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Original Paper

The Diversity of Spontaneous Plants Enhances the Resilience of Urban Green Spaces

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Abstract

Urban spontaneous plant communities exhibit distinct self-succession patterns and autonomous regeneration capacities, which play a pivotal role in enhancing biodiversity, improving ecological resilience, and minimizing maintenance expenditures within urban green infrastructure systems. This investigation aims to elucidate the diversity variations of spontaneous flora across different urban green space typologies and their underlying determinants, thereby providing critical insights for optimizing ecosystem stability and sustainable management practices. This study systematically examined four characteristic green space types in Luoyang City (Henan Province, China) through standardized quadrat sampling. We conducted comprehensive analyses encompassing: species composition characteristics, species importance values, species frequency, multidimensional diversity indices, and phylogenetic diversity of spontaneous plant among different types of green spaces and their influencing factors. The results showed that the species richness and diversity index of the suburban park were the highest. The phylogenetic diversity analysis indicated that, except for the suburban park, the phylogenetic structure of spontaneous plants in other green spaces was of the aggregated type.

Keywords
spontaneous plant, green space types, species diversity, genealogical diversity

1. Introduction

With increasing urbanisation, large tracts of agricultural land, for-ests and wetlands are being lost to urban land use (Peng & Liu, 2007; Yi, Luo, Wu et al., 2014). Biomes that once lived in harmony have been forced apart, resulting in the quality of the soil, water and air being severely affected and the ecological balance being upset. The resulting problems of reduced urban biodiversity and homogenisation of plant landscapes have seriously reduced the quality of the urban ecological environment. As an important part of urban natural ecosystems, Spontaneous plant resources have attracted much attention due to their strong environmental adaptability, diversified life types and high ecological restoration value (Zheng, 2024; Wang, Zhang, & Li, 2024).

Spontaneous plants refer to plant groups that can grow and flour-ish naturally without artificial cultivation and management, and are an important part of the natural ecosystem of the city (Li, Dong, Guan et al., 2018; Chen, Lu, Jia et al., 2021). The ecological value of Spontaneous plants in urban environments should not be overlooked, as they play a pivotal role in maintaining ecosystem sta-bility and promoting sustainable developmen (Chun, Zhang, Wu et al. 2024; Rupprecht, Byrne, Garden et al., 2015). Spontaneous plant communities are not only able to effectively resist the invasion of alien species (Sirbu, 2007; Fan, Yun, Liang et al., 2024), but also provide valuable habitats for a wide range of or-ganisms (Guan, 2023), which in turn improves the stability and biodiversity of community ecosystems. In addition, they play a significant role in regulating urban microclimates, absorbing pollutants, preventing soil erosion and improving soil quality (Cavalca, Corsini, Canzi et al., 2015; Wang, Han, Guo et al., 2024; Zeng & Song, 2023). For some Spontaneous plant resources with ornamental value and special uses can also bring both physical and psychological nourishment to the public (Luo, Zhang, Li et al., 2024).

In this study, different green space types within the urban built-up area of Luoyang City were selected (Figure 1) and compared and analysed in terms of the composition, importance value, species occurrence frequency, species diversity and spectral diversity of Spontaneous plants in dif-ferent green space types, respectively. To explore the differences in the characteristics of Spontaneous plant diversity among the four green space types, in order to formulate scientific and reasonable urban green space management measures, and then to promote the healthy and sus-tainable development of the urban green space system.

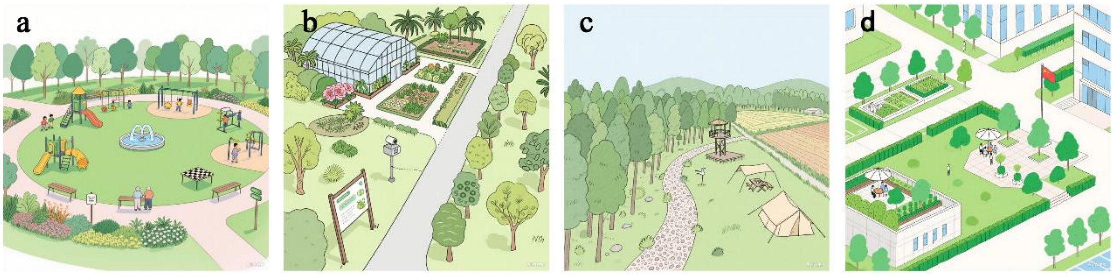

Figure 1. Different Green Space Types

(a) Comprehensive Park; (b) Specialised Park; (c) Country Park; (d) Green Areas Attached to Organizations

2. Method

2.1 Overview of the Study Area

In order to ensure the reliability of the analysis results, homogenised hydrometeorological and other environmental factors (You, Jiang, Yan et al. 2024), four different green space types within the built-up area of the city were selected, i.e.: a comprehensive park (Xingluohu Park), a country park (Zhoushan Forest Park), a specialised park (Botanical Garden of Sui and Tang Dynasty Ruins), and a unit-affiliated green space (Henan University of Science and Technology, Kaiyuan Campus), as shown in Table 1.

Table 1. The Following Is an Example

Type of green space	Name of the green space	Area (hm^2)	Sample area (Number)
Comprehensive park	Xingluohu Park	17.8	396
Specialised park	Botanical Garden of Sui and Tang Dynasty Ruins	72.1	892
Country park	Zhou Shan Forest Park	63.3	764
Green areas attached to organizations	Henan University of Science and Technology, Kaiyuan Campus	12.0	192

2.2 Sample Design

In this study, the grid system sampling method was used for sample control (Liu, Xing, Yao et al., 2024; Pan, Min, Zhao et al., 2024), with the help of Google Earth tool, a grid of 200m×200m was set up along the north-south direction for each of the investigated green spaces. Remove the sample plots falling on the water surface, part of the sample points are adjusted according to the actual situation, and set up a 10m×10m large sample square with each research sample plot as the centre, and record the species, number of plants and growth of Spontaneous plants appearing here as the data of the sample plot (Chen, Mao, Qiu et al., 2020; Ministry of Housing and Urban-Rural Development of the People's

Republic of China, 2018; Editorial Committee of Flora of China, Chinese Academy of Sciences, 1979). The entire investigation lasted from March 2024 to December 2024. A total of 2,244 research samples were finally recorded and divided based on the Urban Green Space Classification Standard (Ilie, & Cosmulescu, 2023) and major Spontaneous plant habitat characteristic (Wang, Song, Li et al., 2023), and details of each urban green space type and sample are shown in Table 1.

2.3 Data Processing and Analysis

2.3.1 Species Frequency Calculations

Species frequency (F) refers to the frequency of occurrence of each species within the total sample of the survey, the probability that the number of sample plots containing an individual occurs in the total number of sample plots (Zhang, 2018).

$$\mathrm{F} = \frac{Si}{N} \times 100\% \qquad (Formula\ 1)$$

where Si is the number of samples in which species i occurs and N is the total number of samples (N>0).

2.3.2 Calculation of plant importance values

Importance value is an important indicator in calculating and assessing species diversity, and expresses the relative importance of a species in a community as a composite value (Yuan, Lu, Xu et al., 1998).

$$\mathrm{Si} = \frac{(RAi + RFi + RCi)}{3} \qquad (Formula\ 2)$$

In Equation 1, Si denotes the significance value of the ith species, and RAi, RFi and RCi denote the relative density, relative significance relative frequency and of the ith species, respectively. where relative density of species = density of the species / sum of the densities of all species in the sample plot.Species density = number of plants (or clumps) of the species / volume of the sample plot.

Species relative significance = significance of the species / sum of the significance of all species in the sample.Species significance = the average logarithmic product of the species.Since the data recorded is the species basal diameter, species significance = π x (mean basal diameter of the species/2)² (π is taken as 3.14).

Relative frequency of species = frequency of the species/total frequency of all species in the sample plot.

2.3.3 Calculation of Species Diversity Indicators and Significance Analysis

Species diversity indices used in this paper include Shannon-Wiener diversity index (H), Simpson diversity index (D), Pielou evenness index (E) and Margalef richness index (R) (Liang, You, Zhu et al., 2023).

(1) Shannon-Wiener Diversity Index (H)

The Shannon-Weiner index reflects the uncertainty of individuals of a species within a community; the higher the uncertainty, the higher the diversity within the community.

$$\mathrm{H} = -\sum_{i=1}^{S} (Pi \ln Pi) \qquad (Formula\ 3)$$

(2) Simpson Diversity Index (D)

Simpson's diversity index is the probability that the number of individuals from two consecutive samples of a community belongs to the same species. the greater the Simpson's diversity index, the greater the number of species in the community, the smaller the dominant species, and the greater the diversity of species.

$$\mathrm{D} = 1 - \sum_{i=1}^{S} Pi^2 \qquad (Formula\ 4)$$

(3) Pielou Uniformity Index (E)

Species evenness is the distribution of the number of individuals of all species in a community or habitat, which reflects the degree of evenness of species composition, with larger values indicating a more even distribution of species.

$$\mathrm{E} = \frac{H}{\ln(S)} \qquad (Formula\ 5)$$

(4) Margalef Richness Index (R)

The species richness index is the number of species in a community or habitat (Webb & Donoghue, 2002). Instead of considering the size of the study area, it is based on the relationship between the number of species and the total number of individuals in a community.A larger richness index indicates greater species richness and higher species diversity.

$$\mathrm{R} = \frac{S-1}{\ln N} \qquad (Formula\ 6)$$

where S denotes the number of species; Ni denotes the number of individuals of species i; N denotes the total number of individuals of all species; and Pi denotes the proportion of the total number of individuals of species i to the total number of individuals in the sample community, i.e., Pi = Ni/N.

The relationship between each green space type and community species diversity was analysed by one-way ANOVA (Yang, 2023), and the sample data were collated and analysed in Excel and SPSS 24.0 software.

2.3.4 Calculation of Genealogical Diversity

(1) Creating a Catalogue and Building a Phylogenetic Tree

Based on the Spontaneous plant data of each site obtained from the survey, a plant list of all the sites was created by adjusting the species information into the format of "family/genus/species name (genus and species names should be concatenated before adding words)" using Excel and Notepad, and the results were saved as a csv file.

The phylogenetic tree was subsequently constructed using the RstudioV.PhyloMaker package (Webb, Ackerly & Kembel, 2008) and the generated .tre file was edited and organised by FigTree v1.4.3 (https://tree.bio.ed.ac.uk/software/figtree/).

(2) For the phylocomputational analysis, prepare a sample file in the following format: the first column is the site number, the second column is filled with a 1 to indicate the presence of the species in the site, and the third column is the scientific name of the species (genera and species are separated by a "_").

The calculation of indices such as PD, NRI and NTI was downloaded and completed using the phylocom software (Feng, 2013; Ji & Luo, 2024).The calculation formula was as follows:

$$NRI_{sample} = -1 \times \frac{MPD_{sample} - MPD_{mdsample}}{sd\left(MPD_{rudsample}\right)} \qquad (Formula\ 7)$$

$$NTI_{sample} = -1 \times \frac{MNTD_{sample} - MNTD_{rndsample}}{sd\left(MNTD_{rndsample}\right)} \qquad (Formula\ 8)$$

The net relatedness index (NRI) was standardised to the mean phylogenetic distance (MPD) of all pairs of species in the sample; the nearest taxon index (NTI) was standardised to the nearest taxon distance of each species in the sample.The mean nearest taxon index (MNTD) was standardised to the mean nearest taxon distance (MPD) of each species in the sample.

Where PD refers to the sum of the evolutionary branching dendritic degrees of all species within the community. mpDsample is the mean pedigree distance of each sample, mpDmdsample is the mean pedigree distance of the null community generated by the stochastic process, sd(mpDmasampie) is the variance of the mean pedigree distances of the null community, and mnPDsmple is the mean neighbouring pedigree distance of each sample, theMNPDmdsampe is the mean adjacent spectral distance of the zero communities generated by the stochastic process, and sd(MNPDdsple) denotes the variance of the mean adjacent spectral distance of the zero communities.

If NRI<0, the average genealogical distance of the sample site is greater than the average genealogical distance of the zero community, indicating that the genealogical structure of the sample site is dispersed.If NRI>0, the average genealogical distance of the sample site is smaller than the average genealogical distance of the zero community, indicating that the community structure of the sample site is clustered.If NRI=0, the average distance is equal to the average distance of the zero community, indicating that the community structure of the sample site is random.If NTI>0, it means that species with close relationship are more likely to coexist in the community, and if NTI<0, it means that species with close relationship are not easy to coexist in the community (Li, Fan, Guan, Zhao et al., 2019; Zhu, 2020). In this section, where applicable, authors are required to disclose details of how generative artificial intelligence (GenAI) has been used in this paper (e.g., to generate text, data, or graphics, or to assist in study design, data collection, analysis, or interpretation). The use of GenAI for superficial text editing (e.g., grammar, spelling, punctuation, and formatting) does not need to be declared.

3. Result

3.1 Analysis of Spontaneous plant Species Composition

A total of 58 Spontaneous plant species, distributed in 28 families and 52 genera, were recorded in the survey in Luoyang City. *Asteraceae* and *Gramineae* were the main plant families, accounting for 53 and 25 per cent of the total number of species, respectively.Country forest parks had the highest number of Spontaneous plant species, 43, followed by specialised parks (36), Comprehensive park (29), and the lowest number of Spontane-ous plant species (23) in unit-affiliated green spaces. Detailed datas were shown in Figure 2.

Life-type analysis showed that perennial herbs (30 species) accounted for 51.72 per cent of the total and mono- and biennial herbs (26 species) accounted for 44.83 per cent.Among the different green space types, the proportion of perennial herbaceous plants was higher in specialised parks and country forest parks.

With regard to the origin of species, 43.1 per cent are native plants and 56.9 per cent are alien plants.The number of alien plants is generally higher than that of native plants in all green space types, indicating that alien spe-cies dominate in urban green spaces.

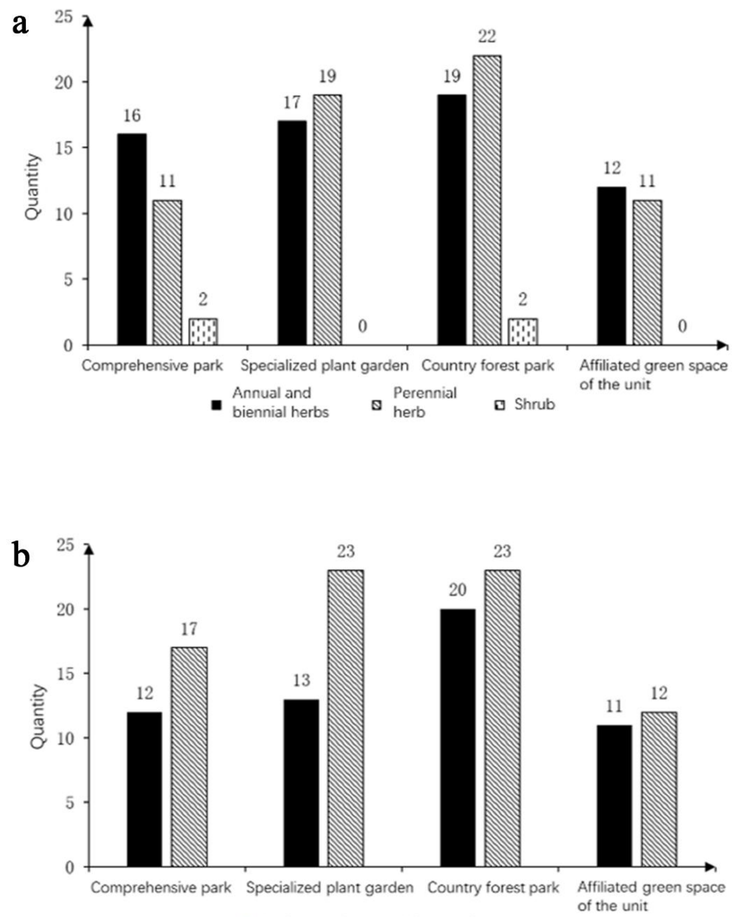

Figure 2. The Differences in the Composition of Autotrophic Plants among Different Types of Green Spaces. (a) Differences in the Life Forms of Native Plants; (b) Differences in the Sources of Autotrophic Plants

3.2 Importance Value

The survey data showed that Arabian Brahmi, yellow-flowered edel-weiss and zephyr paint were dominant species in the four green space types.Dandelion, Snakeberry, Purple Dicot, Flowering Dianthus and Spurge were dominant species in three green space types.Ground elder and matang were dominant in two green space types, with ground elder being more dominant in integrated parks and matang dominant in specialised parks.Artemisia annua and Artemisia cattleya are dominant in the compre-hensive parks, Artemisia cattleya and Artemisia absinthium are dominant in the specialised parks, Artemisia dogwood is dominant in the country forest parks, and Artemisia alba, Artemisia sinensis, Artemisia spp. and Artemisia plantagineum are dominant in the unit-associated greenspaces.

Exhibit 1 shows the top ten species and their importance values in each green space, with yellow-flowered edelweiss having the highest importance value of 0.125 in the unit of attached green space, followed by Arabian Brahmi at 0.119. These data reflect the dominance of plant species in dif-ferent green space types.

3.3 Frequency of Occurrence of Species

A total of 26 plant species were calculated by Excel to have a fre-quency of occurrence of more than 10 per cent in the four types of green spaces.Arabian Brahmi and yellow-flowered edelweiss had the highest fre-quency of occurrence among all green space types, especially in the green spaces attached to Organizations, where the frequency of occurrence reached 68.23 per cent and 66.15 per cent, respectively.In integrated parks, 11 species of plants, including dandelion and snakeberry, had a frequency of occurrence of more than 15 per cent.In the Botanical Specialised Gardens and Coun-tryside Forest Parks, the frequency of occurrence of Pittosporum and Snakeberry also exceeded 15%.In green spaces attached to Organizations, apart from the above two species, seven species of plants, including white axlewort and Zea mays, had a frequency of occurrence of more than 15 per cent.Exhibit 2 lists the frequency of occurrence of species in various green spaces, show-ing the distribution of different plants in different green spaces.

3.4 Species Diversity

The results of species diversity analysis showed (Figure 3): country for-est parks (0.96) > Comprehensive park and plant specialised gardens (0.95) > campuses (0.93), but the difference was not significant ($P > 0.05$); Simp-son's index: country forest parks (3.55) > plant specialised gardens (3.34) > Comprehensive park (3.21) > campuses (2.93), there was significantPielou evenness index: comprehensive park (0.95) > country forest park (0.94) > plant speciality park and campus (0.93), there was no significant difference in the evenness of species distribution ($P>0.05$); Margalef richness index: country forest park (3.42) > plant speciality park (2.85) > comprehensive park (2.32) > campus (1.93), with significant differences ($P < 0.05$). Coun-try parks had the highest Shannon-Wiener index, Simpson's index, Pielou's evenness index and Margalef's richness index, and the lowest for each of the diversity indices in the unit's ancillary green spaces.The differences in Shannon-Wiener and Pielou evenness indices were not significant for the four green space types, while Simpson and Margalef richness indices were significantly higher for country parks than for unit-affiliated green spaces.

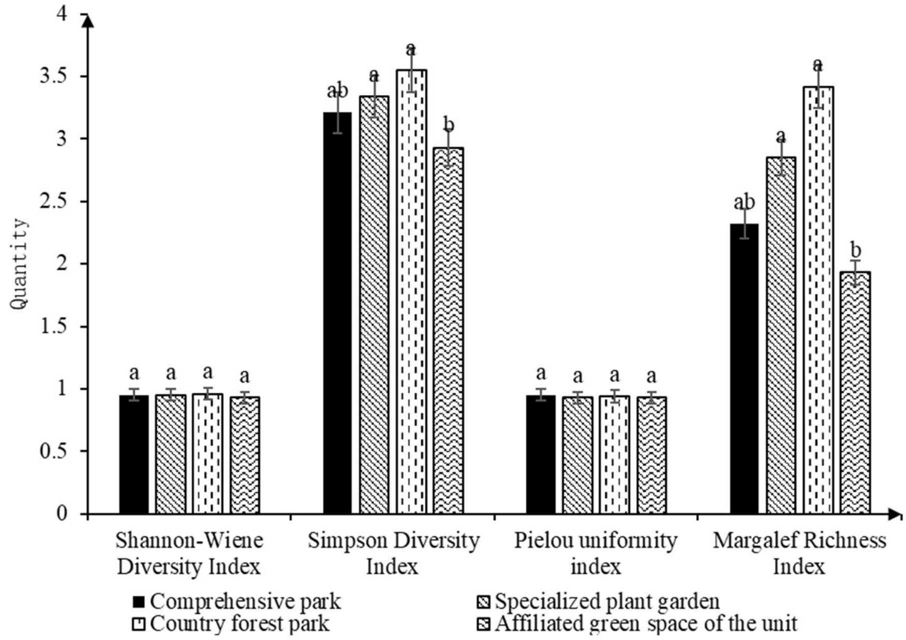

Figure 3. Comparison of Diversity Indices of Different Green Space Types (same letter means that the difference between them is not significant at P=0.05; no same letter means that the difference between them is significant at P<0.05)

3.5 genealogical Diversity

The affinities of plant species in different green space types were re-vealed with the help of the phylogenetic relationship construction method (Figure 4). In Comprehensive park, plants in the families of Comfrey, Labiatae, Genisteinae and Syzygium, as well as the families of Gramineae and Palmae were more closely related; in plant speciality gardens, plants in the families of Plantae and Genisteinae, the genera of Dogwood, Matang, and Carpetgrass in the family of Gramineae, as well as Cynomorium and Fritillaria in the family of Asteraceae, were more closely related; and in country forest parks, plants in the families of Dogwood, Panax paniculatae, Matang, and Dogwood in the family of Gramineae, the families of Labiatae and Genisteinae,Psyllidaceae, as well as plants of the genera Dandelion and Succory in the Asteraceae are more closely related; in the green spaces attached to Organizations, plants of the genera Gynostemma, Psyllidae, Labiatae, as well as plants of the genera Dandelion, False Reduced Ginseng, Succory, and Bitter Endive in the Asteraceae are more closely related.Spectral di-versity analyses showed that, except for the Country Forest Park, the community structures of other green spaces were clustered, and the positive values of NTI indicated that species with close affinities were more likely to coexist in green space communities, see Table 2 for details.

The mean values of NRI and NTI for different sample sites cal-culated by phylocom are shown in Table 2.From the NRI values, it can be seen that among the four different sample sites, only the mean value of NRI in the country park was <0, which indicated that the mean spectral distance of the sample site was greater than that of the zero community, i.e., except for the dispersal of the spectral structure of the community outside the sample site, the spectral structure of the com-munity in the other three sites was clustered; and the results of the NTI of the four green spaces were positive, which indicated that it is easier for the species with closer affinities to be found in the community in the investigated green spaces.The results of NTI in four green spaces were all positive, indicating that species with closer affinity in the investigated green spaces were more likely to coexist there.

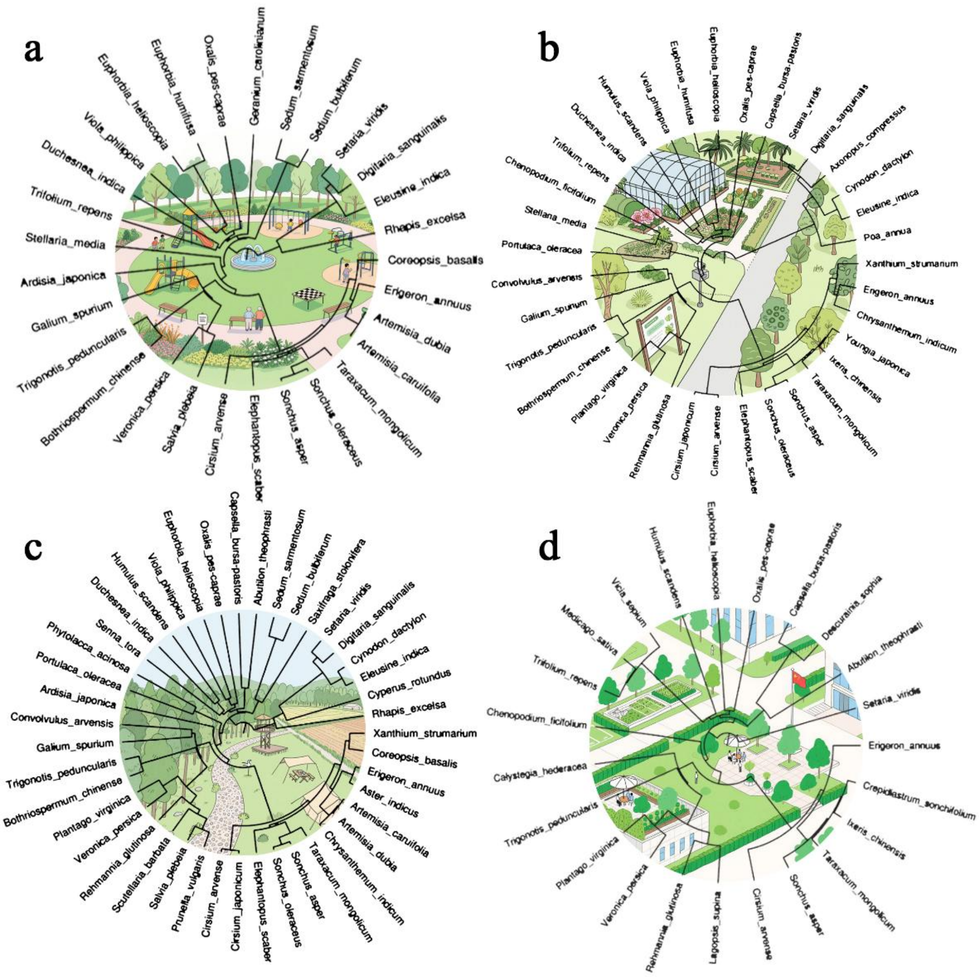

Figure 4. Spectral Tree of Plant Communities in Different Green Space Types (a) Comprehensive Park; (b) Botanical Specialty Gardens; (c) Countryside Forest Parks; (d) Green Spaces Attached to Organizations

Table 2. Results of Pedigree Diversity

Type of green space	NRI	NTI	PD
Comprehensive park	1.10	0.63	2016.08
Specialised park	0.83	1.23	2114.49
Country park	-1.24	0.76	2716.69
Green areas attached to Organizations	0.21	0.43	1632.15

4. Discussion

4.1 Analysis of Spontaneous Plant Species Composition in Different Green Space Types

A total of 58 Spontaneous plant species belonging to 28 families and 52 genera were recorded in this survey, with Asteraceae and Gramineae being the most abundant Spontaneous plant species, accounting for 53 per cent and 25 per cent of the overall total, respectively.Among them, the number of Spontaneous plants in the four green areas was in the following order: country parks > specialised parks > Comprehensive park > green areas attached to Organizations, which is presumed to be related to the area of green areas and human activities (Yang, Yu, Fu et al., 2023). In addition, due to the different maintenance and management requirements and intensity of anthropogenic interference in each green space type, in terms of the species life type of Spontaneous plants, the proportion of its perennial herbaceous plants is higher than the proportion of the 2012 herbaceous plants; in terms of the source of the species, there are a total of 25 species of native plants, which accounts for 43.1%, and a total of 33 species of alien plants, which accounts for 56.9% of the total number of species, which indicates that the invasive species in Luoyang City-phenomenon is more serious. Among them, the higher level of invasive plants are herbaceous plants such as yellow-flowered edelweiss, Zea mays, and Arabian Brahmi, which have a high frequency of occurrence, rapid growth, and easy to form patches of growth phenomenon, which greatly affect the survival of native species, and exacerbate the ho-mogenisation of the landscape (Jiang, Yan et al., 2024).In addition, for the occasional species that appeared in the survey, such as prickly thistle (Cirsium japonicum), wild old stork grass (Geranium carolinianum), and summer grass (Prunella vulgaris), which have a greater contributing role in improving the biodiversity of the urban green space (Li, Zhang, Fan et al., 2024), the develop-ment and utilisation of these germplasm resources should be strength-ened.

4.2 Analysis of Spontaneous Plant Diversity in Different Green Space Types

Plant diversity is the main measure of species richness and vegeta-tion distribution, and the results of Shannon-Wiener diversity index, Simpson dominance index, Pielou evenness index and Margalef rich-ness index analyses showed that country parks had the highest diversity, and the lowest diversity was found in the unit of ancillary green-space.This suggests that the favourable growing environment, superior soil and water fertility conditions in the country parks are responsible for their high diversity of secondary ground covers.In contrast, more human disturbances and serious vehicle pollution in the green space attached to the Organizations led to the low diversity of spontaneous plants in this green space (Jiang, Yan et al., 2024; Zhong, Ye, Wu et al., 2025).

4.3 Analysis of Spontaneous Plant Spectral Diversity in Different Green Space Types

Observation of the generated community genealogy tree shows that the distance and proximity of the spontaneous plant relatives presented in different green space types are different, which is related to the size of the green space, the number of plant species and the distribution of the species (Zhong, Ye, Wu et al., 2025). According to the results of spectral diversity calcula-tions, except for the country park, where the mean value of NRI was <0, i.e., the community spectral structure was dispersed, the community spectral structures of the other three green spaces were aggregated, and it was hypothesised that the interspecific competition caused by the increase of spontaneous plants diversity in the country park not only promoted the differentiation among species, but also made the com-munity structure more complex and diversified.In addition, the spatial heterogeneity of the environment had a significant effect on the com-munity structure, and the higher the spatial heterogeneity of the envi-ronment, the higher the diversity of the community.The more complex the hierarchy and structure of plant communities, the higher the di-versity of communities. This spatial heterogeneity provides diverse environmental conditions for the survival of different populations, and promotes the dispersal of community structure (Zhong, Ye, Wu et al., 2025).

5. Conclusions

This investigation took four different green space types in Luoyang City as examples to conduct a multi-level comparative analysis of the diversity and differences of Spontaneous plant species growing within them.The results of the study showed that the number of Spontaneous plant species, diversity index, evenness index and richness index of park green spaces, such as country parks, Comprehensive park and specialised parks, were higher than those of unit-affiliated green spaces.The results of spectral diversity analysis showed that the PD index of the country park was much higher than that of the other three green spaces, and the affinities among the community species were more distant. The NRI index values showed that the Spontaneous plant spectral structure of the country parks was dispersed, while the Spontaneous plant spectral structure of the remaining three green spaces was aggregated, suggesting that the environmental spatial heterogeneity of the country parks was higher, and the community structure was more complex.The NTI results indicated that the spontaneous plants of the four green spaces were more closely related, and the species were more prone to coexist.The combination of park characteristic factors such as: green space area, park completion time, park type, planting plants, accessibility and management intensity will have an impact on the growth and species differentiation of Spontaneous plants. Based on this, it can be seen that park-specific environmental factors have a significant impact on the dynamics of their habitats, and such changes further contribute to the differential distribution of biodiversity within the park.Therefore, there is an urgent need for future attention and in-depth research on how to accurately grasp the complex associations between these environmental factors and biodiversity in order to better maintain and manage the ecological balance of urban parks.

Author Contributions

Conceptualization, L. W. and D. L.; methodology, L. W.; software, K.Z. and J.C.; validation, Y.M., L.W. and D.L.; formal analysis, G.L.; investigation, J.C., G.L., C.L., X.Y., J.A., J.G., S.S., Y.W. and M.W.; resources, L.W.; data curation, K.Z., J.C., G.L. and Y.M.; writing—original draft preparation, J.C., M.W. and Y.W.; writing—review and editing, K.Z., J.C. and L.W.; visualization, M.W.; supervision, D.L.; project administration, L.W.; funding acquisition, Y.Y., L.W. and D.L. All authors have read and agreed to the published version of the manuscript.

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Note(s)

Note 1. All the research data in this article were uploaded in the form of attachments. For details, please refer to Table S1 and Table S2 in Supplementary Files.