Applied Geography 64 (2015) 121–131

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

A basic assessment of residential plant diversity and its ecosystem services and disservices in Beijing, China

Hua-Feng Wang [a,*], Salman Qureshi [b,c,g], Sonja Knapp [d], Cynthia Ross Friedman [e], Klaus Hubacek [f]

[a] Key Laboratory of Protection and Development Utilization of Tropical Crop Germplasm Resource, Ministry of Education, College of Horticulture and Landscape Agriculture, Hainan University, Haikou 570228, China
[b] Department of Geography, Humboldt University of Berlin, Rudower Chaussee 16, Berlin 12557, Germany
[c] School of Architecture, Birmingham City University, 5 Cardigan Street, Birmingham B2 7BD, United Kingdom
[d] UFZ — Helmholtz-Centre for Environmental Research, Department of Community Ecology, Theodor-Lieser-Str. 4, Halle (Saale) 06120, Germany
[e] Department of Biological Sciences, Thompson Rivers University, 900 McGill Road, Kamloops, British Columbia V2C 0C8, Canada
[f] Department of Geographical Sciences, University of Maryland, College Park, MD 20742, USA
[g] University of Bayreuth, Institute of Sport Science (Sports Ecology), Universitaetstrasse 30, Bayreuth 9544, Germany

ARTICLE INFO

Article history:
Received 22 December 2014
Received in revised form
14 August 2015
Accepted 28 August 2015
Available online 30 October 2015

Keywords:
Urban biodiversity
Urban ecology
Land use change
Urban ecosystem services
Urban ecosystem disservices
Plant conservation
Socio-ecological systems
Urban planning

ABSTRACT

About 52% of the world's population now lives in urban areas, and 41% of urban land in developed countries is used for residential areas. The amount and quality of residential green space, an important element in urban residential infrastructure, is closely correlated to city dwellers' quality of life. The quality of green spaces is not only closely correlated to the ecosystem services they provide, but also to their disservices. In order to (i) examine how plant diversity and plant traits vary in different residential areas, (ii) determine the main socio-economic factors driving plant trait variations across different residential areas, and (iii) provide an overview on selected ecosystem services and disservices related to plant diversity, we investigated the flora and socio-economic properties of 83 residential areas in Beijing, China. We found a total of 369 plant species belonging to 99 families and 150 genera. With respect to plant traits, there were 90 annual species, 174 alien species, 169 pollen allergenic species, and 133 species with edible or pharmaceutical value. The number of perennial, alien, ornamental and edible plant species was largest in residential areas completed in the 1990s. The number of allergenic species was highest in residential areas completed prior to 1980. The Simpson, Shannon and Pielou indices for trees and shrubs were highest in areas completed in the 1990s, while those same indices for herbs were highest in residential areas completed prior to 1980. General Linear Model analyses revealed that richness increased with increasing housing price across all groups of species. Principal Component Analysis indicated that housing price and floor-area ratio are the variables that positively correlate with species richness for all groups of species.

1. Introduction

1.1. The importance of residential green space and plant traits for urban wellbeing

Residential areas represent one of the basic urban structural units in suburban and urbanized areas, and can comprise a substantial amount of urban green space. For example, urban domestic gardens cover between 20% and 30% of land area in cities of Great Britain (Gaston, Warren, Thompson, & Smith, 2005; Loram, Tratalos, Warren, & Gaston, 2007). “Residential green space” refers to the green space within urban residential areas, including green space adjacent to residential areas, but excluding public green space in residential community parks (Ministry of Construction China, 2002). The amount and quality of residential green space is closely correlated to city dwellers' quality of life: green spaces filter and alleviate surface runoff (Whitford, Ennos, & Handley, 2001), reduce energy consumption and improve the microclimate of a city by mitigating hot temperatures (Akbari, 2002), sequester CO_2 (Nowak & Crane, 2002), mitigate air

* Corresponding author.
E-mail address: huafengw82@163.com (H.-F. Wang).

http://dx.doi.org/10.1016/j.apgeog.2015.08.006
0143-6228/

pollution (Jim & Chen, 2008), promote neighborhood harmony (Qureshi, Breuste, & Jim, 2013; Vemuri, 2004), add cultural and aesthetic value for city dwellers (Grove et al., 2006; Qureshi et al., 2013), and provide physical and psychological benefits (Tzoulas & James, 2004). Still, these ecosystem services are accompanied by several disservices (Lyytimäki & Sipilä, 2009), such as the emission of allergenic pollen by certain plant species.

1.2. Socio-economic forces behind urban plant diversity

Many researchers have recently become interested in exploring the driving forces behind changes in plant diversity. The urban plant diversity can be separated in two major categories: spontaneous vegetation (any species that grows in an urban area without assistance from humans, including both native and alien species) and cultivated vegetation (species that have been planted or sown for a specific purpose – including many alien but also native species). According to Kühn, Brandl, and Klotz (2004), the emergence of spontaneous native species in cities is strongly affected by natural drivers such as geology, while spontaneous alien species are mainly driven by urban land use. The manifestation of cultivated species is driven by local residents' preferences; e.g., some urban residents like to bring in ornamental plant species for aesthetic reasons, while others prefer medicinal or edible plants, which in turn affect the overall urban plant diversity (Iverson & Cook, 2000; Martin, Warren, & Kinzig, 2004). In addition, the residents' financial resources needed to meet these preferences affect diversity, a phenomenon that has been referred to as the “luxury effect”: the wealthier the residents of a residential area are, the higher the plant diversity in this residential area becomes (Hope et al., 2003). Besides the luxury effect, there are other socioeconomic variables that affect plant diversity in the residents' surrounding living environment, such as education level and religion (Boone, Cadenasso, Grove, Schwarz, & Buckley, 2010; Cook, Hall, & Larson, 2012; Hope et al., 2003; Lowry, Baker, & Douglas, 2012; Luck, Smallbone, & O'Brien, 2009). On private land, housing age, the rate of vacant houses, and human population density might influence residential green space patterns. For example, socioeconomic status was shown to be an important predictor of vegetation in urban residential areas; i.e., wealthier people prefer to live in areas with higher vegetation coverage, which provides them with a better living environment (Grove et al., 2006; Hope et al., 2003; Martin et al., 2004).

In addition, a number of demographic and lifestyle factors, such as average family size, and percentage of single-family detached homes, was strongly correlated to the amount of land not covered by buildings (Grove et al., 2006; Luck et al., 2009). Finally, changes in vegetation patterns lag behind social and economic changes; this phenomenon is known as the “legacy effect”. An example of the legacy effect was given by Hahs et al. (2009), who showed that modern cities still harbor plant species that are vulnerable to urban land use, but that are likely to go extinct in these cities in the future.

1.3. Research gaps in current studies on urban plant diversity and ecosystem services

In addition to the amount and quality of green spaces, plant traits have the potential to contribute a number of important ecosystem services (i.e., “the benefits people obtain from ecosystems”; Millennium Ecosystem Assessment, 2005: p. V). These services include e.g., cultural services such as aesthetic values provided by ornamental species as well as provisioning services such as food or medicine provided by edible or pharmaceutical species (Millennium Ecosystem Assessment, 2005; Pataki, McCarthy, Gillespie, Jenerette, & Pincetl, 2013). Still, plant traits also contribute disservices (i.e., “functions of ecosystems that are perceived as negative for human wellbeing”; Lyytimäki & Sipilä, 2009: p. 311) such as plants that produce allergenic pollen or invasive alien species that threaten health or economy. The occurrence of plant species in urban residential areas is highly controlled by human activities. Therefore, in order to improve the planning and management of urban green spaces towards an increased provision of ecosystem services and a decrease in disservices, it is important to examine the relationship between residential plant traits and housing characteristics. However, there are only a few studies concerned with the effects of housing characteristics, such as the floor-area ratio (FAR, i.e., the ratio of a building's total floor area to the size of the piece of land upon which it is built) and the residential property management scheme (e.g., trimming and watering frequency) on ecosystem services and disservices.

1.4. Aims of this study

The aims of this paper are to (i) examine how plant diversity and plant traits vary in different residential areas, (ii) determine the main socio-economic factors driving plant trait variations across different residential areas, and (iii) provide an overview on the ecosystem services and disservices related to plant species. We chose Beijing, China as our research area because it is a rapidly urbanizing city and provides an Asian perspective to biodiversity and ecosystem service research, which until now has mainly focused on Europe and North America. Our questions are: (1) How does residential land use affect plant species diversity and the diversity of plant groups that are characterized by specific traits related to ecosystem services or disservices? (2) What are the main socio-economic factors driving the diversity of these plant groups across different residential areas? We explore the mechanisms that drive changes in trait group and species diversity and conclude with ideas for improved planning of future residential areas in rapidly urbanizing landscapes.

2. Methodology

2.1. Study area

This study was conducted within the fifth ring road of Beijing, covering an area of 670 km^2 (Fig. 1), which was regarded as the core of urban Beijing. Beijing, the center of China's political and cultural activities, is located in the northwest edge of the North China plain. Beijing has a temperate, semi humid, continental monsoon climate: hot and rainy in summer, cold and dry in winter, with a short spring and autumn. Its average temperature ranges from −7 to −4 °C in January, and from 25 to 26 °C in July. The annual frost-free period lasts 180–200 days, and 80% of the annual precipitation occurs in the summer months of June, July and August (BMBS, 2014).

Beijing has been undergoing rapid urbanization over the past few decades: its population grew from 8.71 million in 1978 to 21.15 million in 2013 (BMBS, 2014). In 1978, the per capita green space area was 5.07 m^2 and the percentage of urban green space was 22.3%. However, public green area per capita increased to 15.7 m^2 and the percentage of urban green space was as high as 46.8% by the end of 2013 (China Garden website, 2014). In 1978, the per capita housing area was 6.7 m^2, but had become 31.13 m^2 in 2013. In 1978, the built-up area was 232.13 km^2, but by 2013, the built-up area had increased up to 1268 km^2 (BMBS, 2014). The different ring roads signifying urban expansion were established in different years leading to different ages of residential areas, population density and related socioeconomic variables.

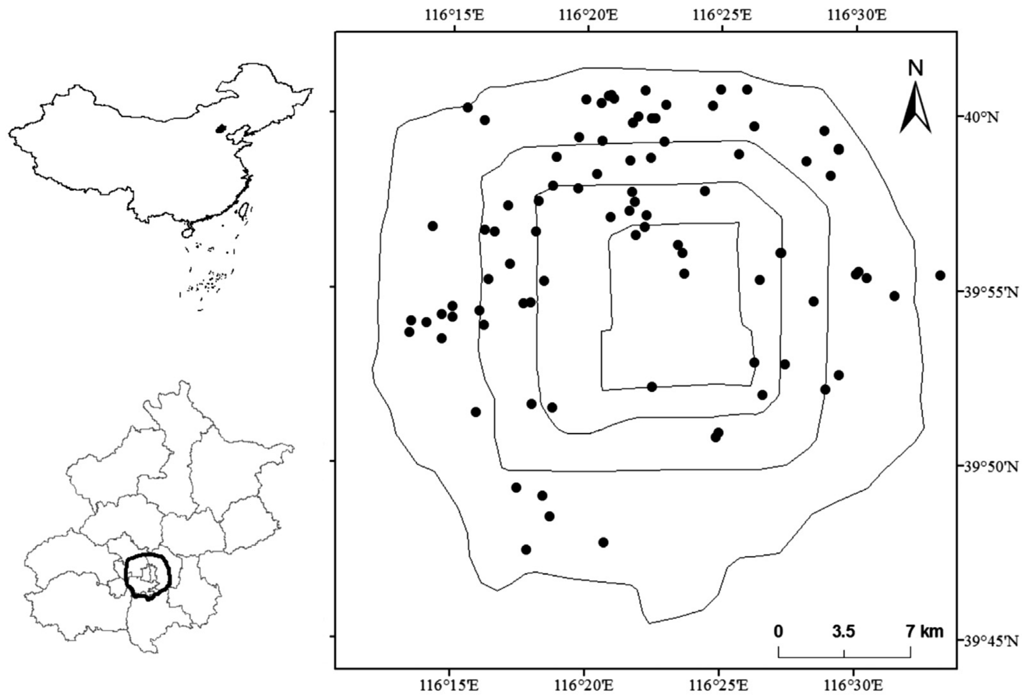

Fig. 1. The location of Beijing within China and the area within the fifth ring road in Beijing. The sampling sites of the residential areas are located within the fifth ring road of Beijing, China. Pictured here are the four rings (second, third, fourth and fifth ring, from inside to outside, respectively). The first (innermost) ring (not shown in this Fig.) is the outside wall of the Forbidden City.

2.2. Sampling

Sampling plant species in urban areas, especially within urban residential areas, is subject to many restrictions and obstacles. Typically, access to a range of private grounds is often denied by the landowner. Moreover, randomly-selected regions often have large areas that are covered with water or some impervious surface, thus making plant sampling impossible or meaningless. Such restrictions and obstacles were present in our case study of Beijing, and so we were unable to use strictly-defined stratified random sampling, which would have been desirable. We therefore adopted a purposive sampling method in this study (based on Wang et al. 2013) in order to gain sites that represent the distribution of socioeconomic variables in Beijing by applying the following procedure, which had key elements of iterative random sampling:

Firstly, we determined where or not the existing 164 2 $\times$ 2 grid-cells within the fifth ring of Beijing (see Wang et al., 2013) qualified as residential areas. A residential area is defined as an urban area dominated by buildings where people live (i.e., an area having only a few businesses or industry buildings, or lacking them entirely). Our selection was based on a zoning map that indicated the areas with the most residential areas, the most universities, etc. If the selected area did not meet the criterion of being a residential area, we discarded it and randomly-selected another residential area.

Secondly, we employed a sampling strategy based on key socioeconomic variables, i.e., population, housing age and income (using housing price as a proxy). Population increases from the 2nd to 5th ring road (Table 4, the second column), so the number of sampling sites also increased from 2nd to 5th ring road (Table 4, the forth column). We did not have data on the spatial distribution of housing prices and housing age at a precise scale (e.g., the 2 $\times$ 2 km scale); therefore, we instead obtained the population data and housing price distribution from each ring road to determine the number of sampling sites for each category. All sampling sites were categorized as belonging to one of the five periods based on completion of construction dates from the Taofang Property Website (http://bj.taofang.com/): prior to 1980s (including 1980s) (17.5%), 1990s (35%), 2000–2003 (25%), and 2004 to 2012 (22.5%). Further, our sampling approach distinguishes housing types of varying socio-economic status: apartments (this is where middle-income earners live), villas (where wealthier people live) and urban villages (where poorer people live). Following the distribution of housing prices, which we used as a proxy for income, we selected the following sample sizes matching the distribution in Beijing (see Anonymous, 2015b “Distribution of housing price in Beijing” in the paper): 16% of our sample sites are from lower priced residential areas (reflecting lower income households), 54% sampling sites are from middle-income residential areas, and 30% are from high-income residential areas.

Lastly, after we made our initial selection, we checked to see whether or not the selected residential area had the right characteristics in terms of age and housing price. In cases where a selected area was missing the characteristics needed to achieve the right distribution, we discarded the site. The above procedure resulted in a total of 93 residential sampling sites. However, ten of these 93 sites were lacking plant data (i.e., numbers of tree, shrub and herb species) because we had not been allowed to investigate plants in these ten private residential areas, and therefore our study uses 83 sampling sites in total.

2.3. Field investigation of plant diversity

Following the methods of Meng, Ouyang, Cui, Li, &.Zheng, 2004, Zhao et al. (2010), Wang et al. (2011, 2012), we randomly sampled the tree, shrub (including liana or vine) and herb species in plots sized 10 $\times$ 10 m, 2 $\times$ 2 m and 1 $\times$ 1 m, respectively, within each of the 83 residential areas. Shrub and herb sampling plots were taken within the 10 $\times$ 10 m tree plots. We recorded the species names and species numbers in each plot including both spontaneous and cultivated species.

Table 1
Plant traits utilized in this study. Here "+" = ecosystem service; "−" = ecosystem disservice; "*" = neither related to ecosystem services nor to disservices.

Trait	Description	Reference of the source for the traits
Life form (*)	1) Trees (evergreen or deciduous), 2) shrubs, 3) lianas or vines, and 4) herbs.	FRPS (1959–2004)
Life history (*)	Annual or biennial, biennial or perennial, biennial, annual or perennial, annual	FRPS (1959–2004)
Origin (*)	Alien, native	Wang et al. (2011); Liu, YU and Zhou (2002)
Allergenicity (−)	Its pollen is allergenic or not	Mao (2012), Mao et al. (2013)
Ornamental use (+)	Its leaves, fruits or the whole individuals are ornamental.	FRPS (1959–2004)
Edible or pharmaceutical use (+)	Only a part or the whole individual could be with edible or pharmaceutical use.	FRPS (1959–2004)

Table 2
Number of plant species per group (categorized by taxonomy, life form, life history, origin, and traits correlated to ecosystem services and disservices) used in this study.

Type	Feature	Value
Flora composition	No. of total family	99
	No. of total genus	150
	No. of total species	369
	No. of species in Rosaceae	32
	No. of species in Gramineae	26
	No. of species in Compositae	20
	No. of species in Fabaceae	14
	No. of species in Rosa	5
	No. of species in Prunus	5
	No. of species in Ficus	4
	No. of species in Euphorbia	4
Life form	No. of species in trees	75
	No. of species in shrubs	67
	No. of species in lianas/vines	23
	No. of species in herb	204
Life history	No. of annual or biennial species	1
	No. of biennial or perennial species	2
	No. of biennial species	2
	No. of annual or perennial species	6
	No. of annual species	90
	No. of perennial species	268
Functional traits	No. of alien species	174
	No. of native species	195
	No. of pollen allergenic species	169
	No. of ornamental species	200
	No. of edible or pharmaceutical species	133

About 30% of the alien species are used as ornamentals, while other alien species are used as medicinal or forage plants, etc. Some ruderal aliens such as *Solanum rostratum*, *Euphorbia maculate*, and *Bidens pilosa* were included in the sampling sites. The pharmaceutical species such as *Rumex japonicas* and *Vaccaria segetalis* were among the alien plants.

2.4. Plant traits

In order to examine how the diversity of plants that are characterized by specific plant traits, including traits related to ecosystem services or disservices, varies in different residential areas, we determined a species' life form and life history as well as whether the species is alien or native, whether it is pollen allergenic or not, whether it has ornamental value, and whether it is edible or of pharmaceutical value (Table 1). Life form distinguishes between trees, shrubs, lianas/vines and herbs, with trees being especially important to a number of ecosystem services such as heat mitigation by evapotranspiration (Lehmann, Mathey, Rößler, Bräuer, & Goldberg, 2014). Alien species are not per se harmful, but some have the potential to become invasive with negative effects on the native flora, human health or economy (Vilà et al., 2010). Although the life history of a species has no direct relationship with ecosystem services or disservices, we include it to provide a basic assessment of the composition of the residential flora of Beijing.

Table 3
The General Linear Models (GLMs) relate the plant trait in different residential areas to socioeconomic variables. The minimum AIC value of the equation to decide whether include the variable in the model, nm: not in model. Signif. codes value > 0.5 is not significant (ns), Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.1.

	Trend between variables and housing price	Housing price	Distance to urban center	Floor-area ratio (far)	Property mgt. fee	Minimum Akaike information criterion	Residual standard error	Multiple R-squared	Adjusted R-squared	F-statistic	*p*-value
Tree richness	Positive	***	*	ns	nm	512.9	5.131	0.5945	0.5791	38.61	<0.001
Shrub richness	Positive	*	ns	*	nm	242.8	1.008	0.1222	0.0888	3.666	0.01573
Herb richness	Positive	***	**	nm	nm	522.44	5.466	0.8273	0.823	191.6	<0.001
Total species richness	Positive	***	***	ns	nm	481.76	4.253	0.2828	0.2556	10.39	<0.001
Perennial species richness	Positive	***	nm	nm	nm	461.71	3.813	0.8688	0.8672	536.5	<0.001
Pollen allergenic species richness	Positive	***	ns	nm	nm	86.306	0.395	0.2257	0.2063	11.66	<0.001
Ornamental species richness	Positive	***	ns	*	nm	517.61	5.279	0.5139	0.4955	27.84	<0.001
Edible species richness	Positive	***	ns	nm	nm	475.22	4.113	0.6327	0.6235	68.91	<0.001
Native species richness	Positive	***	***	nm	nm	549.25	6.424	0.4162	0.4016	28.51	<0.001
Non-Pollen allergenic species richness	Positive	***	**	nm	nm	522.44	5.466	0.1752	0.1546	8.499	<0.001
Non-Ornamental species richness	Positive	***	nm	nm	nm	509.07	5.072	0.6308	0.6263	138.4	<0.001
Non-edible species richness	Positive	***	**	nm	nm	547.66	6.363	0.5425	0.531	47.42	<0.001

Table 4
The number of sampling sites in this study comparing with Beijing population and housing price within each ring road (Anonymous, 2015a).

	Population (ten thousand)	Housing price (Yuan per square meter)	Number of sampling sites within each ring road (one site in the sixth ring road was not taken into account)
2nd ring road	148.1	59 051	7
3rd ring road	257.3	53 324	15
4th ring road	287.5	69 019	20
5th ring road	360.7	41 790	40

2.5. Socioeconomic variables as potential drivers of plant diversity

Distance to the urban center for each sampling site was calculated by ArcGIS 10.0 using the latitude and longitude for sampling sites and Beijing's Tian'anmen Square as the urban center. Distance to the urban center is generally regarded as a poor independent variable (see Ramalho & Hobbs, 2011). However, as in a study of Flanders city (Gurdebeke, De Bakker, Vanlanduyt, & Maelfait, 2003), the distance to the urban centre was used as one variable driving urban plant diversity. Due to limited data availability, we did not use "share of green space", "distance to next green space", or "distance to the next large road" as variables in this study.

In addition, we used the following socioeconomic variables:

(1) Housing price, referring to the unit-price per square meter for each house. The square meter price for living space for hotels or college dormitories was approximated by the housing price of nearby single-family homes instead. While householder incomes would be a useful socio-economic variable (i.e., the higher income, the higher greening percentage/plant diversity living areas could afford, Hope et al., 2003; Luck et al., 2009), these are extremely hard to collect in Beijing urban residential areas. Since the housing price reflects the income level of the residents in Chinese cities (Guo, Fang, & Zhu, 2007), and was already used as a socioeconomic variable to measure the driving force of Beijing urban plant diversity (Wang et al. 2013), we selected housing price as a useful proxy for household income.
(2) The precise house age, referring to the year 2013 (when sampling was done) minus the year when the construction of the house was completed;
(3) Floor-Area Ratio (FAR), referring to the ratio of a building's total floor area to the size of the piece of land upon which it is built. This measure effectively represents the microclimate within different residential areas; i.e., the higher the FAR, the taller the buildings. Taller buildings consume more energy and thus raise local temperatures (Grimm et al., 2008), causing the "urban heat island effect" and ultimately affecting plant species occurences;
(4) Property management fee, referring to the fee paid by householders for local property management agents who are responsible for triming and irrigation, etc. The property management fee is usually calculated per month and per square meter of the built-up area.

The above four variables were obtained from the Taofang Property Website (http://bj.taofang.com/), a reliable website that provides real-time housing prices for each residential area in Beijing to enable convenient transactions between users and providers. Data inquiry for all of the above socioeconomic variables was completed in October, 2013. If one or more of the above variables were not available at the website for a particular area, we contacted at least 30 local residents to determine the average value of that area.

2.6. Plant diversity calculation

Simpson, Shannon and Pielou indices were calculated together with species richness to evaluate the diversity of trees, shrubs, and herb species in each residential area. Since liana or vine species were found only infrequently, and because some sampling plots did not have any liana or vine species at all, the indices were not computed for lianas and vines. The indices were calculated as follows:

(1) Species richness (S), i.e., the number of species in each residential area;
(2) The Simpson diversity index (D) (Simpson, 1949);

$$D = 1 - \sum_{i=1}^{S} P_i^2 \quad P_i^2 = \frac{n_i(n_i - 1)}{N(N-1)}$$

(3) The Shannon index (e-base) H'_e(Shannon, 1948);

$$H'_e = -\sum_{i-1}^{S} P_i \ln P_i$$

(4) The Pielou evenness index (J) (Pielou, 1966)

$$J_e = \frac{H'_e}{H'_{\max}}$$

In the formulae 1 through 4, $S =$ the number of species in each residential area; $P_i = n_i/N$, where n_i is the number of an individual species I, N is individual number of all species, while $H'_{\max}$ is the maximum Shannon index. If $D = 0$, there are no species in the plot.

2.7. Data analysis

The number of perennial, alien, ornamental and edible plant species was compared among five periods: prior to 1980s (including 1980s), 1990s, 2000–2003, and 2004 to 2012. In addition, the Simpson, Shannon and Pielou indices for trees, shrub and herb species were compared among these five periods.

We compiled plant traits and socioeconomic variables for each residential area. We used Minitab 16 (Minitab, Inc.) to test all the residuals of a model for all variables with a D-test (Kolmogorov–Smirnov test) and a W-test (Shapiro–Wilk test) to check whether or not they are normally distributed. If the variables were not normally distributed, Johnson transformation was applied to approach normal distribution. These transformations were required for the following biological variables: richness of all species, trees, shrubs, herbs, perennial species, pollen allergenic species, ornamental and non-ornamental species, edible and non-edible species, native species, non-pollen allergenic species. Similarly, the transformation was used for the following socioeconomic variables: housing price, distance to urban center, floor-area ratio, and property management fee.

Pearson's correlation was applied to test for highly correlated explanatory variables; if the value > 0.5, we excluded one of the variables. In this study, because of the existence of correlation >0.5 between housing age and housing price, we excluded housing age (see Appendix 1). The relationships between the diversity of species with different functional traits and the socioeconomic variables were analyzed using a multiple General Linear Model (GLM) with stepwise selection in R (R Development Core Team, 2013): First, we constructed simple GLMs with one explanatory variable and one response variable each. Then, we conducted a multiple GLM, including all explanatory variables with p -values < 0.1 in the simple GLMs. For cases where no explanatory variables had $p < 0.1$, the variable was not included. Finally, we conducted stepwise selection against the multiple GLM. The model with the lowest Akaike Information Criterion (AIC) was adopted.

Furthermore, we applied Principal Component Analysis (PCA). PCA has the advantage of decreasing the dimensions of variables in a multi-variable correlation analysis, and could determine which variables are most positively and negatively correlated to diversity in a two-dimension ordination. We used the richness of all species groups and five independent variables (i.e., housing price, FAR, distance to urban centre, construction period and property management fee), to conduct PCA in CANOCO 4.5 (ter Braak & Smilauer, 2002).

3. Results

3.1. Species and plant traits in the residential areas of Beijing

A total of 369 plant species (not further categorized as subspecies or varieties) belonging to 99 families and 150 genera were found in this study (Table 2). Among them, the family with most species was Rosaceae (32), followed by Gramineae (26), Compositae (20) and Fabaceae (14). The genera with the highest number of species were *Rosa* and *Prunus* (5 species each), followed by *Ficus and Euphorbia* (4 species each). Trees (including evergreen and deciduous), shrubs, lianas/vines, and herbs comprised 75 (20.3%), 67 (18.2%), 23 (6.2%) and 204 (55.3%) species, respectively. Some of the more common tree species included *Sophora japonica* L. (the Japanese pagoda tree), *Pinus tabuliformis* Carr. (Chinese pine) and *Koelreuteria paniculata* Laxm. (the golden rain tree). The common shrub species included *Euonymus japonicus* Thunb. (Japanese spindle), *Rosa chinensis* Jacq. (China rose) and *Ligustrum* × *vicaryi* Rehder (privet). The common vine or liana plants were *Campsis grandiflora* (Thunb.) Schum. (Chinese trumpet vine). The common herbs included *Petunia hybrida* Vilm. (petunias), *Ixeris sonchifolia* Hance (daisy) and *Humulus scandens* (Lour.) Merr. (Japanese hops).

With respect to life history types listed in Table 1, two members of the "annual or biennial" class (0.5%), four of the "biennial or perennial" class (1.1%), five "annual or perennial" (1.4%), 90 annual (24.4%), and 268 perennial (72.6%) plant species were found, respectively. There were 174 alien species, accounting for 47.15% of all species; the most common species were *Rhus typhina* L. (Staghorn sumac) and *Lolium temulentum* L. (darnel). There were 169 pollen allergenic plant species, accounting for 45.8% of all species; common allergenic pollen plants included *Artemisia argyi* Lévl.(Chinese mugwort) and *Setaria viridis* (L.) Beauv. (green foxtail). We counted 200 species of ornamental value, accounting for 54.2% of all species; frequently found ornamentals included *Yucca gloriosa* L. (Spanish dagger), richly-colored trees, such as *Ixora pavetta* Andrews (the torch tree), and aesthetically appealing shrubs. There were 133 species with edible or pharmaceutical value, accounting for 38.9% of all plant species; the common species included *Solanum lycopersicum* L. (tomato), *Citrullus lanatus* (Thunb.) var. *lanatus* (watermelon), *Cucurbita pepo* L. (pumpkin) and *Lens culinaris* Medik (lentils).

3.2. Species diversity across residential areas of different ages

The number of perennial, alien, ornamental and edible plant species compared to housing age (i.e., construction completed; periods defined in Methods) showed a bell curve trend (Fig. 2) wherein there was an initial increase followed by a decrease. The number of perennial, alien, ornamental species and edible plant species reached its highest in residences completed in 1990s (i.e. 21.4 ± 4.2, 24 ± 5.2, 23.8 ± 5.1, 23.8 ± 4.8, respectively). However, the number of pollen allergenic plant species showed a direct relationship with housing age, and was lowest in the newest residences: that is, before 1980s, the number of pollen allergenic plants species was highest (10.2 ± 2.0), but gradually, the number decreased with time, and the lowest value (5.4 ± 0.81) was obtained in the residential areas completed in 2004–2012 (Fig. 2).

The Simpson, Shannon and Pielou indices for trees were highest in the residential areas completed in 1990s (i.e., 0.74 ± 0.05, 1.49 ± 0.09 and 0.82 ± 0.06, respectively). However, the Simpson, Shannon and Pielou indices for shrubs were highest in residential areas completed before 1980s (i.e., 0.73 ± 0.04, 1.18 ± 0.14 and 0.84 ± 0.06 respectively). Similarly, the Simpson, Shannon and Pielou indices for herbs were highest in the residential areas completed before 1980 (i.e., 0.83 ± 0.07, 2.07 ± 0.25, 0.76 ± 0.10). All indices decreased gradually with newer housing (see Fig. 3).

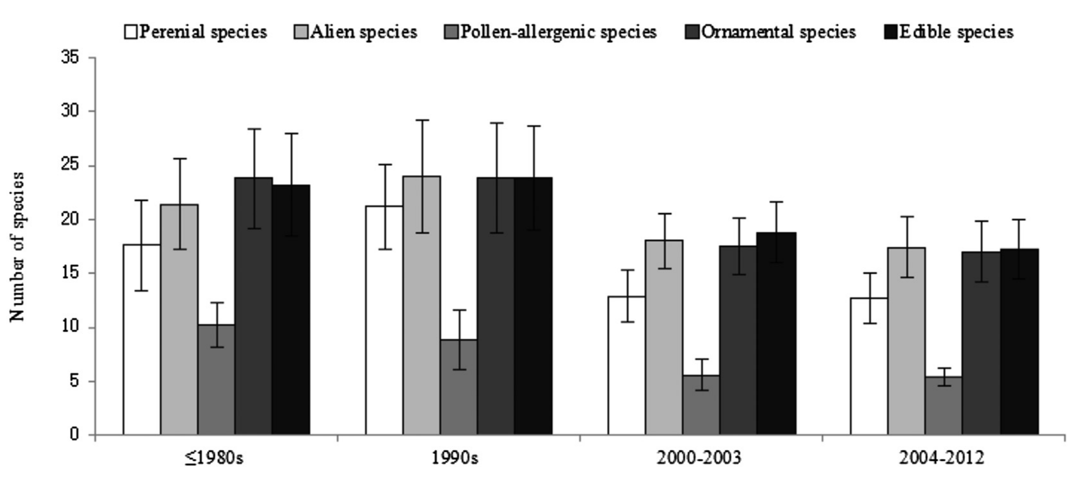

Fig. 2. The number of perennial, alien, ornamental and edible plant species compared with the period housing construction was completed.

3.3. Socioeconomic drivers of plant diversity

Depending on the study site and the respondent group, the model fit (adjusted R^2) of simple GLMs ranged between 0.09 and 0.87 (Table 3). Initially, we selected five independent variables: house age, housing price, distance to urban center, floor-area ratio (FAR) and property management fee; however, after we did a correlation test between pairs of these variables, the Kendall's tau-b correlation between house age and price is higher than 0.5 (Appendix 1), and thus, we removed house age as an independent variable. All indices of species richness used as dependent variables were positively and significantly related to housing price (Signif. level <0.001; Table 3, Appendix 2). Moreover, the richness of all species, herbs, trees, native species, non-pollen allergenic species, and non-edible species are positively and significantly related to distance to urban center (Table 3). FAR only affected the richness of shrubs and of ornamental species. Property management fee was not included in the minimum adequate model (Table 3).

3.4. Relationships among socioeconomic factors and plant composition as well as traits

In the Principal Component Analysis (PCA) using the species richness of trees, shrubs, herbs and the total flora, the first axis explained 54.87 of the variation, and the four remaining axes together explained 87.54 of the variation. In the PCA using the richness of plant trait groups, the first axis explained 64.35 of the variation, and the four other axes explained 84.86 of the variation.

In the PCA analysis, the cosine value of the angle between the variables represents the correlation between them, and the length of the arrow represents the degree of effect, the longer, the stronger. Taking the number of tree species as an example, housing prices as well as FAR are positively correlated to the number of tree species, while the other variables do not show a relationship to the number of tree species The same applies to the number of shrubs and to all species, while herb species richness does not show a close relation to any of the variables (Fig. 5).

In the PCA using the richness of plant trait groups (Fig. 6), housing prices and FAR again were most closely and positively related to richness.

4. Discussion

4.1. Residential vegetation in Beijing

In many areas of the world, cultivated species often belong to a small range of plant families such as Rosaceae, Leguminosae and Solanaceae, and they are introduced as crops or ornamentals plants (Cadotte et al., 2010). Schmiedel (2010) found 3 138 ornamental and crop species cultivated in Germany: 479 species of these were Asteraceae, while other plant families were much less frequent. Our study demonstrates these findings: here, Rosaceae account for a larger percentage (8.74%) of the total flora than any other plant family. Many species of Rosaceae are planted in Beijing, being chosen because of their long flowering period, attractive colors, and ability to handle Beijing droughts (Anonymous, 2010). The rose is also the City Flower of Beijing. In addition, *Prunus persica* L. (peaches), which also belong to the Rosaceae family, is frequently planted, as the people of Beijing love fruit.

We observed 133 plant species with edible or pharmaceutical value, including *S. lycopersicum* (tomato) and *Mentha haplocalyx* Briq. (Chinese mint, a medicinal plant). These species have been artificially introduced, and because they have value as food or medicine, the residents in their own small courtyard plant these species for future consumption.

4.2. Driving forces of plant diversity in residential area of urban Beijing

Unraveling the mechanism behind changes of urban plant diversity has piqued the interest of many researchers over recent decades. The forces driving diversity partly depend on the scale of observation. For example, natural environmental factors (e.g., temperature or rainfall) are better predictors of plant diversity at broad spatial scales across different cities, while at the city scale (within the same city), the luxury effect (i.e., the wealthier the residents, the higher the number of species) and the legacy effect mainly affect plant diversity (Pautasso, 2007; Zhang, 2010). For example, a study by Hope et al. (2003), in which biotic, abiotic and socioeconomic variables were collected and used to explain the mechanism in Maricopa County, Arizona, showed that socioeconomic variables were the main drivers of urban plant diversity. Following this study, other groups did similar studies in different countries/areas, revealing four different mechanisms explaining urban plant diversity variations within cities (cf. Clarke, Jenerette, & Davila, 2013); namely, (1) Climate gradient hypothesis: mild climates should exclude fewer managed species than harsh climates; (2) Land use hypothesis: different management decisions between land uses will create patterns of diversity; (3) Luxury effect: in high income neighborhoods, greater financial resources are available to support large, heterogeneous green spaces; and (4) Legacy effect: older urban areas will harbor higher species richness of long lived perennials.

Our study echoes the legacy effect. The number of perennial species is highest in the 1990s residential areas (Fig. 2), and the Simpson, Shannon, and Pielou indices for herbs are highest in the $\leq$1980s residential areas (Fig. 3C). One explanation is that older residential areas had more time to accumulate species (seeds or young seedlings) by wind, birds or human beings. Also, as the residential areas age, many plants with edible or pharmaceutical value are added, indicating that these plants are largely introduced by the residents. The lower diversity of trees in the younger residential areas may be a result of the lag it takes for trees to grow. We plan to revisit those areas in about five years, where we anticipate a larger diversity of planted trees in younger residential areas.

In addition, our study echoes the luxury effect, with species richness increasing as housing prices increase (Table 3). Similarly, Jenerette et al. (2013) found that there was a significant socioeconomic effect whereby higher income areas had a higher cumulative enhanced vegetation index than lower income areas in seven metropolitan regions in the southwestern United States. In South Africa, more affluent residential urban areas were found to have a larger selection of plant species than less affluent areas (Lubbe, Siebert, & Cilliers, 2010). The correlation of wealth to species richness likely results from peoples' preferences *and* the ability to expand the variety of plants for cultivation. Confirming the luxury effect (Hope et al., 2003), urban residents have more wealth, more money and time to spare for bringing in and cultivating preferred plant species for their fruits, ornamental or medicinal use.

In our study, housing price reflect the socioeconomic status and the ability to introduce and cultivate alien species (Fig. 4). Similarly, greater property management fees should indicate greater expenses for more intensive care (e.g., a higher watering frequency) for the yard plant species; that is, human inference should create a more suitable environment for certain species, while FAR might influence the micro-climate (i.e., with a higher FAR, buildings are also higher, and the higher buildings might affect the amount of sunshine, wind, and rainfall for the residential plants). However, when all three independent variables were included in the GLMs, we found that housing price played the most significant role, which indicates that socioeconomic variables are key factors in driving

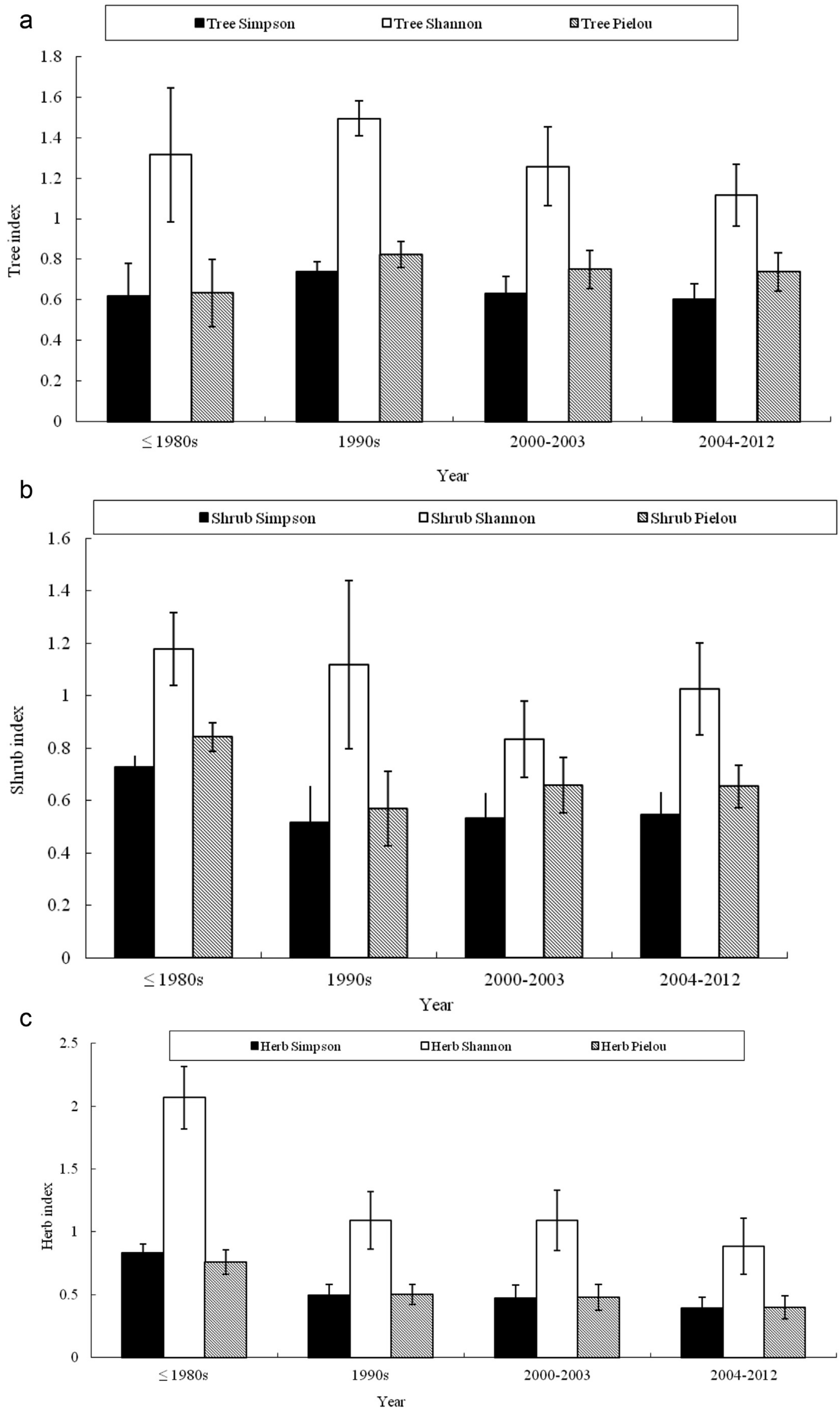

Fig. 3. The Simpson, Shannon and Pielou indices for trees (a), shrubs (b) and herbs (c) compared with the period housing construction was completed.

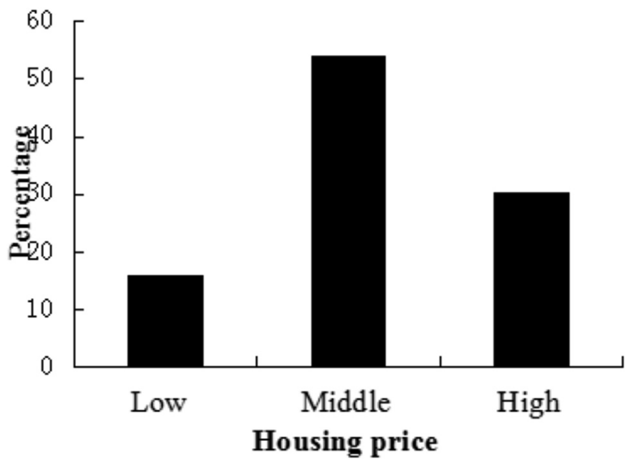

Fig. 4. The relationship between housing price and the percentage of Alien + cultivated species accounting for all species in the residential areas.

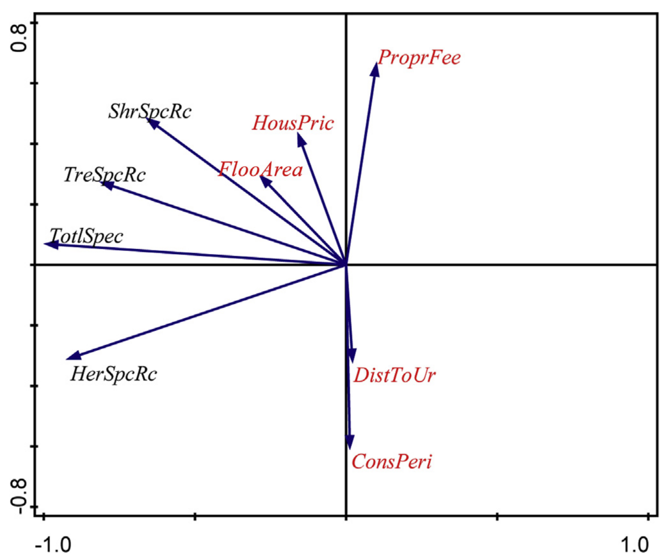

Fig. 5. The Principal Component Analyses (PCA) plot of the relationship between plant composition and its affecting variables, in which the cosine value of the angle between the variables represents the correlation between them, and the length of the arrow represents the degree of effect, the longer, the stronger. Blue arrows with black characters represent species composition variables (i.e., the number of total species, number of tree species, number of shrubs and herbaceous species) in different residential areas. TreSpcRc = Tree species richness, ShrSpcRc = Shrub species richness, HerSpcRc = Herb species richness, TotlSpec = Total species, DisToUr = Distance to urban center, ConsPeri = Construction period, HousPric = Housing price, FlooArea = Floor area ratio (FAR), ProprFee = Property fee. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

urban plant diversity change. Only ornamental species richness and shrub richness are correlated to FAR, as higher FAR usually includes higher buildings, which increase local temperatures and result in more substantial urban heat island effects and water shortage. Heat and drought would likely compromise the plants' physiology, and thus might decrease plant diversity. The property management fee was not a significant driver (see Table 3). In China, residential greening is usually done by property management companies; that is, once the house owner buys a house, property managers will hire people to green, trim, clean, or otherwise maintain the yards. In other words, the house owners did not manage the greening of their yard by themselves, but instead pay for its management. As we could not show an effect of property management fee on species

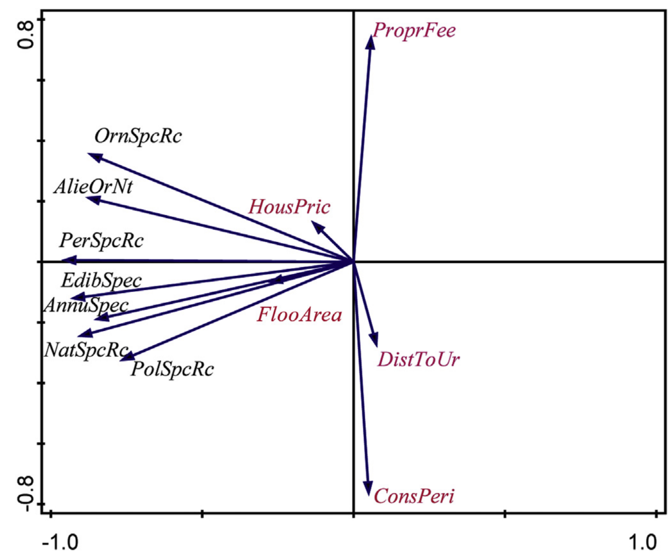

Fig. 6. The Principal Component Analyses (PCA) plot of relationship between plant traits and variables in which the cosine value of the angle between the variables represents the correlation between them, and the length of the arrow represents the degree of effect, the longer, the stronger. AnnuSpec = Annual species, PerSpcRc = Perennial species richness, AlieOrNt = Alien or naturalized species, PolSpcRc = Pollen-allergenic species richness, OrnSpcRc = Ornamental species richness, EdibSpec = Edible species, NatSpcRc = Native species richness, DisToUr = Distance to urban center, ConsPeri = Construction period, HousPric = Housing price, FlooArea = Floor area ratio (FAR), ProprFee = Property fee.

richness, we suspect that companies managing private yards do so homogeneously across yards. In contrast, in the USA, 60%–70% of urban land is privately owned and landscaped, so the householder's income and education level directly affect yard vegetation and plant species richness (Boone et al., 2010; Grove et al., 2006; Troy, Grove, Jarlath, Pickett, & Cadenasso, 2007).

4.3. Ecosystem disservices of residential vegetation in Beijing

Although more and more people are beginning to care about their surrounding living environment, urban greening policy makers and managers seldom consider the ecosystem disservices of plants when they introduce them to urban areas. One of the important disservices that relates to health issues is that plants growing in urban environments can cause allergic reactions (Moro et al., 2009) such as respiratory diseases, eye disease, etc. (Maas, van Dillen, Verheij, & Groenewegen, 2009). Pollen from wind-pollinated plants can cause severe health problems for people with allergies. In our study, we found that the richness of pollen allergenic plant species, such as *Populus tomentosa* Carrière (Chinese white poplar), was significantly and positively correlated to housing prices. As such, we suggest that householders and management companies become better educated about the health implications of the species they cultivate so that fewer pollen allergenic species (and more non-allergenic ones) are planted in urban Beijing.

Moreover, some alien plant species have the potential to become invasive and to cause habitat loss of native species, economic damages or health problems. An example in Beijing is *R. typhina* L. (staghorn sumac), which originates from North America and was previously shown to out-compete other native species (Wang et al., 2011). Although its ornamental value can be seen as a cultural ecosystem service, the sap of *R. typhina* can cause dermatitis in humans (see e.g. http://ias.biodiversity.be). However, it is hard to eradicate this tree, as the financial cost for doing so would be high. Therefore, urban landscape planners should consider the potential effects of alien species before introducing them into new environments. Lyytimäki and Sipilä (2009) argued "that a more balanced treatment of ecosystems services and disservices could provide a fruitful framework for an interdisciplinary and participatory socio-ecological approach" (Lyytimäki & Sipilä, 2009). Although urban plant species can provide a range of beneficial ecosystem services, disservices caused by plants can also be harmful to human health and wellbeing. Therefore, given the complexity of urban green space and plant diversity, we also need a comprehensive consideration of urban green space ecosystems services and disservices from an interdisciplinary approach. In order to take disservices better into account, public participation methods used in urban green management should be adjusted. Local knowledge about disservices should be systematically collected and processed.

5. Conclusions

Understanding how biodiversity is affected by rapidly expanding and heterogeneous urban environments is important for its conservation – and might also be important for regulating the provision of ecosystem services. Not every service is related to high biodiversity (cf. Lyytimäki & Sipilä, 2009) and biodiversity is more than species richness. In the present study, we concentrated on the richness of species characterized by selected traits. However, ecosystem services might also be related to functional, genetic or phylogenetic diversity. Therefore, synthesizing different aspects of biodiversity and their effects on ecosystem services and disservices across spatial scales, especially scales relevant for management will help finding ways to harmonize biodiversity and ecosystem service provision. This harmonization will go a long way toward improving human health and wellbeing, especially in densely populated urban areas.

While we concentrated our study on Beijing, our suggestion that "ecosystem services and disservices should be considered in the management of green urban infrastructure and spaces before introducing alien species" holds for cities worldwide. Still, the diversity of species related to either services or disservices will differ among different cities, requiring individual assessments.

Urban ecology can elucidate the connections between city dwellers and the environment in which they reside (Grimm et al., 2008). Urban nature is seen as an important contributor to solving urban problems and thus is an alternative to technological solutions (Breuste, Schnelinger, Qureshi, & Faggi, 2013). Our finding that the luxury effect plays the most important role for species richness, irrespective of which species group we considered, illustrates the relevance of human preferences for urban biodiversity (Williams et al., 2009). These preferences, however, can also result in the increase of plant-related ecosystem disservices. With socio-economics being important drivers of urban plant diversity, it becomes clear that the future of urban biodiversity relies in educating urban dwellers: Urban planners should consider insights from urban ecology in their planning. One starting point would be to establish a comprehensive list of Beijing's alien and pollen allergenic plant species as well as to identify alternative species that do not promote disservices. Such information could be distributed as promotional literature that educates urban residents about both the benefits plant diversity provides and the potential harm of alien and allergenic species.

Acknowledgment

The authors thank Guo-Hua Xu for his help in the field and Hai-Lei Zhao for entering raw data into the computer. The authors thank the editor and two anonymous reviewers for their constructive suggestions for the manuscript. This study was funded by the National Scientific Foundation of China (41201049).

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2015.08.006.

References

Akbari, H. (2002). Shade trees reduce building energy use and CO_2 emissions from power plants. *Environmental Pollution, 116*, S119–S126.
Anonymous. (2010). *Why Dendranthema morifolium and Rosa chinensis are determined as the Beijing city flower?*. http://zhidao.baidu.com/link?url=QeqdHwUl9-luphCpqHHBZfcuzWYCJYrxZmtqnwtwfH31UCTiSihpMZeE9NQIWgklTMT3bBXDFsu3bfsuUzltsK accessed 08.02.15.
Anonymous. (2015a). *Real estate in Beijing*. http://zhuanti.focus.cn/house/2015/newsdata048qi/ accessed 10.08.15.
Anonymous. (2015b). *Distribution of housing price in Beijing*. http://image.baidu.com/search/detail?ct=503316480&z=0&ipn=d&word=%2C%E5%8C%97%E4%BA%AC%E6%88%BF%E4%BB%B7%E5%88%86%E5%B8%83%E5%9B%BE&pn=3&spn=0&di=97325832890&pi=&rn=1&tn=baiduimagedetail&ie=utf-8&oe=utf-8&cl=2&lm=-1&cs=3900030764%2C1086105225&os=2370472883%2C114539039&adadpic=0&ln=21&fr=ala&sme=&cg=&bdtype=0&objurl=http%3A%2F%2Fimg1.soufun.com%2Falbum%2F2007_12%2F03%2F1196647897325_000.jpg&fromurl=ippr_z2C%22qAzdH3FAzdH3Fks52_z%26e3Bftgw_z%26e3Bv54_z%26e3BvgAzdH3FfAzdH3Fks52_91djwmdka8aaa1tm_z%26e3Bip4s&gsm=0 accessed 13.08.15.
BMBS (Beijing Municipal Bureau of Statistics, NBS Survey Office in Beijing). (2014). *Beijing statistical yearbook 2014*. Beijing: China Statistics Press (in Chinese).
Boone, G. C., Cadenasso, L. M., Grove, M. J., Schwarz, K., & Buckley, G. L. (2010). Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. *Urban Ecosystem, 13*, 255–271.
ter Braak, C. J. F., & Smilauer, P. (2002). *Canoco reference manual and user's guide to canoco for windows-software for canonical community ordination (ver. 4. 5)*. Ithaca, New York: Microcomputer Power.
Breuste, J., Schnelinger, J., Qureshi, S., & Faggi, A. (2013). Urban ecosystem services on the local level: urban green spaces as providers. *Ekológia (Bratislava), 32*(3), 290–304.
Cadotte, M. W., Jonathan, T. D., Regetz, J., Kembel, S. W., Cleland, E., & Oakley, T. H. (2010). Phylogenetic diversity metrics for ecological communities: integrating species richness, abundance and evolutionary history. *Ecology Letters, 13*, 96–105.
China Garden Website. (2014). *Beijing public green area per capita increased to 15.7 square meters*. http://www.18yl.com/fileinfo/201403/343603.shtml accessed: 04.07.2014.
Clarke, L. W., Jenerette, G. D., & Davila, A. (2013). The luxury of vegetation and the legacy of tree biodiversity in Los Angeles, CA. *Landscape and Urban Planning, 116*, 48–59.
Cook, E. M., Hall, S. J., & Larson, K. L. (2012). Residential landscapes as social-ecological systems: a synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosystem, 15*, 19–52.
Gaston, K. J., Warren, P. H., Thompson, K., & Smith, R. M. (2005). Urban domestic gardens (IV): the extent of the resource and its associated features. *Biodiversity and Conservation, 14*, 3327–3349.
Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., et al. (2008). Global change and the ecology of cities. *Science, 319*(5864), 756–760.
Grove, J. M., Troy, A. R., O'Neil-Dunne, J. P. M., Burch, W. R., Jr., Cadenasso, M. L., & Pickett, S. T. A. (2006). Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems, 9*, 578–597.
Guo, J., Fang, Y., & Zhu, B. (2007). Study of selection in price-earnings ratio indication factors. *Journal of Anhui Agricultural Sciences, 35*, 5967–5968 (in Chinese, with English abstract).
Gurdebeke, S., De Bakker, D., Vanlanduyt, N., & Maelfait, J. P. (2003). Plans for a large regional forest in eastern Flanders (Belgium): assessment of spider diversity and community structure in the current forest remnants. *Biodiversity and Conservation, 12*(9), 1883–1900.
Hahs, A. K., McDonnell, M. J., McCarthy, M. A., Vesk, P. A., Corlett, R. T., Norton, B. A., et al. (2009). A global synthesis of plant extinction rates in urban areas. *Ecological Letter, 12*, 1165–1173.
Hope, D., Gries, C., Zhu, W., Fagan, W. F., Redman, C. L., Grimm, N. B., et al. (2003). Socioeconomics drives urban plant diversity. *Proceedings of the National Academy of Sciences USA, 100*, 8788–8792.
Iverson, L. R., & Cook, E. A. (2000). Urban forest cover of the Chicago region and its relation to household density and income. *Urban Ecosystems, 4*, 105–124.
Jenerette, G. D., Miller, G., Buyantuev, A., Pataki, D. E., Gillespie, T. W., & Pincetl, S. (2013). Urban vegetation and income segregation in drylands: a synthesis of seven metropolitan regions in the southwestern United States. *Environmental Research Letters, 8*(4), 044001.
Jim, C. Y., & Chen, W. (2008). Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). *Journal of Environmental Management, 88*, 665–676.
Kühn, I., Brandl, R., & Klotz, S. (2004). The flora of German cities is naturally species rich. *Evolutionary Ecology Research, 6*, 749–764.

Lehmann, I., Mathey, J., Rößler, S., Bräuer, A., & Goldberg, V. (2014). Urban vegetation structure types as a methodological approach for identifying ecosystem services – application to the analysis of micro-climatic effects. *Ecological Indicators, 42*, 58–72.

Liu, Q. R., Yu, M., & Zhou, Y. (2002). A preliminary study on the invasive plants in Beijing. *J Beijing Norm. Univ. (Nat. Sci.), 38*, 399–404 (in Chinese).

Loram, A., Tratalos, J., Warren, P. H., & Gaston, K. J. (2007). Urban domestic gardens (X): the extent & structure of the resource in five major cities. *Landscape Ecology, 22*, 601–615.

Lowry, J. H., Baker, E. M., & Douglas, R. D. (2012). Determinants of urban tree canopy in residential neighborhoods: household characteristics, urban form, and the geophysical landscape. *Urban Ecosystem, 15*, 247–266.

Lubbe, C. S., Siebert, S. J., & Cilliers, S. S. (2010). Political legacy of South Africa affects the plant diversity patterns of urban domestic gardens along a socio-economic gradient. *Scientific Research and Essays, 5*, 2900–2910.

Luck, W. G., Smallbone, L. T., & O'Brien, R. (2009). Socio-economics and vegetation change in urban ecosystems: patterns in space and time. *Ecosystems, 12*, 604–620.

Lyytimäki, J., & Sipilä, M. (2009). Hopping on one leg – the challenge of ecosystem disservices for urban green management. *Urban Forestry and Urban Greening, 8*, 309–315.

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health and Place, 15*, 586–595.

Mao, Qizheng (2012). *Relationship between plant diversity and soil properties in greenspaces of Beijing*. Ph. D thesis. Beijing, China: Research Center for Eco-Environmental Science, Chinese Academy of Science.

Mao, Qizheng, Ma, Keming, Jianguo, Wu, Rongli, Tang, Shanghua, Luo, Yuxin, Zhang, & Le, Bao (2013). Distribution pattern of allergenic plants in the Beijing metropolitan region. *Aerobiologia, 29*(2), 217–231.

Martin, C. A., Warren, P. S., & Kinzig, A. P. (2004). Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix. *AZ. Landscape and Urban Planning, 69*, 355–368.

Meng, X. S., Ouyang, Z. Y., Cui, G. F., Li, W. F., & Zheng, H. (2004). Composition of plant species and their distribution patterns in Beijing urban ecosystem. *Acta Ecological Sinica, 24*, 2200–2206.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

Ministry of Construction China (MCC). (2002). *Code for urban planning and design*. GB 50180–93.

Moro, P. A., Assisi, F., Cassetti, F., Bissoli, M., Borghini, R., Davanzo, F., et al. (2009). Toxicological hazards of natural environments: clinical reports from poison control centre of Milan. *Urban Forestry & Urban Greening, 8*, 179–186.

Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environment Pollution, 116*, 381–389.

Pataki, D. E., McCarthy, H. R., Gillespie, T., Jenerette, G. D., & Pincetl, S. (2013). A trait-based ecology of the Los Angeles urban forest. *Ecosphere, 4*(6), 72.

Pautasso, M. (2007). Scale dependence of the correlation between human population presence and vertebrate and plant species richness. *Ecology Letters, 10*, 16–24.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13*, 131–144.

Qureshi, S., Breuste, J. H., & Jim, C. Y. (2013). Differential community and the perception of urban green spaces and their contents in the megacity of Karachi, Pakistan. *Urban Ecosystems (Springer, USA), 16*(4), 853–870.

R Development Core Team. (2013). *R: A language and environment for statistical computing. R foundation for statistical computing, Vienna.* http://www.R-project.org accessed December 2013.

Ramalho, C. E., & Hobbs, R. J. (2011). Time for a change: dynamic urban ecology. *Trends in Ecology and Evolution*, 1–10.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal, 27*, 379–423.

Schmiedel, A. E. (2010). *Introduction and invasion success of herbaceaous ornamental and crop plant species in Germany*. Thesis. Leipzig, Germany: University of Leipzig.

Simpson, E. H. (1949). *Measurement of Diversity Nature, 163*, 688–688.

Troy, R. A., Grove, J. M., Jarlath, P. M., Pickett, S. T. A., & Cadenasso, M. L. (2007). Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environment Management, 40*, 394–412.

Tzoulas, K., & James, P. (2004). *Finding links between urban biodiversity and human health and wellbeing. Conference paper, International built and human environment research week*. The University of Salford.

Vemuri, A. W. (2004). *The contribution of natural capital to quality of life: A multiscale analysis at the county, region and global scales*. College Park, MD: University of Maryland (PhD dissertation).

Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., et al. (2010). How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in Ecology and the Environment, 8*, 135–144.

Wang, H. F., Lopez-Pujol, J., Meyerson, A. L., Qiu, J., Wang, X., & Ouyang, Z. (2011). Biological invasions in rapidly urbanizing areas: a case study of Beijing, China. *Biodiversity and Conservation, 20*, 2483–2509.

Wang, H. F., MacGregor-Fors, I., & López-Pujol, J. (2012). Warm-temperate, immense, and sprawling: plant diversity drivers in urban Beijing, China. *Plant Ecology, 213*, 967–992.

Wang, H. F., Qiu, J. X., Breuste, J., Ross Friedman, C., Zhou, W. Q., & Wang, X. K. (2013). Variations of urban greenness across urban structural units in Beijing, China. *Urban Forestry & Urban Greening, 12*, 554–561.

Whitford, V., Ennos, A. R., & Handley, J. F. (2001). *City form and natural process–indicators for the ecological performance of urban areas and their application to Merseyside, UK* (Vol. 57, pp. 91–103). Landscape and Urban Planning.

Williams, N. S. G., Schwartz, M. W., Vesk, P. A., McCarthy, M. A., Hahs, A. K., Clemants, S. E., et al. (2009). A conceptual framework for predicting the effects of urban environments on floras. *Journal of Ecology, 97*, 4–9.

Zhang, Y. (2010). *Evaluation of environmental benefits of urban forest in China, Beijing*. Beijing: China Forestry Publishing House.

Zhao, J., Ouyang, Z. Y., Zheng, H., Zhou, W. Q., Wang, X. K., Xu, W. H., et al. (2010). Plant species composition in green spaces within the built-up areas of Beijing, China. *Plant Ecology, 209*(2), 189–204.