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The Impact of Urban Expansion on Plant Diversity Change in Karst Regions of Southwest China

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Abstract: Biodiversity is vital for the integrity and stability of ecosystems and sustainable development. Karst regions of Southwest China is featured for undulating and broken karst terrain as well as high plant diversity. Land use changes induced by the growing population and expanding human settlement have threatened biodiversity preservation in this region. However, the impact of urban expansion on plant diversity remains unclear here. This study focuses on how expanding countryside landscapes affect the recovery rate of plant diversity and demonstrate how urban expansion affects plant diversity conservation in karst regions of Southwest China. In situ biodiversity investigations and multisource remote sensing images were combined to analyze the role of human settlement evolution in the conservation of plant diversity using descriptive statistics and regression analysis. Unmanned vehicle images, historical aerial photographs, and long-term remote sensing images were used to observe the human settlement pattern changes over 40 yr and found that plant diversity is restored faster in countryside ecosystems than in island ecosystems restricted by water. Forests, however, contribute the most to plant diversity conservation in both ecosystems. While the forest area is stable during urban expansion, massive forest patches play an essential role in plant diversity conservation. Arable lands and grasslands shrank but with a fragmenting trend, which was conducive to preserving plant diversity, whereas increased and regularized large patches of built-up areas were not beneficial to plant diversity. Accordingly, forest protection should be prioritized to coordinate future socioeconomic development and plant diversity conservation in karst and broader regions. Furthermore, large built-up patches should be limited, and the irregularity should be improved during urban expansion. Irregular shaped cultivated land and grassland were suggested to promote biological information exchanges as landscape corridors.

Keywords: plant diversity change; urban expansion; countryside landscapes; karst regions; remote sensing; China

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1 Introduction

Plant diversity is a vital basis for maintaining the stability of terrestrial ecosystems and sustaining human survival (Assessment, 2005). Social and economic development, accompanied by drastic land use changes, inevitably leads to urban expansion to fulfill the increasing need for production and human existence (Marques et al., 2019). Many natural ecosystems have been transformed into human-dominated countryside landscapes, including both rural and urban areas, which have induced a series of adverse ecological effects that pro-

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foundly impact plant diversity (Mendenhall et al., 2014; Stuart Chapin III and Díaz, 2020). For example, human-made land use types have prompted a shift in biological populations to tolerate a more arid climate (Williams and Newbold, 2020). The growth of both urban land and arable land has led to a substantial reduction in natural forestland, severely hindering biological information exchange among natural forests (Newbold et al., 2015; Daskalova et al., 2020). The loss of forests also limits the living spaces of birds and other animals that depend on the forest ecosystem (Hadley et al., 2018). However, the expanding countryside landscapes caused by urban expansion do not always have a negative effect on plant diversity. For instance, increasing the heterogeneity of surface landscapes has been determined to improve plant diversity (Fischer et al., 2012; Stein et al., 2014). Hence, it remains unclear how urban expansion will impact plant diversity and how countryside landscape patterns can be correspondingly optimized.

In contrast to human-dominated countryside landscapes, the isolated island landscape, regarded as the natural state of the regional ecosystem, reflects the baseline of the regional ecosystem's evolution from traditional ecological perspectives (MacArthur and Wilson, 1967). Thus, the comparison of island ecosystems and terrestrial countryside ecosystems can effectively reflect the influence of urban expansion on changes in plant diversity throughout the same period. Previous studies have analyzed the impact of agricultural landscapes on the evolution of biodiversity, the living conditions of endemic species and their adaptability after environmental migration, and the comprehensive influence of human activities on rare species through comparisons with island ecosystems (Aitken et al., 2008; Mendenhall et al., 2014; Ocampo-Peñuela et al., 2016). Nevertheless, these studies primarily focus on tropical regions and endemic or rare species (Mendenhall et al., 2013). A recent study has raised the balance between vegetation recovery and human development in islands (Lou et al., 2021). As there is a severe lack of relevant research, current studies lack universal conclusions to support planning suggestions for urban development and biodiversity conservation in broader areas, especially in karst areas, where dense human settlements are distributed that substantially interfere with biodiversity.

Karst regions developed on carbonate rocks account for approximately 10% to 15% of the global total surface area, yet they support water resources for nearly a quarter of the global human population (Ford and Williams, 2007). Because of their unique physical conditions, karst regions feature high spatial heterogeneity and typical biodiversity (Wang et al., 2019). For example, there is limited flat land for urban development in karst regions. Therefore, small-scale but densely distributed human settlements formed in small corrosive depressions have fed large populations (Liu et al., 2018). Additionally, incidental or local rocky desertification has further aggravated the tense human-land relationship, and the rapid urban expansion has already become a severe threat to plant diversity in karst regions (Geekiyanage et al., 2019). For example, the sprawl of urban settlements has seriously encroached on the living space of endemic karst plant species, which have special requirements with respect to water, temperature, and lithology (Nitzu et al., 2018). Urban expansion has also led to the expansion of artificial land use from natural communities, which aggravates rocky desertification in karst areas and seriously damages the local ecological environment (Tong et al., 2016). Thus, analyzing the impact of urban expansion on vegetation restoration and plant diversity change in karst areas is of great significance for biodiversity conservation in widely distributed karst areas worldwide.

Combining multisource remote sensing data, this paper analyzed the impact of urban expansion on plant diversity change by comparing island ecosystems and countryside ecosystems. Karst regions of Southwest China, featuring typical karst plant diversity and highly developed urban areas, were used as the case study. Three questions were raised in this study. 1) How do countryside landscapes affect the vegetation restoration rate? 2) How do various landscape types affect plant diversity in karst areas? 3) How does urban expansion affect plant diversity change? The goal is to clarify the mechanism of plant diversity maintenance by urban expansion and to enrich the application of multisource remote sensing of countryside biogeography theories in karst areas. This paper also provides references and policy recommendations for the rational planning and sound development of countryside landscapes and promotes a balance between urbanization and biodiversity conservation.

2 Materials and Methods

2.1 Study area and sampling sites

The South China karst region is a globally representative area of tropical and subtropical humid karst landforms, and it is one of the 32 global biodiversity hotspots (Myers et al., 2000). The study area of this paper includes two urban watersheds in Guiyang City and the adjacent Hongfeng Lake in the core location of the South China karst region (Fig. 1), which is dominated by karst peaks, dissolved depressions, and plains. Among them, karst peaks are primarily covered by forests and shrubs, while dissolved depressions and plains are covered primarily by arable land and built-up areas. Total forest coverage is high, and human settlements are densely distributed in this area. Guiyang is one of the largest cities in the South China karst region, with the urban area and surrounding rural settlements distributed primarily in two adjacent watersheds, namely, the Maotiao watershed and the Nanming watershed. Hongfeng Lake, located in southwestern Guiyang City, is a typical karst plateau lake, hydrologically connected to the Maotiao watershed. This lake was formed by building an artificial reservoir in the 1950s. After the completion of the reservoir, the original dissolved karst depressions in the Hongfeng area were all submerged, and only the tops of the karst peaks were exposed, forming many isolated islands in the lake.

In this study, 12 sampling sites in the Hongfeng Lake area representing island ecosystems and 14 sampling sites in Guiyang representing countryside ecosystems were systematically selected. The island sampling sites are all isolated islands restricted by waters. The landscape on the islands is dominated by natural vegetation, with bare land distributed on the shores of the island. Natural vegetation in the countryside sampling sites is more luxuriant, but the landscape compositions of the sites are more complex due to more intense human activities. Countryside sampling sites usually include human settlements, so the landscape composition includes land for human infrastructure, arable land, forest, and grassland. Detailed information on the sampling sites is presented in Table 1. Among them, the sampling sites of the island ecosystems include isolated areas experiencing long-term natural restoration (sampling sites 1–3), natural restored islands after short-term human disturbance (sampling sites 4–7), forestland with short-term restoration (sampling sites 8–9), and long-term dis-

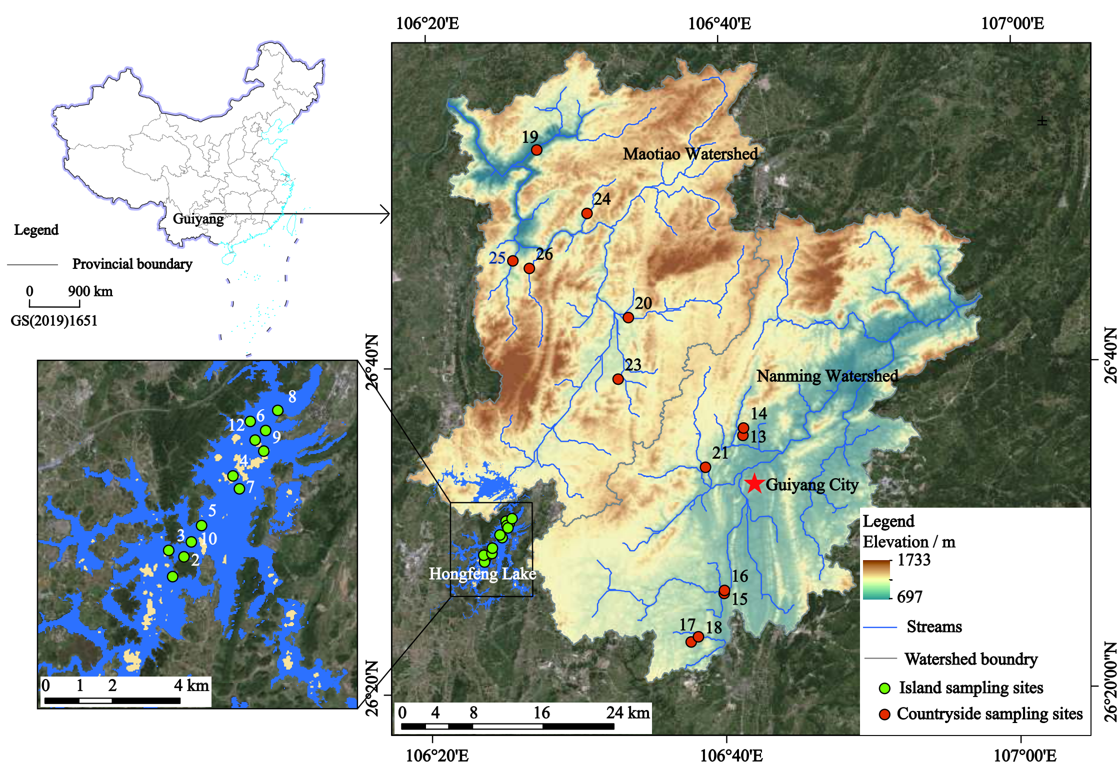

Fig. 1 Location and sampling sites of the urban watersheds in Guiyang and Hongfeng Lake

Table 1 Location and natural restoration time of the sampling sites in urban watersheds in Guiyang and Hongfeng Lake

Sampling sites	Ecosystem type	Longitude / °E	Latitude / °N	Natural restoration time / yr
1	Island ecosystems	106.40	26.47	70
2		106.39	26.47	70
3		106.39	26.48	70
4		106.41	26.50	50
5		106.40	26.48	50
6		106.42	26.51	50
7		106.41	26.49	50
8		106.43	26.51	20
9		106.42	26.50	20
10		106.40	26.48	0
11		106.42	26.51	0
12		106.42	26.51	0
13	Countryside ecosystems	106.69	26.60	300
14		106.69	26.60	300
15		106.67	26.44	80
16		106.67	26.44	80
17		106.63	26.38	50
18		106.64	26.39	50
19		106.46	26.88	20
20		106.54	26.71	20
21		106.65	26.56	20
22		106.56	26.82	20
23		106.55	26.65	20
24		106.52	26.82	20
25		106.43	26.77	0
26		106.45	26.76	0

turbed areas (sampling sites 10–12). The sampling sites in Guiyang include long-term protected primary forests (sampling sites 13–14), protected urban parks (sampling sites 15–16), urban and suburban-rural transition zones (sampling sites 17–18), short-term restoration forests (sampling sites 19–24), and long-term disturbed areas (sampling sites 25–26) (Yang et al., 2021).

2.2 Methods

The research method of this study includes the following steps (Fig. 2). First, the biological information and surface landscape data of the sampling sites were gathered, and the relationship between vegetation restoration and landscape composition was clarified. Second, the plant diversity restoration rates in the different landscape patterns were identified according to the biodiversity and restoration times of the sampling sites. Third, the impact of various landscape types in the countryside ecosystem on plant diversity was explored by comparing the change in plant diversity by different surface landscape combinations. Fourth, the changes in the regional settlement landscape pattern and landscape patch characteristics combined with the impact of various landscape types on plant diversity were analyzed, thus revealing the role of urban expansion on vegetation restoration and plant diversity change.

2.2.1 Sampling and estimation of plant diversity

Surveys of plant diversity were conducted at 26 sites in October 2019, where each sampled site consisted of three 400 m^2 plots (10 m × 40 m, or 20 m × 20 m). The

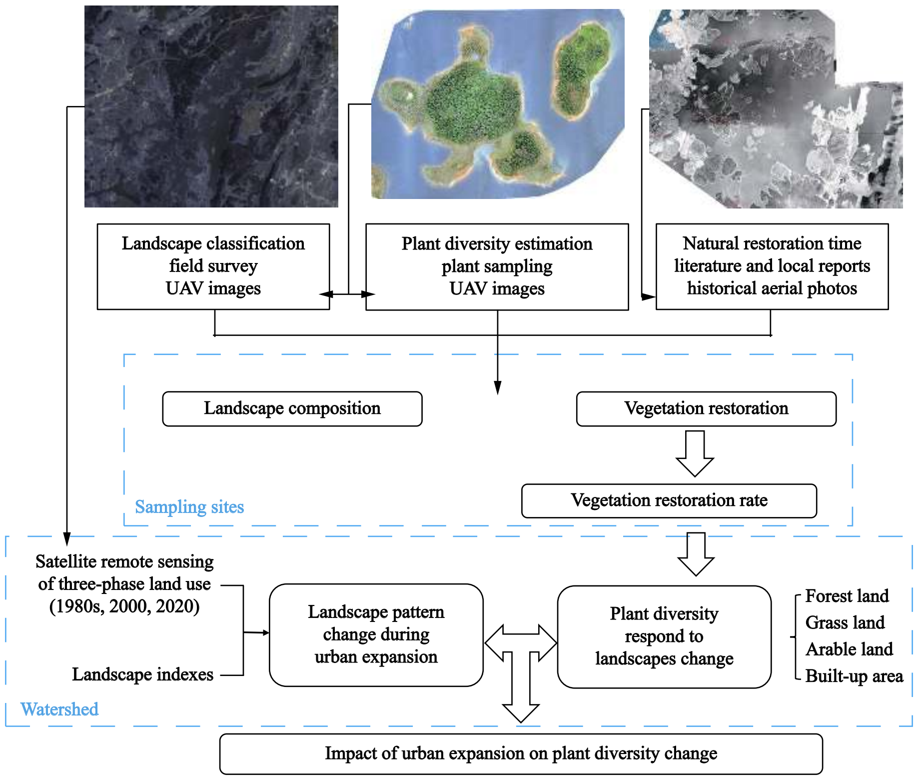

Fig. 2 Flowchart of analyzing the impact of urban expansion on plant diversity change (Unmanned Aerial Vehicle, UAV)

number and abundance of all trees and shrubs were recorded. The tree species richness at each site is a powerful dimension that illustrates plant diversity. The Shannon-Wiener biodiversity index (Shannon and Weaver, 1949), which was calculated to reveal the plant diversity at each site:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \quad (1)$$

where p_i is the proportion of species i at a site and S is the number of species at a site.

Plant beta diversity measures the difference in vegetation species composition among various sampling plots and is expressed as:

$$\beta = \frac{\alpha}{S} \quad (2)$$

where α is the species richness of each sampling site, and S is the total species richness of the survey area. A low value of β index indicates that the species composition is entirely the same among different sites. In contrast, a high value of the β diversity represents an entirely different species composition and no overlap of species among the different sites. A total of 25 species and 12 species were included in the countryside and island ecosystem sampling sites, respectively.

2.2.2 Landscape survey method of the sampling sites

The landscape survey was conducted in a 200-m radius circular buffer at each sampling site using multisource remote sensing images, and in situ aerial images were collected via a small consumer unmanned aerial vehicle (UAV)-DJI Phantom 4 Pro (DJI, China) in October 2019 at each site. A UAV equipped with an ordinary optical camera collected high-resolution true-color ground images. Studies have indicated that the topographic measurement accuracy of the derived UAV images controlled by the Pix4D capture flight control system can attain the centimeter level within the flying height range of 50 to 100 m (Zhang et al., 2018; Yang et al., 2020). During the field survey, the Pix4D Capture flight control system to plan the flight path of the UAVs was used by setting the flight height, flight route, image overlap, and camera angle to ensure that the drone would capture the surface landscape data stably, quickly, and accurately. The UAV aerial images were then processed using the professional image processing software Pix4D Mapper and image point clouds were generated via preliminary processing and air triple encryption to obtain digital orthophoto images (DOMs). ArcGIS 10.4 software (Esri, the United States) was then used to manually interpret the DOM and divide the surface landscape into six categories: forest, grassland, arable land, water area, bare land, and built-up area. Finally, the surface landscapes at each sampling site were further summarized.

In the island ecosystems, historical aerial photos were used to interpret surface vegetation changes and help determine the natural restoration time of vegetation at the sampling site. Specifically, a total of 15 aerial photos of 1∶10 000 in the 1970s acquired from Guizhou Provincial Archives were used, and an Epson Perfection V600 photo scanner was used to convert the images into 1200 dpi digital files. Pix4Dmapper was used to automatically process these digital images according to the tone and texture of the image to obtain the ground orthoimage. Then, using the UAV image as a reference, evenly distributed ground control points were selected to correct the position of the obtained historical DOM in ENVI 5.3 software (Exelis, the United States). The World Geodetic System (WGS) 1984 geographic coordinate system and Universal Transverse Mercator (UTM) 48N projection were used for the DOM.

2.2.3 Statistics of landscape patch changes during urban expansion

The landscape changes during urban expansion in the study area were analyzed using a three-phase (1980s, 2000, and 2020) China Land Use and Land Cover Remote Sensing Monitoring Data (CNLUCC) (http://www.resdc.cn/DOI). The CNLUCC was obtained through human visual interpretation based on Landsat data and is one of the most accurate land use remote sensing products of China. The land was classified into six major types: forest, grassland, arable land, water area, bare land, and built-up area. Landscape indexes were calculated using Fragstat 4.2 software to reveal the countryside landscape pattern change and the statistical characteristics of each landscape type over the past 40 yr (Table 2). The percentage of landscape (PLAND) reveals the proportion of different patch types, with the most significant patch type as the major landscape. Patch density (PD) means the number of patches per 100 ha, revealing the degree of fragmentation and spatial heterogeneity. The largest patch index (LPI) determines the dominant type of landscape and the change in the intensity and frequency of the external disturbance. The larger the LPI is, the larger the most massive patch of the corresponding patch type in the landscape is. The landscape shape index (LSI) reflects the complexity of the overall landscape shape. The larger the LSI is, the more complex the overall landscape shape is.

3 Results

3.1 Vegetation restoration and landscape composition

The landscape composition and the Shannon-Wiener diversity index of the island ecosystem and countryside ecosystem sampling sites in 2019 can be obtained using UAV images and biological survey data obtained in situ (Fig. 3). The landscape of each sampling site in the island ecosystem (sampling sites 1–12) is mainly water, with water barriers between each island and the surrounding land. The island landscape is dominated by forest, grassland, and bare land. In countryside ecosystem sampling sites (sampling sites 13–26), the landscape composition is complex, with various proportions

Table 2 Landscape index characteristics and calculation method

Index	Meaning	Equation
PLAND	The proportion of a specific patch type in the entire landscape	$PLAND = \frac{\sum_{j=1}^{n} a_{ij}}{A} \times 100$ (Equ. (3))
PD	The degree of landscape fragmentation	$PD = \frac{N}{A}$ (Equ. (4))
LPI	The impact of the largest patch on the landscape	$LPI = \frac{\max a_{ij}}{A} \times 100$ (Equ. (5))
LSI	The complexity of the overall landscape shape	$LSI = \frac{e_i}{\min e_i}$ (Equ. (6))

Notes: a_{ij} is the area of patch$_{ij}$; i is the type of patch (i = 1, 2, 3…m); j is the number of each patch type (j = 1, 2 , 3…n); N is the total number of patches of the landscape; A is the overall area of the landscape; maxa_{ij} is the area of the largest patch in the landscape; e_i is the total border length of patches; mine_i is the minimum border length of the patches

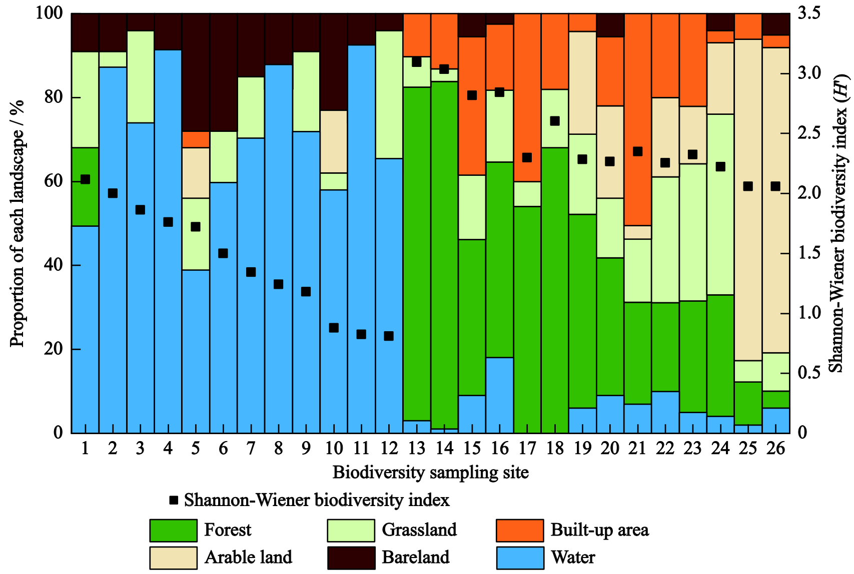

Fig. 3 Landscape composition and plant diversity index of the sampling sites in study area

of different landscapes. Forest and grassland covered more than half of the total area at most sampling sites (sampling sites 13–20 and 22–24), and the plant diversity index decreased with the proportion of forest landscape. Therefore, the plant diversity of sampling sites in both island ecosystems and countryside ecosystems is positively correlated with vegetation restoration. Relative to countryside ecosystems, the water around the islands presents a more substantial spatial barrier to plant diversity. Island ecosystems are less affected by urban development.

3.2 Vegetation restoration rate

According to the plot data of the field survey and the natural restoration time of the sampling sites, the vegetation restoration rate was determined using the relationship between the Shannon-Wiener biodiversity index and the natural restoration time of the sampling sites in two types (Fig. 4). The relationship curve of the island ecosystem sampling sites represents the local baseline of the Shannon-Wiener biodiversity index changes with the natural restoration time. The biodiversity of sampling sites in the countryside ecosystem was better than that of island ecosystem sampling sites with the same natural restoration time. When the plant diversity was the same, the curve of the island ecosystems always exhibited a smaller slope than that of the countryside ecosystems. The best achievable plant diversity of the sampling sites in the countryside ecosystem was 3.07, which exceeded that of the island ecosystem sampling sites at 3.03. Therefore, the countryside landscape is conducive to the maintenance of plant diversity during vegetation restoration. Furthermore, the vegetation restoration in the countryside ecosystem was faster than that in the island ecosystems.

3.3 Plant diversity change with various landscapes

According to the statistics of the plant beta diversity index and landscape proportion in each sampling site of island ecosystems and countryside ecosystems in 2019, the relationship between the plant beta diversity index and the ratio of various landscape combinations in island ecosystems and countryside ecosystems can be obtained (Fig. 5). The correlation between the plant beta diversity index and the surface landscape of the

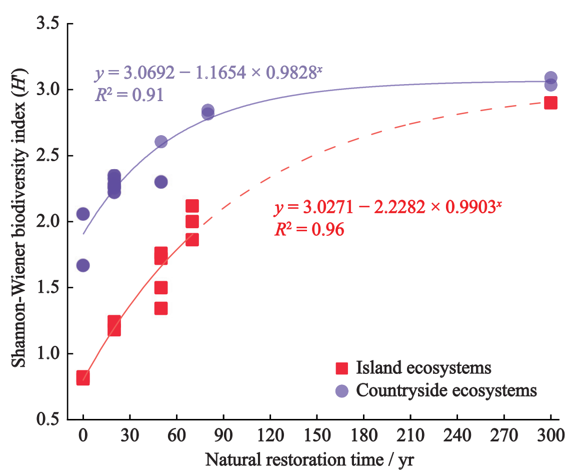

Fig. 4 Plant diversity change with natural restoration time of island and countryside ecosystems in study area

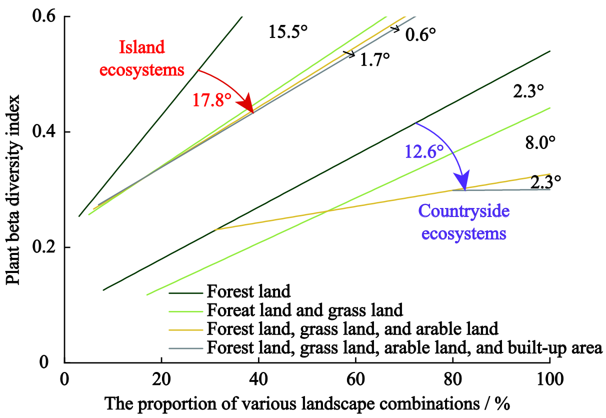

Fig. 5 The relationship between plant beta diversity and the proportion of various landscape combinations of island and countryside ecosystems in study area

sampling sites was the strongest when only the forestland was counted in each ecosystem, and R^2 reached 0.48 and 0.80, respectively. When grassland, arable land, and built-up areas are sequentially added to the surface landscape statistics, the correlation between the beta diversity index and the sum of the surface landscape ratio decreases. In addition, the differences in the rotations of the curves, representing various landscape compositions in the two ecosystems, indicate the role of each land type in plant diversity change. The curve rotating clockwise with a smaller slope indicates a more negligible impact on the plant diversity of the newly added land type than the current land types in the statistics. In island ecosystems, the relationship curve rotates approximately 15.5° when both forest and grassland were considered. When arable land and built-up areas are considered, the curve only slightly rotates. In countryside ecosystems with more complex landscape compositions, the rotation of the relationship curve was different. When grassland, arable land, and built-up areas were separately added to the statistics, the curve of countryside ecosystems rotated 2.3°, 8.0°, and 2.3°, respectively. Therefore, forests are the dominant factor affecting plant beta diversity, and the impact of surface landscape changes on the composition of the plant community is weaker in countryside ecosystems than in island ecosystems. In human-dominated countryside landscapes, grassland contributes to maintaining plant beta diversity and plays a similar maintenance role as pure forestland. Similarly, arable land primarily affects plant beta diversity and enriches the composition of plant diversity, whereas the built-up areas have no apparent impact on plant beta diversity.

3.4 Landscape pattern changes during urban expansion

According to the land use statistics in the 1980s, 2000, and 2020, the percentage of total area and typical landscape indexes of the main land use types in the two urban watersheds are presented in Table 3. While the total area of forest remained relatively stable, the grassland and arable land decreased by approximately 5%.

Table 3 Changes in the total area and landscape indexes of the major land types during urban expansion in 1980s 2000 and 2020 in study area

Year	Landscape index	Total area	Arable land	Forest	Grassland	Water	Built-up area	Bare land
1980s	PLAND	–	17.84	45.40	29.52	1.41	5.71	0.12
	PD	0.72	0.12	0.11	0.40	0.02	0.07	0.00
	LPI	18.23	2.22	18.23	4.43	0.49	2.12	0.03
	LSI	51.48	49.31	47.81	71.91	15.72	25.87	5.06
2000	PLAND	–	18.02	45.23	29.48	1.41	5.74	0.12
	PD	0.72	0.12	0.11	0.40	0.02	0.08	0.00
	LPI	18.10	2.24	18.10	4.64	0.49	2.13	0.03
	LSI	51.81	49.73	48.08	72.24	15.65	26.19	5.09
2020	PLAND	–	13.59	45.67	24.51	1.68	14.50	0.06
	PD	1.14	0.23	0.17	0.59	0.02	0.12	0.00
	LPI	12.75	0.99	12.75	3.76	0.95	4.48	0.01
	LSI	52.01	50.01	47.67	72.88	21.95	30.68	5.11

Notes: The meaning and calculation formula of the landscape index is referred to Table 2

Moreover, the built-up area tripled over the last 40 yr (Table 3). Additionally, the overall PD continuously increased by 58.33%, while the LPI showed the opposite trend, decreasing by 30.06%, thus indicating landscape fragmentation during urban expansion. Forest and grassland occupied more than 70% of the total area and showed a similar change. The increased PD (54.55% and 47.50%) and decreased LPI (–30.06% and –15.12%) of forest and grassland indicate the shrinking and fragmenting trends of these two land use types. For arable land, the PD and LPI of landscapes significantly rose by 91.67% and decreased by 55.41%, respectively. All three indexes of the built-up area showed an increasing trend, with the PD, LPI, and LSI increasing by 71.43%, 111.32%, and 18.59%, respectively. Therefore, considering major landscapes relating to plant diversity change, the landscape pattern has gradually fragmented over the 40-year urban expansion period in the watershed. Specifically, forest, grassland, and arable land landscapes, contributing to plant diversity conservation, were all fragmented. In contrast, the built-up areas, which have devastated plant diversity, have expanded and formed massive shape-regular urban patches.

4 Discussion

4.1 Landscape patterns induce differences in vegetation restoration rates

The regional landscape pattern dramatically influences the rate and results of vegetation restoration and biodiversity recovery (Newbold et al., 2015). In island ecosystems with water isolation, there is little communication with external materials and information. The landscape pattern is relatively primitive, and vegetation grows naturally. Long-term ecosystem evolution is mainly influenced by isolation distances, and the overall vegetation restoration rate is slow (Katovai et al., 2012). In contrast, human production and construction activities are frequent in terrestrial ecosystems, usually forming a complex countryside landscape pattern limited by natural topographic conditions and dominated by human activities (Mendenhall et al., 2013). Therefore, revealing the difference in the vegetation restoration rate in different landscape patterns is the basis to clarify the impact of expanding urban areas on vegetation restoration.

Although high disturbance during rapid social and economic development urban expansion destroyed natural forests and grasslands, the intricate countryside landscape pattern promotes vegetation restoration and maintains the plant diversity. Studies have shown that deforested lands continuously maintain plant functional diversity similar to forests, and countryside ecosystems with diverse landscape types better maintain native herbs and shrubs in Costa Rica (Mayfield et al., 2005; Mayfield and Daily, 2005). In Latin America, countryside farms maintain biodiversity better than other farms and have the ability to maintain species diversity similar to the surrounding forest (Philpott et al., 2008). Studies have further shown that in a highly heterogeneous agricultural ecosystem, appropriate management and the introduction of essential natural and seminatural ecosystem elements effectively promote vegetation restoration and improve the ability of farms to maintain plant diversity on a large scale (Mendenhall et al., 2011; Mendenhall et al., 2016). Furthermore, the intricate landscape pattern provides more shelter and protects species from adverse environmental conditions and climate change by increasing the gradient of environmental factors and increasing the complexity of habitat types and structures, ultimately promoting the maintenance of biodiversity (Hughes and Eastwood, 2006; Kallimanis et al., 2010).

In karst areas, vegetation restoration curves of countryside and island ecosystems have shown that the restoration rate of plant diversity is affected by the landscape pattern in this study. The Shannon-Wiener indexes of plant diversity of the countryside and island ecosystems in the initial period of restoration were 1.90 and 0.80, respectively (Fig. 4). After a rapid recovery period, the restoration of biodiversity entered a stable period with the tree and shrub layers in the community becoming more mature and rich in species. Finally, vegetation restoration will gradually stabilize in the two ecosystems, and biodiversity is expected to reach 3.07 and 3.03, respectively. During the long-term restoration process, the Shannon-Wiener index of plant diversity in the countryside ecosystem has always been higher than that of the island ecosystem. This is because the countryside ecosystem takes approximately 80 yr to recover, whereas the island ecosystem requires a longer recovery time, i.e., approximately 130 yr, to enter a stabilized period. The long recovery time corresponds with the findings in previous studies in which natural recovery rates depend on the nature and severity of the impact and are generally slow, and forested biomes require century-long recovery times in species richness and composition at a global scale (Michael et al., 2014). Therefore, the human settlement landscape promotes plant diversity changes in karst areas, and the vegetation restoration rate in the countryside ecosystem is faster than that on isolated islands.

4.2 Urban expansion affects the plant diversity through landscape pattern changes

Traditional rural settlements are a combination of human adaptation to the natural environment and the transformation of the natural environment into human living space (Brandon et al., 2005). That said, under the pressure of population growth, food production, and social changes, urban areas have expanded rapidly and such large-scale land type transformation has changed the original living space of organisms. The current countryside landscape pattern has had a significant impact on plant diversity (Wittemyer et al., 2008). Therefore, it is essential to reveal the effects of landscape pattern change resulting from urban expansion on plant diversity (Tscharntke et al., 2012).

Previous studies have explored the influence of major land types on plant diversity in countryside landscapes over a wide area. Among them, forests, especially native forests, play an irreplaceable role in maintaining regional plant diversity (Gibson et al., 2011; Watson et al., 2018). The secondary forest also has a significant role in promoting rapid vegetation restoration (Rozendaal et al., 2019). Small forest patches scattered among other landscape patches have crucial ecological functions, maintaining plant diversity by providing a microclimate, increasing soil nutrients, and promoting landscape connectivity (Manning et al., 2006). Grasslands, as well, play a vital role in vegetation restoration and provide ecosystem services (Habel et al., 2013; Bengtsson et al., 2019). According to statistics, grassland restoration measures can increase plant diversity by 32.44% in China (Ren et al., 2016). However, the increasing agricultural intensity of agricultural land and the homogenization of the agricultural landscape will decrease plant diversity (Gámez-Virués et al., 2015; Sirami et al., 2019). Thus, using traditional agricultural farming methods and organic farming methods can better balance biodiversity and agricultural production, as the continuous development of agricultural and forestry landscapes in agricultural systems can also effectively protect biodiversity (Tuck et al., 2014; Sagwe et al., 2015). Moreover, forest–derived agricultural forests can maintain higher plant diversity than developed land, while the growth of villages and urban land has a negative effect on vegetation restoration in many places (Martin et al., 2020). In particular, the formation of large built-up patches in urban expansion has blocked biological information exchange and hindered plant diversity maintenance (Miller and Hobbs, 2002; Crouzeilles et al., 2021).

In karst areas, based on a comparison of the island and countryside ecosystems, the impact of the various landscapes on vegetation restoration (Fig. 5) is similar to previous findings in other regions. In addition, unique karst landforms have restricted urban expansion, which also significantly impacts vegetation restoration in karst areas. Many forests continually centered in peak clusters occupy a dominant role in karst plant diversity maintenance. Therefore, concerning urban expansion in nearly the past half centennial (Table 3), the large patches of forestland with a stable total area are the key to maintaining karst plant diversity. Arable land and grassland, distributed across karst depressions and restricted by karst peaks, shrank and fragmented during the urban expansion, which is conducive to plant diversity maintenance in karst areas. The built-up area rapidly increased during urban expansion. Many large and regularly shaped urban land patches have been formed through the artificial transformation of the terrain, leading to plant diversity loss in urban areas.

4.3 Implications regarding karst urban development planning

As biological resources are the basis of social and economic development, biodiversity is essential for maintaining the stability and function of global ecosystems (Assessment, 2005). In urban development, the drastic change in countryside landscapes has a complex impact on plant diversity. On the one hand, forests and grasslands are transformed into living, production, and agricultural lands on a large scale during urban expansion, which is not conducive to maintaining plant diversity (Čeplová et al., 2017). On the other hand, various landscape types and landscape spatial combinations form diversified countryside landscape patterns. Effective communication among patches of each landscape type with other landscape patches can promote rapid vegetation restoration (Mendenhall, 2020). Therefore, proper planning of landscape patterns during urban expansion can effectively promote vegetation restoration and plant diversity maintenance. It is necessary to consider the evolutionary landscape characteristics of regional settlements and propose urban development planning suggestions from the perspective of plant diversity protection.

Statistics on the changes in the countryside landscape patterns in cities and surrounding watersheds in the past 40 yr (Table 3) have demonstrated that in karst areas, urban expansion has the following landscape characteristics: the total area of forestland and patch shape is relatively stable, forming smaller forest patches; the total area of grassland and arable land is reduced, but the patch shape is relatively stable; and the total area of built-up land is tripled with increasingly larger and more irregular patches. Under the barrier of the karst landforms, all types of major landscapes have exhibited a fragmenting trend with the exception of built-up areas during urban expansion. While these changes in major landscape patterns contribute to the maintenance of local plant diversity, the further urban expansion would considerably pressure plant diversity conservation.

Therefore, the following planning recommendations for urban development in karst areas should be promoted to realize better vegetation restoration for coordinating human production needs and ecosystem stability. First, the stability of the forest areas should be maintained, and increased attention should be given to protecting the natural forest. Second, the regularization of grasslands and arable lands should be avoided, and forest patches should be developed in grassland and arable land ecosystems. Third, large patches of built-up area expansion should be restricted, and the irregularity of urban land in planning should be increased.

5 Conclusions

Social and economic development will inevitably lead to urban expansion, which has had a considerable impact on plant diversity. Karst areas are concentrated in human-dominated countryside landscapes and developed typical plant diversity. Hence, it is of great value to analyze the role of urban expansion in plant diversity changes in karst areas at the decade scale. Combining multisource remote sensing data, this paper uses isolated islands in karst plateau lakes as a reference, proves that plant diversity in karst countryside ecosystems recovers faster. For various landscape types, forests are the dominant factor affecting plant diversity; grassland contributes to maintaining plant beta diversity and plays a similar maintenance role as pure forestland; arable land affects plant diversity primarily through enriching the landscape composition; whereas the built-up areas have no apparent impact on plant diversity. During the urban expansion, large patches of forestland with a stable total area are the key to maintaining karst plant diversity. Arable land and grassland shrank and fragmented during the urban expansion are conducive to plant diversity maintenance in karst areas. Rapidly increasing built-up areas have formed large and regularly shaped urban land patches, which lead to plant diversity loss in urban areas.

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