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Distribution pattern of allergenic plants in the Beijing metropolitan region

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Abstract Urbanization has significantly affected the composition and distribution pattern of plant species within and around cities. Plants with airborne pollens can cause seasonal allergic symptoms that are intensified by increasing air pollution and temperature. In urban landscapes, the reduced native biodiversity, increased exotic biodiversity, and species homogenization may all affect the abundance and distribution of allergenic plants. We investigated the plants with airborne pollens in the Beijing metropolitan region to determine the distribution pattern of allergenic plants as influenced by urbanization. Our results show that native allergenic plants dominated the urban area in the region. The species richness of allergenic plants, particularly the exotic plants with airborne pollens, significantly differed between land use types. The higher the plant diversity in the urban area, the higher the frequency of allergenic plant occurrence. Despite the homogenization of the allergenic plant communities, their characteristic species were still present across the metropolitan region. The flowering allergenic plants also differed between the different land use types. We suggest that some common allergenic plants should be avoided by urban planners, especially those that are exotic to the region. Humans susceptible to pollinosis should stay away from places that are concentrated with allergenic plants, and be aware of the flowering phenology of allergenic plants.

Keywords Allergenic plants · Biodiversity · Urbanization · Plant community

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1 Introduction

Allergenic plants are plants with airborne pollens. Most of them belong to wind pollination plants that are frequently found in natural vegetation, particularly in temperate zones. Plants with airborne pollens are the major cause of pollinosis in many parts of the world (D'Amato et al. 2007). Pollen allergy has a remarkable clinical impact, and nowadays, considerable amount of evidence indicates that the prevalence of respiratory allergic reactions induced by pollens has been widely increasing in places such as Europe and America (D'Amato 2002a; D'Amato and Liccardi 2002; Traidl-Hoffmann et al. 2003). Most previous studies concerned with pollen allergy mainly focus on the

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distribution and allergenicity of pollen grains based on medicine. In particular, studies about the mechanism of pollen allergenicity are common (Ogihara et al. 2011; Oliveira et al. 2009; Pedrono et al. 2009). The dispersion of pollen grains is closely related to the climate and geography and factors such as the temperature, air pollutants, wind speed, humidity, and elevation. Recently, studies on the correlation between plant pollens and allergic respiratory diseases and even the plant flowering phase from the physiological and ecological aspect have been increasing with the deterioration of urban environment (Bartra et al. 2007; Beggs 2004; D'Amato 2000, 2002b; D'Amato et al. 2002; Gonzalo-Garijo et al. 2006; Nicolaou et al. 2005). More studies suggest that the rising incidence of pollen-induced respiratory allergies is related to the high levels of vehicle emissions and higher temperature in urban and adjacent areas (D'Amato 2000, 2002b; D'Amato et al. 2001; Ishizaki et al. 1987). However, fewer studies were focused on the pollen origins, which are the plants with airborne pollens. Thus, clearing the distribution of allergenic plants in urban areas is essential for the urban human health.

With the rapid increase in urbanization space, higher air temperatures in urban areas cause plant flowers to bloom earlier and even undergo a longer flowering phase (Knapp et al. 2010; Neil et al. 2010; Zhang et al. 2004). According to the study of Phillip in 1985, decreased insect population in urban areas indirectly promotes increased wind pollination due to the decrease in the number of pollinating insects (Regal 1982). Increased environmental pollution and extinction of natural habitats can contribute to the decrease in the number of insect pollinators (Benvenuti 2004). Insects and plants more difficultly construct a stable pollination ecosystem due to the higher landscape fragmentation and heterogeneity. Thus, urban plants are forced to tend to air pollination, and this causes the frequent occurrence of allergenic plants. Moreover, the isolation resulting from a building's structure prevents pollen grain dispersion, which can indirectly increase the pollen concentration (McKinney 2008; Regal 1982). All these changes endanger allergic individuals. Thus, the effect of urbanization on allergenic plants is a serious cause for concern, particularly the distribution of these plants and their physiological changes.

As an important component of urban ecosystem, urban vegetation not only provides majority of ecological function, but also provides various ecosystem services such as biodiversity protection, climate regulation, water conservation, soil formation and erosion control, recreation and culture. However, the urbanization process and land use changes had greatly affected the urban ecosystem and the vegetation pattern widely, resulting in a series of problems such as a reduced native biodiversity, increased exotic biodiversity, and species homogenization of the flora or fauna in urban landscapes (Czech et al. 2000; Knapp et al. 2008; McKinney 2002; Thomas et al. 2001). The urban vegetation pattern and structure can be mainly attributed to human planning and management (Knapp et al. 2010). The change in urban vegetation can bring about multiple and complicated effects. First, the increasing plant biodiversity can satisfy the need of human culture and psychology. Even so, the introduction of exotic plants causes significant various ecological or environmental problems. A number of studies focus on the ecological functions or services of urban vegetation and plants (McPherson et al. 2011; Nowak 2000; Nowak and Crane 2000, 2002), as well as on the ecological risks of vegetation fragmentation (Caspersen and Olafsson 2010; Thomas et al. 2001), and invasive plans could cause the extinction of native species, which is an ecological disaster. However, fewer studies focus on the negative effects of vegetation on human health, such as allergenic plants with airborne pollens. In the present study, we hypothesize that changes in urban vegetation and the introduction of exotic plants increase the occurrence of plants with airborne pollens, which is a serious cause for concern.

New evidence suggests that respiratory allergic diseases have been increasing in terms of both the prevalence and severity in most industrialized countries. Subjects living in urban areas are more likely to experience allergic respiratory symptoms, particularly those induced by pollen allergens, than subjects living in rural areas (Nicolaou et al. 2005). Several factors influence this interaction, including higher air pollutant contents in urban areas, plant species, nutrient balance, climatic factors, degree of airway sensitization, and hyper responsiveness of exposed subjects. However, few studies were correlated with allergenic plants. For instance, their distribution pattern in urban areas, species community, richness, and variation of the flowering phase. These factors should also be cleared to decrease pollen allergenicity. The changes

Table 1 Description of five typical land use types in the urban area (Mao 2012)

Land use	Location	Vegetation description	Management/planning
Urban forest	Urban shelter forest mainly distributed in suburbs and around the urban road ring	Large area of vegetation, lower plant diversity, and more native species	Some are managed by the government, whereas others lack consideration
Urban park	Areas devoted to recreation throughout the whole area	Large area and higher plant diversity and exotic species	Unified management by the government
Residential site	Residential area distributed in the whole study area	Higher fragmentation and composed of smaller patches of vegetation	Managed by various greening companies or organizations and resident intervention
Institutional	Government offices and commercial centers found mainly in the urban center	Composed of a smaller patch of vegetation	Managed by various greening organizations
Transportation	Road sides throughout the whole study area	Ribbon distribution and has the fewest plant richness	Unified management by the government

in the distribution of allergen-producing species resulting from climate change have been recognized (Last and Guidotti 1990).

By comparing the increasing damage caused by pollens of allergenic plants to human health and the deficiency of studies on plants with airborne pollens, we suggest that it is important for us to figure out the allergenic species in urban areas and clear their regional distribution. Identifying these plant species patterns in different areas with different land use types is also necessary. The change in the urban environment, decrease in the number of urban insects, and the increase in plant diversity and higher exotic species may bring more allergenic plants and expand the human health risk significantly. The distribution of these plants may differ between a variety of different land use types. Therefore, we made the following hypotheses: (1) the number of allergenic plants can be higher than the other species because of a possible decrease in the number of urban insect pollinators and the higher landscape fragmentation; (2) with the increasing urban plant diversity and exotic species, the diversity of allergenic plants also significantly increase; (3) both the species diversities of allergenic plants and the flowering phase will show a significant difference between different land use types. We applied the related survey and analysis in Beijing to answer these questions.

In this study, we conveyed the allergenic species in an urban area through five types of land use (Table 1). Plants with airborne pollens are categorized into native and exotic including trees, shrubs, and herbaceous species. Then, we compared the species richness of allergenic plants between land use types. We further explored the pollen allergenic period in different land use types by analyzing the plant flowering phase. This work aims to (1) answer the three hypotheses, (2) identify the species community of allergenic plants in an urban area, (3) investigate the variations in allergenic plants in different land use types, and (4) determine the flowering phase of allergenic plants in an urban area. Studies on allergenic plants are particularly useful for urban residents who are allergic to plant pollens by providing information that may help them avoid developing related respiratory diseases.

2 Materials and methods

2.1 Study area

Our study area was located in Beijing, the capital city of China and one of the largest as well as oldest cities in the world. It occupies an area of 16,800 km^2, of which 1,289.3 km^2 is covered by built-up areas. Beijing is located within the warm temperature zone with a continental climate characterized by four distinct seasons. The annual average temperature is 11.6 °C, and the precipitation is 428 mm. The annual daily maximum temperature is 42 °C, and the annual minimum temperature is −27.4 °C. The city is currently home to 22 million people and consists of 18 districts and two rural counties. Beijing is characterized by regularly shaped rectangular structures. Its recent expansion followed a classical outward concentric growth with a series of new ring-shaped

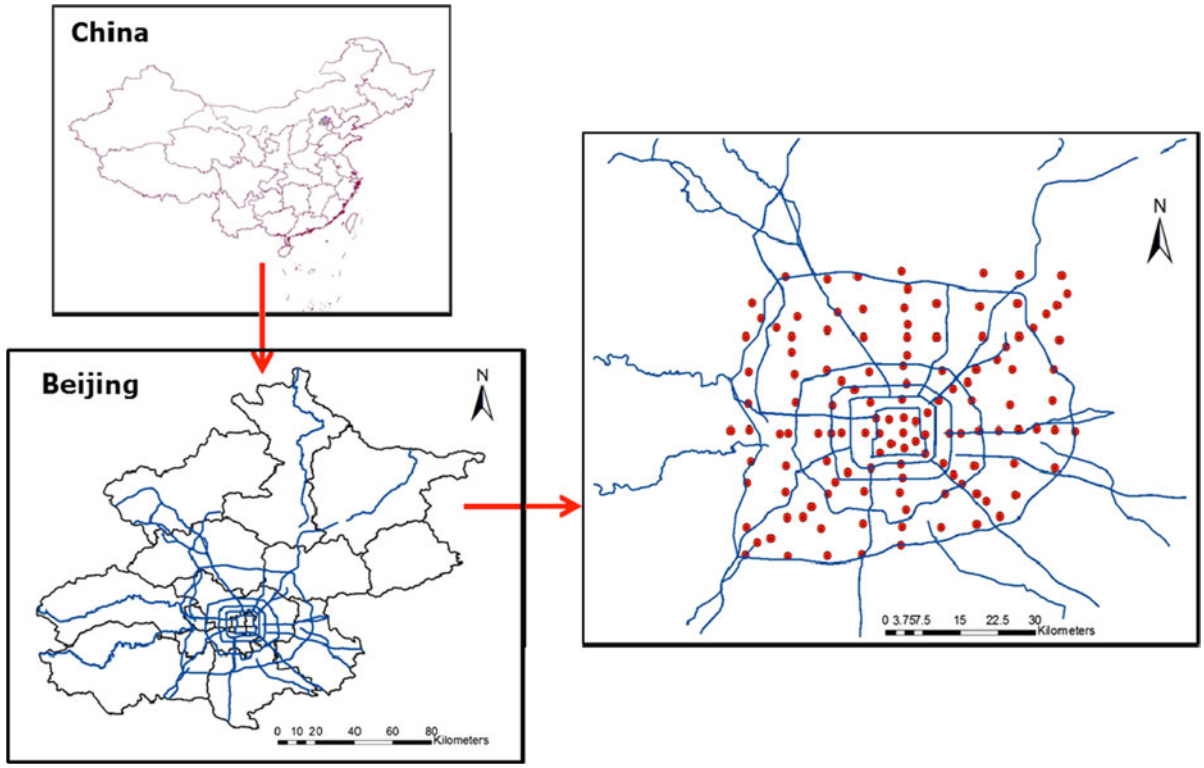


Fig. 1 View of the Beijing region and sampling points. A total of 128 sampling plots with 369 samples are located within the sixth road rings

developments that wrap the urban historical center (Li et al. 2006). Our sampling locations were chosen within the sixth ring of Beijing from the city center to the nearby suburban areas, which roughly forms a rectangular area of 2,827 km^2. It includes both typical urban land uses and a small portion of surrounding farmlands (Fig. 1).

2.2 Plant data collection

We chose 128 plots within the sixth road ring of Beijing along the urbanization gradient based on a 3- and 6-km grid. At every plot, within a roughly 500-m area scope, we chose the five dominant land use types for the vegetation survey (Table 1). Then, at each typical land use, the dominant vegetation covers in every sample were surveyed. Based on these sampling rules, a total of 369 samples involving five land use types are surveyed through the study area. The vegetation survey was conducted during July, August, and September in 2009. The vegetation community in every sample was concerned. The sampling quadrant was 20 m × 20 m (Nowak et al. 2004), and all trees and shrubs species were surveyed within the quadrant. The herbaceous layers were surveyed in three 1 m × 1 m quadrants. Finally, all plant species were recorded in the quadrants. The plant richness, species composition, and vegetation structure of the green space were analyzed. The chosen five main land use/land cover categories and the resulting number of samples were as follows: urban park ($n = 52$), residential sites ($n = 82$), institutional ($n = 56$), transportation ($n = 127$), and urban forest ($n = 44$).

2.3 Statistical analysis

Firstly, we must clear that all allergenic plants were judged according to the book edited by Qiao (2005), which exhaustively described and summarized all the plants with airborne pollens in China. We directly calculated the number of plants with airborne pollens and all the plants in the study area including trees, shrubs, and herbs to evaluate the general distribution of allergenic plants in an urban area. Native and exotic allergenic plants were distinguished accordingly. We chose to use canonical correspondence analysis (CCA) to describe the distribution of allergenic plants in different land use types to further investigate the variations of the allergenic plant community in an urban area (McCune et al. 2002; Ter Braak 1987). Multiple linear regression analysis was performed in analyzing the relationship between plants with airborne pollens and urban plant diversity using the species numbers of allergenic plants and alien allergenic species as independent variables, respectively, and the species richness of exotic plants and total plant diversity as dependent variables. This analysis was operated in SPSS 18.0 and Excel 2010. One-way ANOVA was conducted using the F test to test the effect of land use on the allergenic plant distribution if the plant data was normal, including the richness of allergenic plants, native, exotic plants, and their flowering phases. Otherwise, the difference was determined using the Kruskal–Wallis test (Kruskal and Wallis 1952).

3 Results

3.1 Allergenic plants distribution in urban area

Overall, 271 plants were recorded in the 369 samples. A total of 101 species with airborne pollens were found (37 % of the total number of species). Among these 101 species, 63 % were native species and 37 % were exotic. A total of 170 (63 %) species were not allergenic plants. Among all these allergenic species, 43 % were woody, 31 % were herbaceous plants, and 27 % were shrubs. All of them showed a high proportion of native plants with airborne pollens, and the order was woody plants > herbage > shrub, whereas the order of alien plants was tree > herb > shrub. More exotic plants with airborne pollens were present in the woody and herbage communities, particularly exotic allergenic trees that accounted for approximately 79 % of all the plants, whereas alien shrubs accounted for only 22 %. The proportion of herbaceous plants with airborne pollens was within the middle range (Fig. 2).

3.2 Diversity of allergenic plants under different land use types

The richness of allergenic plants showed a significant difference in the five urban land use types ($P = 0.007$). Plants with airborne pollens were more abundant in the residential sites and urban park than other land use areas. The richness of allergenic plants was lowest in the transportation border than the other sites ($P < 0.001$), whereas the diversity of allergenic plants showed no significant difference from the other sites concerning all species origins. Although the number of native allergenic plants was greater than the number of exotic plants, the difference between the native plants in terms of the land use type was not significant ($P = 0.084$), but the difference for the exotic plants was significant ($P < 0.001$). The richness of exotic allergenic plants in the urban forest was fewer than that of the other urban land use types, and it was most abundant in residential plots than other sites. No difference was found between the park, road rings, and institutional sites. Herbaceous plants accounted for most of the proportion (31 %) among all allergenic plants. However, the distribution was similar among the land use types, but the trees and shrubs differed significantly. We also found that the trees and shrub species in the residential area were significantly greater than those of the other sites and the urban forest has the least number of trees (Fig. 3).

3.3 Allergenic plant composition in different land use types

In our study area, the top five species most frequently found in the city were *Setaria viridis*, *Poa annua*, *Juniperus chinensis*, *Chenopodium album*, and *Pinus tabuliformis*. Fifty species that had a frequency rate of more than 1.4 % were used in the CCA with the ordination of species and urban land use types (Table 2). The first two axes of the CCA are shown in Fig. 4. The two axes were associated with the land use types. The percentage variation of the species data of the first axe was 1.9, and the correlation coefficient of the species and environment axis relations was 0.66. The percentage variation of the species data of the second axe was 0.5, and the correlation coefficient of the species and environment axis relations was 0.43. According to the CCA, the type of urban land use had a weak effect on the distribution of allergenic species. Aside from the five most common allergenic plants, some typical allergenic species were also found in different land use types (Fig. 5). For example, *Toona sinensis*, *Punica granatum*, *Parthenocissus tricuspidata*, and *Cedrus deodara* were found in residential sites. *Platanus occidentalis*, *Ligustrum lucidum*,

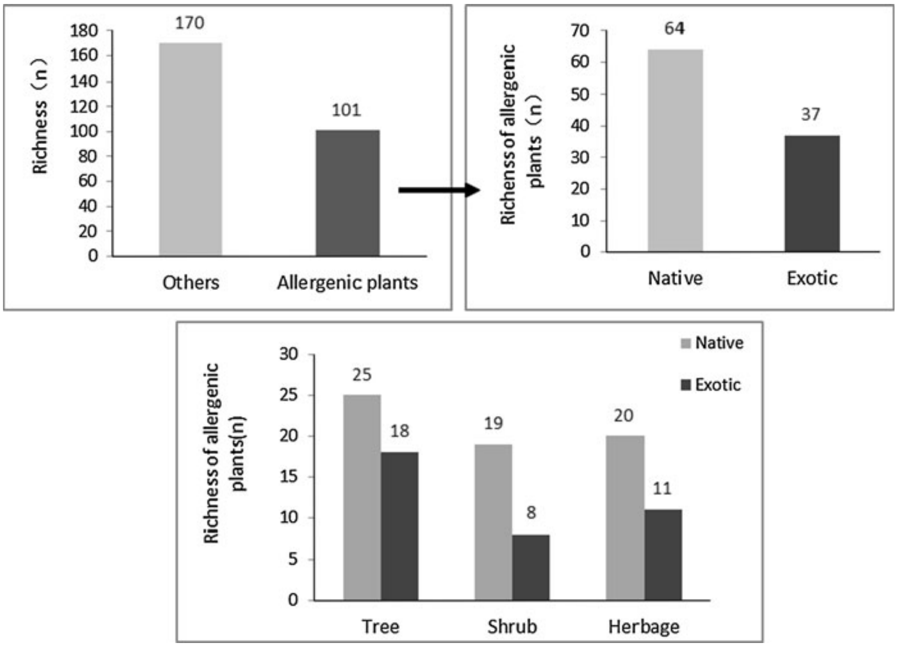


Fig. 2 Richness of plants with airborne pollens in the urban area

Koelreuteria paniculata, and *Amaranthus retroflexus* were found in the transportation area; *Populus tomentosa*, *Humulus scandens*, *Populus* × *canadensis*, and *Salix matsudana* were found in the urban forest; and most species were found in the institutional zones. However, the types of functional zones only explained a 3 % variation of allergenic species composition. More similar species occurred in the different functional zones, and the homogenization of species distribution was also clearly shown in the urban area.

3.4 Flowering-phase distribution of allergenic plants

We found out that more allergenic plants appeared at the end of the spring season, the whole summer, and early autumn by comparing the richness of flowering plants at the five land use types throughout a year (Fig. 6). The richness of plants with airborne pollens in different land use types changed with a similar trend from that of March to November. Although there were no more than three plant species in each sample, the richness of the allergenic plants was significantly different between different land use types and it was more abundant in residential sites than in other areas before July. There were more flowering plants in the institutional sites than the other sites after July. The other three land use types showed no difference. However, the change in the number of flowering plants at different sites and seasons indicated that the risk of allergenic resources showed a significant difference. The flowering phases of allergenic plants are summarized in Fig. 7. Allergenic plants in the urban forest, park, and institutional sites have a longer flowering phase than those in the residential and transport areas. Particularly, the flowering phase of allergenic plants was much longer in the urban forest (approximately 9 months) than in the other sites (8 months in the residential site). The flowering periods of plants with airborne pollens can be related to the seasonal distribution of pollens and the maximum number of flowering plants during these periods can release a huge amount of pollen grains in the air. Therefore, clearing the distribution of flowering allergenic plants throughout a year and determining their flowering phases in different urban areas were essential for the urban residents.

4 Discussion

4.1 Allergenic plant distribution in the urban area

Urban settlement has a higher proportion of wind-pollinated species than arable fields because of the lack of large vegetation areas and specialized sites in the urban or polluted environment for insect pollinators

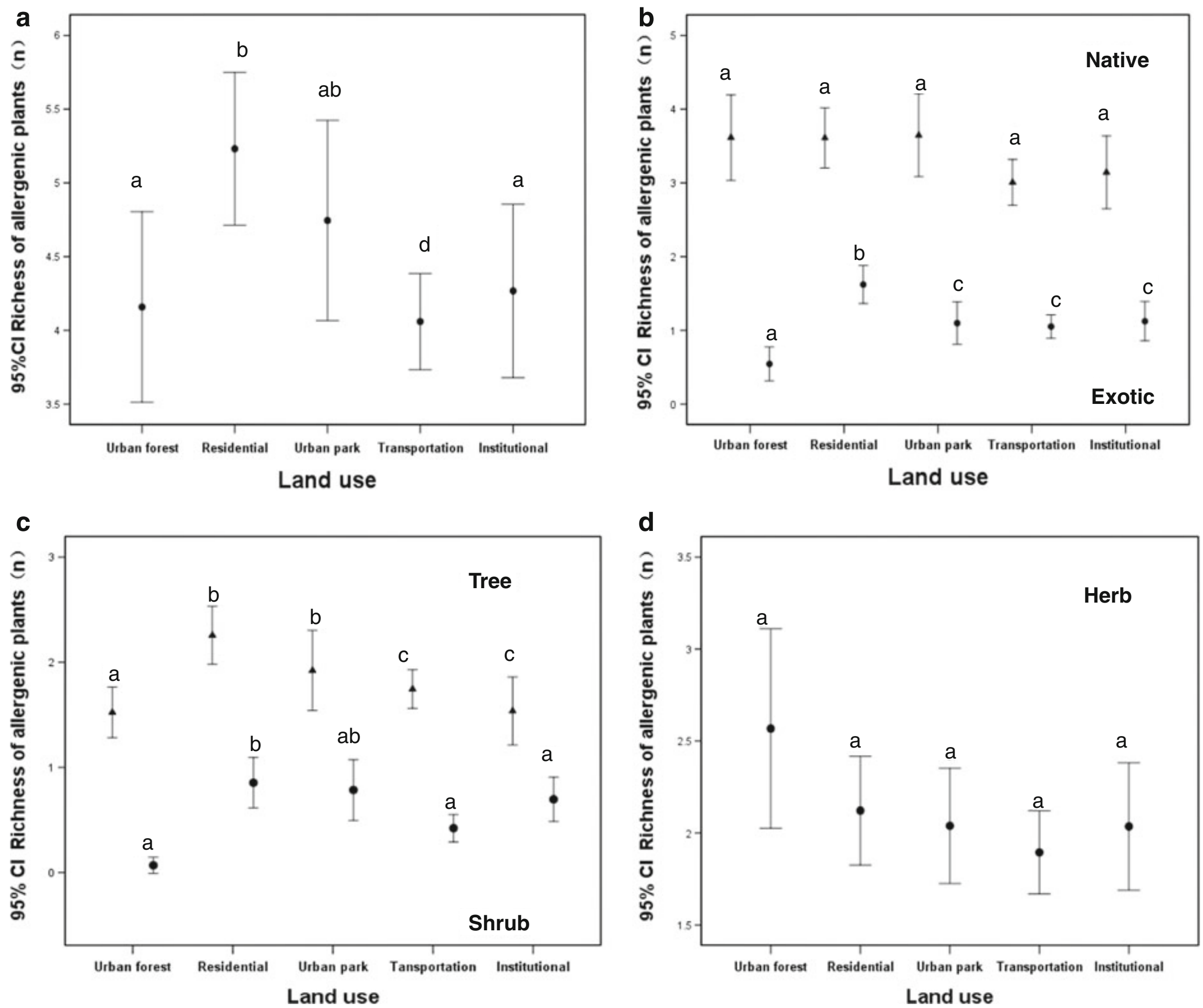


Fig. 3 Richness of allergenic plants in the five land use types in the urban area. The difference between the five typical land use types was tested using the Kruskal–Wallis test (*different letters* indicate significant differences between groups at $P < 0.05$). **a** Richness of total allergenic plants; **b** richness of the native and alien plants with airborne pollens; **c** richness of woody and shrub allergenic plants; **d** richness of herbaceous plants with airborne pollens

(Lososová et al. 2006). Most allergenic plants are related to wind-pollinated species. We previously hypothesized that the proportion of wind-pollinated species was greater than that of the other plants in an urban area. On the other hand, the opposite result was observed in this study. The number of allergenic plants was far lower than the others, which indicates that more plants that depend on other pollination strategies are present in the urban area except for the wind-pollinated species. This finding can be attributed to the heterogeneous urban landscape. Aside from the negative influence of landscape fragmentation, some studies supposed that urban landscape fragmentation built heterogeneous habitats, which supported the higher biodiversity (Angold et al. 2006; Cornelis and Hermy 2004; Sattler et al. 2010). Therefore, some insects can also survive and pollinate for plants regularly. Even so, we recommend that future study should be located in a larger scope with a comparison between the urban and suburban areas or rural areas to detect the effect of urbanization on allergenic plants. However, there is a certainty that fewer allergenic plants in the urban built-up area are beneficial for the urban residents who are commonly allergic to plants with airborne pollens.

Although the richness of allergenic species in the urban area was lower than that of the other plants, they

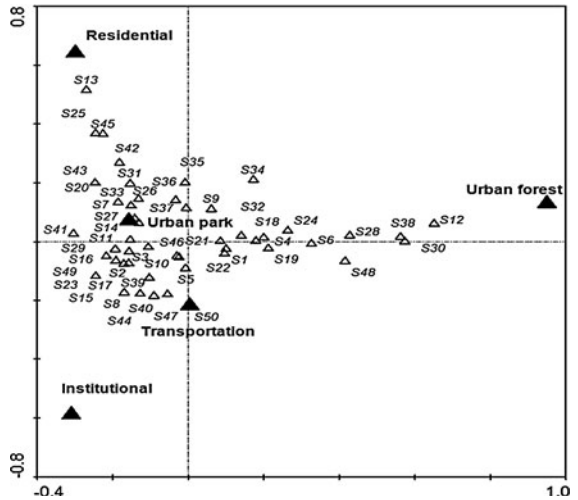


Fig. 4 Allergenic species ordination diagram based on CCA with respect to the five land use types. The axes (*1* horizontal; *2* vertical) are scaled in standard deviation units. Eigen values of the first and second axes were 0.270 and 0.071, respectively. The species numbers are based on their frequency rate in 369 samples. See Table 2 for full names

still accounted for a high proportion (37 %). A greater number of species can be assumed to correspond to a higher occurrence of allergenic plants. As shown in Fig. 8, the richness of allergenic plants was significantly related to the species pools in the urban area ($P < 0.001$, $R^2 = 0.511$). Exotic allergenic plants account for a high proportion among all alien plant species. A number of them were exactly correlated with the richness of the urban alien plants ($P < 0.001$, $R^2 = 0.75$). Urban vegetation has been greatly changed by the rapid urbanization process with the increasing biodiversity and exotic species in urban areas. Numerous studies attributed the increased plant species to the introduction of ornamental species (Knapp et al. 2010). Therefore, the higher frequency of allergenic plants was accompanied by the introduction of alien species. We suggest rigorous selection of the species to be introduced prior to application in urban greening. For example, *P. annua* is the most common alien lawn plant because of its higher tolerance and reproduction. Thus, this alien plant poses a potential risk to human health. *Rhus typhina,* a typical allergenic plant used in road greening for soil and water conservation, is a common invasive plant with a high resistance. This allergenic plant is now widely distributed in Beijing (Wang et al. 2008). The potential risk of its allergenicity needs to be addressed in the future.

Native allergenic plants, particularly trees and herbaceous plants, occupy a far greater proportion than alien plants. Native plants can more efficiently adapt to highly polluted urban environment than alien plants. Thus, some native species with a high tolerance are generally recommended for application in urban vegetation planning. However, parts of the typical native allergenic plants should be avoided during plant selection regarding their allergenicity, such as *P. tomentosa, J. chinensis cv kaizuka, S. matsudana, Salix babylonica, C. deodara* . Herbage is also one of the main allergenic plants. Regarding herbaceous plants with airborne pollens, most of the species belonged to native weeds, such as Asteraceae, Poaceae, and Chenopodiaceae, which were widely present in the urban area. They contain *S. viridis, C. album, A. retroflexus,* and so on. These weeds should be wiped out to decrease the risk of possible health damages. The analysis of allergenic flora distribution shows that the maximum percentage belongs to trees (43 %), followed by herbages (31 %), and shrubs (27 %). The percentage of plant species can later be related to the contributions of allergenic pollens. Despite fewer allergenic plants of shrubs in urban sites, several important shrub species should be given attention, such as *L. lucidum, Syringa oblata* and *Lonicera maackii*.

4.2 Allergenic plant distribution in a typical land use area

An urban area is a typical mosaic composed of multiple landscapes, and heterogeneity is a significant characteristic (Wu et al. 2011). Previous studies reported that plant diversity is significantly different among the land use types, and plant diversity is the highest in urban residential sites and parks, also the numbers of exotic plants were greater in these areas than in the other land use types Transportation or institutional sites have lower plant richness; (Walker et al. 2009; Zerbe et al. 2003). Therefore, we assume that urban allergenic plant distribution also has significant differences between various land use types. In our study, despite the low richness of allergenic plants that appeared in the five land use types, we still found a distinct difference between them. The highest richness of allergenic plants was found in the residential area, whereas the transport sites had the fewest plant species. This phenomenon may have resulted from the difference between the urban vegetation planning and

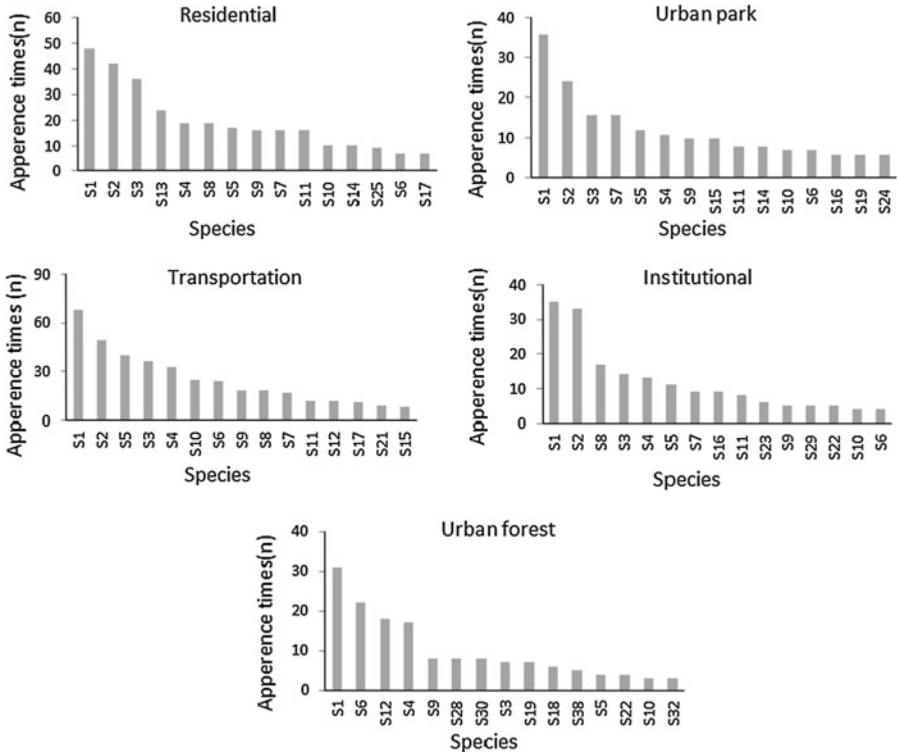


Fig. 5 The top 15 allergenic plants in the five land use types

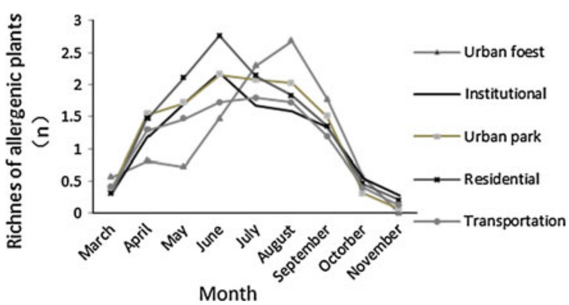


Fig. 6 Richness of flowering allergenic plants in the five land use types

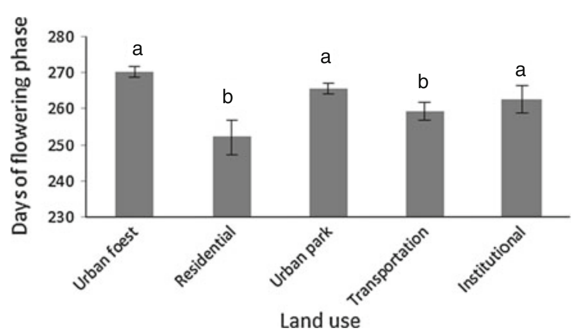
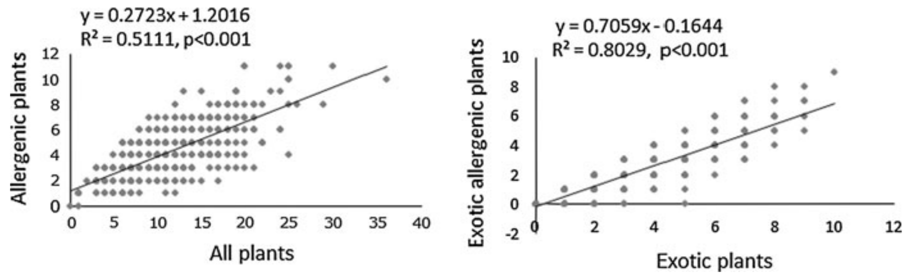


Fig. 7 Flowering phase of allergenic plants in the different land use types

management (Table 1). Distinguished with the natural ecosystem, urban plant biodiversity was also determined by socioeconomic factors except for environmental elements. The resident income, cultural background, and individual favor have affected the selection of plants in the settlement (Hope et al. 2003; Kinzig et al. 2005; Tratalos et al. 2007). Thus, we attributed more allergenic species and the higher exotic proportion to human selection at different land use types, particularly the greater number of exotic allergenic plants in the residential area are possibly related to residents' individual actions for plant selections. Finally, according to the regulation that the greater the number of species, the greater the chances of allergenic plants existing, we recommend that plants in the residential sites should be selected and arranged carefully to greatly decrease the possibility of allergenic pollen production.

A lesser number of plants with airborne pollens around the border of the urban road can be directly linked to the lower plant species resulting from

Fig. 8 Correlation between allergenic plants and plant diversity in the urban area



uniform planning and the higher frequency of management in urban transportation sites. Firstly, most plants selected for transport greening were few particular species that are particularly tolerant to air pollution, soil compaction, and human disturbance. These plants include *C. deodara, P. tomentosa*, and *J. chinensis*. These plants were the most widespread allergenic species at the road sides, and only a few other decorated plant species were present in the transport sites. The deterioration of environmental conditions, particularly automotive vehicle–induced pollution and pedestrian disturbance, may be a potential reason for the lower plant biodiversity and, consequently, fewer plants with airborne pollens. Fewer allergenic plants along urban roads seem to benefit pedestrians. Even so, we must realize that less allergenic plants do not mean absolute security. Several allergenic species that are widely distributed along road sides indicated a higher potential risk to human health.

Native allergenic plants did not significantly differ between different land use types. Thus, the difference between the distributions of allergenic plants was attributed mainly to the exotic plants. In particular, more exotic allergenic plants appeared at the urban residential area, and it should be addressed seriously in the future. Abundance and frequency are also crucial factors affecting urban settlement health except for the richness of allergenic plants. Future studies should combine airborne plant distribution, allergenic pollen grain, and clinical cases together to decrease the risk of plant pollen allergenicity as much as possible.

4.3 Allergenic plant community and their flowering phases

Despite that the richness of allergenic plants was distinctly different between the different types of functional zones, the plant community showed a similar pattern in our study area. We assumed that the similarity of plants with an airborne pollen community can be related with urban plant homogenization. Urbanization is one of the most homogenizing ecosystems, and the main reason is that urban habitats are constructed to meet the narrow demands of urban settlement as much as possible. Roads, residential housing, institutional sites, or commercial sites are indistinguishable inside an urban region, even throughout the world (Michael 2006). Although urban plant homogenization is correlated with similar habitats at a regional scale, the artificial selection of urban plants was the most primary reason for plant homogenization (Michael 2006; Olden et al. 2006). Therefore, the homogenization of allergenic plants can be easily speculated. The most common pollen allergenic plants in urban area are *S. viridis, P. annua, J. chinensis*, and so on. We should clarify the distribution patterns of these allergenic plants to avoid the production of airborne pollen grains greatly. Decreasing the application of these species as much as possible is also an efficient measure and requires the cooperation of urban groups (e.g., government, social organizations, individuals, and others).

Through the analysis of the allergenic plant community in the five different land use types, we still found some allergenic species that commonly grow in different sites despite the occurrence of homogenization. For instance, we also found *P. tomentosa* and *Populus* × *canadensis* in the road border at the suburban area and *C. deodara* and *Platanus* mostly at the urban sites. A large area of a *Populus* × *canadensis* forest around the urban road rings and suburban areas was also found. There is higher allergenic species diversity in the urban park and residential sites than the other sites. Nonetheless, the plant species that were found in the road site with longer ages and a higher tolerance are difficult to change immediately. This finding was the same for the most common native species *L. lucidum* that was better than other plants in defending the forest from the urban environment. However, the planting of *T. sinensis, S. oblata*, and *P. granatum* in urban residential areas should be avoided to benefit of persons with irritable physiques. The most widespread shrub in urban areas, *L. lucidum*, should be seriously addressed in decreasing its risk of causing pollen allergy through all the land use types.

The flowering phase of allergenic plants in Beijing begins in March and ends in November, lasting for about 9 months. More allergenic plants flower at the end of spring, through the whole summer, and early autumn. Despite the fact that the flowering phase of allergenic plants in urban sites was similar, we noticed that the peak of the flowering phase in the urban forest occurred in August, whereas plants in the other places flowered more in June or July. In our study, most of the urban forest we surveyed was located in a suburb. Apparently, the flowering of plants with airborne pollens in urban areas occurs earlier than that in suburban areas. We speculate that this phenomenon can be explained by the small-scale climate change caused by urbanization. Many studies have proven that plant flowering stages apparently changed because of climate change. Urban plants flower earlier than other plants in natural environments, and the flowering phase lasts longer in an urban environment. This phenomenon can be attributed to the increasing temperature with the expansion of the urban environment. Therefore, the earlier flowering phase of allergenic plants indicate that urban settlement, particularly people who suffer from pollen allergy, should be aware of this difference and avoid these kinds of plants and their flowering phases comprehensively. The appearance of more airborne plants in residential sites throughout the entire year should also be considered by combining it with the higher frequency of airborne-pollen plants after July in urban forests.

The abundance of allergenic plants and their flowering phase affect the health of urban settlement. The average flowering phase of allergenic plants in urban areas was approximately 260 days, and it was obviously different between the land use types. Plants located in residential and transportation sites last for approximately 250 days, which is distinctly shorter than plants in other sites. This finding is in contrast to our forecast that the flowering phase is shorter in urban forests that are mostly located in the suburban area than other functional zones because of the increasing temperature in the urban center. We also hypothesized that fewer species in the urban forest have a shorter flowering phase. There are two possible reasons for this result. Our study area is located in a typical urban area with a smaller space scale. Even the urban forest in the suburban area is also branded by urbanization. Therefore, there was no difference in the plant flowering phase between the urban forest and other land use areas. The lower flowering phase in residential and transportation sites can be attributed to several common ornamental plants that flower in a short time mostly in March and April, such as *S. oblata, Prunus persica* versus *rubra-plena, T. sinensis, P. tomentosa, S. matsudana,* and *A. altissima.* However, concerning the allergenic plants, the fact that residential sites have a shorter flowering phase is beneficial for the residents. Besides, the flowering phase showed no obvious difference between the park, urban forest, and institutional areas. Urban parks are those places created mainly for recreation and entertainment, which were usually planned with a larger area and plant diversity. The longer flowering phase of allergenic plants in urban park should be given special attention for the benefit of people who suffer from pollen allergies.

Urbanization is a rapidly growing cause of many environmental problems. We speculate that the risk brought about by allergenic plants can be strengthened by urbanization. Firstly, as the increasing alien plants bring more potential allergenic plants and produce majority of the allergenic pollens, even more alien allergenic plants were introduced. Nowadays, plants with airborne pollens are distributed in and around the urban area even though the flowering period of allergenic plants was different in various land use types and more similar plant species occurred in the urban scope. The sensitization of allergic respiratory diseases may be triggered by urban air pollutants. Pollen grains from heavy transportation were covered with more airborne micro-particulates (D’Amato et al. 2010; Emberlin 1998). Finally, the longer plant flowering phase that was caused by a warmer climate extended the period of pollination, and the peak season of plant pollination must be seriously taken into consideration. We suggest that alien allergenic plants should not be selected for urban greening, particularly in residential sites, to minimize the risk of developing diseases caused by allergenic pollens. Otherwise, if some essential plants cannot be avoided, they should be planted in places where there is adequate ventilation to increase the dispersion of allergenic pollens. Individuals who are sensitive to pollens should stay away from places with a higher richness of allergenic plants. However, future studies of allergenic plants in urban areas should combine the products of airborne pollens, mechanism of distribution, and spread of pollen grains, and the most important aspect is to integrate clinical experiments.

5 Conclusions

Understanding the distribution of allergenic plants in urban areas is necessary for the health of urban residents. Both exotic and native allergenic plants in urban areas should be carefully studied. Our study shows that the homogenization of plant communities due to urbanization affects the distribution of allergenic plants. The significant correlation between the species richness of allergenic plants and the overall urban plant richness, as well as the close relationship between the alien allergenic plant richness and the total alien plant richness, indicates that the urbanization-induced increase in plant diversity tends to add more exotic plants that pose higher risks to human health. Although urban vegetation offers various ecological functions and services, caution is needed in the introduction of urban plants (in particular, allergenic plants should be avoided). Urban residents with allergies should be aware of the hot spots of allergenic plants and the flowering phenology to minimize their health risks.

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Appendix

See Table 2.

Table 2 The most common allergenic plants in Beijing built-up area

Number	Species	Source	Appearance times of species in different land use types in 369 samples (n)				
			Urban forest	Institutional	Urban park	Residential	Transportation
S1	*Setaria viridis*	Native	31	35	36	48	68
S2	*Poa annua*	Native	2	33	24	42	49
S3	*Juniperus chinensis*	Exotic	7	14	16	36	36
S4	*Chenopodium album*	Native	17	13	11	19	33
S5	*Pinus tabuliformis*	Native	4	11	12	17	40
S6	*Populus tomentosa*	Native	22	4	7	7	24
S7	*Ligustrum lucidum*	Native	1	9	16	16	17
S8	*Cedrus deodara*	Exotic	0	17	4	19	18
S9	*Salix matsudana*	Native	8	5	10	16	18
S10	*Amaranthus retroflexus*	Exotic	3	4	7	10	25
S11	*Plantago depressa*	Native	0	8	8	16	12
S12	*Humulus scandens*	Native	18	2	2	3	12
S13	*Toona sinensis*	Exotic	0	2	1	24	2
S14	*Koelreuteria paniculata*	Native	0	2	8	10	8
S15	*Pinus bungeana*	Exotic	0	4	10	5	8
S16	*Syringa oblata*	Native	0	9	6	6	5
S17	*Platanus occidentalis*	Exotic	0	4	4	7	11
S18	*Robinia pseudoacacia*	Native	6	1	4	6	8
S19	*Artemisia argyi*	Native	7	2	6	3	6
S20	*Ailanthus altissima*	Native	2	3	2	6	7
S21	*Fraxinus chinensis*	Native	1	1	4	4	9
S22	*Erigeron acer*	Exotic	4	5	2	4	4
S23	*Lonicera maackii*	Native	0	6	4	6	3

Table 2 continued

Number	Species	Source	Appearance times of species in different land use types in 369 samples (*n*)				
			Urban forest	Institutional	Urban park	Residential	Transportation
S24	*Platycladus orientalis*	Native	3	1	6	3	5
S25	*Punica granatum*	Exotic	0	2	4	9	2
S26	*Ulmus pumila*	Native	1	1	3	5	7
S27	*Sorbaria sorbifolia*	Native	0	2	0	7	8
S28	*Artemisia annua*	Native	8	2	1	2	3
S29	*Ligustrum quihoui*	Native	0	5	0	6	5
S30	*Populus* × *canadensis*	Exotic	8	1	0	1	5
S31	*Buchloe dactyloides*	Exotic	0	0	3	5	7
S32	*Kochia scoparia*	Native	3	2	2	3	4
S33	*Prunus persica* versus *rubra-plena*	Native	0	2	1	4	6
S34	*Acer truncatum Bunge*	Native	2	2	2	3	3
S35	*Broussonetia papyrifera*	Native	3	0	2	4	3
S36	*Amaranthus albus*	Exotic	1	0	0	4	6
S37	*Echinochloa crusgallii*	Native	1	1	0	3	6
S38	*Leonurus japonicus*	Native	5	1	0	1	3
S39	*Salix babylonica*	Native	0	1	1	1	6
S40	*Juniperus chinensis cv. kaizuka*	Exotic	0	2	0	1	4
S41	*Picea wilsonii*	Native	0	2	0	5	0
S42	*Lonicera japonica*	Native	0	0	2	3	2
S43	*Lolium perenne*	Exotic	0	1	0	4	1
S44	*Pinus armandii*	Native	0	1	3	0	2
S45	*Parthenocissus tricuspidata*	Native	0	1	0	3	2
S46	*Prunus davidiana*	Native	1	1	0	1	3
S47	*Pyrus ussuriensis*	Native	1	1	1	1	1
S48	*Xanthium sibiricum*	Native	2	0	0	0	2
S49	*Albizia julibrissin*	Exotic	0	1	2	1	0
S50	*Rhus typhina*	Exotic	0	0	0	0	4

The order of species frequency distribution is as follows: S1 > S2 > S3… > S49 > S50

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