# Detecting Nestedness in City Parks for Urban Biodiversity Conservation

**Rui-Qi Chen**
National Taiwan University
**Su-Ting Cheng** ( chengsuting@ntu.edu.tw )
National Taiwan University https://orcid.org/0000-0003-1786-6049

---

**Research Article**

**Keywords:** Biodiversity conservation, Community ecology, Park, Land use, Nestedness, Urbanization.

**Posted Date:** January 28th, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1041980/v1



---

# Abstract

Urbanization has been a global phenomenon producing great environmental and ecological challenges including species composition shifts in urban areas. To evaluate the interaction networks of the inhabitant metacommunities in urban parks, we applied the nestedness analysis using ecological survey data of birds, reptiles, frogs, and butterflies among 16 parks in the Taipei city of Taiwan, and identified critical environmental factors for biodiversity conservation. Results found significant nestedness of the metacommunities among these parks, which indicated strong interaction networks and the importance of urban parks for sustaining these metacommunities. In addition, results showed that area of parks and area of trees were critical elements for the nested structure. However, abundant bird generalists were found to be highly related to the area of buildings within parks, distance to forests, rivers, and the neighboring parks. Moreover, the exotic species were found to affect the interaction networks of native species; yet reptiles and frogs were appeared to be more easily threatened by land development and habitat fragmentation due to their lower mobility. In this regard, we suggest that conservation action should focus on preserving green space with large areas and constructing the green corridors, creating crucial elements, and increasing the vertical complexity in the parks for various mobility level species. We also recommend to controlling the introduction of the exotic species and retaining healthy interactions and connections of metacommunities for effective biodiversity conservation in urban areas.


# 1. Introduction

The rapid economic developments have motivated and attracted nearly 4 billion people to live in cities worldwide, and it is predicted that nearly 70% of the world population will reside in urban areas by 2050 (United Nations 2018). As urbanization has known to result in a series of economic, social, and environmental changes (Berry 2008), this trend is still undergoing and has led to various ecological impacts. In particular, serious habitat deterioration and fragmentation occur, along with its edge effects that further reduce landscape connectivity (Danielle et al. 2011) and change the inhabitant species composition and distribution (Habel et al. 2019), affecting species abundance, compositional variation, and biodiversity (Alexandre et al. 2008; Danielle et al. 2011). Although some species may have adapted to the niches provided by these urban environments, species with habitat specificity or sensitive to environmental changes, suffer serious threats of survival (Dennis and Eales 1997) and the integrity of metacommunity network. Under the constraints of limited land with increasing human population, land developments are spread out to suburban areas around many cities worldwide. Nowadays, there is general awareness of the importance of green space for species survival and biodiversity conservation (Lepczyk et al. 2017), so that the idea of “wildlife-inclusive urban design” has been recently getting promoted and incorporated into urban planning that give much value of the green space like parks and yards within the urban areas (Apfelbeck et al. 2020).

To explore the importance of green space towards the state of ecological communities, the concept of nestedness proposed by Darlington (1957) has been used to describing the distribution pattern of animals (Bascompte et al. 2003; Tan et al. 2021; Pinheiro et al. 2021). Based on the concept of island biogeography, the richness of species is distributed in association with the migration and extinction probability determined by the size and the isolation level of the correspondent habitat conditions (MacArthur and Wilson 2001). This mechanism drives the biogeographical pattern, which can be depicted by the nestedness, showing that the species presented in species-poorer islands are often a subset of the species composition in species-richer islands (Atmar and Patterson 1993). As a result, the nestedness is an effective way to quantify and provide information of ecological interactions among the community networks.

Quantification of nestedness has been developed from “Temperature index” (Atmar and Patterson 1993) to “Nestedness metric based on Overlap and Decreasing Fill” (NODF) that applied advanced programming and techniques to detect the nested structure and standardize the bias resulted from the size differences of the composition matrix (Ulrich and Gotelli 2007). However, the NODF requires information of species presence and absence (Almeida-Neto et al. 2008), which often causes problem with the existence of rare species. To reduce the influence from rare species, “Weighted Nestedness metric based on Overlap and Decreasing Fill” (WNODF) improved the quantification process by using the weighted method within the abundance matrix (Almeida-Neto and Ulrich 2011) and further considered the inequality and overlap of matrix as a combination of marginal sums of gradients to form the “Weighted nestedness based on overlap and decreasing abundance” (WNODA) (Pinheiro et al. 2019). Under the assumption of the nestedness of WNODA, the internal species composition information can be better predicted within a higher gradient of the marginal sums of composition matrix, confirming stronger habitat-species interactions rather than randomness. Compared with the nestedness index calculated from the presence–absence matrices of binary system, WNODA resolves the rare species influence by more conservatively presenting the nestedness using the abundance matrix to mimic the real interactions among the ecological systems of metacommunities and their habitats (Pinheiro et al. 2019).

Suitable for detecting the metacommunity interactions in isolated habitats (Atmar and Patterson 1993), the nestedness may be applied to explore the ecological relationship and status of green space in urban areas as they are often situated apart as ecological islands, although for some generalized species, they are likely to quickly occupy new niches even in the highly urbanized areas (Čeplová et al. 2017; Apfelbeck et al. 2020). To explore the importance of urban green space in the biodiversity conservation, and to investigate how different environmental factors affect the species composition and connectivity between metacommunities in urban areas, in this study, we apply the WNODA to examine the nestedness of metacommunities interaction networks among the selected 16 parks in the highly urbanized Taipei city of Taiwan. Followed by the nestedness analysis, we examine the relationship between gradients of environmental factors and species incidences from nestedness by the Spearman’s correlation test (Schouten et al. 2007; Ulrich 2009). At the end, we list trade-offs between land development and biodiversity conservation, and provide considerations and suggestions for park design and urban planning.

# 2. Methods

## 2.1. Study area & data description

In this study, we assembled species observation data in the 16 parks in the Taipei city of Taiwan (Fig. 1), which have been selected under the biodiversity monitoring program by the Taipei City Animal Protection Office, Taipei City Government since year 2006 with standard ecological survey process (Lee et al. 2016). The Taipei city (24°N, 121.5°E), capital of Taiwan, is located in the riverine basin situated at the subtropical monsoon climate zone (Huang 1993). With rapid urbanization, the Taipei city has undergone and continued going through land use change (Jim and Chen 2008; Chang et al. 2021). Excluding water fields and wetlands, there are 976 small parks and green spaces distributed across the Taipei City (Parks and Street Lights Office 2018).

The ecological surveys, provided by the Taipei City Animal Protection Office, included observation data of birds, reptiles, frogs, butterflies, dragonflies, fish, and aquatic invertebrate from 2007 to 2017. To represent the interactions among species and their habitats, we conducted the nestedness analysis using only species occurred in all the 16 parks with overlapped time period during 2008 to 2015. As a result, the selected species included metacommunities of bird, reptile, frog, and butterfly. We sorted these species composition data into species-habitats matrix (Atmar and Patterson 1993) using ArcGIS version 10.5. The species composition data were organized into two versions. One included the exotic and native species, and the other included only the native species.

We arranged the species-habitats matrix with vertical axis representing the species composition of each habitat, and horizontal axis the species incidences in all the habitats (Atmar and Patterson 1993; Almeida-Neto and Ulrich 2011) using the software of R 4.0.3. After that, we adjusted the abundance of each species by the frequency of surveys to produce the weighted-abundance.

## 2.2. The nestedness analysis

To evaluate the role of parks and their surrounding configuration for sustaining the biodiversity, we applied WNODA that considers the inequality and overlap of matrix as a combination of gradient presented by marginal sums to examine the nestedness (Pinheiro et al. 2019). The nestedness, therefore, represents the interaction networks of the inhabitant metacommunities of bird reptile, frog, and butterfly among the 16 parks in Taipei and the associated gradient change (Pinheiro et al. 2019). Before calculating WNODA, we filled in the weighted-abundance into each cell to construct the species-habitats matrix. Based on the assumption of the hierarchical relationship shown in the nestedness, in the rows and columns, the matrix was organized in an order by the magnitude of the marginal sums of the weighted-abundance. As such, parks with higher richness were ordered at the upper rows, and species with higher incidences were ordered to the columns at left. After the arrangement, the more general species will be organized into the upper left corner in the matrix (Ulrich et al. 2009). Then, according to the sorted matrix, WNODA can be calculated as (Atmar and Patterson 1993; Pinheiro et al. 2019):

$$\text{WNODA} = \frac{2(\text{WNODAc}+\text{WNODAr})}{m(m-1)+n(n-1)},$$

of which

$$\text{WNODAc} = 100\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{k_{ij}}{N_j},$$

$$\text{WNODAr} = 100\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{k_{ij}}{N_j},$$

where WNODAc represents the nestedness calculated from the information of columns, $i$ is the *i-th* column, and $j$ is the next column of the *i-th*, $n$ is the number of columns, $k$ represents the number of the cell with paired information of column $i$ and column $j$, and $N$ is the number of rows. Once the marginal sum of column $j$ is less than column $i$, the proportion of declined value $k/N$ in column $i$ will be added up to calculate WNODAc. Similarly, WNODAr is the nestedness calculated from the information of rows. After that, WNODAc and WNODAr were standardized and multiplied by 100 to scaling up the range of the nestedness index from 0 to 100 to calculate WNODA. The higher the WNODA, the stronger the nested structure (Pinheiro et al. 2019). Lastly, based on the characteristics of the original matrix, we produced a null model to perform permutation and examine the significance level of WNODA (Ulrich and Gotelli 2007).

## 2.3. Identification of critical environmental factors

As the nestedness is driven by the interaction among heterogeneous environmental conditions, it is associated with different probabilities of selective immigration and extinction of species (Atmar and Patterson 1993; Vázquez et al. 2007), which leads to species compositional variation and unequal abundance. Based on the rationale of island biogeography and the calculated nestedness structure, we allocated potential environmental factors that may affect the survival of species and the interaction networks of the metacommunities (Rico-Silva et al. 2021), including area of different land use types or landscape components within the park, habitat heterogeneity, identification of green space within each park, area or boundary ratio of parks, road or building density around parks, and distance to usable habitats. The landsat-8 satellite image from the USGS Earth Explorer was used to digitalizing the chosen environmental factors. Then we created a correlation matrix, and excluded some of the factors having a correlation coefficient higher than 0.7 and at a significance level of $P < 0.05$ (Dormann et al. 2013). We examined the influence of the surrounding environmental configuration on the interaction networks of the metacommunities using a Spearman’s correlation test that taking account the relationship between ecological gradients and species incidences from nestedness using the following equation (Ulrich 2009):

$$r_s = \frac{\sum_{j=1}^{n}(R_{x_j} - \bar{R_x})(R_{y_j} - \bar{R_y})}{\sqrt{\sum_{j=1}^{n}(R_{x_j} - \bar{R_x})^2 \sum_{j=1}^{n}(R_{y_j} - \bar{R_y})^2}} ,$$

where $r_s$ is the correlation coefficient, ranging from -1 to 1, $j$ is the order of each object, n is the total number of objects, $R_{x_j}$ and $R_{y_j}$ represent the arrangements of habitats in the matrix with the maximum nestedness, and the selected environmental factors of the habitats of $R_x$ in ordered, to the rank of $x$ and $y$ of the $j^{\text{th}}$ object, respectively. After that, we performed a one-thousand-time permutation of $R_y$ and applied two-tailed test to check the statistical significance of $r_s$ on each of the environmental factor (Schouten et al. 2007; Wang et al. 2012).

Below we describe the calculation of the potential environmental factors considered in this study.

A. Area of different land use types within each park.

We calculated the area of each land use type within the parks, including trees, shrubs, grasslands, and water zone, roads, and buildings.

B. Habitat heterogeneity.

We determined the degree of habitat fragmentation in each park by counting the habitat heterogeneity (Harini 2002) that calculates the patch number of each land-use type using the Simpson's diversity index as (Simpson 1949):

$$\mathrm{D} = 1 - \frac{\sum_{1}^{i} u_i(u_i - 1)}{U(U-1)} ,$$

where $D$ represents Simpson's diversity index, $u_i$ is the number of patches of $i^{th}$/land use type, and $U$ is the total number of the land-use types.

C. Identification of green space within each park.

To identify the green space across the 16 parks, we applied indices that can be used to represent the intensity of live green vegetation in each park, including (1) proportion of green space, and (2) average normalized difference vegetation index (NDVI) within green space. To systematically calculate the two indices, we gathered the satellite images of Taipei city from landsat-8 from 2013 to 2015, and performed a geometric correction. We only used the satellite images without clouds to reduce effects from clouds and the derived errors. The NDVI can be calculated as (Rouse et al., 1974):

$$\mathrm{NDVI} = \frac{NIR - RED}{NIR + RED} ,$$

where $NIR$ is the far-red light spectrum value, and $RED$ is the red-light spectrum value.

Based on the calculated NDVI, the "proportion of green space" was determined as where NDVI > 0 within each park, and "average NDVI within green space" can therefore be examined within the chosen green space.

D. Area or boundary ratio of parks.

To represent the possible edge effects, boundary ratio was calculated as the perimeter of the park divided by the area.

E. Road or building density around parks.

Building or road density around parks were determined separately as the proportion of area occupied by buildings or roads within a buffer of 100 m around each park (Rico-Silva et al. 2021).

F. Distance to usable habitats.

To examine the ecological connection between usable habitats, like green spaces and aquatic environments, we calculated the shortest distance from each park to the nearest habitats, including forests, rivers, and the neighbouring parks. In this study, forests were defined as an area occupied by trees larger than 5 hectares.

# 3. Results

## 3.1. Overview of the composition of the metacommunity

We reviewed the selected biological metacommunities of bird, reptile, frog, and butterfly, and organized the observation data into native versus exotic species. Based on the observation records, there were 10 exotic and 77 native bird species. The exotic bird species included Muscovy Duck (*Cairina moschata* (Established Feral)), Rock Pigeon (*Columba livia*), Oriental Magpie (*Pica serica*), Mallards (*Anas platyrhynchos* (Domestic type)), Asian Glossy Starling (*Aplonis panayensis*), Oriental Magpie-Robin (*Copsychus saularis*), Common Myna (*Acridotheres tristis*), Javan Myna (*Acridotheres javanicus*), Black-collared Starling (*Gracupica nigricollis*), and Parakeet (*Conuropsis carolinensis*). In the observed 77 native bird species, Eurasian Tree Sparrow (*Passer montanus*) was found to be the dominant species in these parks.

The observed metacommunity of reptile included 5 exotic and 10 native species, in which the exotic species were Red-eared Slider (*Trachemys scripta elegans*), Cuban Slider (*Trachemys decussata*), Map Turtle (*Graptemys* sp.), River Cooter (*Pseudemys concinna*), and Common House Gecko (*Hemidactylus frenatus*), whereas Swinhoe's Japalure (*Diploderma swinhonis*) was the dominant native species.

The composition data of the metacommunity of frog were found to include 2 exotic and 13 native species. The exotic frog species were American Bullfrog (*Lithobates catesbeianus*) and Brown Tree Frog (*Polypedates megacephalus*); while the native species were mainly composed of Asian Common Toads (*Duttaphrynus melanostictus*). In terms of the metacommunity of butterfly, all of the 71 recorded species were native species, in which *Pieris canidia* was accounted for the majority.

## 3.2. The nestedness structure among metacommunities and parks

Excluding the exotic species in the composition data, results showed that all the metacommunities of native species had significant nestedness among these 16 parks in Taipei (Table 1 and Fig. 2). Reptiles appeared the strongest nestedness (WNODA = 60.93, $P < 0.001$), followed by frogs (WNODA = 51.12, $P = 0.017$) and birds (WNODA = 48.17, $P < 0.001$), and butterflies the weakest (WNODA = 28.91, $P < 0.001$). However, when including the exotic species into the analysis, the nestedness of all the biological groups slightly declined (Table 1 and Fig. 2).

Table 1
The calculated WNODA using the species composition data of the metacommunities of bird, reptile, frog, and butterfly during years 2008 to 2015. The significance level (*P*-value) was calculated based on 1000 times permutation process. To be noted that the recorded metacommunity of butterfly was composed by native species only, so we cannot calculate the WNODA for including the exotic butterfly species.

| Category | Native species only | | Exotic species included | |
|---|---|---|---|---|
| | WNODA | Significance level | WNODA | Significance level |
| Bird | 48.17 | $P < 0.001$ | 47.52 | $P < 0.001$ |
| Reptile | 60.93 | $P < 0.001$ | 55.88 | $P < 0.001$ |
| Frog | 51.12 | $P = 0.022$ | 46.22 | $P < 0.001$ |
| Butterfly | 28.91 | $P < 0.001$ | NA | NA |

## 3.3. Identification of critical Environmental by Spearman’s correlation test

According to the correlation matrix, we excluded some of the highly correlated environmental factors, including area of grass, roads, and buildings, boundary ratio of parks, and road density around parks (Fig. 3). Analysis results from the Spearman’s correlation test found that in general, the land use types within parks showed different level of influence, and the habitat heterogeneity showed lower and non-significant correlations on the nestedness of the metacommunities (Table 2). In particular, we found significant positive correlation between certain land use types with the weighted abundance of native species of birds, reptiles, and butterflies. For example, the correlation coefficients of the area of trees to native birds, reptiles, and butterflies were 0.52, 0.78, and 0.70, respectively. Yet, the correlation coefficient of frogs to the area of trees was at a lower value (0.27), and not significant. In addition, we also found shrubs a critical land use type for birds and butterflies, with a higher positive correlation coefficient of 0.67 for native birds at a significance level of $P < 0.01$, and for butterflies with a correlation coefficient of 0.58 at $P < 0.05$. Furthermore, results found significant correlations of birds and butterflies to the area of parks with a correlation coefficient of 0.54 and 0.47, respectively. Besides, the metacommunity of bird was found to be mostly affected by distance to rivers with a positive correlation coefficient of 0.77 at a significance level of $P < 0.01$. On the contrast, the distance to the neighbouring parks appeared a negative correlation of -0.56 at a significance level of $P < 0.05$ to the weighted abundance of birds (Table 2).

**Table 2.** The correlation among weighted abundance of metacommunity of bird, reptile, frog, and butterfly to the remained environmental factors from the Spearman's correlation test, with "N" indicating the results with "native species only", and "NE" indicating those with "native plus exotic species". In the table, * represents the significance level of $P < 0.1$, ** for $P < 0.05$, and *** for $P < 0.01$. To be noted that because the records of the butterfly metacommunity was composed by native species only, there were no results for it, and were indicated with NA in the table.

| Environmental factors \ Metacommunity | Bird | | Reptile | | Frog | | Butterfly | |
|---|---|---|---|---|---|---|---|---|
| | N | NE | N | NE | N | NE | N | NE |
| **Land use types within parks** | | | | | | | | |
| **(1) Area of trees** | **0.52****  | 0.33 | **0.78***** | **0.87***** | 0.27 | 0.27 | **0.70***** | NA |
| **(2) Area of shrubs** | **0.67***** | **0.78***** | 0.02 | 0.26 | 0.05 | 0.04 | **0.58**** | NA |
| **(3) Area of water zone** | -0.03 | -0.13 | 0.30 | 0.07 | 0.16 | 0.15 | -0.06 | NA |
| **Habitat heterogeneity** | 0.09 | 0.07 | 0.25 | 0.10 | 0.28 | 0.29 | 0.26 | NA |
| **Identification of green space within each park** | | | | | | | | |
| **(1) Proportion of green space** | -0.06 | -0.15 | -0.06 | 0.06 | 0.06 | 0.06 | 0.09 | NA |
| **(2) Average NDVI within green space** | -0.11 | -0.25 | **0.63***** | **0.41*** | 0.38 | 0.39 | 0.23 | NA |
| **Area of parks** | **0.54**** | **0.54**** | 0.26 | **0.42*** | -0.09 | -0.11 | **0.47*** | NA |
| **Building density around parks** | **-0.41*** | -0.34 | -0.12 | -0.28 | 0.03 | 0.04 | -0.4 | NA |
| **Distance to usable habitats** | | | | | | | | |
| **(1) Distance to forests** | **0.51*** | **0.48*** | -0.06 | 0.29 | 0.02 | 0.02 | 0.04 | NA |
| **(2) Distance to rivers** | **0.77***** | **0.75***** | 0.21 | 0.41 | 0.22 | 0.22 | 0.31 | NA |
| **(3) Distance to neighbouring parks** | **-0.56**** | **-0.52**** | 0.09 | -0.15 | -0.11 | -0.10 | -0.35 | NA |

More importantly, results found random effects of exotic species on the interaction networks of native species. For example, when including the exotic species into the analysis, the significance level of the correlation of birds to "area of trees" turned from significant to non-significant. An interesting result was found that with the exotic species, the correlation of building density around parks on birds decreased from -0.41 to -0.34, and the significance level dropped from $P < 0.1$ to insignificance. Similarly, the area of parks was found to be a significant factor whether we included the exotic reptile species. However, "average NDVI within green space" was the factor that changed the correlation from 0.63 ($P < 0.01$) to 0.41 ($P < 0.1$) when the exotic species were included (Table 2).

# Discussion

To examine the interaction networks of metacommunities of bird, reptile, frog, and butterfly among the parks in the urban areas, we applied the nestedness analysis of WNODA to measure and observe the order/disorder of the community ecological patterns in habitats facing fragmentation or isolation conditions (Atmar and Patterson 1993). Results showed significant nestedness of all the metacommunities among these parks, implying the importance of parks in the urban ecosystems as "island-like" habitats governing the assemblage networks and ecological community interactions of bird, reptile, frog, and butterfly. Given the selective colonization and extinction pressure caused by the respective environmental properties of each habitat, the assemblage networks are prone to develop nested structure with unequal biogeographical patterns of the species distribution and abundance (Atmar and Patterson 1993; MacArthur and Wilson 2001). As a result, when the system of these ecological islands become stable, the ubiquity of nestedness shows (Thebault and Fontaine 2010).

Through the analysis of WNODA, the size of the species-habitat matrix representing the nested structure can be standardized allowing unbiased comparison of different communities (Pinheiro et al. 2019). Based on the nestedness calculated from WNODA with native species only, reptiles and frogs showed stronger nested structure than birds and butterflies. We thought that this result may indicate greater influence of habitat fragmentation on the biological groups with lower mobility being more restricted for their movements (Habel et al. 2019). This necessitates the conservation strategy of green spaces during land development for those being threatened or struggling to survive, such as the lower mobility biological groups, in the highly fragmented urban environments. However, with consideration of both the native plus the exotic species in the WNODA calculation, results appeared a declined nestedness of all the four selected metacommunities showing a more disordered interaction networks of the associated assemblages among these parks (Čeplová et al. 2017). We argue that the calculated WNODA with exotic species included may be a result of randomness, rather than a nested structure in the parks of Taipei. This randomness implies that the niches of the exotic species are more general than those inhabitant native species in terms of the adaptation to the urban environments (Atmar and Patterson 1993; Čeplová et al. 2017). As such, for effective biodiversity conservation in urban areas, it is recommended to focus on restricting the spread out of the exotic species and regulating the transaction or trade. If an exotic species has been found to form prolific population in urban areas, it should be considered to lower the risk to the survival of native species by conducting effective control or removal on the exotic species to prevent their territory development or spread out (Gaertner et al. 2016).

Given the importance of parks in sustaining the interaction networks among different metacommunities from the nestedness analysis, we cooperated the Spearman's correlation test to explore the critical environmental factors affecting the metacommunities to provide science-based suggestions of crucial elements and proper designs for landscape planning and improvement (Ulrich et al. 2009). Results found that various types of land use had different effects on the species incidence of birds, reptiles, frogs, and butterflies. In particular, areas of trees and shrubs within parks were found to be positively correlated with the species incidence of native species of birds, reptiles, and butterflies. This reveals that the design of multi-layered environment could potentially benefit biodiversity conservation for providing diverse habitats for different species, enhancing the robustness of the ecological interaction networks (Oliveira and Scheffers 2019).

In addition, area of parks exhibited a positive correlation with the species incidence of birds and butterflies significantly. According to the correlation matrix, we observed a negative correlation of “area of parks” to the boundary ratio of parks, and road or building density around parks (Fig 3). It demonstrates that a larger park with lower boundary and isolation may help reduce the edge effects and maintain diverse natural habitats, which is beneficial to the richness and abundance of birds and butterflies. It also strengthens the knowledge ground for preservation of large green spaces to produce various niches to accommodate different species for biodiversity conservation. Surprisingly, habitat heterogeneity, as a transformed index, did not show significant correlations to birds, reptiles, frogs, and butterflies. It might be due to the scale of the parks in Taipei being relatively small, so that the associated correlation coefficients of the habitat heterogeneity were relatively minor in comparison with other environmental factors. This implies the more direct impacts of the habitat features on shaping the distribution and survival of species (Ulrich 2009), yet the environmental factors interacted with the habitat heterogeneity can together determine the nestedness of communities (Schouten et al. 2007; Rico-Silva et al. 2021). This warns the irreplaceable role of the measurements or observations to be more directly linked to the reality or the in-situ conditions, as well as the use of the transformed index to be taken as a supplementary and/or a more comprehensive addition.

Moreover, our results found that birds were negatively correlated with distance to the neighbouring parks, and positively correlated to distance to the nearest forests and rivers, indicating the importance of the connection between the parks and natural areas as habitats to the bird metacommunities. Studies found that loss of connection could potentially impact the networks and resilience of metacommunities, increasing the probability of extinction (Alexandre et al. 2008). Interestingly, the incidence of birds, either native or exotic, were found to remain a positive correlation with distance to the nearest forests and rivers significantly. This situation may be caused by the habits of the generalist species accounted for the majority of total weighted abundance, such as Eurasian Tree Sparrow (*Passer montanus*) accounted for 33.7% to prejudice the arrangements of the abundance. Nonetheless, since the ecological requirements for the generalists of birds, often the omnivorous, granivorous, or cavity nesting birds, are more easily fulfilled in urban areas (Simberloff and Cox 1987), it may represent that indirect impact of urbanization on the richness of native birds with narrow niches (Chace and Walsh 2006). As a result, improvement on the connection between habitats, such like the urgent advocate of green corridor developments (Simberloff and Cox 1987), increasing the natural designs, planting native nectars and fruits between parks and green space (Akif et al. 2020), and preservation of existing green space, can help stabilize the interaction networks and increase the re-colonization rates of native species. These strategies can uphold the decreasing biodiversity (Alexandre et al. 2008), in the highly urbanized environment, especially for native birds.

When including the exotic species, we observed that the significance level of some correlations shifted. In terms of land use types within each park, the factor of “area of trees” turned into non-significant, while “area of shrubs” remains its positive and significant correlation. Besides, with the inclusion of the exotic bird species, “density of buildings around the parks” became less negative and not significantly related, reflecting the species-specific adaptability of the exotic birds in the urban areas and their utilization of the roads and buildings. If the thrived population of exotic bird species outcompete the native bird species, it may cause the loss of biodiversity (Chace and Walsh 2006). Similarly, the species incidence of native reptiles was found to be significantly correlated to “area of trees” and “average NDVI within each park”, expressing the need of native reptiles, such as Swinhoe's Japalure and Hekou's Gecko (*Gekko hokouensis*), for higher quality of green vegetation and large arbors. However, once the exotic reptile species were included, the correlation coefficient between species incidence and “area of parks” became higher and the correlation to "average NDVI within each park" decreased. These changes may be caused by the dominant exotic species of red-eared sliders, an aquatic species that have often been abandoned in large parks, and have been found to establish their population there (Zhang et al. 2020). In this regard, these results reinforce the need to control the introduction of the exotic species for native species protection. Also, it is vital to preserve and plant native vegetation to conserve the connection or provide niche for native species as another strategy for biodiversity conservation.

In conclusion, metacommunities of bird, reptile, frog, and butterfly showed significant nestedness among the 16 parks in Taipei, indicating strong interaction networks of the metacommunities among these habitats (Atmar and Patterson 1993). As a result, the existence of parks plays a vital role for sustaining these metacommunities (Almeida and Ulrich 2011). In addition, land development may affect the biological groups with lower mobility more seriously, such that in our analysis reptiles and frogs were found to be more easily threatened by habitat fragmentation (Habel et al. 2019). To reduce the impact of urbanization, and help retain healthy interactions and connections of metacommunities among the habitats, we suggest to conserve green space with large areas and construct the green corridors (Alexandre et al. 2008). In the parks, it is recommended to increase the area of shrubs and trees, and create crucial elements such as increase the vertical complexity with large and multi-layered trees for various mobility level species (Oliveira and Scheffers 2019). As for the exotic species, control the introduction is important preventive work for native biodiversity conservation in urban areas. We believe that these strategies are essential to construct wildlife-inclusive cities and conserve the community ecology in urban areas.

# Declarations

Acknowledgements

This study was funded by the Ministry of Science and Technology, Taiwan (Grant No. MOST 108-2621-M-002-010-MY3) for the funding support to this study. We sincerely thank the Taipei City Animal Protection Office for providing observation data of ecological surveys from 2007 to 2017.

Funding information

This study was supported by the Ministry of Science and Technology, Taiwan (Grant No. MOST 108-2621-M-002-010-MY3).

Conflicts of interest

The authors declare no conflict of interests.

Availability of data and material

The ecological survey data used in this study may be available with the permission of the Taipei City Animal Protection Office.

Code availability

Not applicable.

Author contributions

Material preparation and data analysis were performed by Rui-Qi Chen. Funding was acquired by Su-Ting Cheng. All authors contributed to the study conception and design, manuscript writing, and interpretation of the results.

# References


1. Akif K, Engin E, Sertac K, James TA (2020) Bird diversity along a riparian corridor in a moderate urban landscape. Ecol Indic 118: 106751. https://doi.org/10.1016/j.ecolind.2020.106751
2. Alexandre CM, Rafael GP, Jean PM (2008) Relative effects of fragment size and connectivity on bird community in the Atlantic Rain Forest: Implications for conservation. Biol Conserv 141: 2184–2192. https://doi.org/10.1016/j.biocon.2008.06.008
3. Almedia-Neto M, Guimarães P, Guimarães PR, Loyola RD, Ulrich W (2008) A consistent metric for nestedness analysis in ecological systems: reconciling concept and measurement. Oikos 117: 1227–1239. https://doi.org/10.1111/j.0030-1299.2008.16644.x
4. Almeida-Neto M, Ulrich W (2011) A straightforward computational approach for measuring nestedness using quantitative matrices. Environ Modell Softw 26: 173–178. https://doi.org/10.1016/j.envsoft.2010.08.003
5. Apfelbeck B, Snep RPH, Hauck TE, Ferguson J, Holy M, Jakoby C, Jakoby C, Maclvor S, Schär L, Taylor M, Weisser WW (2020) Designing wildlife-inclusive cities that support human-animal co-existence. Landscape Urban Plan 200: 103817. https://doi.org/10.1016/j.landurbplan.2020.103817
6. Atmar W, Patterson BD (1993) The measure of order and disorder in the distribution of species in fragmented habitat. Oecologia 96: 373–382.
7. Bascompte J, Jordano P, Melian CJ, Olesen JM (2003) The nested assembly of plant-animal mutualistic networks. P Natl Acad Sci USA 100: 9383–9387. https://doi.org/10.1073/pnas.1633576100
8. Berry BJL (2008) Urbanization. In Urban Ecology: An International Perspective on the Interaction Between Humans and Nature. Springer US, Boston, MA.
9. Čeplová N, Kalusová V, Lososová Z (2017) Effects of settlement size, urban heat island and habitat type on urban plant biodiversity. Landscape Urban Plan 159: 15–22. https://doi.org/10.1016/j.landurbplan.2016.11.004
10. Chace JF, Walsh JJ (2006) Urban effects on native avifauna: a review. Landscape Urban Plan 74: 46–69. https://doi.org/10.1016/j.landurbplan.2004.08.007

11. Chang CR, Chen MC, Su MH (2021) Natural versus human drivers of plant diversity in urban parks and the anthropogenic species-area hypotheses. Landscape Urban Plan 208: 104023. https://doi.org/10.1016/j.landurbplan.2020.104023
12. Danielle FS, Craig M, Hugh PP, Richard AF (2011) The influence of patch area and connectivity on avian communities in urban revegetation. Biol Conserv 144: 722–729. https://doi.org/10.1016/j.biocon.2010.10.014
13. Darlington PJ (1957) Zoogeography: the geographical distribution of animals. John Wiley & Sons, Inc., New York.
14. Dennis RLH, Eales HT (1997) Patch occupancy in *Coenonympha tullia* (Muller, 1764) (*Lepidoptera: Satyrinae*): habitat quality matters as much as patch size and isolation. J Insect Conserv 1: 167–176. https://doi.org/10.1023/A:1018455714879
15. Dormann CF, Elith J, Bacher S, Buchmann C, Carl G, Carré G, et al (2013) Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36: 27–46. https://doi.org/10.1111/j.1600-0587.2012.07348.x
16. Gaertner M, Larson BMH, Irlich UM, Holmes PM, Stafford L, van Wilgen BW, Richardson DM (2016) Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape Urban Plan 151: 1–9. https://doi.org/10.1016/j.landurbplan.2016.03.010
17. Habel JC, Samways MJ, Schmitt T (2019) Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. Biodivers Conserv 28: 1343–1360. https://doi.org/10.1007/s10531-019-01741-8
18. Harini N (2002) Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Appl Geogr 22: 175–186. https://doi.org/10.1016/S0143-6228(02)00002-4
19. Huang W (1993) Vegetation of Taiwan. China Environmental Science Press, Beijing, China.
20. Jim CY, Chen WY (2008) Pattern and divergence of tree communities in Taipei's main urban green spaces. Landscape Urban Plan 84: 312–323. https://doi.org/10.1016/j.landurbplan.2007.09.001
21. Lee PF, Lin CC, Lo H, Ni MH, Yang SM, Chao WK (2016). Biodiversity of Taipei. Taipei City Animal Protection Office, Taipei, Taiwan.
22. Lepczyk CA, Aronson MFJ, Evans KL, Goddard MA, Lerman SB, MacIvor JS (2017) Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. BioScience 67: 799–807. https://doi.org/10.1093/biosci/bix079
23. MacArthur RH, Wilson EO (2001) The theory of island biogeography. Princeton University Press, Princeton, NJ.
24. Oliveira BF, Scheffers BR (2019) Vertical stratification influences global patterns of biodiversity. Ecography 42: 249–249. https://doi.org/10.1111/ecog.03636
25. Parks and Street Lights Office (2018) Pass through the parks in Taipei City. https://parks.taipei/parks/index.php. Accessed 3 June 2021

26. Pinheiro RBP, Felix GMF, Dormann CF, Mello MAR (2019) A new model explaining the origin of different topologies in interaction networks. Ecology 100(9): 2019, e02796. https://doi.org/10.1002/ecy.2796
27. Rico-Silva JF, Cruz-Trujillo EJ, Colorado Z GJ (2021) Influence of environmental factors on bird diversity in greenspaces in an Amazonian city. Urban Ecosyst 24: 365–374. https://doi.org/10.1007/s11252-020-01042-x
28. Rouse J W Jr., Haas RH, Schell JA, Deering DW (1974) Monitoring Vegetation Systems in the Great Plains with ERTS. NASA Special Publication 351: 309.
29. Schouten MA, Verweij PA, Barendregt A, Kleukers RJM, de Ruiter PC (2007) Nested assemblages of Orthoptera species in the Netherlands: the importance of habitat features and life-history traits. J Biogeogr 34: 1938–1946. https://doi.org/10.1111/j.1365-2699.2007.01742.x
30. Simberloff D, Cox J (1987) Consequences and Costs of Conservation Corridors. Conserv Biol 1: 63–71.
31. Simpson EH (1949) Measurement of Diversity. Nature 163: 688–688.
32. Tan X, Yang X, Chen C, Wang Y (2021) Nestedness and underlying processes of bird assemblages in Nanjing urban parks. Curr Zool 67: 383–392. https://doi.org/10.1093/cz/zoaa069
33. Thebault E, Fontaine C (2010) Stability of Ecological Communities and the Architecture of Mutualistic and Trophic Networks. Science 329: 853–856. https://doi.org/10.1126/science.1188321
34. Ulrich W (2009) Nestedness analysis as a tool to identify ecological gradients. Ecol Quest 11: 27. https://doi.org/10.2478/v10090-009-0015-y
35. Ulrich W, Almeida-Neto M, Gotelli NJ (2009) A consumer's guide to nestedness analysis. Oikos 118: 3–17. https://doi.org/10.1111/j.1600-0706.2008.17053.x
36. Ulrich W, Gotelli NJ (2007) Null Model Analysis of Species Nestedness Patterns. Ecology 88: 1824–1831. https://doi.org/10.1890/06-1208.1
37. United Nations (2018) United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/cities/. Accessed 3 June 2021
38. Vázquez DP, Melián CJ, Williams NM, Blüthgen N, Krasnov BR, Poulin R (2007) Species abundance and asymmetric interaction strength in ecological networks. Oikos 116: 1120–1127. https://doi.org/10.1111/j.0030-1299.2007.15828.x
39. Veenman MVJ, Van Hout-Wolters BHAM, Afflerbach P (2006) Metacognition and learning: conceptual and methodological considerations. Metacogn Learn 1: 3–14. https://doi.org/10.1007/s11409-006-6893-0
40. Wang X, Wang YP, Ding P (2012) Nested species subsets of amphibians and reptiles in Thousand Island Lake. Zool Res 33(5): 439–446. https://doi.org/10.3724/SP.J.1141.2012.05439
41. Zhang Y, Song T, Jin Q, Huang Y, Tang X, Sun X, et al. (2020) Status of an alien turtle in city park waters and its potential threats to local biodiversity: the red-eared slider in Beijing. Urban Ecosyst 23: 147–157. https://doi.org/10.1007/s11252-019-00897-z

# Figures

## Figure 1

A schematic map showing the land-use types in the Taipei city of Taiwan and the location of the selected parks with their names and an example of the land-use types within park #16

## Figure 2

Nestedness plot of the 16 parks with only the native species of (a) bird, (b) butterfly, (c) reptile, and (d) frog

## Figure 3

Correlation matrix of (a) correlation coefficients and (b) *P*-value of original environmental factors. Factors to be excluded were highlighted in red boxes for their high association with other factors (correlation coefficient > 0.7) at a significance level of $P < 0.05$