CHARACTERISTICS OF PLANT COMMUNITIES IN NEIGHBORHOOD GREEN SPACES WITHIN HIGH-DENSITY URBAN AREAS: A CASE STUDY IN SHANGHAI, CHINA

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Abstract. Rapid urbanization has led to the loss and damage of natural land within high-density urban areas. Green spaces in urban neighborhoods, which are closely integrated into the daily lives of urban residents, provide opportunities for people to interact with nature and venues for outdoor recreation. Taking the example of Shanghai city in China, the species composition, diversity, and structural characteristics of plant communities, as the basic units of green spaces, were analyzed along urbanization gradients. In total, 168 plant communities were selected as the study objects by using a stratified random sampling method. The results showed that species diversity and structure characteristics of plant communities were quite different among various green spaces and urban neighborhoods, which were primarily influenced by human factors. Urban neighborhood green spaces exhibited higher species diversity than urban forests, with the former predominantly composed of “arbor + shrub + grass” plant communities (80.1%). Ultimately, the plant communities in green spaces of urban neighborhoods were classified into three types based on their structure characteristics and ecological services: ecological landscape community, grassland community and understory forest community. The typical plan and elevation diagrams for different types of plant community were provided, which could give insights into the design and management of plant communities. This study on plant community characteristics of green spaces in urban neighborhoods can help enhance the comprehensive functions of green spaces in high-density urban areas, and support the improvement of urban green spaces renewal strategies.
Keywords: *landscape & greenery, green spaces, outdoor recreation, structural characteristics, urbanization*

Introduction

According to the report by António Guterres (Secretary-General of the United Nations) in Global Observance of World Cities Day 2020, the world is urbanized to a great extent and 68% of the population is projected to reside in cities by 2050. The considerable magnitude, extent and pace of urban expansion have caused significant damage to natural spaces at different scales, which was found by many studies (McKinney, 2008; Wiesel et al., 2021; De Araujo et al., 2024). Available natural spaces have become increasingly scarce, especially in high-density urban areas. The loss of natural spaces in urban areas not only affect the biodiversity (Qureshi et al., 2013; Wang et al., 2015), but also lead to the deterioration of urban residents’ health (Adeyemi and Shackleton, 2023; Olfato-Parojinog et al., 2024).

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Urban green spaces (UGS) are an integral part of any urban area which could provide some opportunities for people to interact with nature. UGS could provide numerous ecological benefits by acting as urban lungs - absorbing pollutants and releasing oxygen (Mcpherson and Geiger, 2005; Li and Babcock, 2014), provide clean air, water and soil, and balances city's natural-urban environment (Eshetu et al., 2021; Liu et al., 2021b). It has also been proved in many researches that green spaces could provide many spiritual, recreational and restorative opportunities for city residents who may have limited exposure to natural settings especially in high-density urban areas (Coombes et al., 2010; Millward and Sabir 2011; Annerstedt et al., 2012; Liu et al., 2021a). During the process of interacting with nature such as in urban green spaces, most people's restlessness and anxiety will be temporarily relieved, and their body and mind will also be relaxed (Wang et al., 2020). Meanwhile, with the accelerating pace of modern life and great pressure from work and life, especially in the post COVID-19 epidemic era, people's demand for health is more significant (Li and Yang, 2020). Through contacting with natural area, individuals could recuperate from physical and mental stress (Grahn and Stigsdotter, 2010; Shafagh et al., 2019; Chen and Lin, 2023). Therefore, there is a great need for green spaces in urban areas, where people could have more opportunities to interact with nature and out-door recreation (Wolsko and Lindberg, 2013; Jennings and Bamkole, 2019; Yan, 2021; Wang et al., 2024).

As an important component of urban green space system, green spaces in urban neighborhoods are the areas closely integrated into the daily lives of urban residents. With beautiful natural landscapes and open activity spaces, green spaces in urban neighborhoods are the first choice for public people to engage in outdoor physical activities and interact with nature. According to the 2022 National Fitness Trends Report by General Administration of Sport in China, the proportion of people who participate in physical exercise at least once a week is 67.5%, an increase of 18.5% compared to the 2014. About 30% - 40% of these residents choose to exercise in green spaces of urban neighborhoods, and the proportion has increased by 3.6% compared to 2014. More and more people choose to engage in activities in green spaces, accessible and experiential green spaces in urban neighborhoods have become the activity venues that could meet people's outdoor activity needs of getting close to nature.

Plant community, the basic unit that makes up green spaces, is a plant aggregation formed by arranging diverse plants in a certain area according to a certain proportion including horizontal and vertical structure (Yu et al., 2024). Plant communities are the foundation for various ecological services such as environmental regulation, landscape recreation, and cultural education of green spaces (Li et al., 2018; Yu et al., 2024). While compared to natural areas, plant community in the green spaces of urban neighborhood is mainly designed and constructed by humans to meet diversified functional requirements. The structure characteristics of plant community in green spaces of urban neighborhoods and natural areas may be quite different. And many previous studies have studied the characteristics and their relations with ecological/social functions of plant communities in urban green spaces (Bisinger et al., 2015; Zhang et al., 2015; Li et al., 2018). However, these studies mainly focused on some special green spaces in urban areas such as urban parks or green space in residential areas. And residents' usage patterns in green spaces are often overlooked, resulting in a lack of effective guidance on plant community design from the perspective of the target users. Despite the enormous benefits of UGS, dearth of information on the quantity and quality of plant community handicaps planners for managing the UGS, especially green spaces in urban neighborhoods.

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Right now, the green coverage rate in urban built-up areas has reached 43%, and the city has entered a new stage of stock improvement from incremental expansion in China (Zheng et al., 2023). While the lack of available recreational space in high-density urban environments limits the new demand for people to get close to nature, engage in leisure activities, and exercise and fitness. A systematic study on the characteristics of plant community is quite needed to strengthen the open and sharing of urban green spaces, which would promote the integration of cities and parks, and promote harmonious coexistence between humans and nature. Considering the fact that Shanghai in China has experienced a largest and rapidest flux of urbanization (Ding et al., 2021), the increase in urban population and impervious area have resulted in dramatic changes of UGS including plant community. Understanding the characteristic and differentiation of plant community in the process of urbanization is crucial for developing strategics to improve urban green space management. This study was conducted to: (1) determine the characteristics of plant community in green spaces of urban neighborhoods at different levels; (2) investigate the plant community differentiation among various urban green spaces along urbanization gradients; (3) provide some recommendations for plant community design in urban neighborhoods, which could coordinate human and natural systems in urban areas.

Materials and methods

Description of the study area

This study was conducted in Shanghai city (30°82′30″–31°82′70″N and 120°85′20″–121°84′50″E), which was one of China’s major cities. Shanghai has a high level of urbanization and population density, with a total land area of 6340.5 km^2 and a permanent population of 24.7589 million (Shanghai Municipal Bureau of Statistics, 2023). In addition, the urban structure of Shanghai is unique, with a multi-centered layout and diverse community types, leading to distinct patterns of green spaces and plant community compositions across different areas. According to the “14th Five-Year Plan for Park City Construction in Shanghai”, a relatively mature and comprehensive green space system has been developed in Shanghai (Shanghai Landscaping & City Appearance Administrative Bureau, 2023). Thus, selecting Shanghai for research can reveal the characteristics and differentiation of plant community in various urban green spaces along urbanization gradients, and provide valuable guidance and reference for plant community design in other cities. The present study was conducted in three urban neighborhoods located in the Huangpu (Ruijin community), Minhang (Xincheng community), and Songjiang (Fangsong community) districts of Shanghai, which were distributed along urban-rural gradients of the city (*Fig. 1*). According to the development history of Shanghai city, these three districts could represent central city, city suburb and outer suburb respectively. The basic information of these three urban neighborhoods was shown in *Table 1*. The three urban neighborhoods were built at different times, with different architectural forms, green space ratios, and distribution patterns.

Summary of the field work

Identification of plant communities

According to the urban green spaces classification standard of China (CJJ/T85-2017), green spaces in urban neighborhoods could be identified into four types based on their location, function and management objectives in this study: community park, residential

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green spaces, road green spaces and other attached green spaces (*Table 1*). Community park refers to the plant communities in neighborhood parks; residential green space refers to the plant communities in residential areas; road green space refers to the plant communities along roads and streets; other attached green space refers to the plant communities in school yards, hospitals, commercial and business districts etc. The plant communities in these areas serve multiple functions: (1) ameliorating urban environmental conditions; (2) facilitating nature engagement through sensory experiences; (3) providing designed spaces for structured social activities including group gatherings, recreational events, and contemplative viewing.

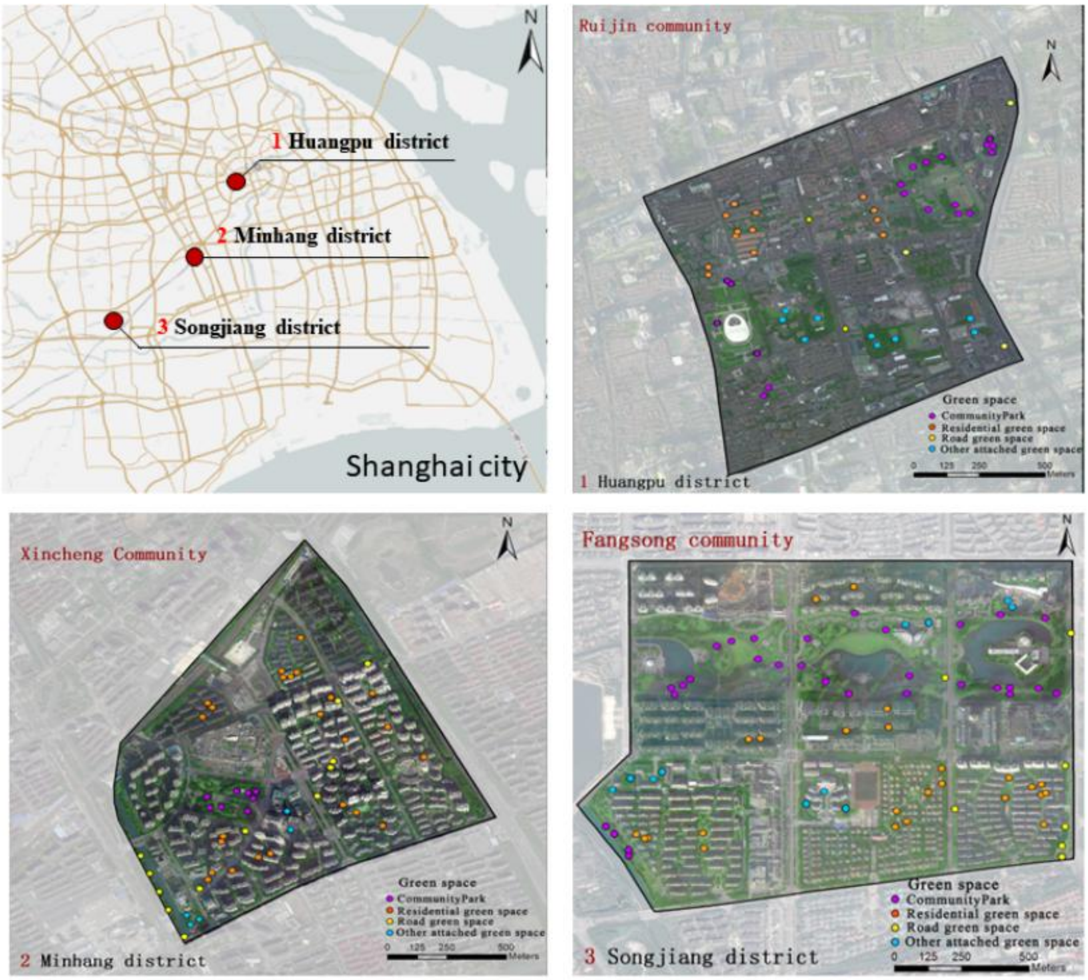

***Figure 1.** Location of sampling plant community plots in three urban neighborhoods (data source: MAP WORLD 2017 http://www.tianditu.com/). The colored circles mean the sample plots in different green spaces*

Next, a stratified random sampling method was adopted to allocate plant communities in the green spaces of three urban neighborhoods based on a high-resolution (0.5 m) image of Shanghai and preliminary field survey (*Fig. 1*). The number of plant community plots selected for each green space was mainly determined by the area of green spaces and the overall heterogeneity of plant community. Each plant community plot occupied ~400 m^2 land and these communities were uniformly distributed in the green spaces.

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During the selection of these target plots, plant communities with steep slopes, which would complicate the field investigation, were eliminated. *Figure 2* showed some field photos of the sampling sites. The plant communities in *Figure 2a, b* facilitated immersive nature experiences through accessible vegetation interfaces, while those in *Figure 2c, d* are specifically programmed to support structured recreational activities. The high-resolution (0.5 m) image of the study area was captured from Shanghai Tiandi Map (MAP WORLD 2017 http://www.tianditu.com/).

Table 1. *Numbers of sampling plant community plots in three urban neighborhoods*

Urban neighborhood	Description/green space ratio	Green space types/No.	No. of sampling plot
Ruijin community	Located in central city, and was constructed in Mid-19th century/19.86%	Community park/4	19
		Residential green space/8	13
		Road green space/3	5
		Other attached green space/7	9
Xincheng community	Located in suburban area, and was constructed in late 1990s/30.17%	Community park/3	8
		Residential green space/11	24
		Road green space/5	12
		Other attached green space/4	5
Fangsong community	Located in outer suburb, and was constructed in early 21st century/35.32%	Community park/6	30
		Residential green space/6	25
		Road green space/4	7
		Other attached green space/5	11
Total		66	168

Figure 2. *Filed photographs of some sampling sites*

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Investigation of plant communities

From July to October 2017, Faurecian survey method was applied to investigate the plant community characteristics. During the field survey of each plant community, sampled trees were evaluated in terms of species, number, height, growth form (evergreen broadleaf, deciduous broadleaf, conifer, palm), and canopy cover etc. While for the shrub and herb layer, species and coverage were also measured and recorded respectively. Furthermore, the leaf area index (LAI) and the canopy density (CD) of each plant community plot were measured based on the studies by Li (2018) and Qi (2009). The LAI measurements were conducted for each plant community using an LAI-2200 plant canopy analyzer (LI-COR, Lincoln, NE, USA), with four paired above/below-canopy readings. The CD was measured using a Sony digital camera with a 35 mm lens. For each plant community, photographs were taken at 1.5 m height with the lens maintained in horizontal orientation. Image processing was performed using Adobe Photoshop CC (Adobe System Inc., San Jose, CA, USA), where RGB images were converted to two-tone grayscale and thresholding was applied to create binary images. Then CD was calculated by using the following calculation:

$$CD = 1 - {}^{b}/_{a} \tag{Eq.1}$$

where a and b are the number of hemisphere and gap pixels of the enclosed canopy district, respectively.

In total, 168 plant community plots were selected and investigated in this study. 46 plant community plots in Ruijin community, 49 plant community plots in Xincheng community and 73 plant community plots in Fangsong community were recorded. The basic information and distribution of these plant communities were shown in *Figure 1* and *Table 1*.

Data analysis

According to some previous studies, the species dominance and diversity indices Magurran, 1988) of plant communities were calculated to identify the plant community form and to compare the species diversity across different green space types and urban neighborhoods. The species diversity indices included species richness (S), Gleason species diversity index (G), Shannon-Wiener species diversity index (H′) and Simpson species diversity index (D). The calculation equations for all indices are as follows:

Dominance value (P):

$$P_i = H_i \times C_i \tag{Eq.2}$$

Species richness (S):

$$\text{S = Number of the species in each plant community plot} \tag{Eq.3}$$

Gleason index (G):

$$G = {}^{S}/_{\ln A} \tag{Eq.4}$$

Shannon-Wiener index (H′):

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$$H' = -\sum_{i=1}^{S} P_i \ln P_i \quad \text{(Eq.5)}$$

Simpson index (D):

$$D = 1 - \sum_{i=1}^{S} P_i^2 \quad \text{(Eq.6)}$$

where Pi is the relative dominance of specie I; Hi is the height of specie i; Ci is the coverage of specie i; A is the area of each plant community plot.

Based on the relative species dominance, clustering analysis was applied to classified the plant community forms. The calculation of species diversity indices and clustering analysis were all performed with PC-ORD version 5.0. Furthermore, a one-way analysis of variance (ANOVA) followed by a LSD test ($p < 0.05$) were conducted to examine differences in plant communities among the four green space types and three urban neighborhoods using SPSS version 18.0.

Results

Plant community forms in green spaces of urban neighborhoods

In this study, a great many plant community forms were categorized in green spaces of urban neighborhood. Based on species dominance and the visual characteristics of plant communities, the 168 plant communities were classified into 65 forms at a 70% similarity level using clustering analysis. These plant community forms including *Magnolia grandiflora* Community, *Cinnamomum camphora* Community, *Cedrus deodara* Community etc. This finding may be attributed to that plant communities in green spaces of urban neighborhoods were mainly artificial. The design preferences and residents' planting preferences vary greatly, resulting in significant differences in the plant compositions and dominance of plant communities.

Furthermore, these 65 plant community forms could be divided into 7 vegetation types based on the classification standards of "Chinese Vegetation." The 7 vegetation types included evergreen broad-leaved forest, deciduous broad-leaved forest, evergreen and deciduous broad-leaved mixed forest, coniferous forest, mixed broad leaf-conifer forest, shrub community and herbaceous community. While deciduous broad-leaved forest, evergreen broad-leaved forest, evergreen and deciduous broad-leaved mixed forest were the main vegetation types in the green spaces of urban neighborhood, with frequency of 28.2%, 26.1% and 25.5% respectively (*Fig. 3*). *Figure 3a-c* showed three images of the main vegetation types, which were taken by the authors.

Species composition and frequency in plant community

In the studied 168 plant community plots, totally 271 plant species were identified. These species belonged to 197 genera and 85 families. While the contributions of individual specie were highly heterogeneous (*Table 2*). *Cinnamomum camphora* and *Osmanthus fragrans* were the two tree species with highest frequency in the 168 plant communities (f > 50%). For the shrubs and herbs, *Buxus sinica* and *Loropetalum chinense* var. *rubrum*, *Ophiopogon japonicus*, *Cynodon dactylon* and *Zoysia matrella* occurred frequently in the plant communities. Totally, about 34 species occurred frequently in the identified plant communities with frequency more than 10% (*Table 2*). These species included 9 evergreen trees species, 11 deciduous trees species, 9 shrubs species and 5

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herbs species including the tree seedlings. Whereas there were also 129 species whose frequency in the plant communities was less than 1%, which showed the occasionality of plant species application in the green spaces of urban neighborhoods.

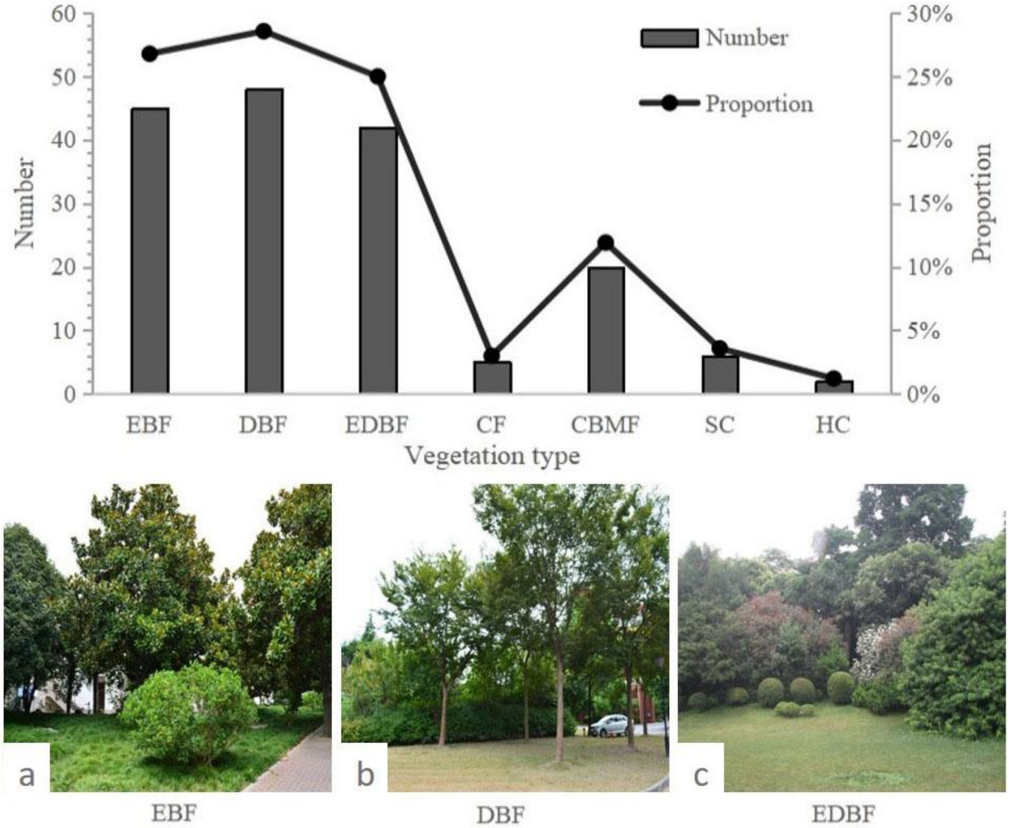

Figure 3. *Number and proportion of plant communities for different vegetation types, images of the main vegetation types. EBF, Evergreen broad-leaved forest; DBF, Deciduous broad-leaved forest; EDBF, Evergreen and deciduous broad-leaved forest; CF, Coniferous forest; CBMF, Coniferous and broad-leaved mixed forest; SC, Shrub community; HC, Herbaceous community*

Table 2. *Main plant species and their frequency in plant communities (f ≥ 10%)*

Frequency (f, %)	Plant species
f ≥ 50	*Cinnamomum camphora, Osmanthus fragrans*
20 ≤ f < 50	*Buxus sinica, Ophiopogon japonicus, Loropetalum chinense* var. *rubrum*
	Cynodon dactylon, Acer palmatum, Ligustrum lucidum
16 ≤ f < 20	*Pittosporum tobira, Trachycarpus fortune, Camellia japonica, Magnolia grandiflora, Ulmus pumila, Magnolia denudate, Lagerstroemia indica*
12 ≤ f < 16	*Rhododendron simsii, Nandina domestica, Cedrus deodara, Ginkgo biloba, Viburnum odoratissimum* var. *awabuki, Fatsia japonica, Cerasus serrulata* var. *lannesiana. Zoysia matrella, Rhododendron × pulchrum*
10 ≤ f < 12	*Melia azedarach* (seedling), *Punica granatum, Malus halliana, Broussonetia papyrifera* (seedling), *Prunus cerasifera* cv. Atropurpurea, *Aucuba japonica* cv. Variegata, *Podocarpus macrophyllus, Albizia julibrissin, Eriobotrya japonica, Verbena hybrida*

f means the frequency of each plant species appearing in plant communities, f = the number of plant community including one certain plant species / the total number of plant communities

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Species diversity of plant communities

The mean value and standard deviation of the species diversity index for the 168 plant communities were calculated. Species richness index was 11.6 ± 6.7, Gleason index was 2.2 ± 1.2, Shannon Wiener index was 1.6 ± 0.7, and Simpson index was 0.7 ± 0.2. According to the species diversity indexes, plant species distributed quite unevenly among different habitats. And even within the same green space type, species diversity varied significantly across districts with different urbanization levels. The species diversity indexes of different green space types in Ruijin (RJ), Xincheng (XC) and Fangsong (FS) communities were shown in *Figure 4*, and the four species diversity indexes basically show the same law.

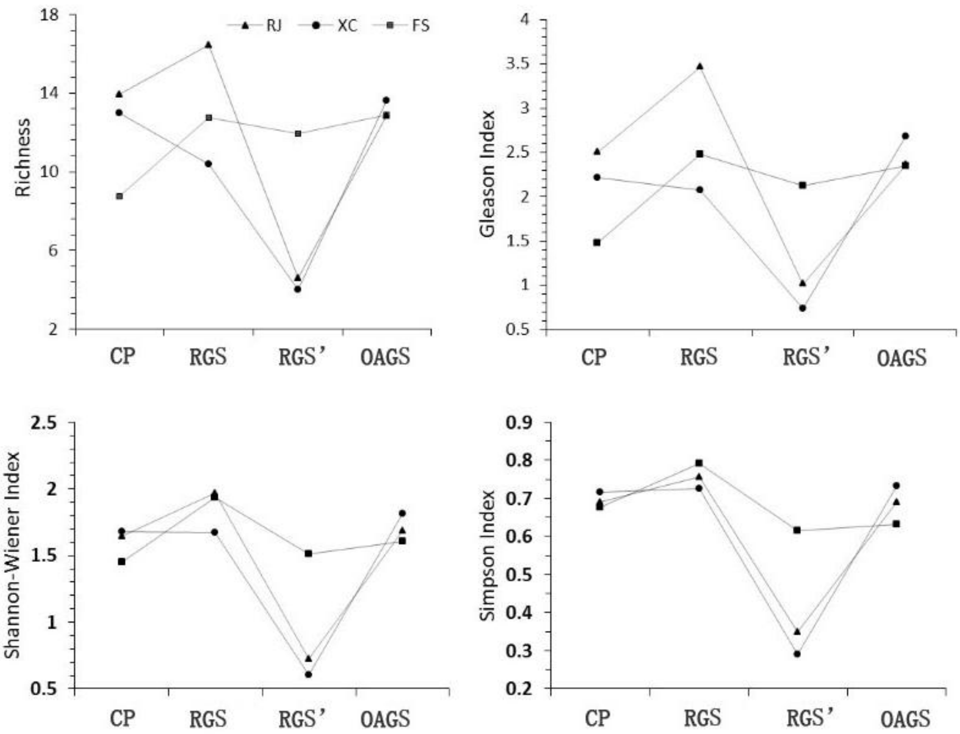

Figure 4. *Species diversity indexes of plant community in various green spaces of urban neighborhoods. RJ, Ruijin community; XC, Xincheng community; FS, Fangsong community; CP, community park; RGS, residential green space; RGS', Road green space; OAGS, other attached green space*

Species diversity differentiation in various green space types

The mean value of species richness, Gleason index, Shannon-Wiener index and Simpson index related to road green space (RGS') was 6.8, 1.3, 0.9 and 0.4 respectively, which were all significantly lower than the other 3 green space types. While for different urban neighborhoods, the species diversity differentiation in green spaces was various (*Fig. 3*). For RJ, the species richness and Gleason index of residential green space (RGS) were significantly higher than the other three types ($p < 0.05$), and the four diversity indexes of RGS' were significantly lower than the other three green space types ($p < 0.01$). For XC, the four diversity indexes of RGS' were also significantly lower than the other three green space types ($p < 0.01$), and the species richness of community park

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(CP) and other attached green spaces (OAGS) were significantly higher than the residential green space ($p < 0.05$). For FS, the species richness and Gleason index of CP were significantly lower than the other three green space types ($p < 0.05$), the Shannon-Wiener and Simpson index of RGS was both significantly higher than the other three green space types ($p < 0.05$).

Species diversity differentiation in urban neighborhoods

The mean value of species richness, Gleason index, Shannon-Wiener index and Simpson index related to all green spaces in XC was 10.35, 1.94, 1.425 and 0.62 respectively, which was all lower than the RJ and FS. While for the green spaces in CP, species richness and Gleason index in FS were significantly lower than those of the other two urban neighborhoods ($p < 0.05$); for RGS, species richness and Gleason index in XC were significantly lower than those of the other two urban neighborhoods ($p < 0.05$); for RGS', 4 species diversity indices in FS were all significantly higher than those of the other two urban neighborhoods ($p < 0.01$); for OAGS, there was no significant difference among the three urban neighborhoods.

Structure characteristics of plant community in green spaces of urban neighborhoods

Vertical structure of plant communities

Vertical structure of a plant community refers to the vertical differentiation in space, also known as stratification by plant layer. Within this study, plant communities were systematically classified into five distinct types based on their vertical stratification: T_1 community, the height of trees in plant community > 8 m; T_2 community, the height of trees in plant community < 8 m; T_{12} community, the height of trees in plant community ranged from < 8 m to > 8 m; S community, shrub community; H community, herbaceous community. *Table 3* showed the 5 vertical structure types of plant community and their proportions in the studied plots. The order of the proportion of each plant community type was: T_2 community > T_{12} community > T_1 community > S community > H community. The cumulative proportions of T_2 (46.3%) and T_{12} (43.1%) plant communities were 89.4%, which constituted the dominant plant community types of green spaces in urban neighborhood. Furthermore, these plant communities cloud be classified into several subtypes based on the association of plant layers. Among all types of plant community, the vertical structure with trees + shrubs + grasses was widely distributed, accounting for a total of 80.1% (T_{12}SH 37%, T_1SH 2.1% and T_2SH 41%). While the subtypes of T_{12}, T_2 and T_1H plant communities were absent in all studied plots.

Table 3. *Different vertical structures of plant community and their proportions*

	T_{12} Community /Proportion (%)	T_1 Community /Proportion (%)	T_2 Community /Proportion (%)	S Community /Proportion (%)	H Community /Proportion (%)
One layer		T_1/2.1	T_2/0	S/1.1	H/0.5
Two layers	T_{12}/0	T_1S/1.1 T_1H/0	T_2S/1.6 T_2H/4.8	SH/3.2	
Three layers	T_{12}S/3.7 T_{12}H/2.1	T_1SH/2.1	T_2SH/41		
Four layers	T_{12}SH/37				
Total	43.1	5.9	46.3	4.3	0.5

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For the green spaces in 3 urban neighborhoods, the proportions of different plant community types based on vertical structure were shown in *Figure 5*. S and H plant communities were both less distributed in urban neighborhoods. For the plant communities with trees, T_1 plant community had the lowest proportion in urban neighborhoods. Furthermore, the proportion of T_{12} plant community and T_1 plant community was decreasing, while the proportion of T_2 plant community was gradually increasing by the order of RJ, XC and FS.

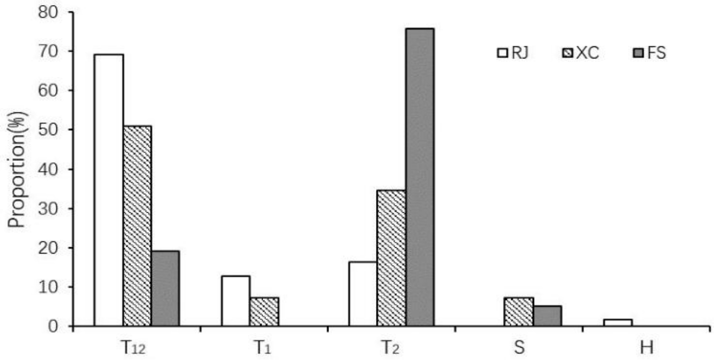

Figure 5. *Proportion of different plant community types based on vertical structure*

Horizontal structure of plant community

Horizontal structure of a plant community refers to the differentiation in horizontal space, manifested as the horizontal distribution pattern of various plants in the community. In this study, community coverage, CD, and LAI were used to analyze the horizontal structures of plant community in green spaces of urban neighborhoods.

The mean coverage of different plant layers in the studied plant communities was shown in *Table 4*. T_2 had the highest coverage (37.0% $\pm$ 25.0%), while T_1 had the lowest coverage (20.4% $\pm$ 27.6%). Furthermore, the horizontal space in a plant community covered by T1, T2, S, and non-turf herbaceous was synthesized as the “activity limit space” (people could not enter in for recreation). This plant combination was denoted as TSH’ layer, and its coverage was denoted as $C_{TSH'}$. While the remaining lawn grass, weeds, bare land, or paved ground not covered by trees and shrubs primarily constitute the activity space (horizontal direction) within the plant community, which was denoted as H_0 layer. Thus, plant communities with lower $C_{TSH'}$ could have relatively large internal activity space for people to enjoy. In this study, the range of $C_{TSH'}$ in all sampled plant community plots was 20% to 100%, with a mean value of 62.5% ± 23.3%.

Table 4. *Coverage of different layers in plant community plots*

Layer	T_1	T_2	S	H	TSH’
Coverage	20.4% ± 27.6%	37.0% ± 25.0%	30.6% ± 25.2%	32.5 ± 23.2%	62.5% ± 23.3%

The mean CD of the sampling plant community plots was 47.2% ± 24.1%, with a median of 50.0%. And the frequency distribution of CD was shown in *Figure 6*, which approximately followed a normal distribution. Plant communities with a CD between 30% and 70% were most widely distributed in urban neighborhoods, accounting for

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62.8% of the total. While the plant community with CD below 30% accounted for 21.8%, and the plant community with CD above 70% accounted for only 15.4%.

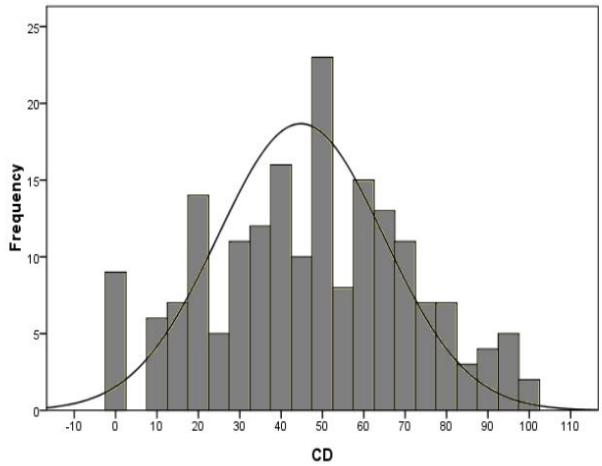

Figure 6. *Frequency distribution of CD across plant communities*

Furthermore, the CD of plant communities distributed in different green spaces and urban neighborhoods was calculated and shown in *Table 5*. For urban neighborhoods, CD of plant communities in RJ was highest, and showed a declining trend by the order of RJ (51.8% ± 23.5%), XC (50.8% ± 24.1%) and FS (45.7% ± 20.7%). For green space types, plant communities in community park had the lowest CD (45.0% ± 25.6%). Whereas there was no significant difference for the CD of plant community in different green spaces ($p > 0.05$) and urban neighborhoods ($p > 0.05$), based on the results of one-way analysis of variance and LSD multivariate comparison.

Table 5. *CD of plant community in different urban neighborhoods and green spaces*

Neighborhoods	**RJ**	**XC**	**FS**	
Canopy density	51.8% ± 23.5%a	50.8% ± 24.1%a	45.7% ± 20.7%a	
Green spaces	**Community park**	**Residential green space**	**Road green space**	**Other attached green space**
Canopy density	45.0% ± 25.6%a	50.6% ± 19.8%a	49.7% ± 23.7%a	51.7% ± 22.9%a

The same letter indicated no significant difference by difference tests

The LAI of a plant community is one of the important parameters for studying community horizontal structure. LAI could reflect the two-dimensional green quantity of plant community, and also reflect the status of plant growth and community health. For all sampling plant community plots, the mean LAI was 2.66 ± 1.21, with a median of 2.60 (*Fig. 7*). The plant communities with LAI between 1 and 4 were most widely distributed, totally accounted for 81.4%. While the plant community with LAI below 1 accounted for only 6.4%, and the plant community with LAI above 4 accounts for 12.2%.

The mean value of LAI for plant communities in different green space types and urban neighborhoods was calculated and shown in *Table 6*. For urban neighborhoods, LAI showed a declining trend by the order of RJ (3.03 ± 1.34), XC (2.74 ± 1.18) and FS (2.34 ± 1.06). And LAI of plant communities was significantly different ($p < 0.01$) in the

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three urban neighborhoods. Multiple comparisons of LSD showed that the LAI of plant communities in RJ was significantly higher than that of XC and FS ($p < 0.01$). Meanwhile, there was no significant difference for LAI of plant communities in different green space types ($p > 0.05$).

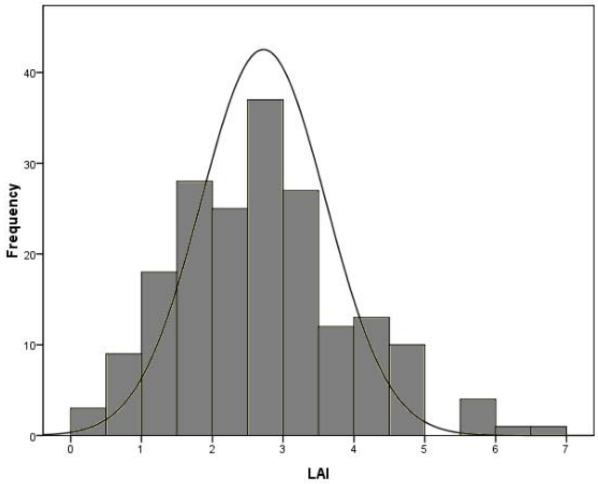

Figure 7. *Frequency distribution of LAI across plant communities*

Table 6. *LAI of plant community in different urban neighborhoods and green spaces*

Neighborhoods	**RJ**	**XC**	**FS**	
LAI	3.03 ± 1.34a	2.74 ± 1.18ab	2.34 ± 1.06b	
Green spaces	**Community park**	**Residential green space**	**Road green space**	**Other attached green space**
LAI	2.44 ± 1.50a	2.67 ± 1.01a	2.67 ± 0.97a	3.02 ± 1.23a

The same letter indicated no significant difference by difference tests; the different letter indicated significant difference by difference tests

Discussion and recommendation

Differences between green spaces in urban neighborhoods and urban forest

Green space in urban neighborhood is the closest area for residents being close to nature (Eshetu et al., 2021; Liu et al., 2021a). To meet the diverse demands of residents, the diversity of ornamental plants is an important requirement for plant community design in green spaces. In this study, a total of 271 species of seed plants in 197 genera, 85 families (excluding weed species) were recorded in the green spaces of urban neighborhoods. And there were 129 plant species with a frequency of less than 1% in green spaces of urban neighborhood, which is about half of all investigated plant species. While in urban forest, a few tree species dominate the entire forest, indicating a clear clustering characteristic (Xu et al., 2010; Zhang et al., 2016). Comparing with urban forest in Shanghai (223 species, 181 genera, 84 families), plant species in green spaces of urban neighborhoods were relatively rich (Koptseva, 2021). For the species diversity, mean species richness of plant community in the green spaces of urban neighborhood (11.6, excluding weeds) was great higher than that of urban forest (2.6, excluding weeds) in Shanghai (Zhang, 2010).

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On the other hand, the vertical structure of plant community in green spaces of urban neighborhoods was dominated by the type of "arbor + shrub + grass" (80.1%). While urban forest in Shanghai was dominated by the type of "arbor + grass" (58.4%), followed by "arbor + shrub + grass" (26.0%). The vertical levels of plant community in green spaces of urban neighborhoods were more diverse, and the widespread shrub layer could enrich the middle space of plant community. All these findings indicated that green spaces in urban neighborhood had a higher level of species diversity than urban forest (Avolio, 2015; Millward and Sabir, 2011).

Comparison of plant community characteristics in different urban neighborhoods

In this study, the plant community characteristics in green spaces across different urban neighborhoods were compared by considering the species diversity and vertical structure, which were found significantly different.

Integrative analysis of species diversity changes on a global scale shows that biodiversity decreases monotonically from rural areas to urban centers (Nielsen, 2014; Zhang, 2016). While in this study, species diversity of plant communities in green spaces of urban neighborhood was not consistent with the gradient of urban and rural areas (Ruijin community in the central city, Xincheng community in the suburban area and Fangsong community in the outer suburb). Taking species richness as an example, which was significantly lower in the community park of Fangsong community than that of the other two communities ($p < 0.05$). This may be attributed to that the community park in Fangsong community was designed with British style. A large number of lawns and sparse forest grasslands were used in plant community design, which resulted in the low species richness. The species richness of residential green spaces in Ruijin community and Fangsong community was significantly higher than that of Xincheng community ($p < 0.05$). For Ruijin community, there are many garden style alleyway residences, which have been constructed for a long time and experienced refined transformation and management. For Fangsong community, there are a large number of multi-story and villa residences. Green spaces in these residential areas were finely designed to meet residents' diverse demands. While in Xincheng community, residential areas were mainly constructed by some real estate developers in the same eras. Green spaces in these areas were designed with the same style, and similar plants were selected for plant community design. In addition, the species richness of road green space in Fangsong community was significantly higher than that of the other two communities ($p < 0.05$). Most roads in Fangsong community were constructed in recent years with over 20 m wide green belts and roadside green spaces, which could result in diverse plants and a high level of species diversity. While in Ruijin and Xincheng communities, road green space was mainly composed of simple street trees and green belts with low shrubs, resulting in a low level of species diversity.

For the vertical structures of plant communities in 3 urban neighborhoods, the proportion of T_1 and T_{12} was gradually decreasing, while the proportion of T_2 was gradually increasing from urban centers to rural areas (*Fig. 4*). Compared to the Ruijin community located in urban centers, there were more small and medium-sized trees planted in the plant communities of urban neighborhoods located in suburban area (Xincheng community) and outer suburbs (Fangsong community). This finding may be attributed to that the plant communities in suburban and outer suburb areas were all constructed in recent years, trees had a short growth period and had not yet formed many tall trees. Especially for Fangsong community, the proportion of T_2 in plant community

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reaches 75.6%, about three quarters of the plant communities was composed of small and medium-sized trees. All these findings above indicated that plant community characteristics of green spaces in urban neighborhoods were mainly determined by human factors (Haas, 2021; Qureshi, 2013), which was not contradictory with some previous studies that biodiversity would decrease with urbanization gradient.

Recommendations for plant community design in urban neighborhoods

Compared to urban forests, green spaces in urban neighborhoods are important places for residents' daily activities, as they are the closest area for residents to connect with nature. Plant communities in green spaces provide multiple ecosystem functions, including ornamental (aesthetic value) and recreational (leisure activities) functions. While these functions were significantly affected by the spatial structures of plant communities, such as TSH' layer coverage, canopy density, and urban-branch height etc., which ultimately determined the usage patterns of residents (Shafagh, 2019; Yu, 2024). Integrating the vertical and horizontal structural characteristics of plant communities (as identified in this study) with residents' usage patterns, we classified plant communities into three distinct structural-functional types. The three types of plant community included ecological landscape community, grassland community and understory forest community. Taking a 20 m × 20 m plot as an example, *Figure 8* showed the schematic diagram of classification process for plant community structure in urban neighborhoods. When $C_{TSH'} > 60\%$ and people could not enter in for recreation, the plant community was an ecological landscape community (*Fig. 8a*). The $C_{TSH'}$ in *Fig. 8a* was 80%. Specially, when the plants coverage distributed uniformly and were dominated by high branching tree layers, this plant community could be defined as understory forest community where people could enter in for recreation (*Fig. 8b*, $C_{TSH'} = 80\%$). When $C_{TSH'} < 60\%$, and H_0 layer coverage was above 40%, this plant community was defined as a grassland community. And this type of plant community could be further classified into two subtypes based on the spatial distribution of plants. *Figure 8c, d* showed the two subtypes of grassland community with $C_{TSH'} = 40\%$. The grassland and understory forest communities belonged to the active entry type of space, which could provide activity space for residents' recreation in plant communities.

For the plant communities in urban neighborhoods, ecological landscape communities mainly undertake ecological and ornamental functions, and people are unable to enter the interior of the plant community or will not actively enter in for recreation ($C_{TSH'} > 60\%$). This type of plant community could be further classified into four subtypes based on the canopy density distribution: shrub grass type ($CD = 0$), sparse forest type ($0 < CD < 30\%$), medium canopy type ($30\% \leq CD < 70\%$) and dense forest type ($CD \geq 70\%$). The shrub grass type and sparse forest type communities have missing tree layers or less tree distribution, mainly covered with ornamental shrubs and grasses. And plant communities with medium canopy density were the dominant subtype of ecological landscape community, which was found during the field investigation. *Figure 9* showed the typical eco-landscape type of plant community with medium canopy density, which could provide reference for the plant community design of the similar type.

In the green spaces of urban neighborhoods, grassland type of plant community was mainly covered by H_0 layer ($C_{H0} > 40\%$), with lawn grass, weeds or dead leaves etc., which allowed people to enter and participate in recreational activities. Thus, this type of plant community mainly undertakes leisure and recreational functions for residents. Furthermore, grassland type communities could be classified into 2 subtypes based on the

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horizontal distribution patterns of TSH' layers. When the TSH' layers gather together at one side of the plant community as background, forming an open recreational space, it is an open grassland type community (*Fig. 8c*); and when the TSH' layers distribute at different positions, dividing the plant community into different sizes of recreational spaces that can meet people's different behavior needs, it is a sparse forest grassland type community (*Fig. 8d*). *Figures 10* and *11* showed the open grassland type and sparse forest grassland type of plant communities in urban neighborhood respectively.

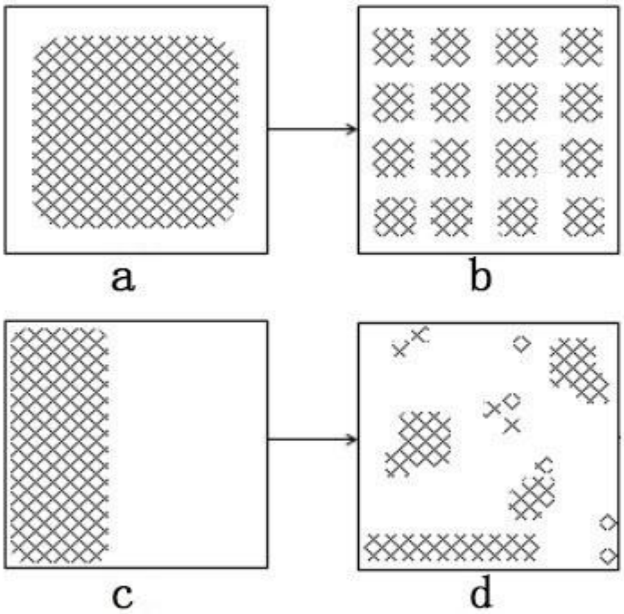

Figure 8. *Schematic diagram of the classification process for plant community structure. The black border in the figure represents the community boundary, the square area represents the TSH' layer and the blank area represents the H_0 layer. a, ecological landscape community, $C_{TSH'}$ = 80%; b, understory forest community, $C_{TSH'}$ = 80%; c, d, grassland community, $C_{TSH'}$ = 40%*

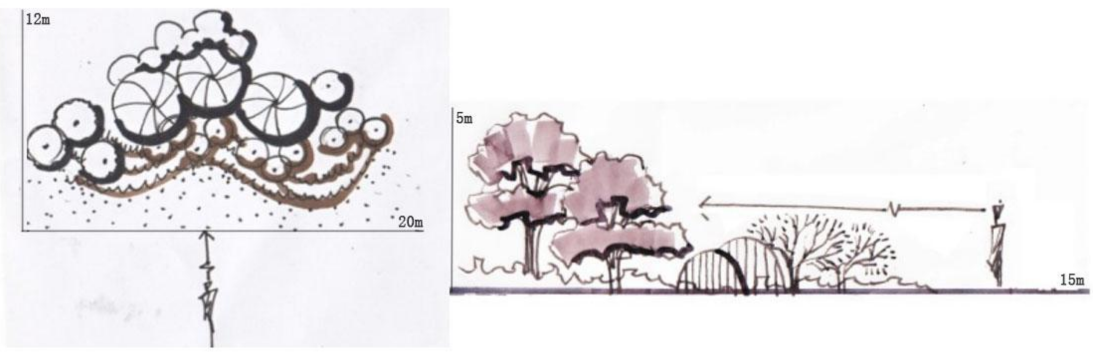

Figure 9. *Plan and elevation for eco-landscape type of plant community*

For the understory forest plant community, tree species are uniformly distributed, with a certain canopy density (>50%), high branching points (>3 m), and the absence or low coverage of SH' layer (<30%) beneath the tree canopy. Thus, this plant community type could form one large understory space, where people could enter and participate in some

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leisure activities. To some extents, this type of plant community cloud be seen as one special type of medium canopy plant community or dense forest plant community (*Fig. 8b*). *Figure 12* showed the plan and elevation for understory forest type of plant community in urban neighborhood to provide reference for the plant community design with similar function demands.

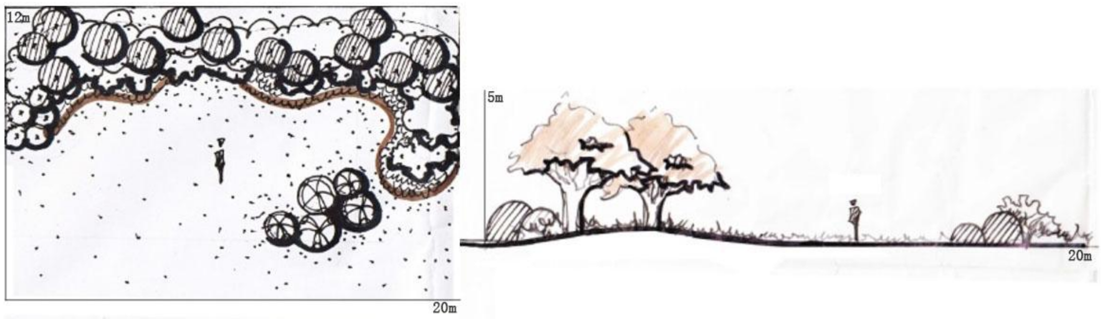

Figure 10. *Plan and elevation for open grassland type of plant community*

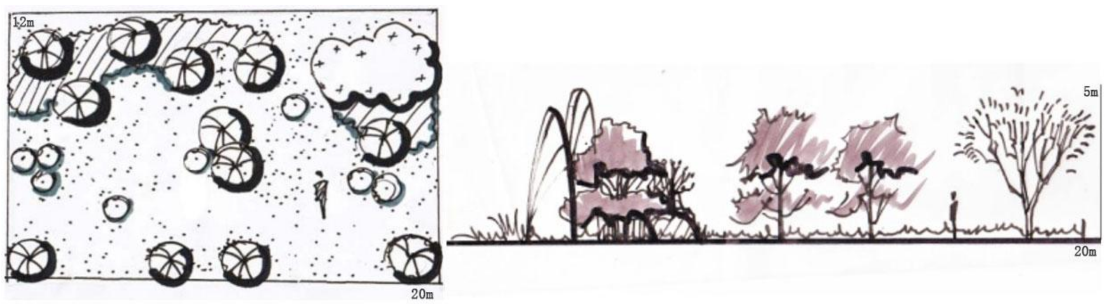

Figure 11. *Plan and elevation for sparse forest grassland type of plant community*

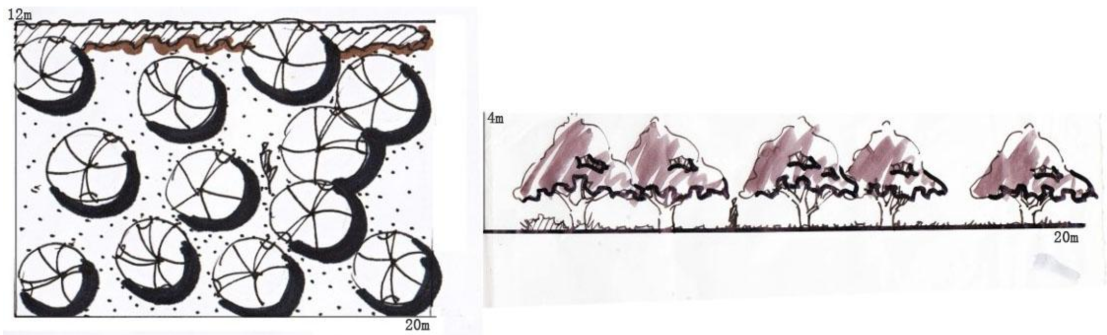

Figure 12. *Plan and elevation for understory forest type of plant community*

Conclusion

According to previous studies, green spaces in urban neighborhoods are essential for human wellbeing and serve as important places for the public to interact with nature. As the basic unit of green spaces, plant communities are the foundations for various ecological services such as environmental regulation, landscape recreation, and cultural education etc. Exploring the characteristics of plant community in urban neighborhood is

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helpful for strengthening the open and sharing of green spaces, providing plant community design schemes, promoting citizens' outdoor recreation. Taking 168 plant communities as the research objects, this study investigated the characteristic and differentiation of plant communities in different green spaces of 3 urban neighborhoods. The results revealed that species diversity and structural characteristics of plant communities in urban neighborhood were quite different by green space types and urbanization gradients. Plant community characteristics of green spaces in urban neighborhoods were mainly determined by human factors. And green spaces in urban neighborhoods had a higher level of species diversity than urban forest. Accompanied with the findings in this study and residents' demands for recreation spaces, corresponding recommendations for plant community design in urban neighborhood were provided, including ecological landscape community, grassland community and understory forest community. All the findings in this study were helpful for improving the renewal strategy of urban green spaces, and can be applied in similar high-density urban areas to enhance the service functions of urban green spaces.

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Conflict of interests. The authors declare no conflict of interests.

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