

Response of Plant Diversity of Urban Remnant Mountains To Surrounding Urban Spatial Morphological Features: A Case Study In Guiyang of Guizhou Province, China

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Research Article

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Abstract

To explore response of plant diversity of urban remnant mountains (URMs) in the built environment to the surrounding urban spatial morphological features during urban expansion, 9 typical URMs were selected as the research objects, the spots in each sample URM were set by the combination way of the slope direction and slope position, a total of 99 plots for plant diversity survey. Taking the edge line of the sample URMs as the datum, annular buffer zones were set successively outward at step lengths of 100 m, a total of 16 buffer zones with a total width of 1600 m. The spatial morphological characteristics within each buffer zone were analyzed by using spatial syntax, then the relationship between spatial morphological characteristics and plant diversity of URMs were analyzed. The results indicated that: ① There were significant differences in plant diversity among different URMs, and there were also significant differences in plant diversity in different slope positions or different directions of the same URM. ② The spatial morphology around the URMs was different, and the road density (D_n) around the URMs tended to be stable with the increase of spatial scale. The space syntactic indices were positively linearly correlated with the buffer width. ③ On the whole, there was a positive correlation between spatial morphology indices and URMs plant diversity indices. Connectivity (C_i), integration (I_i) and road density (D_n) were more comprehensive and specific, and the correlation increased with the increase of spatial scale. However, choice (C), connectivity (C_i) and mean depth (MD_i) were not comprehensive and unstable in response to plant diversity indices. ④ There were differences in the response of different slope positions or different directions of the same URM to the spatial morphology. The response intensity of plant diversity in different slope position of URMs to urban spatial morphology was the foot of mountain > mountainside > mountaintop; There was a weak and unstable relationship between road density (D_n) and plant diversity indices in different directions. The results of this study could provide important scientific basis for the conservation and management of urban plant diversity and urban planning and construction.

Introduction

According to the statistics and projections of the United Nations, by 2050, the urban population will increase by 2.5 billion and the urbanization rate will reach 63 percent. The growth of the world's rural population has been slow since 1950 and is expected to peak within a few years (United Nations, 2018). It can be said that the spatial distribution structure of human economic and social activities has entered a new stage dominated by urban areas. As an important part of urban ecosystem, urban plant diversity provides a series of ecological, economic and social benefits for cities, such as protection of urban natural ecology and native plants, mitigation of urban heat island effect, purification of urban pollution, beautification of urban environment, etc. (Bolund & Hunhammar, 1999; Miller, 2005; Sushinsky, 2011). However, with the continuous advancement of urbanization, the invasion of alien species, the extinction of native species and the homogeneity of urban species composition have led to the decline of plant diversity and other problems (Miller, 2006; McKinney, 2002). In the context of rapid urbanization, how to

protect and maintain urban plant diversity and make it play a powerful role in the ecosystem has become a hot issue in current research.

Urbanization process is the process of land use type transformation, and land use transformation is the main driving factor affecting urban biodiversity (Zhu et al, 2019). Previous studies have systematically elucidated the effects of urbanization on the distribution patterns of biodiversity, exotic/indigenous plants, and plant diversity homogenization at different scales, discussed that the effects of urbanization on plant diversity are mainly land use change, climate change, urban landscape pattern change, urban social economy activity, such as urban environment complex changes caused by the factors of urbanization (Mao et al., 2013). For example, Wirth et al. (2020) monitored the flora of Hungary for 70 years and found that woody plants or alien annual and biennial plants increased with urbanization. Vakhlamova et al. (2014) used the urban-rural gradient method to study changes in plant species composition and richness in Kazakhstan, Siberia, and found that plant diversity increased with distance from the center, at the same time, also affected by land use type and building coverage within the 500 m radius. In addition, study has shown that the combined effect of urbanization and changes in agricultural land use has changed the composition of plant species. Some studies have taken the percentage of total impervious surface area (PTIA) as the key predictor of urban plant diversity in Wuhan, China. Urban plant diversity decreases with the increase of the percentage of total impervious surface area (PTIA). When PTIA reaches 40% or above, plant diversity declines sharply (Yan et al, 2019). The effect of landscape pattern on plant diversity has been verified in many studies. Peng et al. (2019) discussed the impact of landscape metrics on native plant diversity in Shunyi District, Beijing, and determined that landscape units within a radius of 600-700m in Shunyi District, Beijing, were the most optimal spatial scale range for the conservation of native plant diversity. Besides, increasing temperatures in cities encourage the migration of thermophilic plants to urban areas, and adaptations to the environment may make these plants more aggressive, increasing the probability of alien plant invasion (Parmesan & Hanley, 2015). And a study by Čeplová et al. (2017) on 45 Central European settlements showed that species composition was significantly more influenced by local habitat conditions than by urban size, highlighting the important role of habitat conditions on biodiversity of native and alien plant communities. In addition, social, economic and cultural factors are also closely related to urban plant diversity (Monteiro et al., 2013). However, few studies have considered the potential impact of urban spatial morphology on urban plant diversity.

Urban spatial morphology is the spatial arrangement of various urban elements in urban region (Feng & Zhou, 2003), it determines the distribution of people's social and economic activities in the city, and then affects other urban elements, such as transportation, land use function and form of architecture, etc., and ultimately affects the formation and evolution of urban morphology (Han et al, 2018). There is a correlation between urban spatial morphology and environmental change (Barau et al, 2015; Yang et al., 2019). At present, some scholars have explored the relationship between urban spatial morphology and urban vegetation, for example, Bigsby et al. (2014) studied the relationship between tree cover patterns with urban morphology (housing density, parcel size), socioeconomic factors (education, income, lifestyle characteristics), and historical heritage in Baltimore, Maryland, and Raleigh, North Carolina, found that

urban morphology is more effective than socioeconomic factors in predicting tree cover patterns at parcel and neighborhood scales, and concluded that urban morphology as the main driving factors of urban tree cover patterns, may lead to the homogenization of tree canopy. Road system is the carrier of urban spatial morphology, and changes in road density and landscape pattern can explain variables related to land use, land cover and environmental factors (Hawbaker et al, 2005). Cai et al. (2013) found that an increase in road density is often accompanied by an increase in construction land area and a decrease in forest coverage, leading to a significant decline in ecosystem health. Some studies also proved that the non-native perennial grass cover is significantly positively correlated with the road density across the urban landscape (Zeeman et al., 2018). Christen et al. (2009) investigated nonnative plant species along roads in deciduous forest sites in southeastern Ohio, USA, and discovered that roads are both habitats and a conduit for population expansion, its rate of spread depends on the life history of the individual species, these results demonstrated that the hierarchical process of regional invasion, with different dispersal mechanism in different spatial scales. therefore, on the basis of the influence of urban spatial morphological structure on urban plant diversity, it is of great significance to explore whether urban spatial morphology has scale effect on plant diversity, which is of great significance to urban spatial planning and plant diversity conservation.

The city is a complex of spatial arrangement and combination of various elements, and species diversity is affected by multiple factors. Island biogeography is no longer applicable to urban landscapes isolated by natural/semi-natural ecosystems (Niemela, 1999). In mountainous areas of central Guizhou province, China, a large number of natural or near-natural Karst mountains have constantly been embedding into the artificial urban environment in the process of urban expansion, forming a special urban spatial form of "city among the mountains, mountains in the city", and the URM embedded in urban artificial built environment are the main carrier of urban native biodiversity. We asked: 1) Whether urban spatial morphology has an impact on the plant diversity of URM? 2) If the impact exists, what are the factors and the range of the influence? In this study Guiyang, a typical mountainous city in central Guizhou, was taken as the research area. 9 URM in the built-up area were selected as the research object, and the plant diversity in the URM in Guiyang, the urban spatial morphological structure around the URM, and the response relationship between them were studied to explore the relationship between urban spatial morphological structure and plant diversity and their spatial scale dependence, so as to provide a scientific basis for urban spatial planning, biodiversity conservation and maintenance, and eco-city construction.

Materials And Methods

2.1. Study area

Guiyang (26°11' – 26°55'N, 106°07' – 107° 17'E) is located in central Guizhou Province, in the middle of the Yunnan-Guizhou Plateau and in the watershed zone between the Yangtze River and the Pearl River. The landform belongs to the hilly basin area and is mainly composed of karst mountains and hills, the whole terrain is high in the southwest and low in the northeast, with an altitude of about 1100 m, it

belongs to subtropical humid mild climate, the annual mean temperature is 15.3 °C, the annual mean total precipitation is 1129.5 mm. By the end of 2018, it has jurisdiction over 6 districts, 3 counties and 1 county-level city, with a permanent resident population of 4.8819 million and an urban population of 3.6824 million, with an urbanization rate of 75.43%. The built-up area of the central urban area is 368.68 km², and there are 527 Karst remnant mountains in the urban area, with a total area of 44.94 km², and 416 small and medium-sized URMs smaller than 10 hm². This study takes the central urban area of Guiyang as the study area (Fig. 1).

2.2 Subjects

In order to explore the influence of urban spatial morphological structure on plant diversity of URMs, on the basis of the above studies (Shi & Yang, 2019), using kernel density as the index for screening and excluding area differences, 9 sample URMs were selected in central urban area of Guiyang according to the clustering results (Fig. 2), They were NM1 (Sports Park), NM2 (east of Youfang), NM3 (northeast of Guizhou Vocational and Technical College), NM4 (east of Xintian Primary School), NM5 (west of Yanshanyazhu), NM6 (northeast of Dashanghai Residential Area), NM7 (southeast of Meichengxindu), NM8 (Guizhou University), and NM9 (Dongmeng Residential Area). The basic information of the sample URMs is shown in Table 1.

Table 1
Statistical table of basic information of sample urban remnant mountains (URMs).

URMs ID	Location	Kernel density grade	Size (hm ²)
NM1	Guanshanhu	4	4.38
NM2	Guanshanhu	5	4.29
NM3	Guanshanhu	3	4.80
NM4	Wudang	5	4.54
NM5	Wudang	3	3.85
NM6	Wudang	5	3.33
NM7	Huaxi	5	3.30
NM8	Huaxi	4	3.83
NM9	Huaxi	5	3.80

2.3 Research Methods

2.3.1 Plant community sample plot setting, investigation and plant diversity index determination

12 plots were set for each URM according to the method of direction + slope positions (i.e., the sample plot was set respectively at the mountaintop mountainside and mountain foot of south,east, north and west four directions), each plot was 30 m × 30 m. 5 tree quadrates of 10 m × 10 m were set in each

sample plot and five shrub quadrates of 3 m × 3 m were set in each tree quadrate according to the “5 points method”, randomly set 1 m×1 m herbs quadrate in shrub sample. Some sample plots that could not be sampled were removed because the mountain was mined and the rock was exposed seriously and the degree of human disturbance was serious. A total of 99 sample plots were effectively investigated in the whole region. The species name, number of each species, DBH, height and crown width of the trees in each tree quadrate, the species name, number of each species and average coverage of shrubs in each shrub quadrate and the species name, plant number and average coverage of herbs in each herbs quadrate were recorded. At the same time, the geographic coordinates, elevation, slope direction and other information of each quadrate were measured by hand-held GPS.

The Shannon-Wiener index (H'), the Simpson index (D), the Pielou index (Jh) and the Margalef index (R) were used to describe plant species diversity:

$$H' = -\sum P_i \lg(P_i) \quad (1)$$

$$D = 1 / \sum P_i^2 \quad (2)$$

$$Jh = H' / \ln S \quad (3)$$

$$R = (S-1) / \ln N \quad (4)$$

Where N is the total number of individuals; S is the total number of species; And \ln is the natural log base e ; $P_i = n_i / N$, where n_i represents the number of individuals of the i th species.

2.3.2 Measurement of urban spatial morphological structures

Taking the high-resolution Pleiades satellite image (0.5 m spatial resolution) of Guiyang in 2018 as the image data source, through image enhancement, geometric correction, map projection and other preprocessing, visual interpretation of the preprocessed remote sensing image was performed, and the spatial attribute database of the study area was established based on ArcGIS 10.2 software. Taking the edge line of the sample URMs as the baseline, annular buffer zones were successively set outward at step lengths of 100 m. A total of 16 buffer zones were set, with a total width of 1600 m. The road information in each gradient buffer zone around 9 sample URMs were extracted and processed in relevant software (Auto CAD, UCL Depthmap) to obtain the road axis models around 9 sample URMs in Guiyang, which can be used for subsequent measurement of relevant indices of spatial morphology..

Space syntax and road density were used to characterize the urban spatial morphological structure. Space syntax characterizes the relationship between space and its organization and the interaction between human society through a quantitative description of the spatial morphological structure of human settlements, including architecture, settlements, cities and even landscapes (Hillier, 1993). Road density is the main index to reflect the activity degree of regional traffic, economy and commerce, and it is also an important index to explain the urban spatial morphological features. These space formed by the development of human society will inevitably affect the plant diversity in the space. In this study, relevant

spatial morphological structure indices in space syntax and road density index were selected to explore the influence of the spatial morphological structure of buffer zones on the plant diversity of URM. The selected indices are as follows (Table 2):

Table 2 Spatial morphology indices and its meaning

Index	Equation	Description
Choice (C)		It measures the number of times an element to be passed through on all shortest topological routes in any other two spaces in the system. The higher the choice of an element, the greater the potential for crossing traffic in the space.
Connectivity (C_i)	$C_i = k$	k is the number of nodes directly connected to node i . In the actual space system, the higher the connectivity of a space, the better the permeability of the space.
Integration (I_i)	$I_i = \frac{n-2}{2(MD_i-1)}$	n is the total number of nodes in the network (number of axes); MD_i is the mean depth, which represents the overall spatial attribute of a specific area and reflects the accessibility of a space. The higher the integration of space, the higher its accessibility.
Control ($Ctrl$)	$Ctrl = \sum \frac{1}{C_i}$	k represents the number of nodes connected to the i th node; the C_i represents the connectivity of the road i , the degree of control of a spatial node over the intersected space, and the degree of aggregation between local spaces.
Mean depth (MD_i)	$MD_i = \frac{D_i}{n-1}$ $D_i = \sum_{j=1, j \neq i}^n dij$	D_i is the global depth value, n is the total number of nodes (number of axes) in the network; d_{ij} is the depth value from i to j , and MDI is a relative depth value. The greater the value is, the less convenient the spatial node is.
Road density (D_n)	$D_n = \frac{L_n}{A_n}$	D_n is the road density of region n (unit: km/km ²), L_n is the total road length of region n (unit: km), and A_n is the area road density of region n . D_n reflects the density of regional traffic lines, the greater the value, the more convenient the traffic connection in this region will be.

2.3.3 Data processing

Excel 2019 and SPSS 22.0 software were used for statistical analysis. One-way ANOVA and least significant difference method (LSD) were used to compare the differences of plant diversity indices in different directions and different slope positions at the significance level $p = 0.05$. The bivariate analysis method of correlation was used to compare the relationship between flora species diversity indices and urban spatial morphology indices. Origin 2019 software was used for mapping, and the data in the chart were mean \pm standard deviation.

Results

3.1 Spatial differentiation of URM's plant diversity

3.1.1. Plant diversity in different URM's

Variance analysis showed that Shannon-Wiener, Margalef, Simpson and Pielou indices were significantly different among different URM's (Table 3). Further multiple analysis results showed that Shannon-Wiener index and Margalef index were significantly different among URM's, while Simpson index and Pielou index were not significantly different among URM's. The plant diversity index of NM1 was the highest, while that of NM9 was the lowest.

Table 3
Plant diversity in different URM's.

URMs number	H'	D	Jh	R
NM1	$1.150 \pm 0.116a$	$0.884 \pm 0.047a$	$0.360 \pm 0.028a$	$11.013 \pm 1.943a$
NM2	$1.016 \pm 0.125c$	$0.849 \pm 0.060a$	$0.349 \pm 0.032ab$	$8.133 \pm 1.778cd$
NM3	$1.087 \pm 0.112b$	$0.876 \pm 0.046a$	$0.356 \pm 0.026ab$	$9.109 \pm 1.711bc$
NM4	$0.938 \pm 0.246d$	$0.784 \pm 0.168b$	$0.321 \pm 0.067c$	$7.871 \pm 2.223d$
NM5	$1.055 \pm 0.161bc$	$0.851 \pm 0.069a$	$0.341 \pm 0.039b$	$9.580 \pm 2.127b$
NM6	$0.998 \pm 0.127c$	$0.851 \pm 0.051a$	$0.347 \pm 0.028ab$	$8.053 \pm 2.023cd$
NM7	$0.864 \pm 0.168e$	$0.783 \pm 0.088b$	$0.318 \pm 0.039c$	$6.317 \pm 1.770e$
NM8	$1.043 \pm 0.136bc$	$0.859 \pm 0.060a$	$0.351 \pm 0.033ab$	$8.746 \pm 1.993c$
NM9	$0.785 \pm 0.194f$	$0.714 \pm 0.141c$	$0.279 \pm 0.053d$	$6.087 \pm 1.811e$

3.1.2. Plant diversity in different directions

Figure 3 shows the result of comparing the characteristics of plant diversity in different directions of the 9 URM's. Except for NM2 and NM3, there were significant differences in plant diversity indices among different directions of the other URM's. NM1 had significant difference except Margalef index, and Shannon-Wiener index, Simpson index and Pielou index of eastern region were the highest and significantly ($p < 0.05$) higher than western. The Shannon-Wiener, Simpson and Pielou indices of the western position of NM4 were the lowest and significantly ($p < 0.05$) lower than those of other positions, and the Margalef index was significantly ($p < 0.05$) lower than the east and south orientation. The Shannon-Wiener, Simpson and Pielou indices in the northern region of NM5 were the highest and significant ($p < 0.05$) than other directions, and the Margalef index was significantly ($p < 0.05$) higher than the east and west. The Shannon-Wiener and Margalef indices in the northern region of NM6 were the highest and significant ($p < 0.05$) than other directions, Simpson index was only significantly ($p < 0.05$) higher than the east direction, and the Pielou index had no significant difference among different directions. Shannon-Wiener and Simpson in the northern region of NM7 were the lowest and significantly

($p < 0.05$) lower than the east and west orientation, Margalef and Pielou indices were only significantly ($p < 0.05$) lower than the east direction. The Margalef index of NM8 in the north was the highest and significantly higher than that in the south and east, but there was no significant difference in the plant diversity indices in different directions. The Shannon-Wiener, Simpson and Pielou indices in the northern region of NM9 were the highest and significantly ($p < 0.05$) higher than the east and south orientation, and the Margalef index was only significantly ($p < 0.05$) higher than the east direction.

3.1.3. Plant diversity in different slope positions

Comparing the characteristics of plant diversity in different slope positions of the 9 URMs, the results are shown in Fig. 4. There were significant differences in plant diversity index among different slope positions of NM1, NM2, NM4, NM7 and NM9, but no significant difference among other URMs. NM1 mountainside Simpson index and Pielou index were significantly ($p < 0.05$) higher than the foot of mountain, and Shannon-Wiener and Margalef indices had no significant difference among different slope positions. The Pielou index at Piedmont of NM2 was significantly ($p < 0.05$) higher than mountaintop, other indices had no significant difference; Shannon-Wiener, Margalef, Simpson and Pielou indices at Piedmont of NM4 were significantly ($p < 0.05$) higher than the mountainside, showing that foot to mountain > mountaintop > mountainside. In NM7, only the Margalef index at Piedmont was significantly ($p < 0.05$) higher than that on the mountainside, but there was no significant difference in other plant diversity indices among different slope positions. In NM9, only the Margalef index at Piedmont was significantly ($p < 0.05$) higher than that at mountaintop, and other plant diversity indices had no significant difference among slope positions.

3.2 Urban spatial morphological features around the sample URMs

Regression analysis was used to detect the relationship between the surrounding spatial morphology indices and buffer gradient of 9 URMs. Figure 5 shows that there were differences in the spatial morphology around the URMs, and the road density (D_n) tends to be the same with the increase of spatial scale. The space syntax index was generally in a positive linear correlation with the buffer gradient, but the choice (C) fluctuates with the increase of spatial scale.

3.3 Response of plant diversity in URMs to surrounding urban spatial morphology

3.3.1. Plant diversity and surrounding urban spatial morphology indices

According to the correlation analysis of URMs plant diversity and various indices of the surrounding urban spatial morphology (Fig. 6), plant diversity indices were significantly correlated with most indices of the surrounding urban spatial morphology. The choice (C) was positively correlated with Shannon-Wiener, Simpson and Pielou indices only at 600 m, but not with Margalef index. The choice (C) was positively correlated with all plant diversity indices in the range of 1100 m, and negatively correlated with them beyond 1100 m. Connectivity (C_i) was positively correlated with Shannon-Wiener, Pielou and Margalef indices at 400 m, and then fully responded with each index at 600 m. At the 400 m scale, the integration (I_i) showed a response relationship with each index of plant diversity, then a fault appears at 600 m, and at the 700 m scale, only had a significant positive correlation with Shannon-Wiener and

Margalef indices, and showed a comprehensive response at subsequent scales. The control (*Ctrl*) were positively correlated with Shannon-Wiener, Simpson and Pielou indices at 600m and 800m scales, and only fully responded with each index at 700 m. The mean depth (MD_i) was significantly positively correlated with Shannon-Wiener, Simpson and Pielou indices at 600 m, and significantly positively correlated with Simpson and Pielou indices at 700m. Road density (D_n) was positively correlated with Shannon-Wiener, Simpson, Pielou and Margalef indices, and the response relationship began to appear at 400 m scale, the response of Shannon-Wiener and Margalef indices were more significant with the enlargement of spatial scale, and Simpson and Pielou indices did not continue to respond after 400 m scale, but showed a significant positive correlation after 1400 m.

3.3.2. Plant diversity in different slope positions and surrounding urban spatial morphology indices

There was a response relationship between plant diversity indices and urban spatial morphology in different slope positions of the 9 URMs, and the response intensity showed a trend of foot of mountain > mountainside > mountaintop. The response relationship between choice (C) and plant diversity among different slope positions was mainly concentrated at 600m scale, and the response intensity was the highest at the foot of mountain. The relationship between integration (I_i) and plant diversity at different slope positions began to respond from 400 m, and the relationship at foot of mountain first increased and then decreased with the increase of spatial scale, while the relationship at other two slope positions showed an upward trend; The mean depth (MD_i) was only correlated with the Shannon-Wiener, Simpson and Pielou indices at Piedmont in the range of 400–1200 m; Connectivity (C_i) has a comprehensive response to plant diversity index at Piedmont from 400 m, and has a response with each index at the mountainside from 600 m to 1600 m, and has a response to each index at the mountaintop from 400 m. The control (*Ctrl*) and plant diversity index began to respond at 300 m at Piedmont, and only responded at 600 m at the mountainside and the mountaintop. The response relationship between road density (D_n) and plant diversity at different slope positions all started from 400 m, and the correlation increased with the enlargement of spatial scale, the response relationship between different slope positions was not completely consistent (Fig. 7).

3.3.3. Plant diversity in different directions and urban spatial morphology indices in corresponding directions

There was no obvious relationship between plant diversity and road density (D_n) at different directions in the 9 URMs (Fig. 8). NM1, NM3, NM5 and NM7 have no significant relationship with the road density (D_n) of each gradient. The response relationship of other URMs mainly concentrated in the range of 700 m–1000 m, and the response frequency was relatively high with the Pielou index. Overall, spatial morphology and the URMs plant diversity were significantly positively related to, but the correlation between plant diversity in each directions of different URMs and road density (D_n) was different, NM2 showed negative correlation in the range of 1200 m and positive correlation in the range of 1300–1600 m, NM3 and NM9 were negatively correlated in all gradient ranges, positive correlation between NM5 and NM7 in the range of 1000 m, and negative correlation outside the range.

Discussion

4.1 Effects of slope positions, directions and anthropogenic disturbance on plant diversity

Plant community is an ecological complex by long-term mutual adaptation between different plants and the environment in a certain region (Bo et al., 2016), and the plant diversity is closely related to topographic factors. At the regional and landscape scales, slope position and direction, as important topographic factors, affect plant community structure, species composition and species diversity characteristics by regulating spatial redistribution of solar radiation, water and soil resources (Shuai et al., 2017; Zhang et al., 2018; Paudel & Vetaas, 2014). In this study, we found that plant diversity of different slope direction of URM was significantly different. On the whole, the southern part of the URM had the lowest plant diversity among all directions, which may be related to sufficient sunshine time but fast water evaporation, serious soil weathering, serious soil erosion and difficult nutrient enrichment, so the harsh environment inhibited vegetation growth, leading to the lowest plant diversity in the southern part of the mountain. Mountain plant diversity exists significant difference between different slope positions, NM2, NM9 plant diversity decreased with slope upward, it conforms to the Karst area topography. The vegetation diversity on the mountaintop was the lowest due to the poor soil, high temperature of direct sunlight, strong wind and poor water retention performance (Jiang et al., 2021). The plant diversity of NM1 was the highest on the mountainside, while that of NM4 was the lowest on the mountainside. Other URM did not show obvious variation patterns, which may be due to the fact that human activities in mountainous cities tend to choose slope sections with better site conditions to reclaim for cultivated land or orchard, and anthropogenic disturbance affects spatial differentiation of mountain vegetation (Ma et al., 2002). It has been confirmed that the species composition, distribution and diversity of plant communities are not only affected by natural environmental factors such as light, soil nutrients, moisture and terrain, but also affected by surrounding human activities and environmental changes (Xu et al., 2014). Guiyang is a city developed under the special Karst landform. The urban spatial morphology with the city and mountain inlaid each other makes the contradiction between people and mountains prominent and human interference strong, so human factors have become the key factors affecting the diversity of plants in urban remnant mountains (Vollstädt et al., 2017). Besides, in the complex urban ecosystem, human socio-economic activities and decision-making behaviors also greatly affect urban biodiversity (Pandey, 2021).

4.2 Effects of urban spatial morphology on URM plant diversity

It was showed that there was a significant correlation between plant diversity of URM and urban spatial morphology, which confirmed that there is some mapping relationship between urban spatial form, social function and ecological environment quality (Liu & Yu., 2012; Desylas & Duxbury, 2001; Alalouch et al., 2019). On the whole, there was a significant positive correlation between plant diversity of URM and surrounding urban spatial morphology, and the responses of plant diversity to connectivity (C_i), integration (I_i) and road density (D_n) were more comprehensive. Therefore, the plant diversity was higher in the urban spatial agglomeration, large flow of people, strong spatial permeability and developed traffic

areas. The reason for this may be that the road network, as a transmission corridor, played a key role in the spread of alien plants in the urban matrix (Carlton & Ruiz, 2005; Von der Lippe & Kowarik, 2008; Zeeman et al., 2018). Also, with the increase of road density (D_n), human entry and interference effects tend to increase (Forman, 2014; Forman & Alexander, 1988). The response of plant diversity to choice (C) and the mean depth (MD_i) was not comprehensive, possibly because the choice (C) expressed the probability of a certain spatial node being selected, which is usually used to measure the traffic potential of commercial roads (Ma et al., 2019). In the small scale buffer zone near the URM, the traffic attraction brought by the increasing choice (C) would promote the material exchange and increase the plant diversity, but on a larger scale, the potential service range of road choice (C) goes beyond the threshold of the attraction of a mountain to surrounding traffic, which attracts the traffic flow around the mountain to other spaces, so that the influence on plant diversity decreases with the enlargement of the space.

On the whole, plant diversity was positively correlated with urban spatial morphology. Locally, there were differences in response to urban spatial morphology at different slope positions and directions of the same mountain. The response intensity of plant diversity to urban spatial morphology on different slope positions of URM was the foot of mountain > mountainside > mountaintop, indicating that the change of human activity intensity from low altitude to the high altitude gradually weak (Sharma et al., 2009), it is confirmed that there was certain correlation between the species richness and management strength and structure characteristics of the road (such as the edge of the road disturbance characteristics) (Pourrezaei et al., 2021). While the response relationship in different directions was not stable, indicating that the same problem has different effects on the ecological factors at different scales (Arteaga et al., 2009).

4.3 Scale effects of spatial morphology

It was clarified that there were significant differences at different scales. Existing studies have shown that the overall spatial morphological structure of the city was significantly negatively correlated with the plant diversity (Xiang et al., 2021), while in a smaller scale, the plant diversity of the mountain had a significant positive correlation with the surrounding spatial morphology. Urban development encroaches on natural green space, making the connected natural green space broken into vegetation patches of different areas. The fragmentation of urban landscape reduces the plant diversity (Kuhn et al., 2004; Heilman et al., 2002). On a local scale, the road system around the mountain may make plant seed spread along the road (Zeeman et al., 2018), and moderate anthropogenic disturbance increases plant diversity in the mountain. At the beginning of the study, we assumed that the spatial morphological threshold of plant diversity change could be found through spatial gradient analysis. The results showed that there was no such threshold, but the response relationship between spatial morphology and plant diversity began to appear at the scale of 400-700m. Mensing et al. (1998) studied riparian biodiversity in the north temperate zone and found that plants, amphibians and birds are affected by land use at 500m and 1000m, and fish respond to land use at larger landscape scales (2500m and 5000m). Studies have shown that landscape indicators in Shunyi District of Beijing play an important role in plant diversity within the range of 600-800m, and it is believed that the radius of 600-700m is the optimal range for the

protection of plant diversity in Beijing (Peng et al., 2019). These findings emphasize that plants and low-mobility species are significantly responsive to urbanization at the medium spatial scale, while high-mobility species are significantly responsive to urbanization at the larger scale when discussing biodiversity response to urbanization (Concepción et al., 2015).

Conclusion

There were significant differences in plant diversity among different URM, and there were also significant differences in plant diversity at different slope positions or different directions of the same URM. Spatial morphology around the URM was different, and the road density (D_n) around the URM tends to be stable with the increase of spatial scale. Space syntactic indices were positively linearly correlated with the buffer gradient. The plant diversity and the difference of spatial morphology were the premise to discuss the response relationship. On the whole, there was a positive correlation between spatial morphology and URM plant diversity. Connectivity (C_i), integration (I_i) and road density (D_n) were more comprehensive and specific, and the correlation increased with the increase of spatial scale. However, choice (C), connectivity (C_i) and mean depth (MD_i) were not comprehensive and unstable in response to plant diversity. There are differences in the response of different slope positions or different directions of the same URM to the spatial morphology. The response intensity of plant diversity and urban spatial morphology on different slope positions of URM was the foot of mountain > mountainside > mountaintop; There was a weak and unstable relationship between road density (D_n) and plant diversity in different directions.

In the future, the planning of urban spatial morphological structure and the planning of plant diversity should be coordinated, the urban land use should be rationally planned, the urban spatial morphology should be optimized, and the urban planning and landscape design should adopt more indigenous plants, reflect the regional characteristics, and strengthen the protection of urban plant diversity. Also, it is necessary to consider the scale-dependence effect, select the appropriate spatial morphology index and consider the influence of various spatial scales, which are different in different parts of the world.

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 Ning Kong. Writing-review and editing by Zhitai Wang. The first draft of the manuscript was written by Ning Kong and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

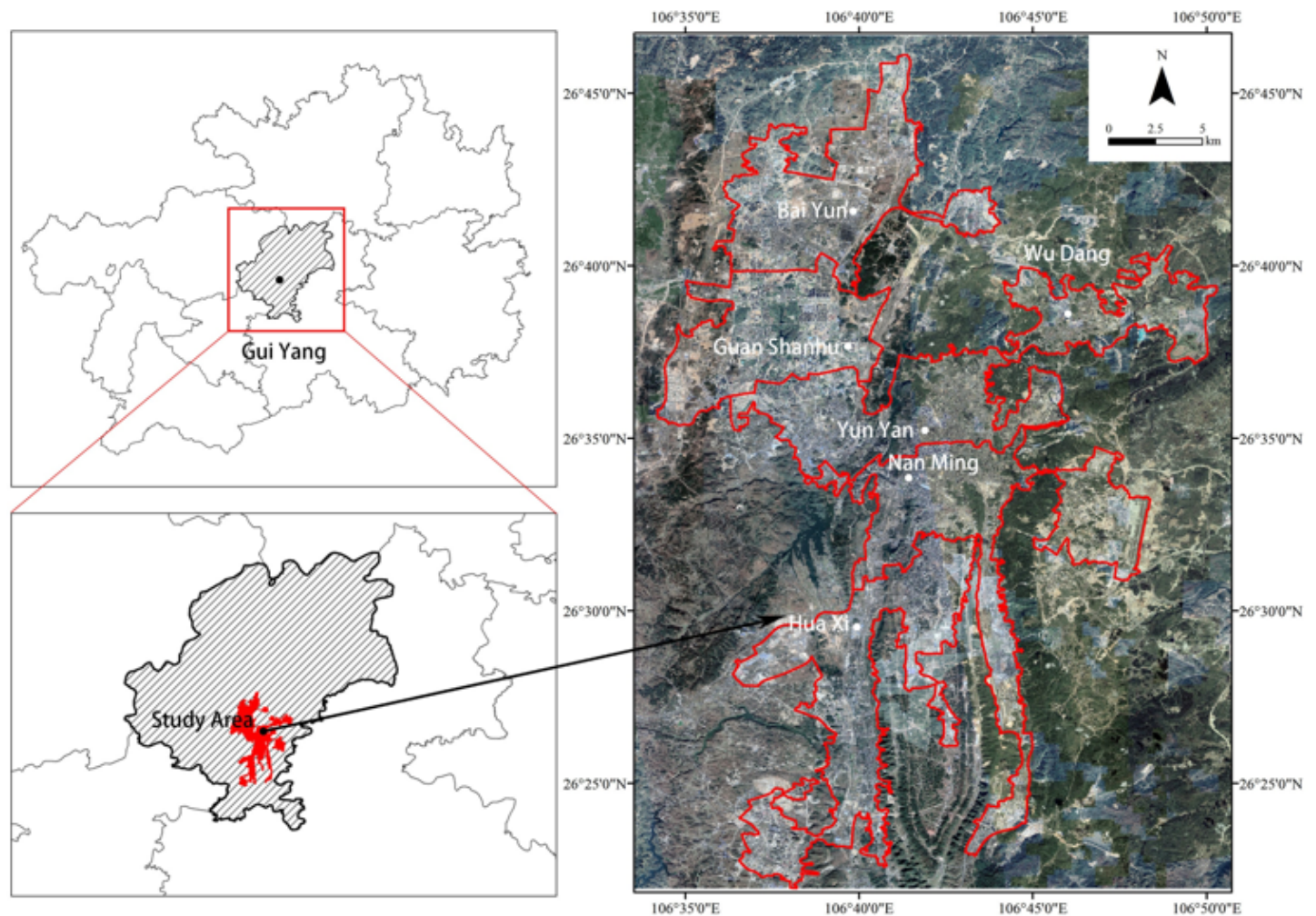


Figure 1

Study area. 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.

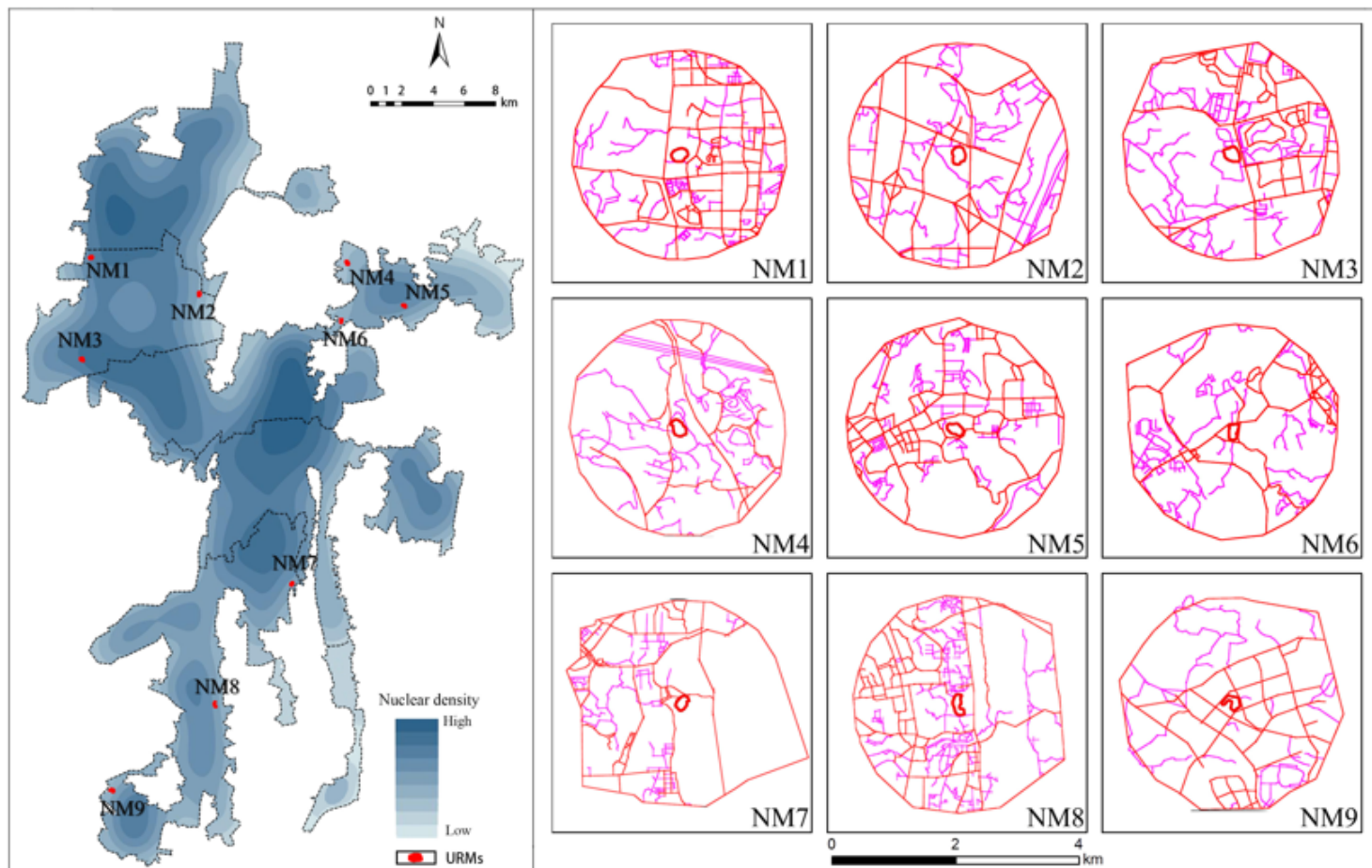


Figure 2

Sample urban remnant mountains (URMs) distribution map. 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.

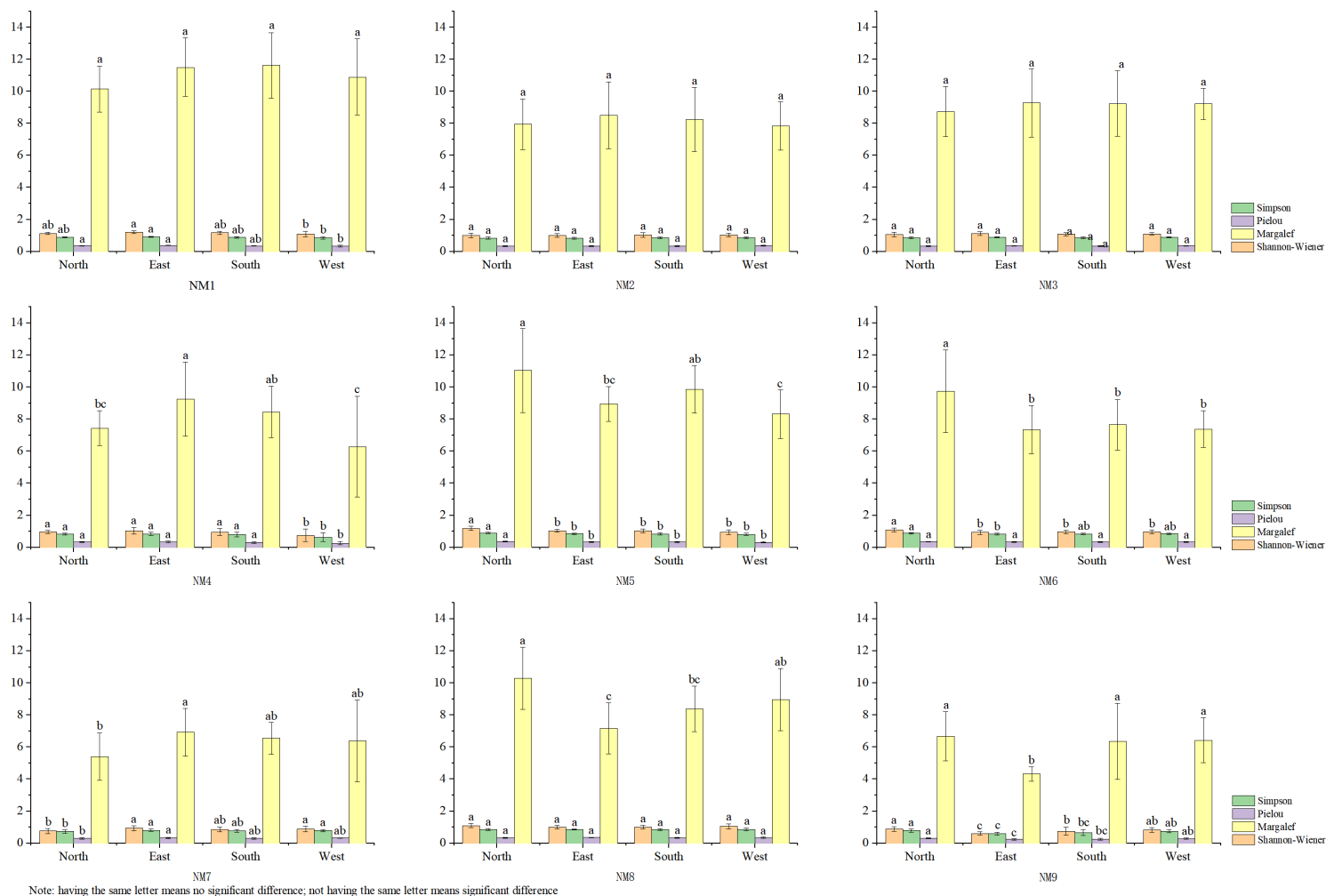


Figure 3

Plant diversity indices in different directions..

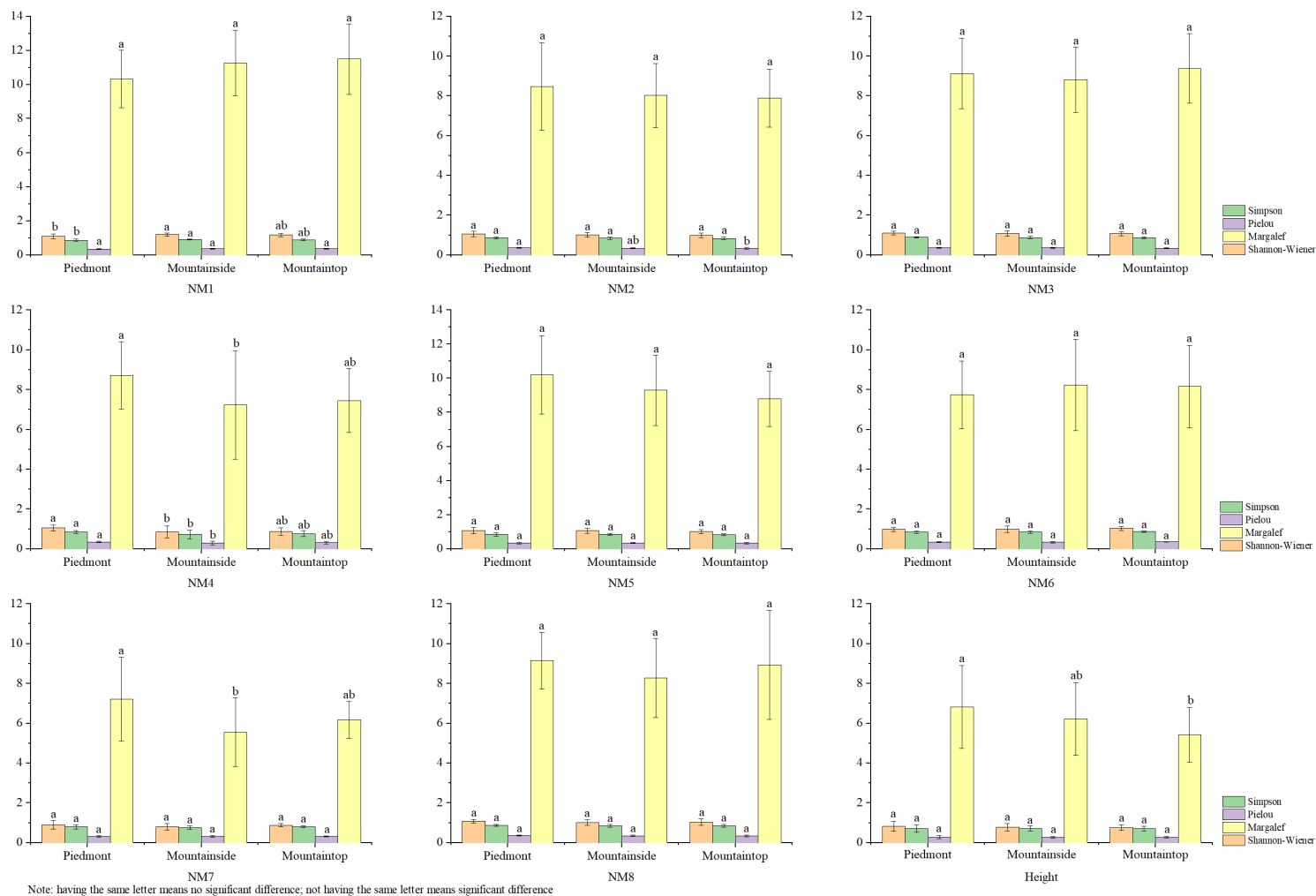


Figure 4

Plant diversity indices at different slope positions.

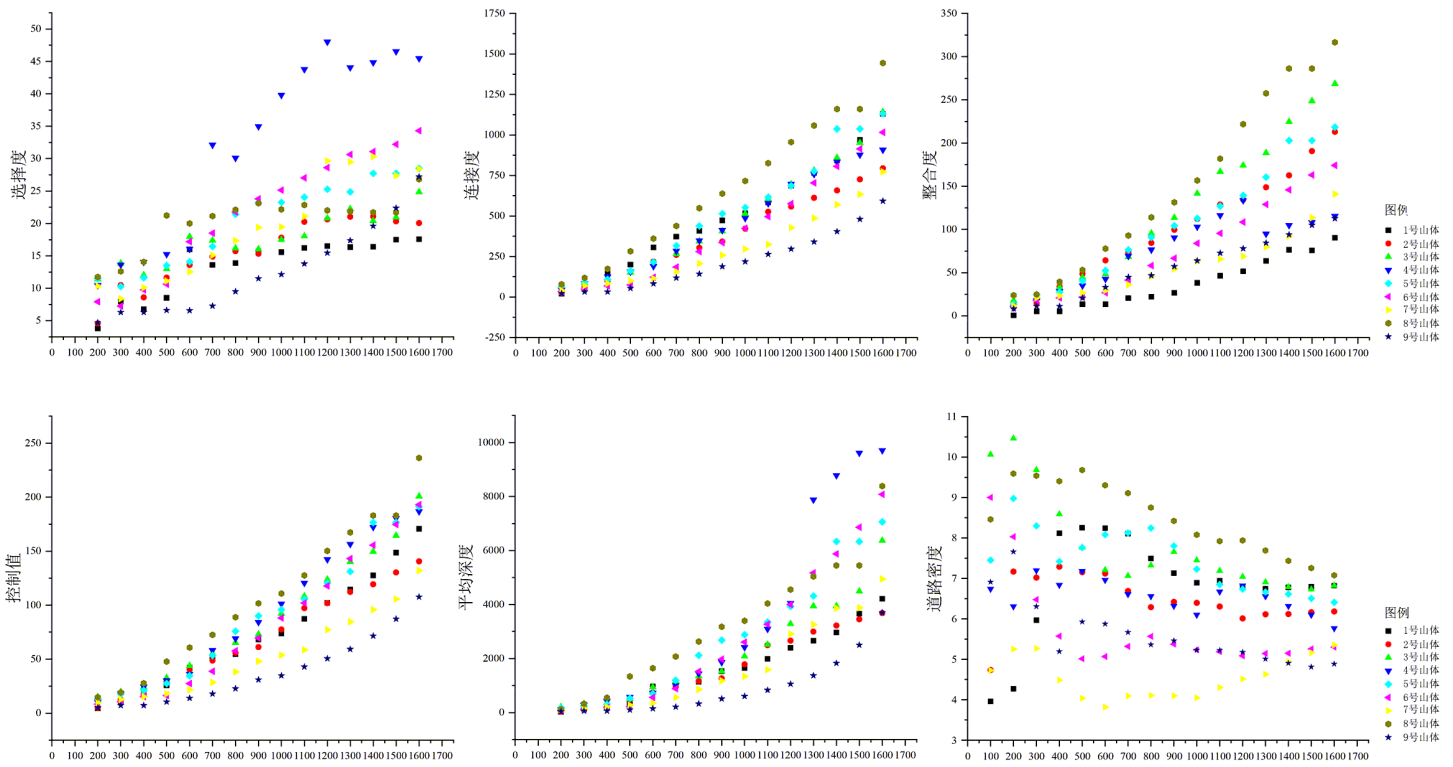


Figure 5

Urban spatial forms under different spatial scales.

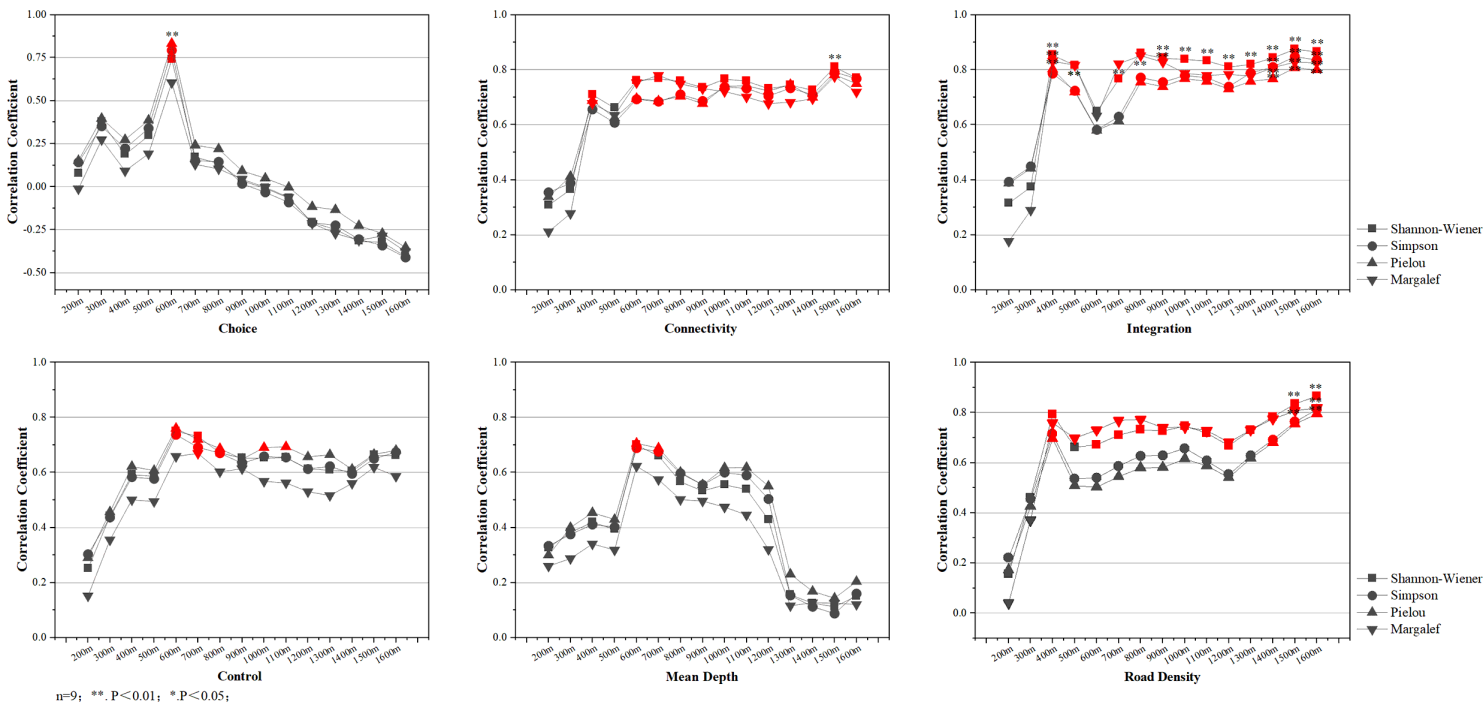


Figure 6

Space syntax and plant diversity correlation coefficient.

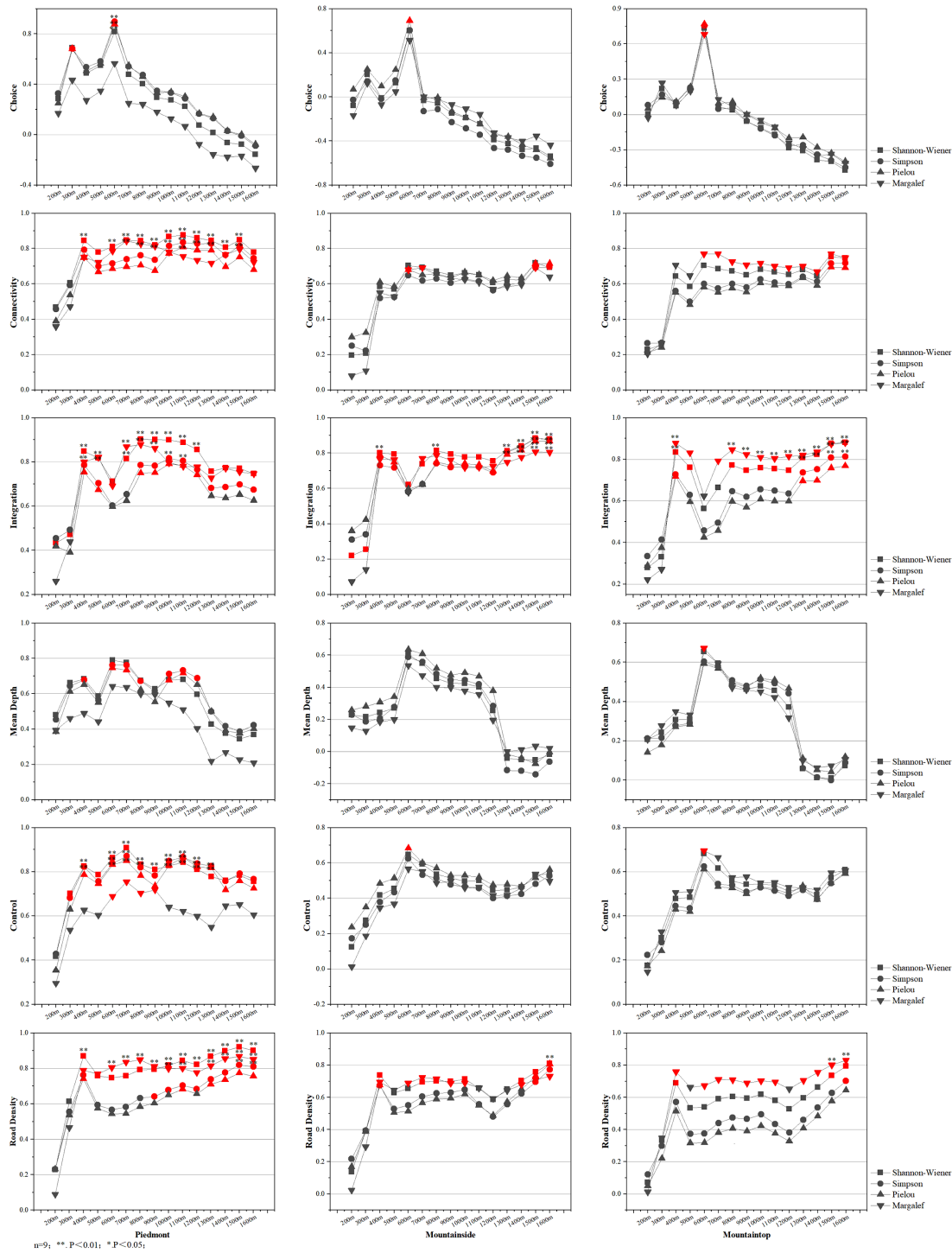


Figure 7

Correlation coefficient between road density and plant diversity at different heights.

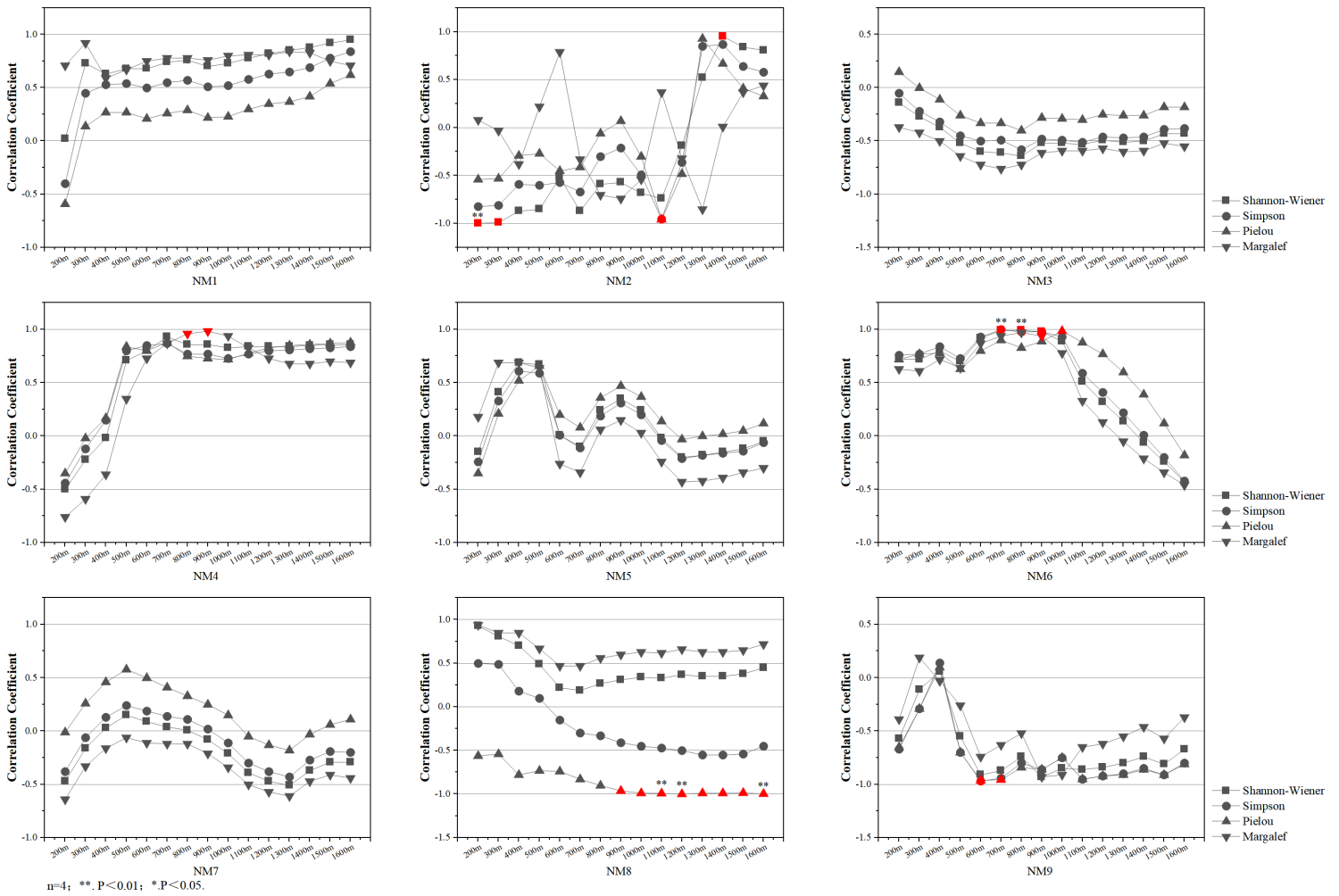


Figure 8

Correlation coefficient between road density (Dn) at different directions and plant diversity at different directions.