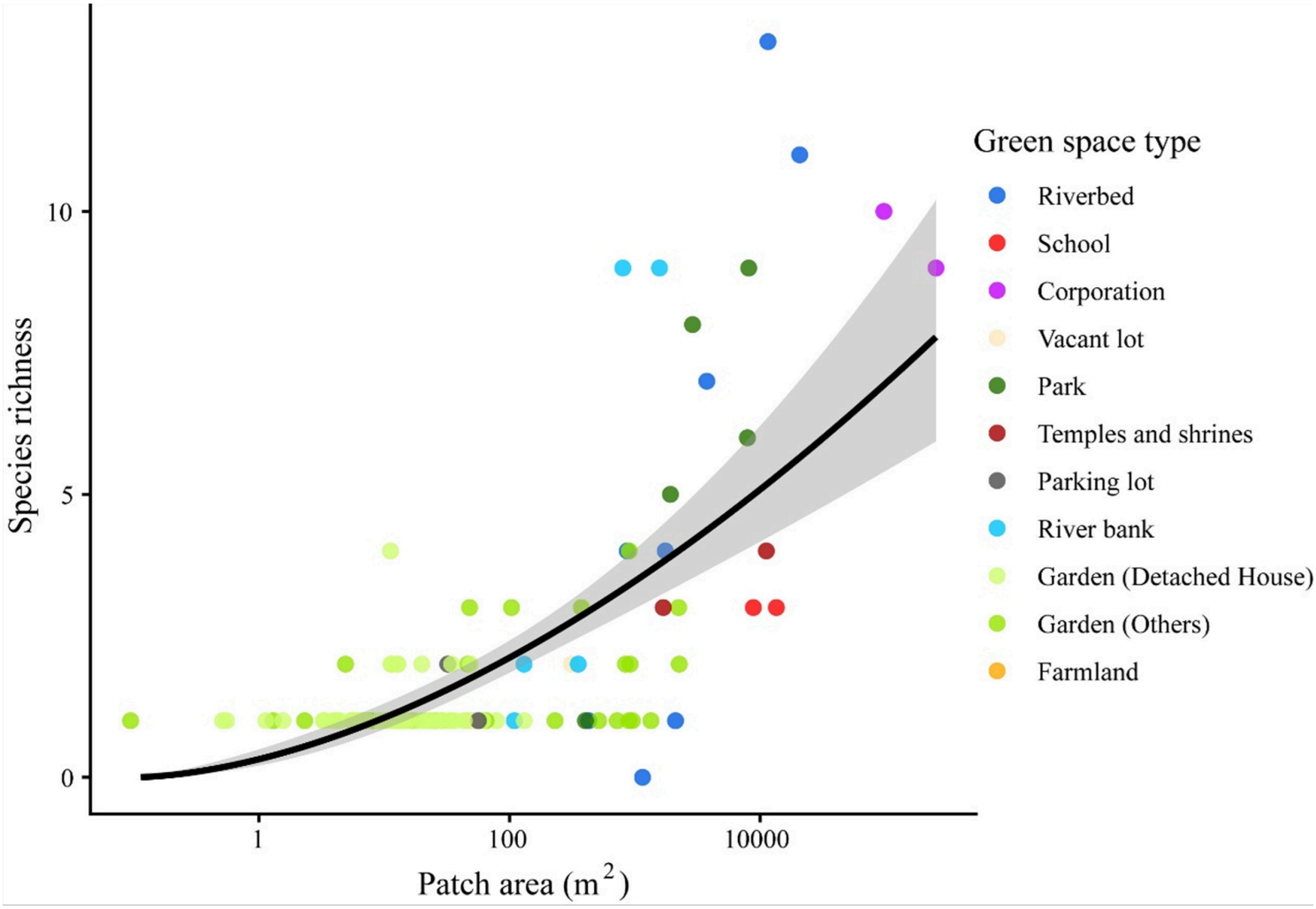


Figure 8

Relationship between patch area and species richness of acoustically active Orthoptera. The x-axis is shown on a logarithmic scale because patch area varied substantially among sites. Species richness increased with increasing patch area.

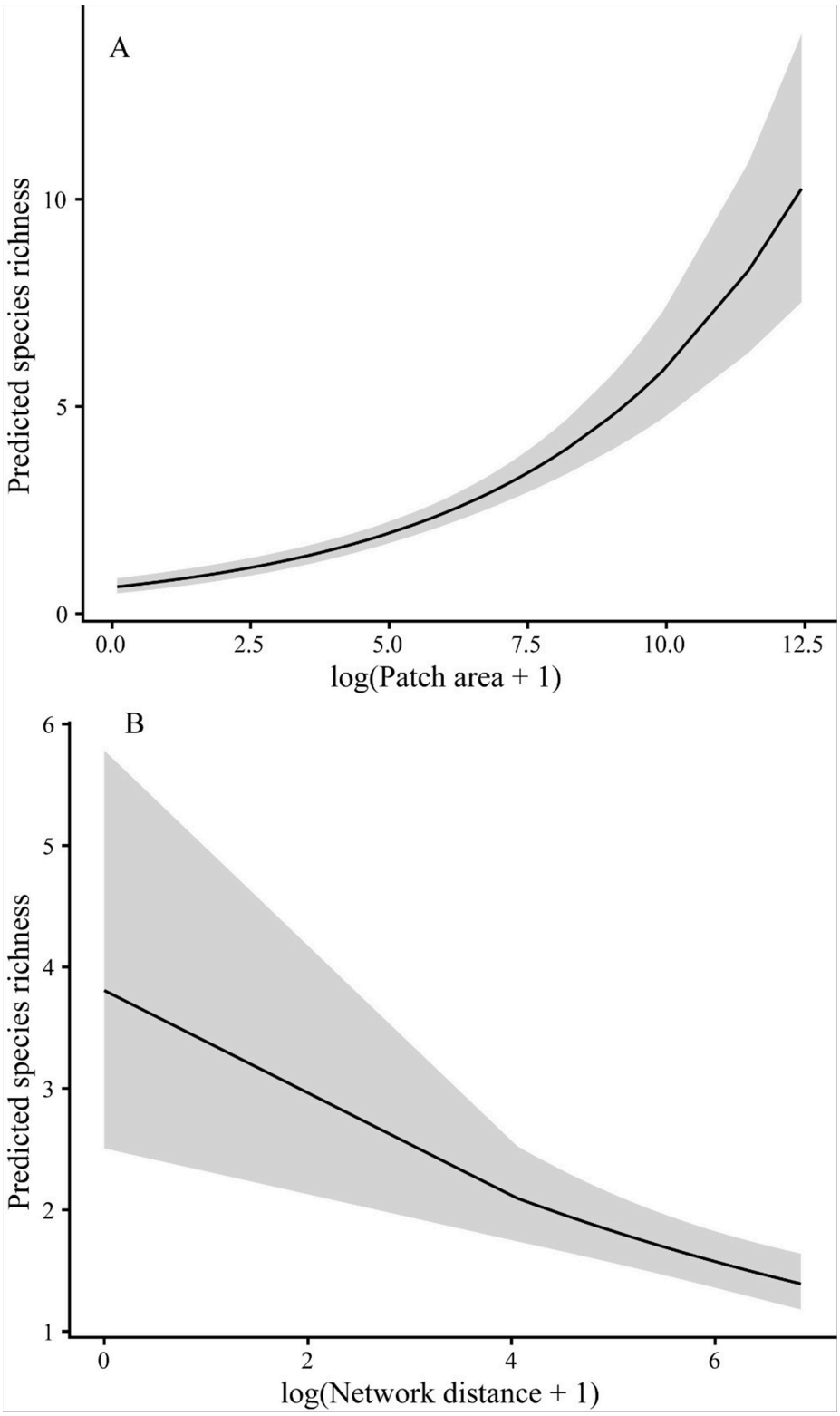


Figure 9

Partial effects of patch area and network distance on species richness of acoustically active Orthoptera. (A) Partial effect of patch area. (B) Partial effect of network distance from the Katsura River riverbed. Shaded areas indicate 95% confidence intervals.

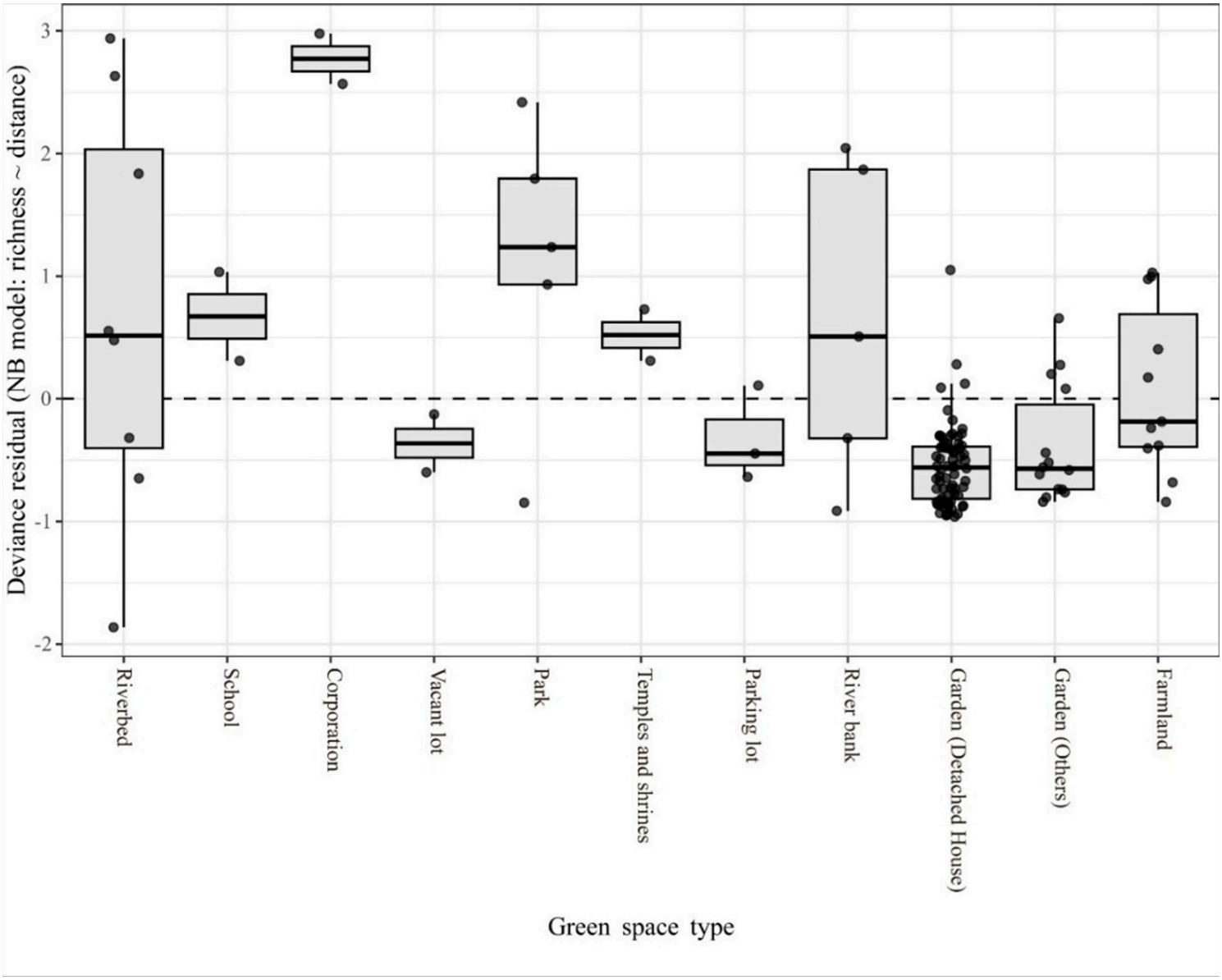


Figure 10

Deviation residuals from the negative binomial model (species richness ~ network distance) by green space type. Boxes show medians and interquartile ranges, and points represent individual survey sites. Positive residuals indicate sites with higher species richness than predicted by spatial distance alone. Differences among green space types were tested using a Kruskal–Wallis test ($\chi^2 = 35.25$, df = 10, $p < 0.001$; see Table 2).