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Spatial Heterogeneity of Plant Diversity within and between Neighborhoods and Its Implications for a Plant Diversity Survey in Urban Areas

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Abstract: The spatial heterogeneity of plant diversity at the neighborhood scale has less been understood, although it is very important for the planning and management of neighborhood landscape. In this case study of Beijing, we conducted intensive investigations of the plant diversity in different neighborhoods along a rural–urban gradient. The results showed that the mean numbers of plant species per neighborhood were 30.5 for trees, 18.8 for shrubs, and 31.9 for herbs, respectively. There were significant logarithmic relationships between the numbers of species and patch area, indicating that larger patches within neighborhoods could harbor more plant species. Hierarchical linear modeling showed that the variations in plant diversity within neighborhoods were higher than those between neighborhoods. The number of species increased logistically with both the number of patches within neighborhoods and the number of neighborhoods, suggesting that it is important to sample a sufficient number of patches within neighborhoods, as well as a sufficient number of neighborhoods in order to sample 90% of the plant species during the investigation of plant diversity in urban neighborhoods. So the hierarchical design of sampling should be recommended for investigating plant diversity in urban areas.

Keywords: plant diversity; neighborhood; species–area curve; sampling

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1. Introduction

Urban green spaces provide a wealth of available habitats for plants and animals, as well as multiple ecosystem services for residents by mitigating heat stress and the occurrence of flooding, reducing air and water pollution, enhancing carbon sequestration and aesthetic value, and promoting human health [1,2]. Because of easy accessibility, green spaces have increased rapidly in neighborhoods, especially in recently developed neighborhoods with high-rise residential buildings in modern cities [3–5]. The green spaces within neighborhoods account for 13% of the total area of the green spaces in Beijing, China [6]. The increases in green spaces within neighborhoods from 1989 to 2004 exceeded those in other urban functional units, such as roadsides, riparian zones, and scenic spots, in Jinan, China [7]. Thus, many studies of green spaces in neighborhoods have been conducted in urban areas [3,8].

Plant diversity as a fundamental element of green spaces determines the ecosystem functions and services that can be derived directly by residents. Green spaces in neighborhoods host a substantial level of plant diversity, especially for the native species that contributed 52.4% of the total number of tree species of neighborhoods in Beijing, China [9,10]. In addition, green spaces in neighborhoods often have a higher percentage of native species than those in other land-use types, such as roadsides, institutional areas, community parks, and commercial areas [10]. However, alien species, such as *Buchloe dactyloides* native to America, have invaded the green spaces in neighborhoods in Beijing [9]. Thus, the survey of plant diversity in neighborhoods is of great significance for the protection of native species and the application of native species to create new urban landscapes. The plant diversity in neighborhoods has been investigated widely at the city scale, country scale, and continental scale to optimize biodiversity conservation strategies, enhance ecosystem services, and improve the quality of life for city dwellers [1]. At the city scale, it was demonstrated that the plant diversity varied with gradients in terms of land use, population density, and biophysical conditions (e.g., air temperature) [3,11], as well as according to socio-economic factors [5,12] and landscape features [13]. At the country or continental scales, the homogenization of plant diversity has been confirmed due to the dominant effects of human activities [14–16].

Homogenization of residential plant compositions has been demonstrated based on genetic, taxonomic, and functional similarities [15–18] across large spatial scales, such as country and continent scales, because of similarities in the management and preferences of residents [17,18], as well as the planning and development of neighborhoods [3,19], and/or the microenvironments among neighborhoods [14,20]. Taxonomic homogenization has been reported frequently. Neighborhood-adaptable species have become increasingly widespread in neighborhoods [16]. For example, *Lolium perenne* was found in 90% of the residential lawns surveyed in Boston, USA [16], more than 50% of the lawns in Paris, France [21], and more than 80% of the lawns in Christchurch, New Zealand [22]. Residential plant communities generally comprise few species, with a greater proportion of individuals from certain species relative to those in natural plant communities [21–24].

The homogenization of plant species compositions or heterogeneity of plant diversity indices has been demonstrated by comparing the species compositions and diversity among neighborhoods at the city scale, country scale, and/or continental scale [3,12,14,24]. However, the plant compositions and diversity within neighborhoods have been analyzed less frequently, although they are spatially heterogeneous. In old cities, the front and back yards differ in terms of their vegetation composition and structure [25]. Front yards host more ornamental species with high ornamental value compared with backyards, and the latter contains more food plants for consumption by city dwellers [1]. In new or intensively developed urban areas, the neighborhoods comprise mosaic patches of buildings, paved lands, and green spaces [3,19]. The green patches within these neighborhoods vary in terms of their size, shape, and distance from the nearest green patches and the boundaries of neighborhoods [26,27], but they are also designed with various species compositions in order to create diverse landscape appearances with high aesthetic value and multiple services [12,27]. The variations in the species compositions and plant diversity among patches within neighborhoods directly determine the diversity level and management practices for the whole neighborhood. Thus, it is important to improve the accuracy of plant diversity assessments to enhance the effectiveness of residential green spaces to protect urban biodiversity and provide ecosystem services to residents.

In this study, we intensively investigated the green spaces in 12 neighborhoods in the urban areas of Beijing, China, in order to determine the heterogeneity of the species composition and plant diversity in this urban environment. In particular, we addressed the following questions. (1) Is the plant diversity within neighborhoods significantly heterogeneous? (2) Do significant species–patch area relationships exist in neighborhoods? (3) How many patches and neighborhoods need to be investigated to assess the plant diversity in Beijing?

2. Materials and Methods

2.1. Study Sites

This study was conducted in the built-up area of Beijing, China (40°00′ N, 116°20′ E). The study area located in the northeast of the Huabei Plain in north China is characterized by warm temperate deciduous broad-leaved forests [28]. Beijing has a temperate, humid, monsoonal continental climate characterized by hot and rainy summers, cold and dry winters, and short spring and autumn seasons [6]. The average annual precipitation and temperature are around 500 mm and 11–12 °C, respectively [6].

Twelve neighborhoods were selected from south to north throughout the urban area of Beijing (Figure 1 and Table 1) based on the following criteria: (1) the surveyed sites were spatially distributed in a balanced manner in the south–north direction (Figure 1), with different degrees of urbanization [29,30]; (2) the sites covered the common sizes of the neighborhoods in Beijing [31], where the areas of the neighborhoods ranged from 3.29 ha to 22.11 ha (Table 1); (3) the whole range of house prices in Beijing was covered [32] in the house transaction price range from 41,901 yuan/m^2 to 118,947 yuan/m^2 (Table 1) during 2018; and (4) the neighborhoods covered the 30 years when Beijing was developing rapidly [33,34] from 1980 to 2011 (house ages from 7 years to 38 years) (Table 1).

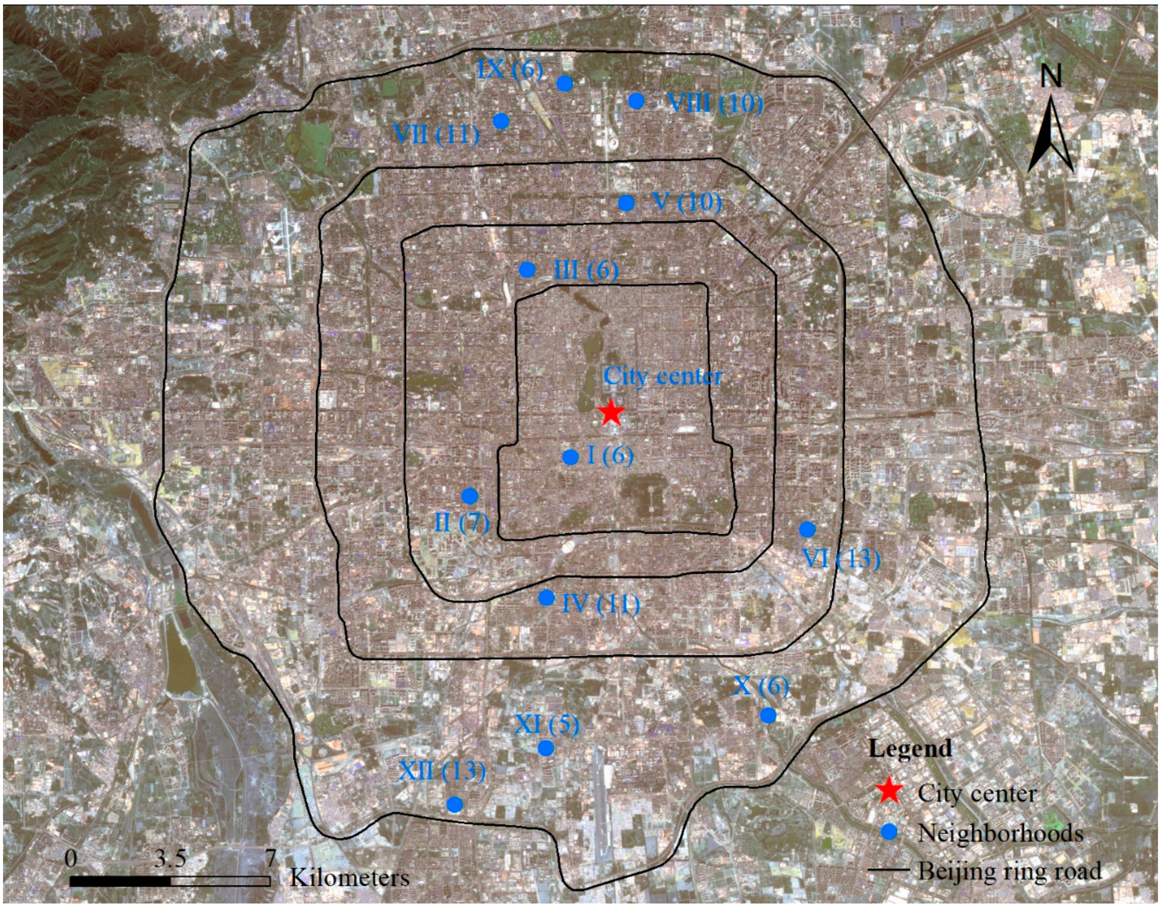

Figure 1. The location of neighborhoods investigated along the urban-rural gradient in Beijing. The numbers in parentheses indicate the numbers of patches investigated in the neighborhood. I: Chunshuyuan; II: Xiaohongmiao; III: Jindianhuayuan; IV: Jiayuanerli; V: Anzhenxili; VI: Songyudongli; VII: Dongwangzhuang; VIII: Huizhongbeili; IX: Lincuixili; X: Delinyuan; XI: Nantingxinyuan; XII: Ruihaijiayuan.

Table 1. Basic information of neighborhoods investigated.

Neighborhood [a]	Distance from City Center (km)	Area (ha) [b]	Green Land (ha) [b]	House Price (10^3 Yuan/m^2) [c]	House Age (year) [c]
Chunshuyuan (I)	2.15	6.61	1.80	115.49	19
Xiaohongmiao (II)	5.73	3.29	1.25	90.55	38
Jindianhuayuan (III)	5.82	3.53	0.97	95.99	18
Jiayuanerli (IV)	7.01	22.11	7.93	56.03	24
Anzhenxili (V)	7.46	11.25	3.74	89.30	33
Songyudongli (VI)	7.96	13.83	4.02	62.58	26
Dongwangzhuang (VII)	11.02	15.39	6.04	76.93	20
Huizhongbeili (VIII)	11.11	9.90	4.26	69.69	20
Lincuixili (IX)	11.81	6.25	1.74	74.89	14
Delinyuan (X)	12.11	9.90	5.01	48.94	17
Nantingxinyuan (XI)	12.20	8.11	1.59	42.78	7
Ruihaijiayuan (XII)	15.02	11.25	3.74	41.90	17

[a] The Romania number within brackets indicates the labels of neighborhoods in Figure 1. [b] The information was obtained using an image from Google Maps TM on 11 July 2015 to map the land cover of the 12 neighborhoods. [c] The information was derived from the real estate website https://bj.lianjia.com/ and https://bj.fang.anjuke.com/ in December 2018.

2.2. Field Survey

The green spaces within neighborhoods were designed as fragmented units in different patches for construction and management purposes. Thus, the green patches were assigned as sampling units or plots in the present study [6]. The number of patches surveyed per neighborhood ranged from five to 13 (Figure 1 and Appendix A Figure A1). All patches surveyed are artificial green spaces [35], and there is no natural or semi-natural vegetation. The patches surveyed in each neighborhood were spatially balanced and they covered more than 55% of the green patches with sizes larger than 400 m^2 (except in Jiayuanerli, which contained an excessive number of patches). Plant species were investigated in August and September during 2017. The species was identified and named based on the Flora of China [36] and the Flora of Beijing [37]. The life form and source of species were determined according to the Flora of China [36], the Flora of Beijing [37], and Zhao et al. [6]. In each plot, we recorded all tree and shrub species as well as their abundances, and three to five herb quadrats (1 m $\times$ 1 m) were randomly selected to record all herb species and their coverage levels. In total, 104 patches were investigated in 12 neighborhoods. The areas and locations of patches were measured using a global positioning system device (Unistrong Industrial Co. Ltd., Beijing, China).

2.3. Plant Diversity Indices

The commonly used plant diversity indices [5,38] comprising the species number, Gleason index, and Shannon index were calculated for each patch and each neighborhood. Equations (1) and (2) were used to calculate the Gleason index and Shannon index [39,40]:

$$\text{Gleason index} = \frac{S}{\ln A} \tag{1}$$

$$\text{Shannon index} = -\sum_{i=1}^{S} P_i \ln P_i \tag{2}$$

where S is the number of species in each patch or each neighborhood, A is the area of each patch or each neighborhood, P_i is ni/N where ni is the number of an individual species i, N is the individual number of all species, and the individual number of herbs was replaced by the coverage with herbs.

2.4. Species–Area Relationship

The relationships between the number of species in patches and the areas of patches were modeled for trees, shrubs, and herbs using a power function (Equation (3)) [41,42]:

$$\ln(S) = z\ln(A) + c \tag{3}$$

where S is the number of species, A is the area of patches, z is the slope, and c is the intercept of the log–log regression equation.

2.5. Species Accumulation Curve

Species accumulation curves were modeled using a power function (Equation (4)) between the number of species and area of the green patches surveyed and the area of the neighborhood surveyed [41,42] in order to compare the species turnover between patches and between neighborhoods:

$$\ln(S') = z\ln(A') + c \tag{4}$$

where S' is the cumulative number of species, A' is the cumulative area of patches or the cumulative survey area of neighborhoods, z is the slope, and c is the intercept of the log–log regression equation.

Species accumulation curves also were modeled using a logistic function (Equation (5)) between the number of species and number of patches and the number of neighborhoods [41] because the logistic curves could be used to test whether the curves reached an asymptote:

$$S' = \frac{a}{1 + e^{-k(N-b)}} \tag{5}$$

where S' prime is the cumulative number of species, N is the cumulative number of patches or the cumulative number of neighborhoods, a represents the upper asymptote of the curves, and k and b are parameters that both affect the curvature of the curves. The minimal number of patches and the minimal number of neighborhoods were estimated at the point on the logistic curves where 90% of the theoretical species pool in the patch and neighborhood were found.

2.6. Data Analysis

Plant diversity indices were calculated using the diversity function in the "vegan" package in R software [43]. Our data were hierarchical with patches "nested" within neighborhoods. Hence, we performed hierarchical linear modeling (HLM) using HLM software version 6 [44] to test whether there were significant differences in the plant diversity indices between neighborhoods and to decompose the variance in the plant diversity indices into between patches within neighborhoods and between neighborhoods [45].

The relationship between the number of species and the patch area was fitted with SPSS 22.0 for Windows (IBM, Armonk, NY, USA). Species accumulation curves were fitted using OriginPro software (OriginLab, OriginPro 2018, Northampton, MA, USA) with a repeated and random ordering of all the samples [42,46] in R version 3.3.1 [47]. We conducted t-tests to compare the slopes of the species–area accumulation curves between patches within neighborhoods and between neighborhoods with SPSS 22.0 for Windows (IBM, Armonk, NY, USA).

3. Results

3.1. Species Diversity at Neighborhood Scale

Within a neighborhood, 46.9% of the species occurred only in one patch, 11.2% in more than half of the patches, and 0.89% in all investigated patches (Figure 2a). For one patch, the average species number was 6.11 for trees, 3.84 for shrubs, and 8.00 for herbs. The average Gleason index was 0.95 for trees, 0.60 for shrubs, and 1.27 for herbs. The average Shannon index was 1.35 for trees, 0.95 for shrubs, and 1.32 for herbs (Table 2).

For one neighborhood, the average total number of species was 87, with 30.5 for trees, 18.8 for shrubs, and 31.9 for herbs (Table 2). The average Gleason index was 3.33 for trees, 2.07 for shrubs, and 3.47 for herbs. The average Shannon index was 2.83 for trees, 2.20 for shrubs, and 2.58 for herbs (Table 2).

The number of species per patch for trees, shrubs, and herbs increased significantly and logarithmically with the patch area (Figure 3). The number of species–patch area relationship had a lower slope (0.23, R^2 = 0.09) for herbs compared with trees (0.37, R^2 = 0.33) and shrubs (0.28, R^2 = 0.17) (Figure 3).

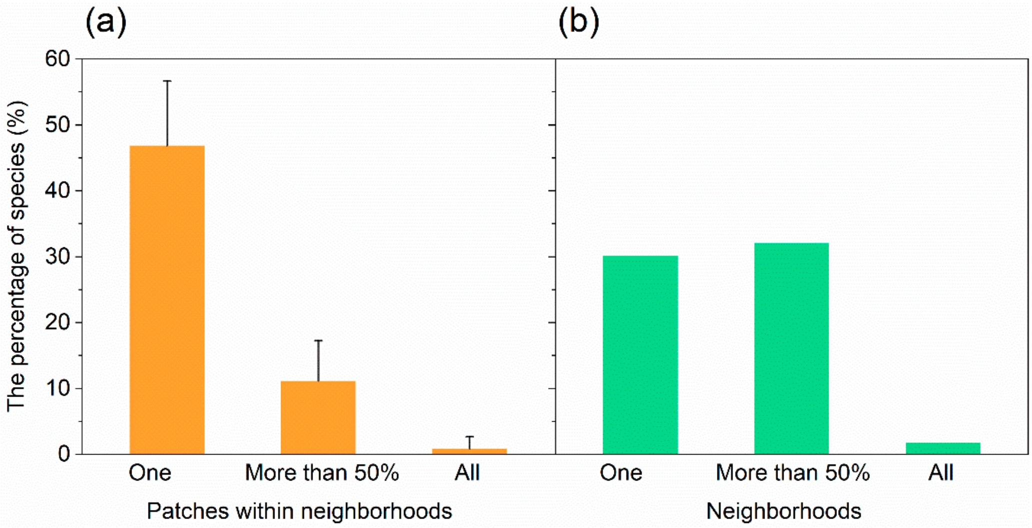

Figure 2. The percentage of species were found (**a**) in one, more than 50% and all patches within neighborhoods and (**b**) in one, more than 50% and all neighborhoods investigated.

Table 2. Diversity index statistics within and between neighborhoods.

Scale	Index	Tree	Shrub	Herb
Within neighborhoods	Species number	6.11 ± 3.61	3.84 ± 1.96	8.00 ± 3.13
	Gleason index	0.95 ± 0.50	0.60 ± 0.27	1.27 ± 0.47
	Shannon index	1.35 ± 0.67	0.95 ± 0.51	1.32 ± 0.47
Between neighborhoods	Species number	30.50 ± 4.10	18.80 ± 5.00	31.90 ± 10.70
	Gleason index	3.33 ± 0.42	2.07 ± 0.58	3.47 ± 1.13
	Shannon index	2.83 ± 0.18	2.20 ± 0.29	2.58 ± 0.88

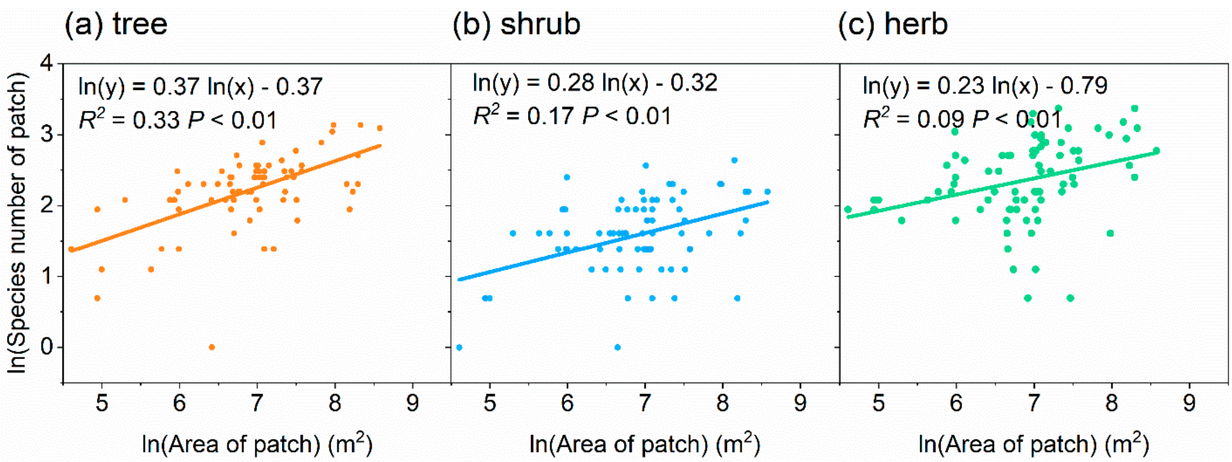

Figure 3. Relationships between patch area and number of species of the patch for trees (**a**), shrubs (**b**) and herbs (**c**).

The number of species for trees, shrubs, and herbs increased significantly and logistically with the number of patches within each neighborhood (Figure 4). We estimated that the minimum number of patches required for investigating plant diversity at the neighborhood scale ranged between 4–8 for trees, 3–7 for shrubs, and 4–8 for herbs (Figure 4).

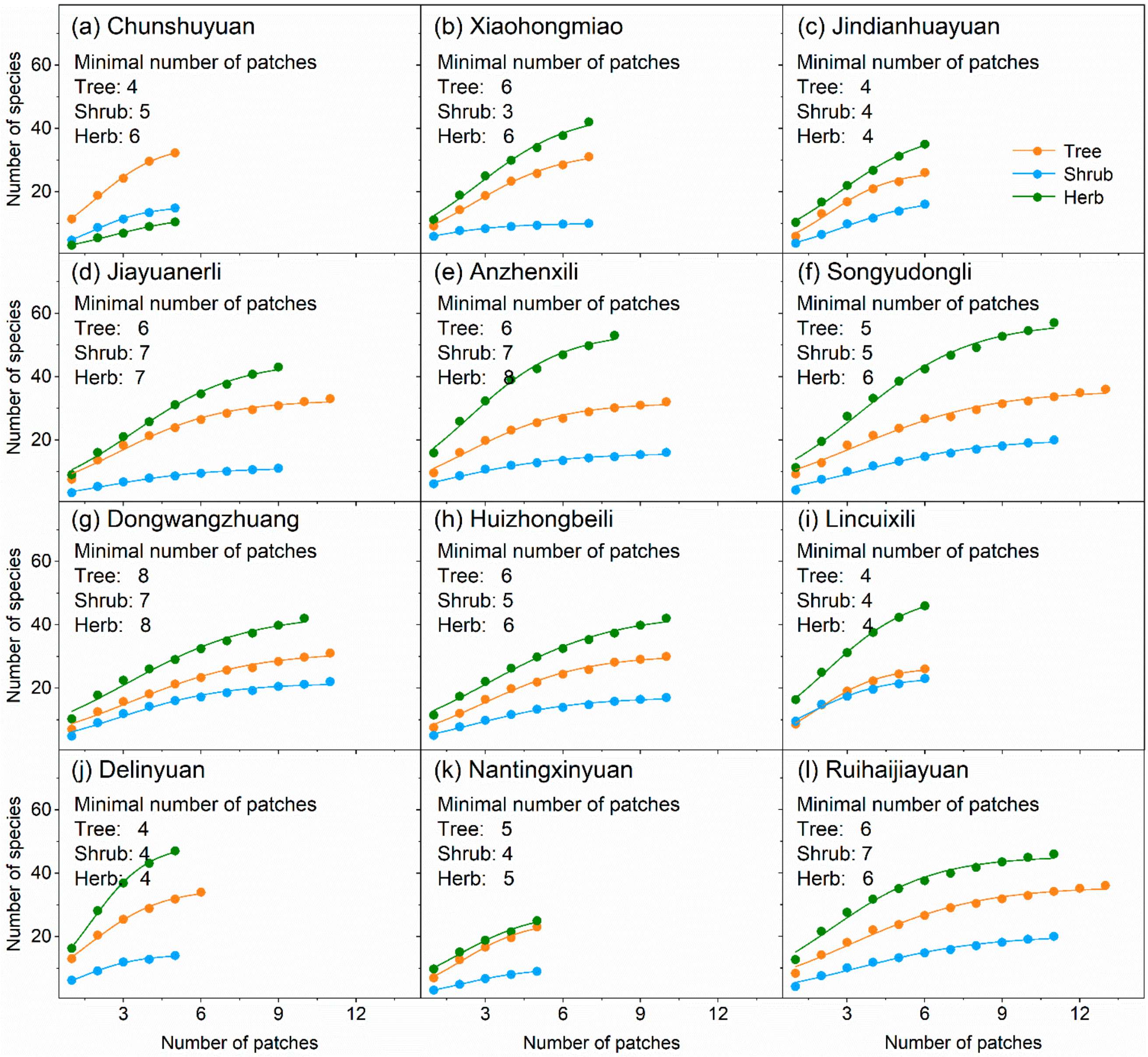

Figure 4. Number of species-number of patches accumulation curves based on logistic function. Adjusted R^2 for all curves was more than 0.98. F value for all curves was extremely significant.

3.2. Differences in Plant Diversity between Neighborhoods

In the 12 neighborhoods, we recorded 218 species (Appendix A Table A1) belonging to 153 genera and 68 families. The most common plant species belonged to Rosaceae (including 27 species), followed by Asteraceae (24), Oleaceae (11), and Poaceae (10). The genera with the highest number of species were *Prunus*, followed by *Populus*, *Malus*, and *Viola*. Trees, shrubs (including lianas), and herbs comprised 72 (33.03% of all species), 46 (21.10%), and 100 (45.87%) species, respectively. For trees, shrubs, and herbs, there were 36, 16, and 53 native species, 22, 18, and 13 alien species from other areas of China, 14, 11, and 25 alien species from abroad, and 0, 1, and 9 invasive species, respectively.

We found that there were 66 species (30.3% of all species) occurring in just one neighborhood, and 70 species (32.1%) occurring simultaneously in more than half of all the neighborhoods (Figure 2b). The most common species that occurred in all neighborhoods were *Ginkgo biloba* L., *Toona sinensis* (A. Juss.) Roem., *Euonymus japonicus* Thunb., and *Eleusine indica* (L.) Gaertn. The number of species increased significantly and logarithmically with the number of neighborhoods (Figure 5). We estimated that the minimum number of neighborhoods required for sampling was 9 for trees, 7 for shrubs, and 14 for herbs (Figure 5).

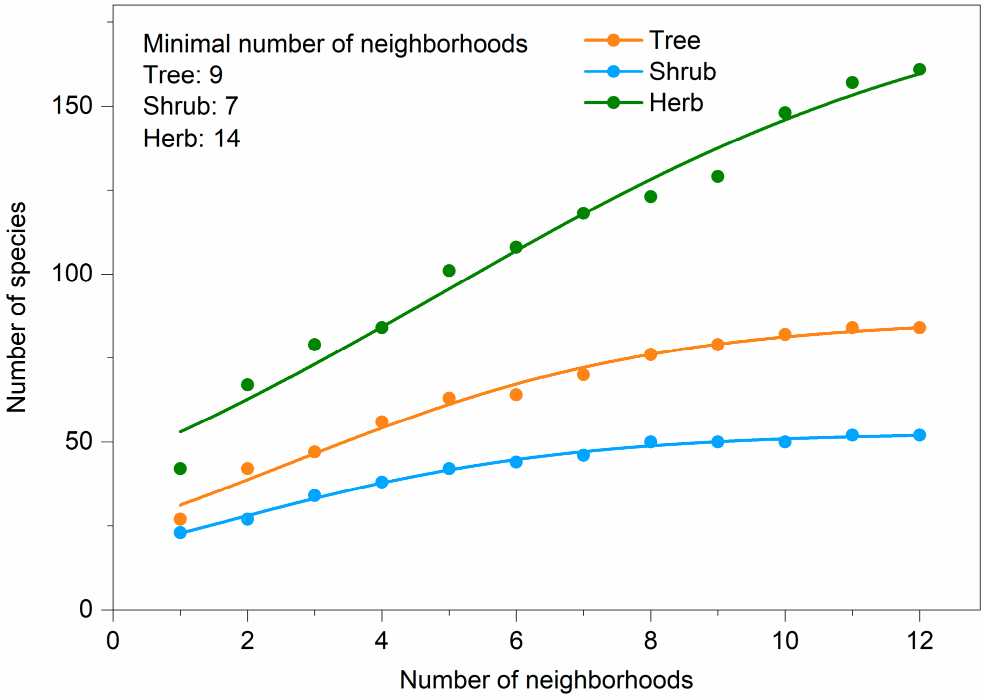

Figure 5. Number of species—number of neighborhoods accumulation curves based on logistic function. Adjusted R^2 for all curves was more than 0.97. *F* value for all curves was extremely significant.

3.3. Comparison of the Variations in Plant Diversity within and between Neighborhoods

Based on the power function, the slopes of accumulation curves for species number–area of the green patches surveyed ranged from 0.49 to 0.81 for trees, from 0.27 to 0.79 for shrubs, and from 0.53 to 0.76 for herbs, and were significantly higher than the slopes for species number–area of the neighborhood surveyed (for trees, t = 9.34, $p < 0.01$; for shrubs, t = 2.23, $p < 0.05$; for herbs, t = 4.75, $p < 0.01$). These results indicated that the species turnover between patches was significantly stronger than that between neighborhoods.

HLM detected significant differences in the shrub and herb diversity indices between neighborhoods ($p < 0.01$), but not between the tree diversity indices ($p > 0.05$, Table 3). The percentage of the variance of plant diversity within neighborhoods was higher than that between neighborhoods, ranging from 99.94% to 99.98% for trees, from 54.34% to 81.20% for shrubs, and from 52.33% to 72.83% for herbs (Table 3), indicating that the heterogeneity of plant diversity within neighborhoods was higher than that between neighborhoods.

Table 3. Variance in diversity index within and between neighborhoods based on hierarchical linear modeling.

Plants	Diversity Indices	χ^2	*p*-Value	Percentage of Variations in Diversity Indices (%)	
				within Neighborhoods	between Neighborhoods
Trees	Species richness	12.23	>0.05	99.94	0.06
	Gleason index	10.26	>0.05	99.98	0.02
	Shannon index	10.38	>0.05	99.94	0.06
Shrubs	Species richness	61.77	<0.01	60.87	39.13
	Gleason index	76.74	<0.01	54.34	45.66
	Shannon index	29.74	<0.01	81.20	18.80
Herbs	Species richness	39.68	<0.01	72.83	27.17
	Gleason index	44.54	<0.01	69.41	30.59
	Shannon index	78.17	<0.01	52.33	47.67

4. Discussion

4.1. Homogeneity of Plant Species Compositions and Diversity between Neighborhoods

In this study, we found that Rosaceae, Asteraceae, Oleaceae, and Poaceae were the most common families in the 12 neighborhoods investigated. Similarly, Song [27] found that these families were the most common families in 92 neighborhoods in Beijing. Zhao, et al. [6] also found that these four families and Liliaceae were the most common families in six types of green spaces in Beijing comprising park green spaces, protection green spaces, institutional green spaces, street green spaces, vacant land spaces, and residential green spaces.

Plant assemblages are similar between neighborhoods [15,17,20]. In the present study, 32% of the total species detected occurred in more than half of all the neighborhoods (Figure 2b). Similarly, in previous studies, 10% of the species occurred in more than 40% of all residential yards (424 yards) along the Río Piedras watershed in Puerto Rico [1], and 18% of the species were shared among residential lawns (174 lawns) in the USA [16]. We found that *Ginkgo biloba* L., *Toona sinensis* (A. Juss.) Roem., *Euonymus japonicus* Thunb., and *Eleusine indica* (L.) Gaertn. occurred in all neighborhoods investigated. Song [27] also reported that *Ginkgo biloba* and *Euonymus japonicus* occurred in more than 60% of all the quadrats (345 quadrats) sampled in neighborhoods of Beijing. Certain species occur simultaneously in different neighborhoods [1,16,27], possibly because most of the residents living in different neighborhoods prefer species with brightly colored flowers or leaves, those that provide food or medical materials, or plants that are easy to manage due to their resistance to adverse environments [14,17,18,20,23].

The level of the homogenization of plant diversity varies among habitat types [48,49]. Green spaces in neighborhoods might harbor more similar plant diversity compared with other habitats, such as wasteland with little disturbance and those abandoned for many years [49]. The following three causes might contribute to these similarities. First, similarities in plant diversity may be attributed to the management and preferences of residents. Residents with similar lifestyle characteristics (e.g., age, socioeconomic status, life stage, and ethnicity) and social preferences (e.g., values and interests) across different neighborhoods have similar landscaping preferences and practices. For example, there is little variation in fertilization regardless of the differences in climate or other environmental conditions [17]. Residents also prefer trees to herbs as well as plants with ornamental traits compared with plants lacking these traits [18,23]. Second, similarities in plant diversity may be related to the planning and development of neighborhoods. Neighborhoods are usually implemented by local real estate developers to meet the similar requirements imposed by the government and city dwellers, and thus, the neighborhoods comprise pavements, housings, grasses, shrubs, and trees with similar landscape structures and available habitats for plants [3,19]. Third, similarities in plant diversity may be related to the microenvironment. The soil in residential landscapes is often lacking in nutrients with high alkalinity. The microclimate is also similar in residential ecosystems, especially the high air temperatures caused by the urban heat island effect [14,20]. Thus, the similar microenvironment may act as a key filter to ensure that residential flora is under similar effects imposed by natural selection, and thus homogenization can occur [50].

The spatial homogenization of plant species compositions between neighborhoods depends on the different plant life forms. The increase in the number of species with the number of neighborhoods saturated for trees and shrubs but not for herbs (Figure 5) because of the following reasons: (1) the total numbers of tree and shrub species are lower than those of herb species (Figures 4 and 5); (2) herbs with smaller sizes require less space to grow than trees and shrubs, and they are also disturbed less by human activities [23,51]; and (3) trees and shrubs are mostly planted in special patches by managers, who are highly focused on landscape architecture for aesthetic and recreational values rather than their intrinsic ecological value, whereas herbs are more likely to disperse and grow spontaneously within various patches [52].

4.2. Heterogeneity of Plant Species Compositions and Diversity within Neighborhoods

The green patches within neighborhoods vary in terms of their isolation, size, and ecosystem function, thereby leading to variations in plant migration, resource availability for plants, and the ecosystem services provided by plants [1,26]. Hence, the plant species compositions can vary among patches [1,25]. In the present study, 46.9% of the species in each neighborhood occurred in only a single patch (Figure 2a) and the number of species increased logistically with the number of patches (Figure 4).

Neighborhoods provide green spaces for residents to enjoy [2,19]. Neighborhoods generally contain many small green patches with different features in order to provide multiple services for residents and to adapt to the altered habitat due to the influence of roads, buildings, and pre-existing physical conditions [1,2,50]. These green patches differ in terms of their plant diversity, where they range from patches with a few plant species (e.g., newly built patches) to those with high plant diversity (e.g., remnant patches of native habitat). Thus, the plant diversity within neighborhoods is spatially heterogeneous.

The variations in shrub and herb diversity between neighborhoods were significant in the present study, but the contributions of the variations in plant diversity for trees, shrubs, and herbs to the total variation were higher between patches within neighborhoods than those between neighborhoods (Table 3). Similar differences in plant diversity were found previously where the within-yard variation in the species compositions was higher than that among yards [1]. These results can probably be explained by the similar green space configurations between neighborhoods [27], although there may be differences in terms of isolation, size, and the functions of green spaces within neighborhoods [1,26,27]. Designers and managers often prefer to grow different plants in each patch to increase the number of ecosystem services provided by green spaces [1,27,53]. Thus, understanding the heterogeneity of plant diversity within neighborhoods is essential for plant diversity assessments, landscape design, and managing and maintaining neighborhoods.

4.3. Effect of Patch Area on the Number of Species

The importance of patch characteristics, such as the patch area and patch isolation, for plant composition and diversity has been highlighted in previous theoretical and empirical ecological studies [54–56]. The number of species was dependent on the patch area in the present study (Figure 3). Similar relationships between the number of plant species and the area of urban forest patches were obtained in the Twin Cities of Minnesota, USA [57], Hannover in Germany, Haifa in Israel [43,58], and in the northern part of Belgium [59].

Angold, et al. [60] suggested that the patch size is positively correlated with the diversity and richness of patches. Thus, small patches harbor fewer species than large patches, probably because small patches contain less diverse habitats or the populations in small patches may be influenced by density-dependent, stochastic extinction processes [45,61].

The relationship between the species number and patch area was weaker for herbs than trees and shrubs (Figure 3), possibly because herbs are more sensitive to unpredictable disturbances by residents and they regenerate more readily [49,62]. The species–area curves is universal and suitable for urban neighborhoods, and it can be constructed to describe and predict the relationship between the number of species and patch size based on knowledge of the pre-disturbance species richness [58].

4.4. Implications for Plant Diversity Surveys

Previous investigations of residential plants [12,19,50] rarely considered the allocation of efforts to surveys within and between neighborhoods. In Beijing, we surveyed 12 neighborhoods (the average survey area in each neighborhood was 12,495 m^2), whereas 32 (2400 m^2) were sampled by Lang, et al. [63], 92 (400 m^2) were sampled by Song [27], and 83 (1002 m^2) were sampled by Wang, et al. [5]. We recorded 218 species, whereas 273 were recorded by Lang, et al. [63], 315 were recorded by Song [27], and 369 were recorded by Wang, et al. [5]. In the present study, we constructed the accumulation curves for the numbers of species versus the number of patches and neighborhoods, before estimating the number of patches within neighborhoods and the number of neighborhoods that need to be sampled. Due to the high similarity of the species compositions between neighborhoods (Figures 2b and 5), it would be useful to investigate more patches within neighborhoods to assess the plant diversity in cities, which may reduce the time and money spent traveling to and from neighborhoods as well as reducing the effort required to access neighborhoods.

Comprehensive investigations of all the green patches in a neighborhood would be the ideal approach, but the cost could be prohibitive. The numbers of patches sampled previously within neighborhoods ranged from one to 10 or more, and the areas from 100 m^2 to 4000 m^2 or more [5,11,64–66]. A low sampling intensity might lead to a high likelihood of missing rare or even moderately rare species in a neighborhood [67]. By contrast, a high sampling intensity might incur high costs in terms of time, energy, and money. In the present study, we found that the spatial heterogeneity of the plant diversity was higher between green patches within neighborhoods than between neighborhoods (Table 3), thereby suggesting the possibility of reducing the total effort if adequate sampling is conducted in each neighborhood investigated.

Given the important effects of the specific survey methods employed when assessing plant diversity [42,67], it is essential to identify an adequate sampling approach in terms of balancing the data quality and the amount of money and time available, as well as considering the characteristics of species compositions and plant diversity at the patch and neighborhood scales.

5. Conclusions

In this study, based on intensive investigations of 12 neighborhoods in Beijing, we analyzed the variations in the plant species compositions and diversity within and between neighborhoods. Neighborhoods shared more plant species with ornamental, medicinal, or edible value and/or diverse ecological niches than patches. The homogeneity of the species composition and plant diversity was lower within neighborhoods than between neighborhoods, thereby suggesting that more effort should be made to increase the sampling number or area of patches within neighborhoods. We tentatively recommended the numbers of patches that should be sampled both within neighborhoods and between neighborhoods to assess the plant diversity in urban areas based on species–patch and –neighborhood accumulation curves established in our study based on Beijing. However, in future research, it will be important to balance the number of neighborhoods sampled and the numbers of patches sampled within neighborhoods under the constraints of limited resources, as well as considering additional factors that might influence the heterogeneity of plant compositions and diversity when designing urban biodiversity surveys.

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Appendix A

Table A1. The list of the collected species.

Scientific Name	Life Form	Source
Sabina chinensis (L.) Ant.	Tree	Alien species from other area of China
Prunus cerasifera Ehrhar f. *atropurpurea* (Jacq.) Rehd.	Tree	Alien species from other area of China
Magnolia denudata Desr.	Tree	Alien species from other area of China
Ginkgo biloba L.	Tree	Alien species from other area of China
Toona sinensis (A. Juss.) Roem.	Tree	Alien species from other area of China
Malus × *micromalus* Makino	Tree	Alien species from other area of China
Amygdalus persica L.	Tree	Alien species from other area of China
Zanthoxylum bungeanum Maxim.	Tree	Alien species from other area of China
Juglans regia	Tree	Alien species from other area of China
Juniperus formosana Hayata	Tree	Alien species from other area of China
Paulownia tomentosa (Thunb.) Steud.	Tree	Alien species from other area of China
Amygdalus persica L. var. *persica* f. *atropurpurea* Schneid.	Tree	Alien species from other area of China
Albizia julibrissin Durazz.	Tree	Alien species from other area of China
Prunus salicina Lindl.	Tree	Alien species from other area of China
Eucommia ulmoides Oliver	Tree	Alien species from other area of China
Pinus bungeana Zucc. ex Endl.	Tree	Alien species from other area of China
Fontanesia fortunei Carr.	Tree	Alien species from other area of China
Phyllostachys propinqua McClure	Tree	Alien species from other area of China
Pinus armandii Franch.	Tree	Alien species from other area of China
Ligustrum lucidum Ait.	Tree	Alien species from other area of China
Armeniaca vulgaris Lam.	Tree	Alien species from abroad
Robinia pseudoacacia	Tree	Alien species from abroad
Cedrus deodara (Roxb.) G. Don	Tree	Alien species from abroad
Platanus occidentalis L.	Tree	Alien species from abroad
Cerasus serrulata (Lindl.) G. Don ex London var. *lannesiana* (Carr.) Makino	Tree	Alien species from abroad
Fraxinus pennsylvanica Marsh.	Tree	Alien species from abroad
Platanus orientalis L.	Tree	Alien species from abroad
Punica granatum L.	Tree	Alien species from abroad
Populus × *canadensis* Moench	Tree	Alien species from abroad
Cerasus yedoensis (Matsum.) Yu et Li	Tree	Alien species from abroad
Fraxinus americana Linn.	Tree	Alien species from abroad
Platanus acerifolia Willd.	Tree	Alien species from abroad

Table A1. *Cont.*

Scientific Name	Life Form	Source
Malus pumila Mill.	Tree	Alien species from abroad
Populus alba	Tree	Alien species from abroad
Acer truncatum Bunge	Tree	Native species
Ulmus pumila L.	Tree	Native species
Populus tomentosa	Tree	Native species
Salix matsudana var. *matsudana* f. *pendula* Schneid.	Tree	Native species
Diospyros kaki Thunb.	Tree	Native species
Crataegus pinnatifida	Tree	Native species
Amygdalus davidiana (Carrière) de Vos ex Henry	Tree	Native species
Morus alba L.	Tree	Native species
Koelreuteria paniculata Laxm.	Tree	Native species
Sophora japonica Linn. var. *japonica* f. *pendula* Hort.	Tree	Native species
Malus spectabilis (Ait.) Borkh.	Tree	Native species
Sophora japonica Linn.	Tree	Native species
Broussonetia papyrifera (Linn.) L'Hér. ex Vent.	Tree	Native species
Syringa pekinensis Rupr.	Tree	Native species
Ailanthus altissima (Mill.) Swingle	Tree	Native species
Platycladus orientalis (L.) Franco	Tree	Native species
Amygdalus persica L. var. *persica* f. *duplex* Rehd.	Tree	Native species
Fraxinus chinensis Roxb.	Tree	Native species
Salix babylonica	Tree	Native species
Salix matsudana	Tree	Native species
Diospyros lotus L.	Tree	Native species
Pyrus ussuriensis Maxim.	Tree	Native species
Pinus tabuliformis Carr.	Tree	Native species
Amygdalus triloba (Lindl.) Ricker	Tree	Native species
Ziziphus jujuba Mill. var. *spinosa* (Bunge) Hu ex H. F. Chow	Tree	Native species
Ziziphus jujuba Mill.	Tree	Native species
Picea wilsonii Mast.	Tree	Native species
Picea meyeri Rehd. et Wils.	Tree	Native species
Larix principis-rupprechtii Mayr	Tree	Native species
Ulmus pumila L. 'Tenue'	Tree	Native species
Syringa oblata Lindl.	Tree	Native species
Acer palmatum Thunb.	Tree	Native species
Cotinus coggygria Scop.	Tree	Native species
Populus hopeiensis	Tree	Native species
Firmiana platanifolia (L. f.) Marsili	Tree	Native species
Tamarix chinensis Lour.	Tree	Native species
Juglans mandshurica	Tree	Alien species from other area of China
Malus spectabilis (Ait.) Borkh. var. *riversii* (Kirchn.) Rehd.	Tree	Alien species from other area of China
Lagerstroemia indica L.	Shrub	Alien species from other area of China
Jasminum nudiflorum Lindl.	Shrub	Alien species from other area of China
Hibiscus syriacus Linn.	Shrub	Alien species from other area of China
Sorbaria sorbifolia (L.) A. Br.	Shrub	Alien species from other area of China
Kerria japonica (L.) DC.	Shrub	Alien species from other area of China
Buxus sinica (Rehd. et Wils.) Cheng subsp. *sinica* var. *parvifolia* M. Cheng	Shrub	Alien species from other area of China
Cercis chinensis Bunge	Shrub	Alien species from other area of China

Table A1. *Cont.*

Scientific Name	Life Form	Source
Viburnum opulus Linn. var. *calvescens* (Rehd.) Hara	Shrub	Alien species from other area of China
Buxus sinica (Rehd. et Wils.) Cheng	Shrub	Alien species from other area of China
Paeonia suffruticosa Andr.	Shrub	Alien species from other area of China
Philadelphus incanus Koehne	Shrub	Alien species from other area of China
Spiraea vanhouttei (Briot) Zabel	Shrub	Alien species from other area of China
Ligustrum quihoui Carr.	Shrub	Alien species from other area of China
Berberis thunbergii var. *atropurpurea* Chenault	Shrub	Alien species from abroad
Ficus carica Linn.	Shrub	Alien species from abroad
Buxus megistophylla Levl.	Shrub	Alien species from abroad
Rosa multiflora Thunb.	Shrub	Alien species from abroad
Sabina procumbens (Endl.) Iwata et Kusaka	Shrub	Alien species from abroad
Ligustrum × *vicaryi* Rehder	Shrub	Alien species from abroad
Lonicera maackii (Rupr.) Maxim.	Shrub	Native species
Forsythia suspensa (Thunb.) Vahl	Shrub	Native species
Rosa chinensis Jacq.	Shrub	Native species
Weigela florida (Bunge) A. DC.	Shrub	Native species
Rosa xanthina Lindl.	Shrub	Native species
Sorbaria kirilowii (Regel) Maxim.	Shrub	Native species
Swida alba	Shrub	Native species
Lycium chinense Mill.	Shrub	Native species
Lespedeza bicolor Turcz.	Shrub	Native species
Sambucus williamsii Hance	Shrub	Native species
Sabina vulgaris Ant.	Shrub	Alien species from other area of China
Kerria japonica (L.) DC. f. *pleniflora* (Witte) Rehd.	Shrub	Alien species from other area of China
Hibiscus rosa-sinensis Linn.	Shrub	Alien species from other area of China
Dioscorea nipponica Makino	Liana	Alien species from other area of China
Parthenocissus quinquefolia (L.) Planch.	Liana	Alien species from abroad
Luffa cylindrica (L.) Roem.	Liana	Alien species from abroad
Pharbitis nil (L.) Choisy	Liana	Invasive species
Vitis vinifera L.	Liana	Alien species from abroad
Phaseolus vulgaris Linn.	Liana	Alien species from abroad
Cucurbita moschata (Duch. ex Lam.) Duch. ex Poiret	Liana	Alien species from abroad
Metaplexis japonica (Thunb.) Makino	Liana	Native species
Rubia cordifolia L.	Liana	Native species
Humulus scandens	Liana	Native species
Cynanchum chinense R. Br.	Liana	Native species
Lonicera japonica Thunb.	Liana	Native species
Clematis intricata Bunge	Liana	Native species
Gynostemma pentaphyllum (Thunb.) Makino	Liana	Alien species from other area of China
Perilla frutescens (L.) Britt.	Herb	Alien species from other area of China
Teucrium tsinlingense C. Y. Wu et S. Chow var. *porphyreum* C. Y. Wu et S. Chow	Herb	Alien species from other area of China
Iris tectorum	Herb	Alien species from other area of China
Hemerocallis fulva (L.) L.	Herb	Alien species from other area of China
Impatiens balsamina L.	Herb	Invasive species
Hylotelephium erythrostictum (Miq.) H. Ohba	Herb	Alien species from other area of China
Ixeris denticulata (Houtt.) Stebb.	Herb	Native species
Ixeris polycephala Cass.	Herb	Alien species from other area of China
Viola verecunda A. Gray	Herb	Alien species from other area of China
Calystegia sepium (L.) R. Br.	Herb	Alien species from other area of China
Urtica fissa E. Pritz.	Herb	Alien species from other area of China
Malva crispa Linn.	Herb	Alien species from other area of China

Table A1. *Cont.*

Scientific Name	Life Form	Source
Cleome spinosa Jacq.	Herb	Alien species from abroad
Mirabilis jalapa L.	Herb	Alien species from abroad
Phytolacca americana L.	Herb	Invasive species
Pharbitis hederacea (L.) Choisy	Herb	Invasive species
Helianthus tuberosus L.	Herb	Invasive species
Glechoma longituba (Nakai) Kupr	Herb	Alien species from abroad
Cosmos bipinnata Cav.	Herb	Alien species from abroad
Amaranthus retroflexus	Herb	Invasive species
Capsicum annuum L.	Herb	Alien species from abroad
Amaranthus viridis	Herb	Invasive species
Chloris virgata Sw.	Herb	Invasive species
Trifolium repens L.	Herb	Alien species from abroad
Euphorbia maculata L.	Herb	Alien species from abroad
Aster subulatus Michx.	Herb	Alien species from abroad
Galinsoga parviflora Cav.	Herb	Alien species from abroad
Viola tricolor L.	Herb	Alien species from abroad
Datura stramonium Linn.	Herb	Invasive species
Pharbitis purpurea (L.) Voisgt	Herb	Invasive species
Solanum melongena L.	Herb	Alien species from abroad
Symphyotrichum novi-belgii (L.) G.L.Nesom	Herb	Alien species from abroad
Rudbeckia hirta L.	Herb	Alien species from abroad
Portulaca grandiflora Hook.	Herb	Alien species from abroad
Dahlia pinnata Cav.	Herb	Alien species from abroad
Lactuca sativa L.	Herb	Alien species from abroad
Helianthus annuus L.	Herb	Alien species from abroad
Physostegia virginiana Benth.	Herb	Alien species from abroad
Echinacea purpurea (Linn.) Moench	Herb	Alien species from abroad
Oxalis corniculata L.	Herb	Native species
Viola philippica	Herb	Native species
Hosta plantaginea (Lam.) Aschers.	Herb	Native species
Leonurus artemisia (Laur.) S. Y. Hu	Herb	Native species
Acalypha australis L.	Herb	Native species
Duchesnea indica (Andr.) Focke	Herb	Native species
Taraxacum mongolicum Hand.-Mazz.	Herb	Native species
Euphorbia humifusa Willd. ex Schlecht.	Herb	Native species
Ophiopogon japonicus	Herb	Native species
Digitaria sanguinalis (L.) Scop.	Herb	Native species
Kalimeris indica (L.) Sch. -Bip.	Herb	Native species
Portulaca oleracea L.	Herb	Native species
Solanum nigrum L.	Herb	Native species
Chenopodium glaucum L.	Herb	Native species
Arthraxon hispidus (Thunb.) Makino	Herb	Native species
Zoysia japonica Steud.	Herb	Native species
Setaria viridis (L.) Beauv.	Herb	Native species
Trigonotis peduncularis (Trev.) Benth. ex Baker et Moore	Herb	Native species
Calystegia hederacea Wall.ex.Roxb.	Herb	Native species
Plantago asiatica L.	Herb	Native species
Mentha haplocalyx Briq.	Herb	Native species
Pinellia ternata	Herb	Native species

Table A1. *Cont.*

Scientific Name	Life Form	Source
Chenopodium album L.	Herb	Native species
Tribulus terrester L.	Herb	Native species
Bidens pilosa L.	Herb	Native species
Artemisia annua	Herb	Native species
Rehmannia glutinosa (Gaetn.) Libosch. ex Fisch. et Mey.	Herb	Native species
Potentilla chinensis Ser.	Herb	Native species
Commelina communis	Herb	Native species
Inula japonica Thunb.	Herb	Native species
Myosoton aquaticum (L.) Moench	Herb	Native species
Lythrum salicaria L.	Herb	Native species
Oplismenus undulatifolius (Arduino) Beauv.	Herb	Native species
Aster tataricus L. f.	Herb	Native species
Polygonum aviculare L.	Herb	Native species
Convolvulus arvensis L.	Herb	Native species
Poa annua L.	Herb	Native species
Paeonia lactiflora Pall.	Herb	Native species
Dendranthema morifolium (Ramat.) Tzvel.	Herb	Native species
Melica scabrosa Trin.	Herb	Native species
Viola pekinensis	Herb	Native species
Potentilla supina L.	Herb	Native species
Cyperus nipponicus Franch. et Savat.	Herb	Native species
Cirsium setosum (Willd.) MB.	Herb	Native species
Iris lactea Pall. var. *chinensis* (Fisch.) Koidz.	Herb	Native species
Cyperus fuscus L.	Herb	Native species
Achyranthes bidentata Blume	Herb	Native species
Platycodon grandiflorus (Jacq.) A. DC.	Herb	Native species
Belamcanda chinensis (L.) Redouté	Herb	Alien species from other area of China
Eleusine indica (L.) Gaertn.	Herb	Native species
Allium tuberosum	Herb	Alien species from abroad
Hylotelephium pallescens (Freyn) H. Ohba	Herb	Native species
Ixeridium sonchifolium (Maxim.) Shih	Herb	Native species
Artemisia argyi Levl. et Van.	Herb	Native species
Ophiopogon bodinieri	Herb	Alien species from other area of China
Erigeron annuus (L.) Pers.	Herb	Alien species from abroad
Axyris amaranthoides L.	Herb	Alien species from other area of China
Conyza canadensis (L.) Cronq.	Herb	Alien species from abroad
Beta vulgaris L. var. *cicla* L.	Herb	Alien species from abroad
Canna indica L.	Herb	Alien species from abroad
Amaranthus tricolor	Herb	Alien species from abroad

Figure A1. The location of patches investigated in each neighborhood. The red stars indicate the location of patches. The dotted blue lines indicate the boundaries of the neighborhoods.

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