Plant species composition in green spaces within the built-up areas of Beijing, China

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Abstract Plant species composition is a critical issue in ecological research. Studies on the characteristics of plant species composition in the built-up areas, however, are hampered by a lack of basic field-based investigation. In this article, the plant species composition in the built-up areas of Beijing, China, is investigated using abundant field observations. The origin of species, chorological spectra, life forms and plant communities were determined. The characteristic species in each type of green space were determined by *k*-means classification, and urban plant communities were identified by two-way indicator species analysis (TWINSPAN). Plant species composition in the built-up areas was further compared with that in natural mountain floras in Beijing to reveal the differences in life form composition and chorological spectra, and the coincidence of species in the two

communities. A total of 618 plant species belonging to 349 genera and 103 families were identified. Our results revealed wide chorological spectra with trees dominated by deciduous species. Although native plant species were widely distributed, 53% of the plant species were aliens, among which 67% were introduced from America and other Asian countries. Furthermore, the characteristics of the plant species composition in the built-up areas are significantly different from those of the natural habitats. Our results highlight the dramatic changes in characteristics of plant species composition in the built-up area of Beijing. Several suggestions are proposed to increase the diversity of native species through the planning and management of green spaces.

Keywords Urban greening · Urban ecology · Species origin · Chorological spectra · Life form · Plant community

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Introduction

The urban landscape now accounts for 2.8% of the Earth's terrestrial surface and accommodates 50% of the world's population (Millennium Ecosystem Assessment 2005). The importance of built-up areas for biodiversity conservation has been demonstrated (Godefroid and Koedam 2007). Even densely settled

environments contain elements of biodiversity that deserve the attention of conservationists (Miller and Hobbs 2002). As cities continue to sprawl and the urban population continues to grow, the remaining habitats and biodiversity within cities will be of disproportionate importance (Crane and Kinzig 2005). However, habitats and green spaces within cities have become fragmented, modified, and degraded, which has caused dramatic changes to urban plant species composition (Sukopp 1998; Kühn and Klotz 2006).

The predominant horticultural aesthetics of many urban habitats are attained by intensively managing environmental conditions and by planting a wide variety of alien species (Turner et al. 2005). Owing to a common propensity for the choice of species, planting designs, and tree care practices (Sudha and Ravindranath 2000), human activities have changed the species composition and diversity of urban plant communities (Smart et al. 2005). Urban plant communities are typically characterized by greater species richness (Gilbert 1989), replacement of native species with alien species (Wania et al. 2006; Godefroid 2001; Millard 2008), increased habitat patchiness, low stability, and increased landscape conversion toward the urban center (McKinney 2002).

It is predicted that the changes to the physical environment and the altered disturbance regimes in urban settings will drive remnant habitats toward reduced diversity and simpler community structure, with a narrower suite of plant traits (Williams et al. 2005, 2009). Taxa originating from America and Asia dominate adventive floras in the Mediterranean (e.g., Quezel et al. 1990) and central Europe (e.g., Pyšek et al. 1995). Widely planted woody ornamentals that escaped cultivation led to the increase of the phanerophytes in cities of Italy compared to the surrounding landscape (Celesti-Grapow and Blasi 1998). In addition, a small subset of popular species contributes to the bulk of the urban forest stock, with the remaining species playing a minor role in terms of biomass but a notable role in landscape, ecological, and botanical dimensions (Jim 2002; Sudha and Ravindranath 2000).

A major challenge in urban ecology is to determine the structure and composition of the species assemblage in an urban environment, and to identify its underlying mechanisms (Sudha and Ravindranath 2000). The high human impact in urban areas indeed reduces conservation success with respect to species

diversity (Knapp et al. 2008a). Studies on the phylogenetic relationships and traits of species in addition to species richness are crucial for a better understanding of how species assemblages develop and change with a changing environment (Knapp et al. 2008b). Identifying plant traits that are favored or lost through urbanization provides a basis for identifying species and habitats likely to be of conservation concern, or conversely plants that maybe naturalized in urban areas (Thompson and McCarthy 2008; Williams et al. 2009). Such an understanding would greatly enhance our ability to preserve ecological diversity in all types of human-modified environments (Sudha and Ravindranath 2000).

Beijing, the capital of China, is one of the largest and oldest cities in the world. The densely built-up area in the inner city has grown from 84 to 670 km² over the last 50 years since the foundation of the People's Republic of China (Li et al. 2006). With an urban construction history of more than 2,000 years, the inner city is now congested with a large and dense human population, which results in fewer and smaller natural and semi-natural open spaces (Li et al. 2006). These various green spaces in the inner city provide not only recreational, aesthetic, and historical values, but also represent the last refuge for a diversity of organisms in this highly developed city environment.

There have been a number of studies on urban plant habitats in Beijing that focused on specific species (Liu et al. 2002; Xin et al. 2007), the plant species composition of specific green spaces (Li et al. 2006; Zheng and Liu 2006), and the plant species diversity or the landscape structure of green spaces (Meng et al. 2004; Wu 2006; Wang et al. 2007). However, there is a lack of specific insights into the characteristics of the plant species composition in the various types of green spaces in the urban area of Beijing. Considering the design and management of artificial green spaces as well as the land-use-determined species composition, we would expect that plant communities in urban areas differ in various aspects of plant species composition from natural habitats. Therefore, in this study, we combined comprehensive field surveys, analysis of species composition, and indicator species analysis to quantify the plant species composition in six types of green spaces within the built-up areas of Beijing, and to explore the characteristics that have resulted from human activities.

The specific objective of this research was to investigate attributes of species composition, including origin, chorology, life form, and plant-community composition, for the main types of green spaces in the built-up areas of Beijing, and their implications for the management of urban green spaces.

Methods

Study site

The study was conducted within the built-up areas of Beijing City. The city is located in the northeast of the Huabei Plain in north China (39°28′–41°25′ N, 115°25′–117°130′ E). The study sites were located within the fifth ring road. The geophysical conditions within the study sites are relatively similar, with typical conditions of a temperate, humid, monsoonal, and continental climate. The average elevation is less than 50 m above sea level, the annual average temperature is 11–12°C, and annual average precipitation is around 500 mm.

The city is 3,000 years old and has been a capital city for 850 years during four dynasties since 1153 AD (Li et al. 2006). The fundamental structure of the city is a regular grid. The development pattern of Beijing in the last 50 years is a typically concentric expansion, with distinct ring-shaped expansion from the inner center to the outskirts (Li et al. 2006).

In this article, “urban plant species” refers to the plant species growing in the built-up areas within the fifth ring road of Beijing. Plants in the city were mostly planted, distributed in the Royal Gardens and modern green open spaces. The modern green spaces

in the built-up areas of Beijing were designed using contemporary landscape-architecture styles to serve citizens and to improve the city’s environmental quality. In contrast, some historical green spaces were designed using the Royal style. In the urban area of Beijing, the total area of green spaces is 306.11 km², including 82.65 km² of public green spaces, 33.67 km² of street green spaces, and 39.79 km² of residential green spaces, 70.41 km² of institutional green spaces, 76.53 km² of protection green spaces, and 3.06 km² of productive green spaces (Gardening and Bureau 2005). The per capita area of public green land is 11.11 m², and the percentage of greenery coverage is 40.22% (Gardening and Bureau 2005).

Sampling and field survey

A field survey was conducted in July and August 2003, and in August 2007. We combined the data collected from the two surveys for analysis, since few changes of species composition occurred during a 4-year time period. The species survey covered an area of 670 km², and sampling was conducted by stratified random selection. Study sites were randomly selected and stratified by types of urban green spaces. The surveys covered the main types of urban green spaces defined in the classification of green spaces in the Urban Garden and Afforestation Survey Collection of Beijing (Gardening and Bureau 2000), including park green space, protection green space, institutional green space, residential green space, street green space, and vacant land space (Table 1). Vacant land space is also included in our study because urban vacant lands are considered as habitats of crucial importance in urban areas (Muratet et al. 2007).

Table 1 Definitions of the six types of green spaces used in the survey of urban plant species in Beijing

No.	Type of green space	Definition or interpretation
I	Park green space	Open to the public, set aside mainly for human recreation and enjoyment, also possess ecological and environmental functions and serve as places of refuge
II	Protection green space	Urban green space set aside for sanitation, insulation and security purposes, including sanitation greenbelts, roadway protection green space, windbreak forest, and grouped greenbelts
III	Institutional green space	Green space in an institutional area, including schools and institutional units
IV	Residential green space	Green space in residential area excluding residential community parks, including grouped greenbelts, house-side green space, and residential subdistrict roadway green space
V	Street green space	Green space in the area of roadways and piazzas, including street tree avenues, traffic island green space, traffic square green space, and parking lot green space
VI	Vacant land space	Green space in vacant land with no definite land use

The number of sites selected from each type of green spaces was proportional to the area of the green space. As a result, 124 study sites in total were selected.

In each study site, area-proportional plots were randomly selected within green patches. We used green patches as the unit of sampling to select plots because 99% of the ornamental green spaces in the built-up areas of Beijing were designed using the patch as the organizational unit (Gardening and Bureau 2000, 2005; Wu 2006). The number of green patches selected for each site was determined according to the distribution of green patches within the site documented in Gardening and Bureau (2000) and Wu (2006). Except for protection green spaces where only 0.6% of the total numbers of green patches were sampled, 6% of the patches were sampled for the other five types of green spaces (Wu 2006). As the protection green space is largely planted and only contains a few species, the one-tenth sampling effort would not decrease the sampling efficiency.

The area of each green patch was measured from a patch map drawn in the field by a Global Positioning System (GPS) device, using the MobileMapper Office software provided by Thales Navigation SA, California. For each selected ornamental patch, all the trees in the patch were referred to as a tree plot, all the shrubs in the patch were referred to as a shrub plot, and several herb plots (1 m × 1 m) chosen in the patch were referred to as herb plots. The number of herb plots chosen in each green patch was determined by species diversity observed by sight in the field and patch size estimated from high-spatial resolution Quickbird imagery collected on July 5, 2002.

In this study, we used quadrats of 10 × 10 m for trees and shrubs, as green patches of natural plant assemblages in parks or protection forests usually have relatively few tree/shrub species in a small area. As for elongated street trees, only 100-m strips of trees were sampled for each tree/shrub plot, since the street tree strips usually consist of several species occurring at intervals. As a result, 856 tree plots, 858 shrub plots, and 2,285 herbaceous plots were included in the survey.

For each plot, vascular plant taxa were recorded: for tree plots only trees, for shrub plots only shrubs, and for herb plots only herbs were recorded. For each tree plot, the number of individuals, height, diameter at breast height, and canopy dimension were measured for each tree species. In shrub and herb plots,

the number of individuals, average height, and coverage were measured for each species.

The measurements of trees/shrubs were conducted according to the manual of UFORE (Nowak et al. 2005). For herb plots, the average height of each species was measured as the average height of three individuals that appeared to be of median height. The coverage for each species was estimated to the nearest 5% by sight. The number of individuals for each herb species was primarily counted by hand. In cases where individuals of an herb species (especially grass-like species) in a plot were too abundant, individuals in a sub-plot with smaller size (0.1 m × 0.1 m) were counted, from which the total number of individuals in the entire herb plot was calculated.

It is necessary to point out that with the stratified random sampling, a complete inventory of all species was impossible. There were a number of sparsely distributed species missing from the regular sample plots. The number of samples in this research, however, is sufficient for the analyses of species composition according to the species–sample number curve. All the dominant species in Beijing city were included in our sample plots.

Data analyses

The nomenclature followed the *Flora of China* (Compilation committee of the Flora of China 1959–2004), and each variety and subspecies was treated as a full species.

Importance value of plant species

The importance value represents the relative importance of a species in a specific study range, and it was calculated for each green space type as (Zhang 2004):

$$\text{For trees/shrub } S_i = (D_i + F_i + C_i)/3 \quad (1)$$

$$\text{For herbs } S_i = (F_i + C_i)/2 \quad (2)$$

where S_i is the importance value for the i th species, and D_i , F_i , and C_i represent the relative density, relative frequency, and relative coverage, respectively, for the i th species. For each type of green space, D_i was obtained by dividing the total number of individuals of the i th species in all plots by the total number of individuals of all the species in that type of green space, F_i was obtained by dividing the

frequency of the i th species in all plots by the total number of all the species, and C_i was obtained by dividing the accumulated coverage of the i th species by the total accumulated coverage of all the species.

Determination of species origin

The origin of each plant species was determined by reference to species' origins specified in the *Flora of China* (Compilation committee of the Flora of China 1959–2004) and the *Beijing Flora* (He et al. 1993). The species origin composition was analyzed by the proportional distribution of native and alien species in the central built-up areas of Beijing. The species origin of plants in Beijing was identified according to their immigration status (Pysek et al. 2004).

Native plant species (e.g., indigenous plant species): taxa that originated in Beijing area without human involvement or that arrived in Beijing without intentional or unintentional intervention of humans from an area in which they are native.

Alien plant species (e.g., exotic plant species, introduced plant species, non-native plant species, non-indigenous plant species): plant taxa whose presence in Beijing is due to intentional or unintentional human involvement, or which have arrived in Beijing without the assistance of people from an area in which they are alien.

Invasive plant species: a subset of naturalized alien plant species that produce reproductive offspring, often in very large numbers, at considerable distances from the parent plants, and thus have the potential to spread over a large area.

Determination of life form and chorological spectra

The life form of each species was first determined by reference to the *Flora of China* (Compilation committee of the Flora of China 1959–2004) and the *Beijing Flora* (He et al. 1993). The composition of life form was then determined by the proportion of life form for each species.

For those species having more than one life form, the most commonly observed life form for the species under the specific urban environment of Beijing was chosen.

The chorological spectrum, or areal type and chorological type, refers to the geographical distribution

of specific genera in the world (Wu 1991). The determination of a specific chorological spectrum for each genus followed the method presented in Wu (1991). The chorological composition of plant species in the built-up areas of Beijing was analyzed by proportional distribution of each type of chorological spectrum.

Following the determination of life form composition and chorological spectra, the life form composition and chorological spectra in the built-up areas were compared with those from natural mountain floras in Beijing (Zhao 2005).

Classification of plant communities

The dominant species in each type of green spaces was determined by k -means classification, and the importance value of each species in each green space. Classification of the plant communities was obtained by TWINSpan analysis (Hill 1979) using PC-ORD (version 4.20, MjM Software, Gleneden Beach, Oregon, U.S.A.) with all parameters assigned as the default values. Plots with species having frequencies less than 1% were excluded from the dataset used in the TWINSpan analysis to reduce noises. As a result, 848 tree plots, 797 shrub plots, 2,209 herbaceous plots, and 1,188 tree/shrub plots with herbaceous plots sampled in the same tree/shrub plots (hereinafter referred to as tree/shrub/herb plots), were included in the analysis.

Results

Dominant plant species in the built-up area of Beijing

A total of 618 species belonging to 349 genera and 103 families were identified in this study. Importance value of a plant species ranged from 0.001 to 0.226 and varied by types of green spaces. In each type of green spaces, 5–10 dominant species were particularly significant (Table 2 in Appendix), due to their relatively high cumulative importance values in each green space (ranging from 0.409 to 0.819). According to the species-frequency distribution in different types of green spaces (Fig. 1), the amount of species with a relatively high frequency was small. The first

Table 2 Dominant species of trees, shrubs and herbs in different types of green spaces in the built-up areas of Beijing

Green space	Dominant species
Tree	
Park	<i>Pinus tabulaeformis</i> , <i>Sabina chinensis</i> , <i>Sophora japonica</i> , <i>Populus tomentosa</i> , <i>Pinus bungeana</i> , <i>Salix matsudana</i> var. <i>matsudana</i> f. <i>pendula</i> , <i>Ginkgo biloba</i> , <i>Salix matsudana</i> , <i>Koeleria paniculata</i> , <i>Robinia pseudoacacia</i>
Protection	<i>R. pseudoacacia</i> , <i>P. tomentosa</i> , <i>S. matsudana</i> , <i>P. tabulaeformis</i> , <i>S. japonica</i> , <i>Populus</i> × <i>canadensis</i> , <i>Cedrus deodara</i> , <i>Fraxinus pennsylvanica</i> , <i>S. matsudana</i> var. <i>matsudana</i> f. <i>pendula</i> , <i>Prunus cerasifera</i> f. <i>atropurpurea</i>
Institutional	<i>S. chinensis</i> , <i>S. japonica</i> , <i>P. tabulaeformis</i> , <i>P. tomentosa</i> , <i>C. deodara</i> , <i>P. bungeana</i> , <i>G. biloba</i> , <i>R. pseudoacacia</i>
Residential	<i>S. japonica</i> , <i>P. tabulaeformis</i> , <i>K. paniculata</i> , <i>G. biloba</i> , <i>Ailanthus altissima</i> , <i>R. pseudoacacia</i> , <i>C. deodara</i> , <i>P. tomentosa</i> , <i>S. chinensis</i> , <i>Amygdalus persica</i> var. <i>persica</i> f. <i>duplex</i> , <i>P. cerasifera</i> f. <i>atropurpurea</i>
Street	<i>S. japonica</i> , <i>P. tomentosa</i> , <i>S. chinensis</i> , <i>G. biloba</i> , <i>S. matsudana</i> var. <i>matsudana</i> f. <i>pendula</i> , <i>P. tabulaeformis</i>
All	<i>S. japonica</i> , <i>P. tabulaeformis</i> , <i>P. tomentosa</i> , <i>S. chinensis</i> , <i>G. biloba</i> , <i>R. pseudoacacia</i> , <i>P. bungeana</i> , <i>S. matsudana</i> var. <i>matsudana</i> f. <i>pendula</i> , <i>C. deodara</i>
Vacant land	<i>Fraxinus chinensis</i> , <i>R. pseudoacacia</i> , <i>S. japonica</i> , <i>S. matsudana</i> , <i>P. tabulaeformis</i>
Shrub	
Park	<i>Euonymus japonicus</i> , <i>Rosa chinensis</i> , <i>Sabina procumbens</i> , <i>Buxus sinica</i> var. <i>parvifolia</i> , <i>Forsythia suspensa</i> , <i>Sabina vulgaris</i> , <i>Lonicera maackii</i> , <i>Berberis thunbergii</i> f. <i>atropurpurea</i>
Protection	<i>Ginkgo biloba</i> , <i>Fraxinus pennsylvanica</i> , <i>Ligustrum vicaryi</i> , <i>E. japonicus</i> , <i>Broussonetia papyrifera</i> , <i>Kerria japonica</i> , <i>R. chinensis</i> , <i>Robinia pseudoacacia</i> , <i>Cercis chinensis</i>
Institutional	<i>E. japonicus</i> , <i>L. vicaryi</i> , <i>B. sinica</i> var. <i>parvifolia</i> , <i>F. suspensa</i> , <i>B. thunbergii</i> f. <i>atropurpurea</i> , <i>R. chinensis</i> , <i>Buxus sinica</i> , <i>S. vulgaris</i>
Residential	<i>E. japonicus</i> , <i>R. chinensis</i> , <i>B. sinica</i> var. <i>parvifolia</i> , <i>B. thunbergii</i> f. <i>atropurpurea</i> , <i>L. vicaryi</i> , <i>B. sinica</i> , <i>F. suspensa</i>
Street	<i>E. japonicus</i> , <i>L. vicaryi</i> , <i>R. chinensis</i> , <i>B. thunbergii</i> f. <i>atropurpurea</i> , <i>K. japonica</i> , <i>S. vulgaris</i> , <i>Lagerstroemia indica</i> , <i>S. procumbens</i> , <i>B. sinica</i> var. <i>parvifolia</i> , <i>F. suspensa</i>
All	<i>E. japonicus</i> , <i>L. vicaryi</i> , <i>R. chinensis</i> , <i>B. thunbergii</i> f. <i>atropurpurea</i> , <i>B. sinica</i> var. <i>parvifolia</i> , <i>F. suspensa</i> , <i>S. vulgaris</i>
Vacant land	<i>Vitex negundo</i> var. <i>heterophylla</i> , <i>Ziziphus jujuba</i> var. <i>spinosa</i> , <i>Amygdalus triloba</i> , <i>Lycium chinense</i> , <i>Prunus cerasifera</i> f. <i>atropurpurea</i> , <i>Lespedeza bicolor</i>
Herb	
Park	<i>Poa pratensis</i> , <i>Ophiopogon japonicus</i> , <i>Setaria viridis</i> , <i>Digitaria sanguinalis</i> , <i>Buchloe dactyloides</i> , <i>Oxalis corniculata</i>
Protection	<i>Setaria viridis</i> , <i>Ixeris denticulata</i> , <i>Chenopodium glaucum</i> , <i>Humulus scandens</i> , <i>Eleusine indica</i> , <i>Portulaca oleracea</i> , <i>Orychophragmus violaceus</i> , <i>Kochia scoparia</i> , <i>Amaranthus lividus</i>
Institutional	<i>P. pratensis</i> , <i>O. japonicus</i> , <i>B. dactyloides</i> , <i>S. viridis</i> , <i>D. sanguinalis</i> , <i>O. corniculata</i> , <i>Viola prioantha</i>
Residential	<i>P. pratensis</i> , <i>S. viridis</i> , <i>O. japonicus</i> , <i>E. indica</i> , <i>O. corniculata</i> , <i>B. dactyloides</i> , <i>D. sanguinalis</i>
Street	<i>P. pratensis</i> , <i>E. indica</i> , <i>S. viridis</i> , <i>B. dactyloides</i> , <i>P. oleracea</i>
All	<i>P. pratensis</i> , <i>S. viridis</i> , <i>O. japonicus</i> , <i>B. dactyloides</i> , <i>E. indica</i> , <i>D. sanguinalis</i> , <i>O. corniculata</i>
Vacant land	<i>S. viridis</i> , <i>D. sanguinalis</i> , <i>E. indica</i> , <i>K. scoparia</i> , <i>S. viridis</i> , <i>Echinochloa crusgali</i> , <i>P. oleracea</i> , <i>O. violaceus</i> , <i>H. scandens</i> , <i>Chenopodium album</i>

eight classes including 7% of the species that had an importance value above 0.034 were the dominant species of the urban plants, according to the *k*-means classification (Table 2 in Appendix).

The most common families in order of decreasing species abundance were Compositae, Gramineae, Rosaceae, Leguminosae, Oleaceae, Liliaceae, Labiatae, Convolvulaceae, Salicaceae, and Caprifoliaceae, which collectively consisted of 49.4% of all species identified. The dominant families in order of

decreasing importance value were Gramineae, Compositae, Liliaceae, Rosaceae, Oleaceae, Celastraceae, Oxalidaceae, Cyperaceae, Chenopodiaceae, and Violaceae; the accumulative importance value for all species in these families was 0.703. Therefore, the importance of several families was evident, especially those that were both common by species abundance and dominant by importance value, i.e., Gramineae, Compositae, Liliaceae, Rosaceae, and Oleaceae.

Fig. 1 The species-frequency curves for plants in different types of green spaces in the built-up areas of Beijing

Species origin of urban plant species in Beijing

Among the total of 618 species, 293 were native species, 166 were alien species from other areas of China, 142 were alien species from abroad (“foreign aliens”), and 17 species had no clear records of origin. Native species contributed 41–85% of the total number of plant species and varied by different types of green spaces. The native species made up 68.3% of the total plant cover, 77.5% of the total number of plant individuals, and 74.3% of total plant species occurrence frequency. However, a large proportion of the plant species composition was alien species. For example, more than 24% of the shrub and tree species were from abroad, and more than 15% of the shrub and tree species originated from other areas in China in most types of green spaces. While the proportion of the aliens originating from different continents varied by types of green spaces, most of the aliens of foreign origin were introduced from America or Asia, up to 45% and 18% of the total number of alien species, respectively (Fig. 2).

Life form of urban plant species in Beijing

The annual:biennial:perennial ratio for herbs was 6:1:9, and the tree:shrub:herb:liana ratio was 4:4:11:1. The most common life forms by pooled data were perennial herb (31.6%), annual herb (19.7%), deciduous tree (17.3%), and defoliate shrub (13.2%) (Fig. 3). Deciduous woody plant species

Fig. 2 The continental origin of foreign aliens in different types of green spaces in the built-up areas of Beijing

were dominant compared to evergreen woody plant species (ratio 3:1), a typical feature of the defoliate broadleaf forests naturally occurring in the warm-temperate region where Beijing is located.

Chorological composition of urban plant genera in Beijing

The chorological spectra of the 349 genera in the built-up areas of Beijing included 15 chorological types and 11 subtypes (Table 3 in Appendix). The most common chorological type was North Temperate, which

Fig. 3 The life form of plant species found in different types of green spaces in the built-up areas of Beijing

had 63 genera (18.1%). Other common chorological types were Pantropic and Cosmopolitan, with 15.5% and 10.6% of all genera, respectively. In most green spaces, the majority of the chorological spectra were the above three chorological types. The cumulative percentages of such genera ranged from 48.2% to 66.7% (Table 3 in Appendix).

Most of the 15 chorological types occurred in all green spaces, except for a few that were absent in certain types of green spaces. For example, both the “3” distribution (Trop. Asia & Trop. Amer. Disjuncted) and the 6” distribution (Trop. Asia to Trop. Africa) were absent in the protection green space. The “15” distribution (Endemic to China) was absent in the vacant land space, and the “12” distribution (Mediterranea W. Asia to C. Asia) in both protection green space and vacant land space. However, only three of the 11 chorological subtypes occurred in all types of green spaces, including the “10-1” (Mediterranea. W. Asia (or C. Asia) & E. Asia disjuncted), the “14-2” (Sino–Japan), and the “8-4” (N. Temp. & S. Temp. disjuncted). The least frequent chorological types were the “12-3” distribution (disjunct Mediterranean to Temperate-Tropical Asia, Australia, and South America), which only occurred in the park

green space, and the “4-1” distribution (Tropical Asia, Africa [or East Africa, Madagascar]), which only occurred in the institutional green space.

Plant communities of urban plants in Beijing

TWINSPAN classification was conducted on the species composition of the four types of plant plots, including 848 tree plots, 797 shrub plots, 2,209 herbaceous plots and 1,188 tree/shrub/herbaceous plots. The plots were clustered into 43, 54, 38, and 41 groups, respectively. Table 4 in Appendix lists the main groups that have a relatively large proportion of the plots, together with an indication of the common community members. Table 4 in Appendix also presents the plot composition represented by the percentage distribution of plots in various groups of each type of community for each type of green space.

The results indicated that some community groups were predominant in one type of green space, but rare in others. These groups had a much higher percentage of plots in certain green space than other types of green spaces. Therefore, these groups were considered “characteristic” of their associated green spaces. For example, communities in groups TSH-5 (the

Table 3 The chorological spectra of urban plant species in Beijing

Symbol	Chorological spectra	Distribution of plots of each kind of green space in various chorological spectra (%)					
		Park green space	Protective green space	Institutional green space	Residential green space	Street green space	Vacant land space
1	Cosmopolitan	12.8	13.8	11.3	10.6	11.7	24.1
2	Pantropic	16.6	23.0	16.4	17.4	17.3	21.5
3	Tropical Asia and Tropical America (disjunct)	4.3	0.0	4.7	7.8	4.9	1.3
4	Old World Tropics	2.1	1.1	1.2	1.4	3.1	1.3
5	Tropical Asia and Tropical Australasia	2.1	3.4	3.1	3.7	1.9	1.3
6	Tropical Asia to Tropical Africa	0.9	0.0	1.2	2.8	2.5	1.3
7	Tropical Asia (Indo–Malesia)	2.6	2.3	2.7	2.8	1.2	2.5
8	North Temperate	20.9	29.9	20.7	20.2	20.4	17.7
9	East Asian and North America (disjunct).	7.2	4.6	7.8	4.6	4.9	5.1
10	Old World Temperate	6.0	3.4	6.3	6.4	8.0	8.9
11	Temperate Asia	2.1	2.3	1.6	1.4	1.9	1.3
12	Mediterranean, West Asia to Central Asia	1.3	0.0	1.2	1.8	1.2	0.0
13	Central Asia	0.4	1.1	0.8	0.9	0.6	1.3
14	East Asia	3.8	1.1	3.5	3.7	3.7	5.1
15	Endemic to China	3.0	2.3	2.7	2.3	1.9	0.0
2-1	Tropical Asia, Australasia (to New Zealand) and Central to South America (or Mexico) (disjunct)	0.4	0.0	0.4	0.5	0.6	0.0
2-2	Tropical Asia, Africa and Central to South America (disjunct)	0.4	0.0	0.8	0.5	0.6	0.0
4-1	Tropical Asia, Africa (or East Africa, Madagascar) and Australasia (disjunct)	0.4	0.0	0.4	0.0	0.0	0.0
8-4	North Temperate and South Temperate (disjunct) (“Pan-temperate”)	3.4	2.3	3.9	2.8	2.5	5.1
8-5	Eurasia and Temperate South America (disjunct)	0.9	0.0	0.4	0.5	0.6	0.0
9-1	East Asia and Mexico (disjunct)	0.4	0.0	0.8	0.5	0.6	0.0
10-1	Mediterranean, West Asia (or Central Asia) and East Asia (disjunct)	2.1	4.6	1.6	2.3	2.5	1.3
10-2	Mediterranean and Himalaya (disjunct)	0.9	1.1	0.8	0.9	1.2	0.0
10-3	Eurasia and South Africa (sometimes also Australasia) (disjunct)	0.9	0.0	1.2	0.5	1.9	0.0
12-3	Mediterranean to Temperate-Tropical Asia, Australia and South America (disjunct)	0.0	0.0	0.0	0.5	0.0	0.0
14-1	Sino-Himalaya (SH)	0.9	1.1	0.8	0.9	0.6	0.0
14-2	Sino-Japan (SJ)	3.4	2.3	3.9	2.8	3.7	1.3

Kochia scoparia–*Amaranthus retroflexus*–*Abutilon theophrasti* group) and H-6 (the *K. scoparia*–*A. retroflexus* group) were the most dominant groups in the vacant land space, representing 74.4% of the tree/shrub/herb plots, and 43.8% of the herb plots. Similarly, groups S-11 accounted for 10.1% of the shrub plots (the *Ailanthus altissima*–*Buxus sinica*–*Rosa chinensis*–*Lagerstroemia indica* group), and

T-6 (the *Ginkgo biloba*–*Pinus tabulaeformis*–*Amygdalus persica* var. *persica* f. *duplex*–*A. altissima* group) accounted for 13.6% of the tree plots in the residential green space. Groups S-4 (the *Broussonetia papyrifera*–*Ulmus pumila* group) accounted for 21.9% of the tree plots in the protection green space.

Some community groups were common in all types of green spaces. For example, communities in

Table 4 Classification of plant communities in different types of green spaces in the built-up areas of Beijing obtained from TWINSpan analysis (Green space type: I Park, II Protection, III Institutional, IV Residential, V Street, VI Vacant land)

Type of community	Group no.	Number of plots	Indicators	Percentage distribution of plots for each kind of green space (%)						Preferential taxa
				I	II	III	IV	V	VI	
Tree/Shrub/ Herb	TSH-1	363	<i>P. pratensis</i> , <i>O. corniculata</i> , <i>P. oleracea</i>	29	6	38	45	24	0	<i>Plantago asiatica</i> , <i>Euphorbia humifusa</i> , <i>Taraxacum mongolicum</i> , <i>Inula japonica</i> , <i>Scorzonera austriaca</i> , <i>V. prionantha</i> , <i>R. chinensis</i> , <i>P. tabulaeformis</i>
	TSH-2	149	<i>S. viridis</i>	17	2	17	5	7	13	<i>Ixeris sonchifolia</i> , <i>P. pratensis</i> , <i>P. asiatica</i> , <i>O. corniculata</i> , <i>Ixeris chinensis</i> , <i>C. album</i> , <i>Solanum nigrum</i> , <i>Metaplexis japonica</i> , <i>D. sanguinalis</i> , <i>O. japonicus</i> , <i>Acalypha australis</i> , <i>I. japonica</i> , <i>V. philippica</i> , <i>P. tabulaeformis</i> , <i>S. chinensis</i>
	TSH-3	83	<i>P. oleracea</i> , <i>S. austriaca</i>	2	18	4	6	17	10	<i>Calyptegia hederacea</i> , <i>A. australis</i> , <i>Potentilla chinensis</i>
	TSH-4	75	<i>E. japonicus</i> , <i>L. vicaryi</i> , <i>Berberis thunbergii</i> f. <i>atropurpurea</i>	4	12	3	12	10	0	/
	TSH-5	66	<i>K. scoparia</i> , <i>Amaranthus retroflexus</i> , <i>Abutilon theophrasti</i>	2	14	1	3	7	74	<i>E. crusgali</i>
	TSH-6	59	<i>P. tabulaeformis</i>	6	4	7	4	3	0	<i>Platycladus orientalis</i> , <i>Juniperus formosana</i> , <i>K. paniculata</i> , <i>P. cerasifera</i> f. <i>atropurpurea</i>
	TSH-7	54	<i>O. japonicus</i> , <i>R. pseudoacacia</i>	5	4	5	5	4	3	/
	TSH-8	53		6	2	4	4	4	0	/
	TSH-9	43	<i>O. corniculata</i>	5	0	5	3	1	0	<i>O. japonicus</i> , <i>R. chinensis</i>
	-10	40	<i>F. suspensa</i>	4	4	1	2	7	0	<i>S. procumbens</i> , <i>Ulmus pumila</i>
	TSH -11	33	<i>V. prionantha</i> , <i>O. violaceus</i>	3	16	1	1	2	0	<i>R. glutinosa</i> , <i>Dendranthema lavandulifolium</i> , <i>B. papyrifera</i> , <i>Rubia cordifolia</i> , <i>I. denticulata</i>
	TSH -12	22	<i>B. papyrifera</i> , <i>P. tabulaeformis</i> , <i>A. australis</i>	2	0	5	1	0	0	<i>D. lavandulifolium</i> , <i>L. chinense</i> , <i>Bidens pilosa</i> , <i>C. album</i> , <i>Pharbitis hederacea</i> , <i>M. japonica</i> , <i>R. cordifolia</i> , <i>Oplismenus undulatifolius</i> , <i>U. pumila</i> , <i>O. violaceus</i> , <i>A. altissima</i> , <i>Cotinus coggygria</i> , <i>F. suspensa</i> , <i>P. bungeana</i> , <i>S. japonica</i> , <i>S. chinensis</i>
Herb	H-1	607	<i>P. pratensis</i> , <i>S. austriaca</i>	20	31	22	39	44	26	<i>E. humifusa</i>
	H-2	429	<i>O. corniculata</i> , <i>O. japonicus</i> , <i>T. mongolicum</i> , <i>V. prionantha</i>	19	11	26	21	12	1	/
	H-3	367	<i>O. corniculata</i>	19	2	22	13	13	0	/
	H-4	205	<i>C. album</i>	16	4	7	4	4	11	<i>I. sonchifolia</i> , <i>S. nigrum</i> , <i>Viola philippica</i>
	H-5	167	/	11	0	8	7	3	2	/

Table 4 continued

Type of community	Group no.	Number of plots	Indicators	Percentage distribution of plots for each kind of green space (%)						Preferential taxa
				I	II	III	IV	V	VI	
Shrub	H-6	146	<i>K. scoparia</i> , <i>A. retroflexus</i>	2	15	3	4	13	44	<i>E. crusgali</i> , <i>C. glaucum</i>
	H-7	109	<i>C. glaucum</i>	5	29	4	4	3	5	<i>R. cordifolia</i>
	H-8	30	<i>Lolium perenne</i>	2	0	1	2	0	0	<i>I. chinensis</i> , <i>P. oleracea</i> , <i>D. sanguinalis</i> , <i>L. perenne</i>
	H-9	24	<i>Poa annua</i>	0	0	2	3	1	0	/
	S-1	115	<i>L. vicaryi</i> , <i>B. sinica</i> var. <i>parvifolia</i> , <i>R. chinensis</i> , <i>B. thunbergii</i> var. <i>atropurpurea</i>	10	13	17	18	18	0	<i>L. indica</i>
	S-2	80	<i>A. altissima</i> , <i>F. suspensa</i>	8	3	11	14	12	0	<i>E. japonicus</i> , <i>R. chinensis</i>
	S-3	66	<i>E. japonicus</i>	6	3	9	12	10	0	/
	S-4	49	<i>B. papyrifera</i> , <i>U. pumila</i>	8	22	4	6	4	0	<i>R. pseudoacacia</i>
	S-5	42	<i>B. sinica</i> var. <i>parvifolia</i>	4	0	5	7	6	0	/
	S-6	39	<i>L. indica</i>	4	3	5	3	10	0	<i>F. suspensa</i> , <i>R. chinensis</i>
	S-7	33	/	6	9	2	1	5	0	<i>B. sinica</i> var. <i>parvifolia</i> , <i>Sorbaria sorbifolia</i> , <i>C. chinensis</i> , <i>P. cerasifera</i> f. <i>atropurpurea</i>
Tree	S-8	32	/	4	3	4	4	4	0	/
	S-9	28	<i>F. suspensa</i> , <i>A. triloba</i>	2	0	6	2	4	0	/
	S-10	26	<i>F. suspensa</i>	7	0	2	1	1	0	/
	S-11	26	/	1	0	4	10	2	0	<i>A. altissima</i> , <i>B. sinica</i> , <i>R. chinensis</i> , <i>L. indica</i>
	T-1	132	<i>S. japonica</i> , <i>K. paniculata</i> , <i>P. tabulaeformis</i>	19	6	10	12	6	0	/
	T-2	120	<i>P. bungeana</i> , <i>A. persica</i> var. <i>persica</i> f. <i>duplex</i> , <i>A. altissima</i> , <i>P. cerasifera</i> f. <i>atropurpurea</i>	7	0	13	20	11	0	/
	T-3	115	<i>J. formosana</i> , <i>S. chinensis</i>	11	6	15	6	12	0	/
	T-4	76	<i>S. matsudana</i> var. <i>matsudana</i> f. <i>pendula</i>	11	6	4	6	8	0	/
	T-5	73	<i>G. biloba</i>	4	3	12	8	3	0	/
	T-6	70	<i>G. biloba</i> , <i>P. tabulaeformis</i> , <i>A. persica</i> var. <i>persica</i> f. <i>duplex</i> , <i>A. altissima</i>	4	0	7	14	6	0	<i>Malus spectabilis</i> , <i>Magnolia denudata</i> , <i>S. chinensis</i>
	T-7	66	/	5	6	4	8	12	0	/
	T-8	50	<i>P. bungeana</i>	3	0	6	6	5	0	<i>P. cerasifera</i> f. <i>atropurpurea</i>
	T-9	46	/	4	12	5	3	6	0	/
	T-10	39	<i>G. biloba</i> , <i>P. tabulaeformis</i> , <i>S. chinensis</i>	6	0	1	4	4	0	<i>Platanus × acerifolia</i>
	T-11	37	<i>P. bungeana</i> , <i>C. deodara</i>	5	6	2	2	5	0	/

Table 4 continued

Type of community	Group no.	Number of plots	Indicators	Percentage distribution of plots for each kind of green space (%)						Preferential taxa
				I	II	III	IV	V	VI	
	T-12	34	<i>S. japonica</i>	4	0	4	1	4	0	<i>P. orientalis</i> , <i>S. chinensis</i>
	T-13	25	/	3	18	1	0	3	0	/
	T-14	23	<i>Eucommia ulmoides</i> , <i>Diospyros kaki</i>	2	0	4	3	1	0	<i>Toona sinensis</i>

group H-1 (the *Poa pratensis*–*Scorzonera austriaca* group) were the most common herbaceous community, because they represented the largest proportion (20–57%) of plots in all types of green spaces (Table 4 in Appendix). Communities in group TSH-1 (the *Poa pratensis*–*Oxalis corniculata*–*Portulaca oleracea* group) were also widely distributed in various types of green spaces. Groups H-2 (the *O. corniculata*–*Ophiopogon japonicus*–*Taraxacum mongolicum*–*Viola prionantha* group) and S-1 (the *Ligustrum* × *vicaryi*–*Buxus sinica* var. *parvifolia*–*R. chinensis*–*Berberis thunbergii* var. *atropurpurea* group) were also common, representing 10–26.5% of plots in all types of green spaces.

Discussion

While the total number of 618 vascular plant species recorded in this survey exceeds those found in previous studies (536 species in Meng et al. 2004; and 559 species in Wu 2006), it is still 664 species less than that recorded in the mountain areas surrounding Beijing (Zhao 2005). A large proportion of native species found in the mountain areas do not occur in the built-up urban environments, where the plant species have been mostly planted since 1949 (Wang et al. 2007). Therefore, while not all those mountain species are capable of growing in an urban environment, there is still great potential to increase the diversity of native plant species in the central built-up areas of Beijing.

Alien species in the built-up areas of Beijing accounted for 53% of all species recorded in our survey. While this percentage is close to the 54.8% of alien plant species reported by Wang et al. (2007), it is much larger than the 28.6% that were recorded by Zheng and Liu (2006), a study conducted in the constructed urban areas of Beijing. It is also greater than the range of 19.3–45.7% that was found in a study of eight cities in the eastern and mid-western United States, including New York City (Clemants and Moore 2003). The relatively large percentage of aliens found in our study may be partly due to the difference in the regions surveyed. In this study, we focused on the highly urbanized central areas, where intensive human intervention occurred in the process of green space construction. In fact, the records of the construction history of green spaces in the built-up

areas of Beijing indicate that 99% of the trees in our study areas were planted after 1949. Previous studies also found that proportions of alien plant species may vary by survey regions. For example, the proportion of non-native plant species increases from 6% in nature preserves outside the city of Berlin, Germany, to 25% in the suburbs, and to 54% in the most intensively urbanized central areas (Kowarik 1995). While Polish villages have an average of 30% non-native plant species, medium-sized towns have an average of 40–50%, and cities have an average of 50–70% non-natives (Kowarik 1990).

Thirty three invasive species were recorded in this study, including four harmful invasive species that were previously reported in another study on the urban flora of Beijing (Wang et al. 2007). These were *Alternanthera philoxeroides*, *Conyza canadensis*, *Galinsoga parviflora*, and *Lolium temulentum*. Among the invasive species, *Buchloe dactyloides*, *Eleusine indica*, *Oxalis corniculata*, and *Robinia pseudoacacia* have become dominant in the built-up areas. These species have spread into various types of green spaces and may present a severe threat to local habitats (Keane and Crawley 2002). Considering that native animals are best adapted to utilize native plant communities (Batten 1972), the conservation of indigenous plant species is also appropriate from the perspectives of ecological integrity and the ecocentric worldview (Turner et al. 2005). It is suggested that revegetation efforts should emphasize indigenous plant species (Livingston et al. 2003).

The results revealed the dominance of a few families and species in the built-up areas in Beijing. In addition, alien plant species were dominated by species of American and Asiatic origin. These results are consistent with those from studies conducted in other Chinese cities. Taxa of American and Asiatic origin also dominate the adventive floras of Patras (Chronopoulos and Christodoulakis 2000), the Mediterranean (Quezel et al. 1990), and central European regions (Pyšek et al. 1995). The dominance of a single species is also reported in Chicago where buckthorn accounts for 12.76% of the tree population (Nowak 1994), in Guangzhou city where a small subset of common species contributes to the bulk of the urban forest stock (Jim 2002), and in Bangalore urban forest where a few species account for more than 70% of the tree density (Sudha and Ravindranath 2000). While the exact cause of this pattern remains to be rigorously

investigated, it seems likely that the large number of common urban species is related to transportation and habitat (McKinney 2006). Humans tend to favor many of the same non-native species, and they tend to transport the same ones into different settlements (Mack and Lonsdale 2001). Therefore, the dominance of certain types of species in the urban area maybe the results of intensive benefit-oriented species selection by humans. Such dominance of several species may predispose the urban forest to potentially devastating effects from pest and disease outbreaks (Alvey 2006).

The effects of this benefit-oriented species selection are further reflected by the dramatic differences between the urban and the mountain flora investigations of Beijing. First, while the proportion of all temperate chorological elements in the urban area are lower than that in the mountains (mean 42.7%), the proportion of all tropical elements are greater (mean 198.6%) (Zhao 2005). Second, the proportions of tree, shrub, and liana species in the urban area are increased by 167.3, 87.7, and 242%, respectively, whereas that of herbaceous species is reduced by 31.9% in the mountains. Third, fundamental differences exist in the species composition of plant communities: only 11 common species were found among the 174 species identified in the primary mountain communities and the 75 species identified in the major urban communities.

Furthermore, other differences reported from previous studies may also occur in the urban floras of Beijing, and should be further explored. For example, the increased occurrence of thermophilous plant species in the urban flora was observed in other urban regions (Sukopp and Wurzel 2003). The trait patterns of plant species in urban area or human settlements were reported to be more often biennials or perennials, C-strategists, wind-pollinated, summer flowering, reproducing both by seeds and vegetatively, wind or human dispersed, neophytes, species with high demands for light and nutrients and with more continental distribution ranges (Lososová et al. 2006), and UV-reflecting flowers (Knapp et al. 2008c).

The rural filters differ from the urban filters by temperatures, disturbances and land use (Lososová et al. 2006). Shifts in land use can change the trait state composition of plant assemblages, and further urbanization might consequently homogenize the flora with respect to trait state frequency (Knapp et al. 2008c). These observed changes following

urbanization revealed the effects of species selection by humans in the urban flora, which might be a threat to the local ecosystem.

The results indicated that the plant species composition in the built-up areas of Beijing has been dramatically changed by humans. This result was not surprising, given the emphasis commonly placed on aesthetic and economic cost, rather than ecological effects, in the design and management of green spaces. Though proclamations were issued by the Greening and Gardening Bureau of Beijing to prohibit suppression of naturally occurring herbs and promote native plant species, large areas of lawn with a single herbaceous species and decorative alien plants are still preferred by many designers. Management of green spaces was mostly designed to ornament the environment by constructing new landscape sites or introducing ornamental plants to attract more visitors. The impacts of alien and invasive species were mostly ignored. In fact, the high proportion of alien plant species, the expanded distribution of harmful invasive plant species, and the totally different species composition from native habitats have already threatened local habitats. Therefore, including more native species into plant communities of green spaces should be pursued as a design and management option. In order to promote more native plant communities in the greening construction, more detailed and effectively forceful regulations should be created to determine or guide the use of the plant species recommended or prohibited in the greening activities. In addition, programs should be designed to educate the public, and in particular, the managers of the green spaces, on the importance of planting or cultivating plants to obtain a more complex species composition and natural community structure, with sufficient consideration for ecological values. Furthermore, additional research should be conducted to evaluate the intrinsic ecological values of green spaces and to incorporate characteristics of species composition with ecological functions and aesthetic effects. This research will enhance our understanding of how ecological knowledge can be more effectively incorporated into urban green space planning and management.

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Appendix

See Tables 2, 3 and 4.

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