Effects of Urban Matrix on Plant Diversity of Urban Remnant Mountains in Karst Area: A Case Study of Guiyang, Guizhou Province, China.

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Abstract

With the rapid development of urbanization, large numbers of cone-shaped or tower-shaped isolated peaks and peak forest were surrounded by a human-dominated urban matrix in the process of urban expansion in Karst areas, forming urban remnant hills (URHs), which are important resources of indigenous plant diversity from the urban environment in these areas. Although the studies on urban plant diversity have been extensive, studies on the plant diversity of the remnant habitats, especially those based on URHs, is very weak. In this study, a total of 143 sample plots were set up on 15 hills based on the combination of slope direction and elevation. Alpha diversity was calculated at four levels, i.e., tree, shrub, herb and whole plant. Four urban matrix characteristic indices, namely, percent total impervious surface area (PTIA), land use, vegetation coverage (VC) and fragmentation indices (*F_i*), were measured for each hill. Twenty scales, ranging from 100 m to 2000 m and with increasing steps of 100 m, were used as spatial scales. Pearson correlation analysis and linear regression model were used to study the relationship between URHs plant diversity indices and urban matrix indices. The results showed the following: (1) There was a significant positive correlation between the overall plant diversity of URHs of different sizes and PTIA in the surrounding urban matrix within 1600 m. The overall plant diversity of URHs of different scales was significantly correlated with single or multiple Land-use types. There was no significant correlation between *VC*, *F_i* and URHs overall plant diversity. (2) There was a significant linear relationship between plant diversity at all levels of different scales URHs and the four urban matrix indices. In addition to the small URHs herbaceous diversity, plant diversity at all levels of URHs was jointly affected by double or multiple factors at the 1800 m spatial scale. plant diversity of URHs of different scales in hilly Karst cities are extremely complex under the combined action of multiple factors and multiple scales.

1. Introduction

With the rapid growth of global urbanization and urban populations, many cities have been experiencing large-scale Land-use conversion (Ramalho, et al., 2014). Urban areas continue to expand to (semi-) natural areas outside their boundaries, and a large number of (semi-) natural areas are rapidly lost, split (Hayriye, et al., 2009), degraded or dispersed and embedded in a heterogeneous artificial built-up environment to form islands or island-like isolated "remnant habitats" (Fernández, et al., 2019; Han, et al., 2019). In most areas, urban expansion has destroyed (semi-) natural habitats (i.e., completely converted to the artificial environment), and few cities can retain these (semi-) natural habitats in the process of urbanization (Müller, et al., 2015). The process of habitat loss and fragmentation caused by the gradual transformation of intact habitat patches from natural land cover to impervious surfaces in urbanized areas usually has a large and negative effect on plant community species diversity (Fahrig, 2003; Kowarik & von der Lippe., 2018). Therefore, urbanization is considered to be the main cause of urban biodiversity loss and a serious threat to urban biodiversity conservation (McKinney, 2006). Urban remnant habitats are valuable ecological resources and important potential conservation core areas of species diversity in cities (Mona, et al., 2016; Alvey, 2006; Frank, et al., 2020). They can maintain urban native biodiversity and various ecosystem processes and provide ecological well-being for urban residents (Han, et al., 2019; Guirado, et al., 2006). Due to the complexity of the urban artificial environment, research on the maintenance mechanism of species diversity in urban remnant habitats has become a popular and difficult issue in global urban ecology (Ramalho, et al., 2014) and has attracted extensive attention in the field of urban ecology (Ramalho, 2012; Schlesinger, et al., 2008). However, the scope and mechanism of the effects of urban matrix environment composition and configuration on the plant diversity of remnant habitats and at different levels are still unclear.

The particularity of urban remnant habitats was that they are completely exposed to the heterogeneity of urban artificial built-up environments, and the matrix and the surrounding environment, in terms of both material exchange and spatial relationships, are relatively complex. In particular, the mutual influence between different landscape types and functions and changes in landscape structure and function of the influence of remnant habitat are complex and diverse (Patarkalashvili, et al., 2017; Shi, et al., 2020). Most previous studies have used the "gradient method" to explore how urbanization factors such as distance from urban centres and population density affect biodiversity in urban substrates (Kinzig, et al., 2005; Malkinson, et al., 2018). Several studies have also shown that the urban species richness had an obvious urban gradient effect (Breuste, et al., 2008; McDonnell & Hahs, 2008). However, other scholars regarded that urban biodiversity patterns (e.g., birds and plants) were influenced by the cultural and economic status of urban residents rather than by population density, distance from urban centres, or time after disturbance (Evan, et al., 2020; Luck, et al., 2009; Hope, et al., 2003). The urbanization gradient can be used as a proxy for causal mechanisms such as disturbance state, pollutant load or predation pressure, but it does not directly affect biodiversity (Kinzig, et al., 2005). To a greater extent, it could depend on the differences in adjacent patch characteristics, landscape fragmentation, Land-use composition, and structural changes in remnant habitats with different urbanization gradients.

Some of the case studies have used indicators of urbanization as potential drivers of urban biodiversity. For example, in a study on urban plant diversity in Wuhan, China, Yan et al. (2019) showed that urban impervious surface area was an important indicator that can be used to effectively measure the impact to urban plant diversity. When the proportion of urban impervious surface area exceeds 40%, urban plant diversity declined sharply. Hayriye et al. (2009) analysed the impact of accelerated urbanization on open space protection in the Phoenix Metropolitan Area of Arizona, USA, using time series and three indicators of matrix effect, isolation and connectivity, and the results showed that increased Land-use intensity adjacent to the reserve may increase the edge effect and reduce the habitat value of the inner or core habitat area. De Souza et al. (2020) used fractional Brownian motion to study how patterns of dynamic habitat loss and fragmentation affected the level of biodiversity in an ecosystem, and the results showed that both patterns of habitat loss and environmental heterogeneity affected species distribution patterns. Ramalho et al. (2014) evaluated the impact of urban fragmentation on plant species richness in 30 Banksia remnant habitats in Perth, Australia, the results showed that the impact of rapid urban fragmentation on residual vegetation was great and complex, and these effects may take several decades to show a significant relationship. Fahrig et al. (2003) showed that multiple mechanisms may lead to positive or negative landscape scale responses to habitat fragmentation and may change with environmental change. Studies on the effects of urbanization on plant diversity in Africa, Europe and Asia have confirmed that patch size and adjacent Land-use type were important factors determining plant species composition and richness, but the direct or indirect effects of disturbance mechanisms and surrounding environmental changes may be different (Frank, et al., 2020; Guirado et al., 2006; He, et al., 2019).

Additionally, other scholars have begun to explore the potential relationship between urbanization and species diversity on a spatial scale. Fernández et al. (2019), using a multitemporal and spatial scale approach, assessed the effects of urban matrix vegetation patterns on the primary productivity of natural heritage habitats in 10 cities in Santiago (Chile), the results showed that the primary productivity of all remnant natural habitats decreased, and this decrease was spatially related to the change in vegetation cover in the surrounding urban matrix within 900 m and was more strongly related to the composition of the matrix. Peng et al. (2019) found that, during the urbanization process, landscape units with a radius of 600–700 m and different land uses had the most appropriate spatial scale range for the conservation of native plant diversity in the study on the optimal landscape

pattern for the conservation of native plant diversity in Shunyi District, Beijing. Planchuelo et al. (2020) analysed urban matrix characteristics (e.g., impervious surface area, average floor area) within a 500-m radius around endangered plant species in Berlin, Germany, and revealed the negative impact of urbanization dynamics in Berlin (increase in the impervious surface) on the survival of endangered plant species. Although studies have revealed the potential relationships between some urbanization indicators/predictors and urban biodiversity patterns at different spatial scales, there is no unified and optimal methodological indicator to measure and evaluate the impact of urbanization development on urban biodiversity in all regions (Yan, et al., 2019). Therefore, the selection of appropriate urban matrix drivers and spatial scales could make it easier to collect data and accurately predict or reflect the effects and mechanisms of urbanization on plant diversity in remnant habitats.

The Karst area in southern China, centred on the Guizhou Plateau, is the most typical, complex and abundant Karst area in the world, as well as the largest and most concentrated ecologically fragile area (Wang, et al., 2015). Due to the special geomorphological form of solitary peaks and peak forest, in the process of urban expansion in this area, a large number of Karst hills of different scales were left as islands or island-like (hemi-) natural remnant habitats in the artificial built-up heterogeneous urban environment, formed the Karst "urban remnant hills" (URHs) habitat and the landscape mosaic of "city among the hills, hills in the city". The spatial form of the Karst hilly city embedded with the hills not only creates a unique city style but also forms the precious remnant ecological resources of the urban hills in the Karst hilly city (Ren, et al., 2018). Thus, this area provides an ideal research place for the ecological study of remnant habitat in an artificial urban environment.

Guiyang, located in the middle of Guizhou Province, is a typical Karst hilly city with a large number of URHs in the built-up area of the central urban area. In this study, 15 URHs in the urban built-up area of Guiyang were selected as the research object, and four indicators of urban matrix characteristics, namely PTIA, Land use, *VC* and *FI*, were adopted to explore the following questions: 1) Are there any correlations between the urban matrix characteristics and the plant diversity at different levels of the remnant hills? 2) If there is a correlation between the two, what are the main influencing factors of the characteristics of the urban matrix on the plant diversity of the remnant hills? and what is the scale effect? 3) Are the responses of plant diversity at different levels to the characteristics of the urban matrix in the remnant hills consistent?

2. Materials And Methods

2.1. Study area

This study was carried out in the central urban area of Guiyang (106°07'-107°17'E, 26°11'-26°55'N) (Fig. 1), which is located in the hinterland of the Karst region in central Guizhou, the middle of the Yunnan-Guizhou Plateau, and the watershed zone between the Yangtze River and the Pearl River. The landform belongs to the Karst hilly basin area dominated by Karst solitary peaks and peak forest (Wang, et al., 2015). The zonal vegetation in the area is subtropical humid evergreen broad-leaved forests with abundant plant resources in history (Zhang, et al., 2015). In the 1980s, the total built-up area in the central urban area of Guiyang was only 22.19 km², due to the topography of the closed Karst basin, as well as the restriction of backward economic development and a low construction level. By 2018, the total built-up area in the central urban area of Guiyang was 368.39 km², an increase of 16.6 times in 30 years. According to statistics, the permanent resident population in 2018 was 4.8819 million. The remnant hills in the built-up area are mostly scattered in the heterogeneous urban matrix environment in the form of small, fragmented and isolated. In fact, most of the URHs at the beginning of being surrounded into built-up area still retained a large patch area, as the densification inside the city gradually approaching to the URHs, they are

occupied and divided into smaller patches or completely devoured, this process has not yet stopped(Fig. 2). Furthermore, there is little or no protection and management of the URHs, and the number and area of the patches are decreasing rapidly. The ecological environment is fragile and has obvious spatial heterogeneity (Mu, et al., 2020); thus, it is necessary to protect these special URH habitats .

2.2. Selection and sampling design of URHs

The URHs were divided into 3 scales: large ($\geq 10\text{ hm}^2$), medium ($3\text{--}10\text{ hm}^2$) and small ($\leq 3\text{ hm}^2$). Five URHs of each type were randomly selected, and a total of 15 URHs were taken as research objects (Table 1). Sample plots were set according to the four-direction method (east, south, west and north), extending from the top to the foot of the each hill. Large and medium-sized URHs included 3 plots in each direction, while small URHs included 2 plots in each direction, each with an area of $30\times30\text{ m}^2$, and a total of 143 survey plots were included. Five investigation quadrats were set up in each plot according to the following criteria: tree ($10\times10\text{ m}$), shrub ($3\times3\text{ m}$) and grass ($1\times1\text{ m}$). The interval between each quadrat was no less than $3\text{--}5\text{ m}$, and the quadrats were nested. A field investigation was conducted from July to October 2019 and from July to October 2020. The species name, number, height, DBH and canopy width of the trees,, the species name, height, canopy diameter and the number of trees of shrubs (including small trees), and the herbaceous species name, plant number and coverage in each quadrat were recorded. Based on the survey results, a database of plant-related information and community characteristics was constructed in Excel. Considering that the response of plants at different levels to disturbance may be different in urban continuous disturbance, therefore, four species diversity indexes (Shannon-Wiener index (H'), Margalef species richness index (R), Simpson index (D) and Pielou index (JH) were calculated for the whole plant diversity and the plant diversity at different levels namely trees, shrubs and herbages(Ma,1995). Classification of native species refered to the China Plant Science Data Center (<https://www.plantplus.cn/cn>) and “Flora of Guizhou”.

Table 1

Guiyang URHs basic information table								
Large			Medium			Small		
Number	Area/hm ²	District	Number	Area/hm ²	District	Number	Area/hm ²	District
L1	10.19	Wudang District	M1	4.05	Wudang District	S1	1.86	Baiyun District
L2	10.52	Guanshanhu District	M2	4.36	Yunan District	S2	2.57	Wudang District
L3	11.23	Yunan District	M3	5.59	Nanming District	S3	1.85	Nanming District
L4	14.01	Nanming District	M4	4.99	Huaxi District	S4	2.89	Huaxi District
L5	17.40	Huaxi District	M5	3.83	Wudang District	S5	1.46	Baiyun District

2.3. Classification of landscape types

The 2018 Pleiades high-resolution satellite image (0.5 m spatial resolution) of the study area was obtained as the basic data source for buffer analysis and urban matrix analysis. According to the Classification of Land Use Status

(GB/T21010-2017) and based on the ArcGIS software platform, landscape types were divided into two categories: construction land and non-construction land. Construction land was further divided into residential land (R), public management and public service land (A), commercial service facilities land (B), industrial land (M), logistics and storage land (W), transportation facilities land (S), public facilities land (U) and green land (G). The non-construction land was further divided into cultivated land (E21), woodland (E22), grassland (E31), water area (E1), natural mountain (EG) and unused land (E32). The spatial attribute database was established for the research area.

2.4. Urban matrix characteristic indexes

In this study, four urban matrix characteristics (PTIA, Land use, VC , and FI) were selected to explain the potential effects of urban matrix composition and structural complexity on URH plant community species diversity (Yan, et al., 2019; Hayriye, et al., 2009; Wu, 2007). The calculation was as follows:

$$PTIA = (BZT_{PTIA} / BA) \times 100\%$$

In the formula, the percent total impervious area of the buffer zone (BZT_{PTIA}) refers to the sum of the land area of 7 types: R, A, B, M, W, S, and U. Buffer area (BA) refers to the total area of all land types in the buffer zone.

$$VC = (BZT_{VC} / BA) \times 100\%$$

In the formula, the total vegetation cover of the buffer zone (BZT_{VC}) refers to the sum of 6 land uses: G, E21, E22, E31, E1, and EG. Buffer area (BA) refers to the total area of all land types in the buffer zone.

$$FI = P_i / S_i$$

where P_i is the number of patches of landscape i , and S_i is the total area of landscape i .

2.5. Urban matrix characteristic indexes

Since multiple (potential) ecological processes affected by the urban matrix landscape structure occur at different spatial scales, their scope of influence and relative importance may vary with the size of the landscape (Smith, et al., 2011). In this study area, in order to quantify the potential effects and spatial scale effects of the above matrix indicators on URHs plant diversity at all levels, based on Arcgis10.2 Multiple Ring Buffer tools, the foot lines of 15 sample hills were used as baselines, 20 annular buffers were generated at 100 m step length of, with a maximum buffer width of 2000 m. The buffer zone was superimposed with the landscape type attributes of the study area established in Sect. 2.3 to calculate the urban matrix characteristics of the buffer zones.

The landscape surrounding each sample hill was assessed in terms of the landscape metrics given in Sect. 2.4, and they were calculated for each buffer zone in each of the 15 URHs.

2.6. Urban matrix characteristic indexes

Pearson correlation analysis was used to detect the significant relationships between the four diversity indices and the four urban matrix indices, and between the diversity indices and the urban matrix indices, and a multiple linear regression model was established. The correlation and significance of urban matrix characteristic indices on the plant diversity at different levels in the URHs were compared to try to find the most suitable urban matrix characteristic factors and influence scale range to explain URHs plant diversity in Karst hilly cities. Data analysis was performed using Microsoft Excel and SPSS 19.0 software.

3. Results

3.1. Species composition, structure and diversity of URH plant communities

In total, 581 plant species belonging to 456 genera and 150 families were recorded in this survey. Among them, 347 species belonging to 295 genera and 112 families were recorded in large URHs, and 220 native and 127 alien species were recorded. A total of 333 species belonging to 279 genera, 105 families, 226 native species and 107 alien species were recorded in medium-scale URHs. A total of 383 species belonging to 308 genera, 128 families, 238 native species and 145 alien species were recorded in small-scale URHs. There was no significant difference in the average number of families, genera, species, native species and alien species and in the mean species number of trees, vines and herbs, but there was a significant difference in the shrub layer among the three scales of URHs, and decreasing with the increase in scale as follows: small URHs (35) > medium URHs (32) > large URHs (25) (Fig. 3).

There were significant differences in all levels plant diversity among the three scale types of URHs, showing that the overall plant diversity of different scale URHs was medium URHs > small URHs > large URHs, the plant diversity of trees and herbs of different scale URHs were large URHs > medium URHs > small URHs, and the shrub plant diversity of different scale URHs showed a trend of small URHs > medium URHs > large URHs (Fig. 4).

3.2. Effects of urban matrix characteristics on plant diversity in URHs

3.2.1 Influence of PTIA on plant diversity indices at different levels in the URHs

There were significant spatial scale effects on the effect of buffer zone PTIA to overall plant diversity indices of all scales URHs. The width of buffer zone of best-fitting relationships between of PTIA and overall plant diversity indices was 1400 m, 1600 m and 100 m for large, medium and small URHs respectively, and the overall plant diversity indices showed significant positive correlations with PTIA (Fig. 5).

The diversity indices of trees were negatively correlated with PTIA in the 1500 m buffer zone of large URHs, 900 m buffer zone of medium URHs respectively, but was positively correlated with PTIA in 600 m buffer zone of small URHs. There were significantly positive correlation between the diversity indices of shrub and PTIA in the 100 m buffer zone of large URHs and in the 1700 m buffer zone of medium URHs respectively, but not correlation with PTIA of buffer zone of small URHs. The diversity indices of herbs was negatively correlated with PTIA in 100 m buffer zone of medium URHs, but had no significant correlation with PTIA of buffer zone of large and small URHs (Fig. 5).

3.2.2 Impact of Land-use type on overall plant diversity and plant diversity indices at all levels in URHs

The overall plant diversity of large URHs was positively correlated with residential land R. The overall plant diversity of medium URHs was negatively correlated with Land-use types A, G, E21, and E1. There was a significant negative correlation between the overall plant diversity of small URHs and the E32 Land-use types (Fig. 6).

The responses of plant diversity indices of different levels of URHs in different scales to Land-use types were different. Large URHs tree diversity indices were negatively correlated with R, E1, and E31; shrub diversity indices

was negatively correlated with E1; and herbs diversity indices were positively correlated with G and E1 and negatively correlated with E21 and E22. The tree diversity indices of medium URHs were negatively correlated with M, and shrub diversity indices were positively correlated with E22 and negatively correlated with A and E1, but herbs diversity was not significantly correlated with Land-use type. There were a significant positive correlation between the diversity indices of tree and shrub and E32 in small URHs and a significant negative correlation between herb diversity indices and EG and E32 (Fig. 8).

3.2.3. Effects of VC on the species diversity of URH plant communities

The results showed that there was no significant correlation between overall plant diversity indices in all URHs and VC in any scale buffer (Fig. 7).

There were significant differences in the spatial response of plant diversity indices at different levels to buffer VC in URHs of different sizes. Among them, the herbs diversity indices of large URHs were significantly negatively correlated with VC in the 100 m buffer zone. There was a significant positive correlation between the diversity indices of shrubs of medium URH and VC in the range of 300 m. There was a significant negative correlation between the diversity indices tree and shrub of small URHs and VC at 700 m and 1800 m, respectively. There was no significant correlation between the diversity indices of trees and shrubs of large URH and VC in any scale, as well as trees and herbs of medium URH and herbs or small URH (Fig. 7).

3.2.4. Impact of urban substrate FI on overall plant diversity and plant diversity at different levels in URHs

Figure 8 showed that there was no significant correlation between buffer FI and overall plant diversity indices in large- and medium-sized URHs. However, there was a significant negative correlation between buffer FI and the overall plant diversity of small URHs within 200 m.

Figure 8 shows the relationship between plant diversity at different levels of URHs and FI in buffer zone. Result showed that: there was no consistency in the spatial scale response of plant diversity at different levels of URHs to FI of buffer zone, there was a significant positive correlation between the shrubs diversity of large URH and FI within 400 m buffer zone, a significant positive correlation between tree diversity and FI at 1600 m in medium URHs and a significant negative correlation between shrub diversity and FI at 200 m, a significantly negative correlation between the diversity indices of trees and shrubs of URHs and FI in the range of 100 m.

3.2.5 Multiple linear regression analysis of urban matrix characteristic indexes and URHs for overall plant diversity and plant diversity at different levels

According to the regression simulation results (Fig. 9), PTIA, Land use, FI and VC were the important driving factors for explaining and predicting the effects of urban matrix on plant species diversity of URHs. The overall plant diversity of URHs was significant linear relationship with PTIA and Land use but no significant correlation with FI, VC. However, there was a significant linear relationships between plant diversity at all levels of different scales URHs and the four indices. The diversity of trees, shrubs and herbaceous plants in large and medium-sized URHs and the diversity of trees and shrubs in small URHs were both influenced by the superposition and coupling of double or multiple driving factors. Herbaceous diversity of only small URHs was affected by a single driver of Land use.

4. Discussion

4.1 Species composition and diversity of URH plant communities

Previous studies have shown that patch size was a key determinant of species diversity but may differ due to direct or indirect impacts of human activities on urban environments (Guirado, et al., 2006). The results of this study showed that although patch area was one of the factors that explained the plant diversity at different levels URHs, but the relationship was weak. There was no significant difference in the plant community composition and structure of URHs in different scale. Medium URHs could maintain higher overall plant diversity, large URHs could maintain high tree and herbaceous diversity, while small URHs showed higher shrub diversity. The urban artificial environment is characterized by continuous and repeated interference by human factors (Zarzycki, et al., 2002). In the human-dominated urban matrix environment, the maintenance of species diversity and ecological processes in the remnant habitat are largely determined by the type, degree, and frequency of interference of human activity. In particular, the strong human disturbance caused by the transformation of the landscape basement greatly changed the relative influence of patch size and even topographic factors on the species diversity of the remnant habitats (Matlack, 1993). Therefore, considering patterns of plant diversity in patch characteristics alone is not enough to explain the potential effects of other disturbances.

4.2 PTIA and plant diversity at various levels of URH

The PTIA is an important indicator to measure the urban environment and urbanization degree. Some scholars have confirmed that PTIA had a negative impact on the plant diversity in urban area (Yan, et al., 2019; Peng, et al., 2019). A study by Planchuelo et al. (2020) on the impact of urbanization dynamics on endangered plant species in Berlin also showed that 36% of endangered plant species were locally extinct within 10 years with increase of PTIA. In contrast, the results of this study showed that PTIA had a positive impact on the overall plant diversity of all scale URHs in the range of 100–1600 m. In addition, the effects of PTIA on plant diversity at different levels of URH of different sizes were significantly different in the range of 100-1700m (for example, tree diversity of large and medium-sized URHs was negatively correlated with PTIA, while shrub diversity was positively correlated). The complicating factors that explain this result may be follows: (1) URHs were mostly surrounded by transportation networks and residential areas, which are more conducive to plant propagation or pollen spread to some extent. (2) There is a phenomenon of park utilization in URHs of different scales, and the artificial introduction and planting of garden ornamental plants (though most of them are probably alien species) provide a good growth environment and conditions. (3) The phenomenon of reclamation and cultivation by the surrounding residents exists in most of the URHs. To provide good illumination and growth conditions for crops, not only were the upper trees and shrubs cut down, but herbicide was also used to remove the herbaceous plants, which increased the probability of the introduction or invasion of alien species. These factors suggest that rational planning management may be beneficial to maintaining a high level of plant diversity (Muratet, et al., 2008). However, excessive human disturbance would change the disturbance mechanism between the habitat environment and adjacent substrates, leading to differences in the responses of plant diversity at different levels to the environment.

4.3. Land use and URM overall plant diversity and plant diversity at different levels

The urban matrix is a complex mosaic composed of different landscape units. Matrix type is an important component of the landscape background, especially in human-dominated urban landscape environments (Vandermeer & Carvajal, 2001; Kupfer, et al., 2006). The landscape structure formed by different Land-use types and

their configurations can significantly shape and regulate the composition and diversity of plant communities (Walz, 2015). The results of this study showed that Land-use composition in 1600 m width buffer zone significantly affected the plant diversity at all levels in URHs, but the correlations were significantly different. Similar to the results of Sect. 3.2, residential and industrial Land-use types may have positive impacts on plant diversity, while non-construction Land-use types such as woodland, cultivated land, and grassland may have negative impacts; moreover, they may be influenced by multiple Land-use types at the same time. This result also proved that the composition and structure of land cover and land use on a small scale space are highly complex and dynamic (Luck & Wu, 2002). The complex urban matrix mosaic was formed by the superposition and interaction between the Land-use types of Karst hilly cities and the topography of Karst basin. The high connectivity of impervious surface land uses might lead to the superposition effect of a single land use type on URHs plant community, or lead to different land use between the mechanism of action of offset each other, which might lead to differences in the results. Additionally, different Land-use types have different effects on the integrity of remnant habitat and the change degree of habitat conditions and have different effects on plant communities. Moreover, differences in adaptability and anti-disturbance ability of different plant community structures and species characteristics to urbanization disturbances might lead to different results.

4.4. VC and URH overall plant diversity and plant diversity at all levels

Of course, not all urban matrix factors have positive or negative effects on URH plant community species diversity. The results of this study showed that *VC* had no significant correlation with the overall plant diversity of URHs of different areas within the buffer radius of 2000 m. Further analysis of the potential effects of buffer *VC* on plant diversity at all levels of different URH showed that: there were significant differences in the response of plant diversity at different URHs levels to *VC* within the buffer range of 100–1800 m. In some areas, the composition and structure of matrix vegetation cover can play an effective role in regulating the negative impacts of fragmentation on biodiversity in remnant habitats (Ruffell, et al., 2017; Brunbjerg, et al., 2018). In contrast, some studies have shown that there is a quadratic relationship between urban matrix vegetation cover and neighbourhood age, but there is not a significant positive correlation until approximately 45 years (Grove, et al., 2006; Troy, et al., 2007). This result suggests that improving substrate quality by increasing vegetation cover in a short period may not be a useful strategy to maintain or protect the species diversity and ecosystem integrity of URH plant communities.

4.5. FI and plant diversity at different levels of URHs

Although the impacts of landscape fragmentation on the plant communities in remnant habitats are diverse and complex, it doesn't necessarily have a direct impact (Ramalho, et al., 2014). In this study, we found that buffer *FI* had no significant effect on the plant diversity of large and medium URHs. However, there was a negative effect between buffer *FI* and overall plant diversity in small URHs at 200 m buffer. It might be the time-delay effects of fragmentation on plant diversity in the remnant habitats. Generally, remnant habitats with larger areas, better landscape connectivity, and long-lived species, might need a longer time to respond to fragmentation, while those with smaller areas might have a quick response in shorter time to fragmentation (Planchuelo, et al., 2020). The rapid development of urbanization in Guiyang began almost 30 years ago, so it is not clear to what extent and spatial scale the overall plant diversity of large and medium-sized URHs would be affected by fragmentation. These answers could be revealed only after long-term observation and recording. Further analysis of the effects of fragmentation on the plant diversity at different levels of URHs showed that fragmentation in the range of 1600 m was correlated with the trees and shrubs diversity of URHs. However, there was no significant correlation between buffer fragmentation and herbs plant diversity of URHs. These results indicated that different remnant habitats and

different plant community structures had different responses to dynamic changes in the urban matrix. At present, Guiyang city is in a stage of rapid urban expansion and internal densification. Long-term and continuous direct human activities have caused vegetation degradation in this area for a long time, and there are serious ecological problems, such as soil erosion, soil reaction, and rock exposure (Shen, et al., 2020). Under the synergistic effect of internal habitat conditions and external urban matrix changes, plant diversity at all levels might easily change with disturbance, even if the patch area is relatively large.

4.6. Spatial scale dependence of overall plant diversity and plant diversity at different levels in URHs

Since multiple (potential) ecological processes affected by the urban matrix landscape structure occur at different spatial scales, their scope of influence and relative importance might vary with the size of the landscape (Smith, et al., 2011). Chase et al. (2018) regarded that biodiversity was multidimensional and scale dependent, and the scale effect of one influencing factor does not well predict the scale effect of another factor. Both natural factors and human drivers could affect or significantly change biodiversity at different scales in multiple ways. The plant diversity of URHs was influenced by the superposition and coupling of double or multiple urban matrix indices at the 1600 m scale. However, the influence range and relative importance of different urban matrix indices on plant diversity of URHs were significantly different with changes in the substrate environment and disturbance mechanism. In addition, the diversity of different level plant had different responses to urban spatial forms at different spatial scales. Some responded to environmental changes at a small scale (100–400 m), while the others responded to urban spatial forms at a larger scale (1600–1800 m). These results further supported the conclusion of Sadler et al. (2006) that "different taxa/species respond to urban spatial forms at different spatial scales", and also indicated that the overall plant diversity of URHs, the influencing factors and the spatial scale range of plant diversity at all levels were complex and diverse.

According to the results of this study and the theory of "extinction debt" and previous studies, it is known that the response of remnant habitat plant communities to urbanization might be significantly negative correlation after decades or longer. The results of this study confirmed the previous hypothesis that the response of plants at different levels to urban matrix disturbance was different when the URHs were continuously disturbed by human beings. Therefore, future studies should consider the impact of dynamic changes of landscape patterns in urban matrix (historical evolution of land use) on plant diversity in remnant habitats. Therefore, future studies should consider the impact of dynamic changes of landscape patterns in urban matrix (historical evolution of land use) on plant diversity of remnant habitats, and refine the effects of intensity and frequency of human activity interference (engineering construction, engineering facilities, slope hardening and greening, cultivation, cemeteries, etc.) within remnant habitats on plant communities and different levels of plants. It is suggested that in the process of urban development and construction in the future, multiple influencing factors and mechanisms should be considered for different remnant habitats in the time dimension and different spatial scales.

5. Conclusions

The ecological processes and community structure changes of URHs in the artificial built-up environment of Karst hilly cities are more complex due to the combined effects of multiple factors on different scales. The complexity of the influencing factors increase the challenge of URHs protection and management. Based on this study, it is concluded that (1) There was a significant positive correlation between the overall plant diversity of URHs of different sizes and PTIA in the surrounding urban matrix within 1600 m. The overall plant diversity of URHs of

different scales was significantly correlated with single or multiple Land-use types, but the impact effects were significantly different. There was no significant correlation between *VC*, *F* and URHs overall plant diversity. (2) There was a significant linear relationship between plant diversity at all levels of different scales URHs and the four urban matrix indices. In addition, the herbaceous plant diversity of small size remnant hills showed a significant linear relationship with only Land use, but in other URHs, the plant diversity at all levels was affected by double or multiple factors at the range of 1800 m. Plant species diversity and community structure of URHs of different scales in hilly Karst cities are extremely complex and diverse under the combined action of multiple factors and multiple scales. Therefore, in the process of urban green space ecology system planning, urban spatial planning and urban renewal, the multiple influence factors and their mechanism to different scales URHs at different scales should be considered to provide a scientific reference and to help protect remnant habitat plant community species diversity.

Declarations

Ethics approval and consent to participate

All authors have read and approve this version of the article, and due care has been taken to ensure the integrity of the work. No part of this paper has published or submitted elsewhere.

Consent for publication

All authors have read and consented to the article being submitted or published in the journal.

Availability of data and materials

The acquisition, processing and writing of data and materials in this paper were conducted in accordance with the author's guidelines and did not pose any threat to personal or national security.

Conflicts of Interest / Competing Interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Na Tang, Yu Bao, Xinyu Ma and Guangfu Wei. Writing-review and editing by Zhitai Wang. The first draft of the manuscript was written by Na Tang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

All authors have read and approve this version of the article, and due care has been taken to ensure the integrity of the work. No part of this paper has published or submitted elsewhere. No conflict of interest exists in the submission of this manuscript.

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Tables

Table 1 Guiyang URHs basic information table								
Large			Medium			Small		
Number	Area/hm ²	District	Number	Area/hm ²	District	Number	Area/hm ²	District
L1	10.19	Wudang District	M1	4.05	Wudang District	S1	1.86	Baiyun District
L2	10.52	Guanshanhu District	M2	4.36	Yunan District	S2	2.57	Wudang District
L3	11.23	Yunan District	M3	5.59	Nanming District	S3	1.85	Nanming District
L4	14.01	Nanming District	M4	4.99	Huaxi District	S4	2.89	Huaxi District
L5	17.40	Huaxi District	M5	3.83	Wudang District	S5	1.46	Baiyun District

Figures

Figure 1

Area of study Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

URH being eroded and destroyed by urbanization (left) and completely surrounded by impervious urban matrix (right) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Analysis of the species composition of the URH plant community in the built-up area of Guiyang city

Figure 4

Analysis of the species diversity characteristics of the URH plant community in the built-up area of Guiyang city

Figure 5

Relationship between plant diversity of URHs and PTIA in buffer zone

Figure 6

Relationship between plant diversity of URHs and Land use in buffer zone

Figure 7

Correlation analysis between land use in the buffer zone and plant community structure and species diversity in URHs

Figure 8

Relationship between plant diversity of URHs and FI in buffer zone

Figure 9

Linear regression simulation analysis