Biodivers Conserv (2011) 20:2483–2509
DOI 10.1007/s10531-011-9999-x

ORIGINAL PAPER

# Biological invasions in rapidly urbanizing areas: a case study of Beijing, China

**Hua-Feng Wang · Jordi López-Pujol · Laura A. Meyerson · Jiang-Xiao Qiu · Xiao-Ke Wang · Zhi-Yun Ouyang**

Received: 6 August 2010 / Accepted: 24 January 2011 / Published online: 8 February 2011


**Abstract** Urbanization is widely recognized as a major factor promoting biological invasions worldwide. In this article, we provide insights into the patterns of biological invasions in Beijing, one of the largest and quickly urbanizing cities of the world, by developing a comprehensive list of naturalized and invasive flora and their associate traits (e.g., distribution, life form, habitat, or geographic origin). One hundred and twelve naturalized (including 48 invasive) plants have been identified within the Beijing Municipality. Most of the naturalized and invasive plants belong to four families (Asteraceae, Poaceae, Amaranthaceae, and Euphorbiaceae) and are annual herbs that preferentially grow in disturbed sites. North and South America are the main contributors to the naturalized and invasive flora of Beijing. As expected, those Beijing districts that have recently experienced the highest human population growth, urban expansion, and the largest economic growth are also those with the highest number of naturalized and invasive species. Urban expansion is predicted to continue in the near term making additional invasions likely that will significantly increase the proportion of introduced species in Beijing's flora. An integrated management strategy for the whole municipality is urgently needed that includes comprehensive scientific research that documents the extent of invasions and their effects on Beijing's economy and environment.

**Keywords** Growth · Urbanization · Invasive species · Naturalized species · Horticulture · Management

Hua-Feng Wang and Jordi López-Pujol are equally contributed to this work.

H.-F. Wang (✉) · J.-X. Qiu · X.-K. Wang · Z.-Y. Ouyang
Beijing Urban Ecosystem Research Station, State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
e-mail: hfwang@rcees.ac.cn

J. López-Pujol
Botanic Institute of Barcelona (CSIC-ICUB), Passeig del Migdia s/n, 08038 Barcelona, Spain

L. A. Meyerson
University of Rhode Island, Kingston, RI 02881, USA

## Introduction

China has a very long history of introducing alien species but its historical isolation precluded large-scale introductions. Such introductions were relatively uncommon until the 1980s when the country adopted market-oriented reforms and opened to international trade. Since then, the number of reported invasive alien species has significantly increased (Lin et al. 2007; Weber and Li 2008). While these data reflect greater efforts to detect invasions (but see Lin et al. 2007), increasing invasions should also be attributed to the unprecedented economic development of China (Ding et al. 2008). In addition, the domestic boom of industrial and transportation infrastructures, coupled with unparalleled rates of urbanization and rampant ecological degradation, have fostered alien species establishment and spread throughout China (Lin et al. 2007; Ding et al., 2008; Weber et al. 2008).

Urbanization plays a significant role in promoting biological invasions in large part because cities contain heterogeneous, highly disturbed habitats that provide ecological niches for alien species (Mack et al. 2000; Kowarik 2008; Ricotta et al. 2009). Moreover, urban areas often act as immigration gateways where alien species can enter through airports, harbors, or train stations, markets, gardens and urban parks, and can become propagule sources for spread to natural areas (Pyšek 1998; Wittig 2004; von der Lippe and Kowarik 2008). Within this context, biological invasions may pose an even greater future global threat than today. The world's urban population is rapidly expanding: whereas only 10% of the global population lived in urban areas in 1900, the percentage now exceeds 50% and is expected to increase even more in the next 50 years (Grimm et al. 2008). Most of this predicted demographic growth will take place in cities of the developing world, and nearly all of the world's megacities (those with >10 million) are currently located in the developing world—such as China and India (Grimm et al. 2008).

Urbanization has already been identified as a main factor promoting biological invasions in China (Lin et al. 2007) where almost half of the world's new building construction is currently taking place (Xinhua 2007). Since the 1970s, China's urban population has increased by more than 400 million (Yusuf and Saich 2008), and in the future up to 300 million more people are expected to migrate from rural areas to cities (Grimm et al. 2008). Beijing, the capital of China, has one of the fastest urbanization rates in the world (expanding at more than 35 $km^2$ per year since the late 1970s; Mu et al. 2007; Fig. 1), fueled by the almost 100-fold increase of the city gross domestic product (GDP) (Beijing Municipal Bureau of Statistics & NBS Survey Office in Beijing (BMBS) 2009). As a consequence, it has undergone a radical transformation from an essentially rural city in the mid-twentieth century to one of the largest industrial, commercial, and transport hubs of Asia (Haw 2007). Accompanying this rapid economic development has been the introduction and establishment of invasive alien species, sparking serious concern in the city administration about the environmental degradation and economic losses associated with biological invasions (Li 2004; Ding et al. 2008).

A first step in identifying the patterns of biological invasions in a given territory (whether a large country or a city) is to develop a comprehensive invasive flora and fauna database that includes information such as biological characteristics, geographical distribution, and mode and rate of introduction. This information not only allows comparisons of invasive floras or faunas in different regions, but also provides basic knowledge to further identify the most aggressive invaders, and facilitates the development of appropriate strategies to control and/or eradicate weeds, pests, and other harmful species (Pyšek 1998; Rejmánek 2000; Pyšek et al. 2004; Wu et al. 2004, 2010; Guézou et al. 2007; Jiménez et al. 2008; Weber et al. 2008). Fortunately, relatively accurate databases for

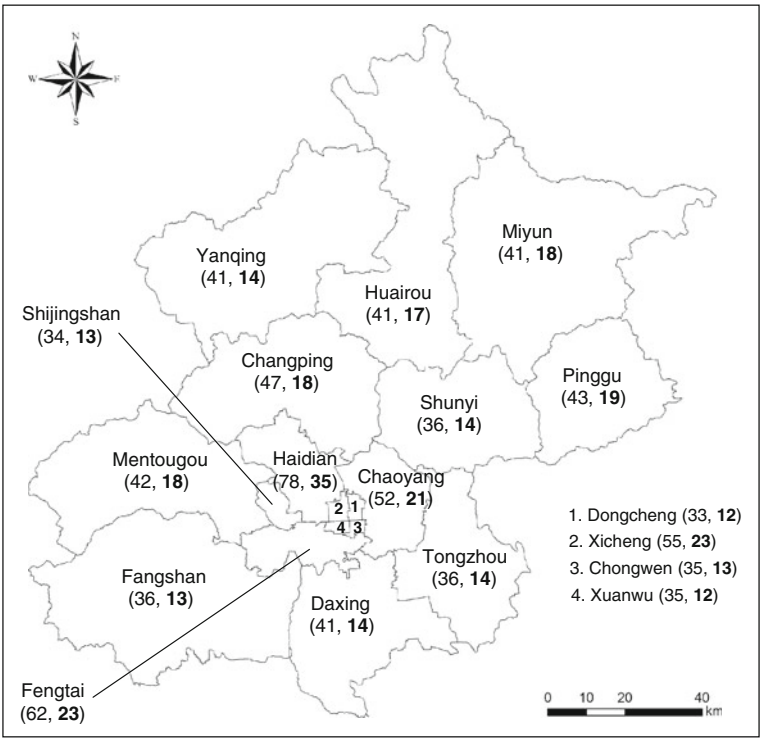


**Fig. 1** Distribution of naturalized and invasive plant species in Beijing Municipality by administrative unit. The first number is the total number of naturalized species; the second value (*bold*) is the total number of invasive species. According to BMBS (2009), Urban core area includes: Dongcheng, Xicheng, Chongwen, and Xuanwu; Urban expansion area includes Chaoyang, Fengtai, Shijingshan, and Haidian; Suburban area includes Fangshan, Tongzhou, Shunyi, Changping, and Daxing; Exurban area includes Mentougou, Huairou, Pinggu, Miyun, and Yanqing

naturalized and invasive species in China are becoming available at the national, provincial, and at smaller scales (e.g., Li and Xie 2002; Ng and Corlett 2002; Wu et al. 2004, 2010; Xu et al. 2006; Qin et al. 2008; Weber et al. 2008). However, in Beijing, invasive species are rarely studied and checklists are preliminary and incomplete (Liu et al. 2002; Yang et al. 2009), creating a major data gap for one of the world's fastest growing major cities. To fill this gap, we developed a comprehensive catalog of the naturalized flora of the Beijing Municipality to help us elucidate invasion patterns. We take Beijing as a case study to illustrate how biological invasions are quickly progressing in the rapidly forming megacites of developing countries.

## Materials and methods

### Study area: Beijing Municipality

Beijing Municipality is a province-level administrative unit and China's current capital. With a total area of 16,410 km$^2$, it is located in the northern tip of the North China Plain with a typical warm temperate semi-humid continental monsoon climate. Mountainous

lands account for 61.2% of the municipality (Wang et al. 2007), and are mainly distributed in the western and northern regions (Xi, Jundu and Yan Mountains). Their mean elevation is approximately 1,000 m, with several peaks surpassing 2,000 m. In contrast, the central and southeastern parts are markedly flat, with an altitude of less than 100 m. There are more than 200 large and small rivers, in addition to numerous reservoirs and lakes.

Beijing has over 3,000 years of history of urban construction, and more than 800 years of history as a capital. The population has grown rapidly during the most recent decades, increasing nearly fourfold since the 1950s (Tang and Kunzmann 2008), making it one of the most populated cities of the world today. As a consequence, its urban areas have significantly expanded, especially since the 1970s. Whereas in 1975 the built-up area of Beijing was <200 $km^2$, in 2005 this surpassed 1,200 $km^2$, i.e., a sixfold increase (Mu et al. 2007). This rapid urbanization is mostly attributable to the concentric expansion of the capital at the expense of the croplands located in the plain area of the municipality (Wu et al. 2006; Tang and Kunzmann 2008).

Based on population density and urbanization level, the 18 administrative divisions of Beijing (16 districts and 2 counties) can be classified into four functional areas: urban core, urban function expansion, suburban, and exurban area (Fig. 1). The urban core area includes the districts of Chongwen, Dongcheng, Xicheng, and Xuanwu, and its urbanization level is almost 100% with a population density over 22,500 people/$km^2$. The urban function expansion area also includes four districts (Chaoyang, Fengtai, Haidian, and Shijingshan) with an urbanization level ranging from 52 to 67% and a population density of about 6,500 people/$km^2$. The suburban area has an urbanization level of 17–33% with a population density of ca. 750 people/$km^2$, and includes five additional districts (Changping, Daxing, Fangshan, Shunyi, and Tongzhou). Finally, exurban area includes three districts (Huairou, Mentougou, and Pinggu) and two counties (Miyun and Yanqing) and has much lower proportion of urban land and population density (6–15% and about 200 people/$km^2$, respectively; BMBS 2008, 2009).

## Catalog of naturalized and invasive species: definitions and methodology

In this study, we defined naturalized species as alien species that reproduce consistently and sustain self-replacing populations over many life cycles without direct intervention by people (or in spite of human intervention) (sensu Richardson et al. 2000; Pyšek et al. 2004). Those alien species that do not form self-replacing populations (i.e., casual alien species as well as subspontaneous and adventive; Pyšek et al. 2004) were not considered as naturalized and thus not included. We define the term "invasive" as those species that cause apparent damage or pose potential threats to species, ecosystems or to the economy (International Union for the Conservation of Nature (IUCN) 1999; McNeely et al. 2001). In this sense, invasives should be considered as a subset of naturalized species capable of spreading considerably and with harmful effects, a definition which could also be equated with the terms "transformers" and "weeds" as defined by Richardson et al. (2000) and Pyšek et al. (2004).

In order to develop a comprehensive list of the naturalized and invasive flora of Beijing Municipality, we first reviewed all the relevant literature concerning naturalized and invasive species, both at national level and specifically for Beijing area (e.g., Li and Xie 2002; Liu et al. 2002; Meng et al. 2004; Xu and Qiang 2004; Liu et al. 2005; Wan et al. 2005; Liu et al. 2006; Lin et al. 2007; Weber et al. 2008; Fang and Wan 2009; Yang et al. 2009; Feng and Zhu 2010; Wu et al. 2010; Zhao et al. 2010). Extensive fieldwork was then carried out to verify the presence of these species in Beijing, and to identify previously undetected species. In

addition, we visited some species' populations several times from July to October in 2004 and 2007 to ascertain whether these species could survive at the same location for more than one life cycle. If they did, then these species were considered as likely naturalized. Our fieldwork, combined with expert consultation, also allowed us to designate some of the naturalized species as "tentatively" or "potentially" invasive, i.e., those for which we obtained evidence of causing large damage to local habitats or ecosystems in Beijing. Nevertheless, the magnitude and extent of these impacts (either environmental or economic) have been not assessed in this study, which would merit further research.

### Characterization of species and analyses

To gain insights into the biological invasion patterns in Beijing, we complemented the checklist of naturalized and invasive flora occurring in the municipality with information on the following traits for each species: (i) taxonomic position (to which family the species belongs); (ii) distribution (i.e., presence of the species in the different districts and counties of Beijing); (iii) habit (annual, biennial, or perennial); (iv) life form (herb, shrub, or tree); (v) habitat (ruderal habitat and urban areas, agricultural areas, grasslands and shrub lands, forests, wetlands or water bodies, and other types of ecosystems); (vi) native range; (vii) invasive in China or elsewhere; and (viii) the introduction pathway.

Information about habitat types refers to those in which a given plant species usually occur (gathered from Flora of China and other general floras); listing the specific habitats in which each species grows in Beijing was beyond the scope of this paper. Mode of introduction refers to how the species entered Beijing (Liu et al. 2002 and Yang et al. 2009). The native ranges were mainly obtained from the Germplasm Resources Information Network (GRIN) of the United States Department of Agriculture (www.ars-grin.gov) or from Wiersema and León (1999), although other relevant sources were also checked (e.g., Flora of China). Authoritative lists or compendiums such as the Global Invasive Species Database (www.issg.org/database) and the Global Compendium of Weeds (www.hear.org/gcw/) were used to determine whether the species recorded in this study are invasive elsewhere.

To unravel the distribution patterns of both the naturalized and invasive flora within Beijing Municipality, we first converted the distributional data of all species into a presence/absence matrix for each of the 18 administrative units (separately for naturalized and for invasive flora) and then created distribution maps based on the total number of species per administrative region using ArcGIS 9.3. The relationships between numbers of naturalized and invasive species and several urbanization and socio-economic factors (population density, population growth, proportion of urban land area, loss of plowland area—taken as an indirect measure of the urbanization progress——green areas, present GDP, and GDP growth during the period 2001–2009) were tested with linear correlations (Pearson's coefficients); samples were logarithmically transformed when needed (i.e., if not normally distributed).

## Results

### Amount, taxonomy, distribution of naturalized and invasive species in Beijing Municipality, and their relationships with socio-economic factors

One hundred and twelve naturalized plant taxa (species, subspecies or varieties) were identified in Beijing Municipality (Appendix 1, Table 4). All naturalized taxa were

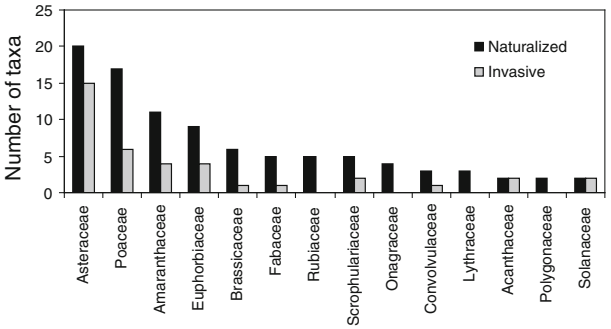


**Fig. 2** Taxonomic structure of the naturalized and invasive flora of Beijing Municipality. Only the families with two or more representatives of naturalized species are shown

angiosperms (83.9% were dicotyledons and 16.1% monocotyledons), belonging to 81 genera and 32 families. The family that contributed the most to the naturalized flora of Beijing was Asteraceae (17.8% of the total), followed by Poaceae, Amaranthaceae, and Euphorbiaceae (Fig. 2). These four families accounted for half (50.9%) of all naturalized species in Beijing. In contrast, 18 families (56.2% of the total number of families) had just one representative. The genera with the highest number of naturalized species were *Amaranthus* (nine taxa) and *Euphorbia* (eight taxa). Of the 112 naturalized plant taxa, 48 were identified as tentatively invasive in Beijing (Appendix 1, Table 4), mostly dicotyledons (85.4%), and represented by 39 genera and 20 families. Asteraceae alone represented almost one-third (31.2%) of the invasive taxa (Fig. 2). The above-mentioned four families accounted for 60.4% of all invasive plants, whereas 13 families contributed with just one taxon.

In terms of the distribution patterns, 35 taxa of the naturalized plants were widely distributed in Beijing (that is, present in all the districts and counties of Beijing), whereas 36 were restricted to a single district or county. Haidian district was the administrative unit of Beijing with the highest number of naturalized species (Fig. 1, Table 1). By functional areas, 90 species occurred in the urban expansion area, followed by exurban (60), urban (59), and suburban (55) (Table 1). The naturalized floras of the last three functional areas were essentially the same (sharing about 60% of the plant species). Plant species exclusive to functional areas were very few (nine for the urban core and four for both suburban and exurban), with the exception of the urban expansion area, which had 28 exclusive naturalized plants.

Of the invasive plants, 13 were found everywhere, and 15 were restricted to a single administrative unit. As occurred for naturalized species, Haidian had the highest invasive species richness in all of Beijing (Fig. 1, Table 1). The richness of invasive species by functional areas followed the same order as that found for naturalized species: urban expansion (37 species) > exurban (28) > urban (24) > suburban (21) (Table 1). In fact, species richness per administrative unit of naturalized and invasive plant species were significantly correlated ($r = 0.960$, $p < 0.000$).

Regarding the relationships between the numbers of naturalized and invasive species in each district and the collected urbanization and socio-economic data for each district ($N = 18$; Table 1), for most cases, we found positive correlations, but these were not statistically significant except for present GDP and GDP growth ($p < 0.05$); for the population growth, correlation was marginally significant ($p = 0.1$) (Table 2).

**Table 1** Demographic and socio-economic data and number of naturalized and invasive species by Beijing functional regions and districts

| District or county | Area ($km^2$) | Population density (people/$km^2$)[a] | Population density growth rate (1990–2008) (%)[a] | Proportion of urban land (%)[b] | Loss of plowland (1990–2008) (%) | Green areas (%; ha)[c] | GDP (gross domestic product) (2009) (billion Yuan) | GDP growth (2001–2009) (billion Yuan) | Naturalized species | Invasive species |
|---|---|---|---|---|---|---|---|---|---|---|
| Dongcheng | 25.34 | 21,823 | −11.10 | 100 | 0 | 44.40; 1,125 | 82.00 | 56.10 | 33 | 12 |
| Xicheng | 31.62 | 21,284 | −15.52 | 100 | 0 | 25.68; 812 | 151.00 | 123.10 | 55 | 23 |
| Chongwen | 16.52 | 17,978 | −31.57 | 100 | 0 | 32.00; 529 | 15.60 | 8.89 | 35 | 13 |
| Xuanwu | 18.91 | 29,614 | −12.26 | 100 | 0 | 43.00; 813 | 30.52 | 14.22 | 35 | 12 |
| **Urban core area** | **92.39** | **22,546** | **−17.61** | **100** | **0** | **35.49; 3,279** | **279.12** | **202.31** | **59** | **24** |
| Chaoyang | 455.08 | 6,775 | 120.22 | 67.12 | 19.76 | 43.00; 19,568 | 208.92 | 158.82 | 52 | 21 |
| Fengtai | 305.80 | 5,733 | 120.98 | 65.30 | 11.98 | 42.70; 13,058 | 54.10 | 37.13 | 62 | 23 |
| Shijingshan | 84.32 | 6,997 | 85.35 | 58.56 | 2.50 | 44.46; 3,749 | 21.00 | 9.92 | 34 | 13 |
| Haidian | 430.73 | 6,802 | 100.83 | 52.50 | 14.04 | 44.65; 19,232 | 230.00 | 169.70 | 78 | 35 |
| **Urban expansion area** | **1,275.93** | **6,549** | **106.85** | **61.18** | **14.82** | **43.75; 55,607** | **514.02** | **375.57** | **90** | **37** |
| Fangshan | 1989.54 | 455 | 108.23 | 17.44 | 5.79 | 43.03; 85,610 | 24.53 | 10.83 | 36 | 13 |
| Tongzhou | 906.28 | 1,146 | 81.84 | 32.98 | 17.62 | 39.10; 35,435 | 23.40 | 15.70 | 36 | 14 |
| Shunyi | 1019.89 | 711 | 27.08 | 31.75 | 19.54 | 43.00; 43,855 | 53.50 | 40.20 | 36 | 14 |
| Changping | 1343.54 | 701 | 131.03 | 26.85 | 9.59 | 49.00; 65,833 | 34.00 | 22.80 | 47 | 18 |
| Daxing | 1036.32 | 1,059 | 104.68 | 29.46 | 14.17 | 40.67; 42,147 | 23.59 | 14.80 | 41 | 14 |
| **Suburban area** | **6,295.57** | **748** | **71.09** | **25.98** | **11.91** | **43.93; 272,880** | **159.02** | **104.33** | **55** | **21** |
| Mentougou | 1450.70 | 190 | -6.42 | 6.49 | 0.70 | 40.02; 58,057 | 7.05 | 2.99 | 42 | 18 |
| Huairou | 2122.62 | 169 | 65.33 | 6.13 | 2.67 | 56.00; 118,867 | 14.33 | 9.11 | 41 | 17 |
| Pinggu | 950.13 | 448 | 24.70 | 13.08 | 7.11 | 45.00; 42,756 | 8.80 | 4.56 | 43 | 19 |
| Miyun | 2229.45 | 205 | 12.26 | 14.62 | 0.25 | 41.40; 92,299 | 11.50 | 5.84 | 41 | 18 |

**Table 1** continued

| District or county | Area ($km^2$) | Population density (people/$km^2$)[a] | Population density growth rate (1990–2008) (%)[a] | Proportion of urban land (%)[b] | Loss of plowland (1990–2008) (%) | Green areas (%; ha)[c] | GDP (gross domestic product) (2009) (billion Yuan) | GDP growth (2001–2009) (billion Yuan) | Naturalized species | Invasive species |
|---|---|---|---|---|---|---|---|---|---|---|
| Yanqing | 1993.75 | 144 | 3.91 | 7.14 | 1.40 | 57.76; 115,159 | 6.16 | 3.00 | 41 | 14 |
| **Exurban area** | **8,746.65** | **206** | **19.96** | **9.34** | **1.92** | **48.86; 427,138** | **47.84** | **25.50** | **60** | **28** |
| **Beijing Municipality** | **16,410.54** | **1,033** | **50.53** | **20.26** | **6.74** | **46.24; 758,904** | **1000.00** | **707.71** | **112** | **48** |

[a] Data from Jing et al. (2004) and BMBS (2009)

[b] Data from BMBS (2008). "Urban land" is defined as a continuous area covered by residential, industrial or commercial constructions and facilities

[c] Green areas do not include farmlands

**Table 2** Pearson correlation coefficients between the no. of naturalized or invasive species of each district and several demographic and socio-economic parameters

| | Population density (people/km$^2$) | Population density growth rate (1990–2008) (%) | Proportion of urban land (%) | Loss of plowland (1990–2008) (%) | Green areas (%) | GDP (gross domestic product) (Billion Yuan) | GDP growth (2001–2009) (Billion Yuan) |
|---|---|---|---|---|---|---|---|
| No. of naturalized species | $r = 0.118$, $p = 0.641$ | $r = 0.397$, $p = 0.102$ | $r = 0.099$, $p = 0.695$ | $r = 0.281$, $p = 0.331$ | $r = -0.081$, $p = 0.750$ | **$r = 0.542$, $p = 0.020$** | **$r = 0.551$, $p = 0.018$** |
| No. of invasive species | $r = 0.032$, $p = 0.900$ | $r = 0.316$, $p = 0.202$ | $r = 0.006$, $p = 0.981$ | $r = 0.158$, $p = 0.589$ | $r = -0.115$, $p = 0.649$ | **$r = 0.480$, $p = 0.044$** | **$r = 0.492$, $p = 0.038$** |

Statistically significant cases are in bold

## Ecological characteristics

Most of the naturalized plant species recorded in Beijing Municipality were short-lived (annual or biennial) herbs (77.7%; Fig. 3). Only two shrubs (*Amorpha fruticosa* and *Rhus typhina*) and one tree (*Robinia pseudoacacia*) were present among the naturalized. For the invasive plants, a similar composition was found (Fig. 3).

The naturalized flora of Beijing was mainly composed of species that usually occur in disturbed sites: nearly 85% of the naturalized plant species can grow in ruderal and urban habitats, whereas 78.6% are also usually found in agricultural areas. A similar pattern was also found when considering the invasive species alone (Fig. 4).

## Geographic origins and mode or pathway of introduction

The Americas were the main source of the naturalized flora of Beijing (47.3%) (Fig. 5). Almost half of them (23 species) were native to North America sensu stricto (Canada, the United States, and Mexico), four to North America sensu lato (that is, from Canada to

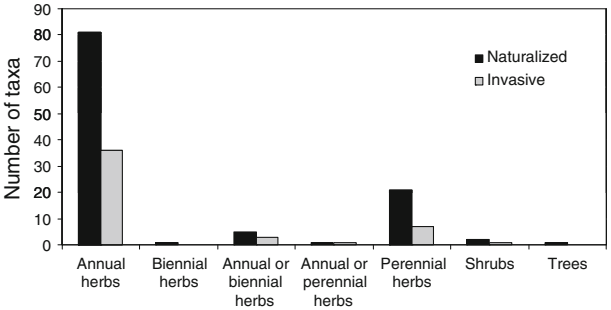


**Fig. 3** Habit and life form of the naturalized and invasive flora of Beijing Municipality

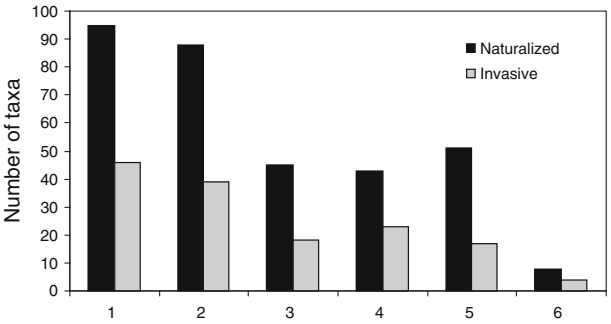


**Fig. 4** Distribution of the naturalized and invasive flora of Beijing by habitat type. *1* ruderal habitats (i.e., roadsides, disturbed places, etc.), urban areas (i.e., urban parks and gardens); *2* agricultural areas (i.e., cultivated fields, orchards, etc.); *3* grasslands and shrublands; *4* forests or forest margins; *5* wetlands (i.e., marshes, riverbanks, streamsides, lakeshores, etc.) or water bodies (rivers, lakes, ponds, reservoirs, irrigation canals); and *6* other (i.e., rocky outcrops, sandy places, etc.). Plant species may occur in more than one habitat type. Assignment of species to habitats relies on information in the general literature and does not reflect the habitat occupation of species in Beijing

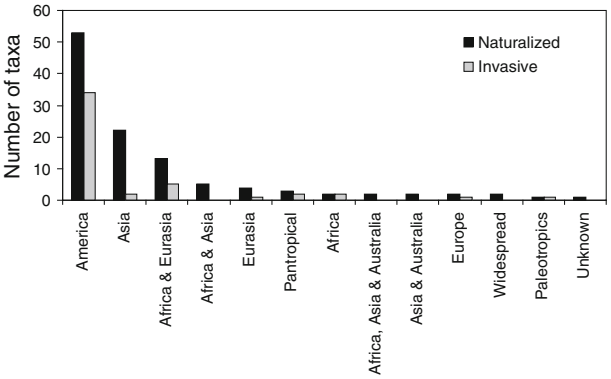


**Fig. 5** Geographic origin of the naturalized and invasive flora of Beijing Municipality. A species has been classified as widespread if it is native to more than three continents. Each species is allocated to one category only

Panama), six species to South America, 16 to the neotropics, and four were widespread throughout America. Up to 15 plant species included China within their native ranges (Appendix 1, Table 4). For the invasive species, American species were even more predominant with 70.8% (Fig. 5). Similar to the naturalized flora, North America s. s. also accounted for nearly half of the invasive species of American origin. Interestingly, none of the invasive plant species recorded in Beijing Municipality had China as part of its native range.

Many naturalized plant species in Beijing are accidental introductions (40.2%). Only a small fraction (20.5%) is known to have been introduced deliberately as useful plants whereas no information is available for the remaining 44 species on how and/or why they were introduced (Appendix 1, Table 4). Many accidental introductions (24 species) have occurred through the escape of garden and landscape plants, but other accidental introductions include exchange or importation of crop seeds (eight species), importation of foods (six species) and livestock products (two species), and transportation of luggage (five species). Of the intentional introductions, most plants are used as ornamental (11 species), followed by medicinal and forage plants (four species each one). Of the invasive plants in Beijing, 37.5% represent accidental introductions (mainly through importation of garden and landscape plants), nearly 15% are deliberate introductions (mostly ornamental), and the rest (47.9%) are unknown introductions.

## Discussion

### Effects of urbanization in numbers and distribution of the naturalized and invasive flora of Beijing Municipality

The study of the alien biota, especially naturalized and invasive species, is a relatively new research field in China (Weber et al. 2008; Wu et al. 2010), and this study is the first comprehensive catalog of the naturalized flora of the Beijing Municipality. We identified 112 plant species as naturalized, which represents a $\sim$23% increase from the previous report of Liu et al. (2002) for the capital of China and its surrounding areas (91 species). This suggests that biological invasions have increased over the last decade. Economic development in China has fostered biological invasions (e.g., Ding et al. 2008) and particular sectors such as

**Table 3** Naturalized and invasive floras of the other Chinese and Asian large cities studied

| City | Area ($km^2$) | Population (in million) | Total flora | No. of naturalized species | No. of invasive species | References |
|---|---|---|---|---|---|---|
| *China* | | | | | | |
| Beijing | 16,410[a]; 1,368[b] | 16.95 | 2,276[a]; 1,235[b] | 112[a]; 100[b] | 48[a]; 40[b] | This study; Wang et al. (2007) |
| Zhongshan | 1,800 | 1.42 | 610 | – | 81 | Jiang et al. (2008) |
| Liuzhou | 658[a]; 110[b] | 1.89 | 853 | – | 51 | Qiu et al. (2007); Shi et al. (2009) |
| Hong Kong | 1,074 | 11.04 | 2,130 | 238 | 180 | Ng and Corlett (2002) |
| Shanghai | 7,037 | 18.88 | 850 | 350 | 84 | Xu (1999) |
| *Asia* | | | | | | |
| Singapore | 636 | 4.99 | 4,192 | 223 | – | Chong et al. (2009) |

[a] All the municipality

[b] Only urban areas (urban core and urban expansion areas)

residential construction, GDP, industry, increased freight, passenger traffic, and length of transportation routes are correlated with the number of invasives (Lin et al. 2007; Wu et al. 2010). In Beijing, the present and recent GDP and population growths are positively correlated with the number of naturalized and invasive plant taxa. Other parameters, such as loss of plowland or population density, demonstrate a positive though not significant relationship with the number of naturalized and invasive plants (Table 2).

The number of naturalized and invasive plant species in Beijing remains modest compared to other large Chinese and Asian cities such as Shanghai, Hong Kong, or Singapore (Table 3). This is not surprising because all of these cities harbor the busiest seaports in the world (Maatsch et al. 2009) and have had large industrial and commercial centers open to international trade since at least the nineteenth century. Beijing, in contrast, was a relatively isolated administrative and cultural center where large-scale trade, industry, and transport facilities remained largely undeveloped until the 1960s. For example, in 1957, Beijing's industrial production was less than one-sixth of Shanghai's and about half that of the neighboring Tianjin; in the early 1950s, the public transport in Beijing was virtually absent, just a few streets were paved, and only a very small percentage of the population had running water and electricity (Haw 2007).

In general, the urban expansion districts exhibit higher numbers of naturalized and invasive plants (Table 1, Fig. 1), and this appears to be due to land-use and demographic factors. The urban expansion districts constitute the functional area of Beijing with the highest population growth in recent decades, and these currently have the highest GDP and the largest GDP growth (Table 1). Similarly, these districts have undergone the greatest urban expansion (Wu et al. 2006; Tang and Kunzmann 2008) to cope with the huge demand for new housing (the inner districts were already completely urbanized since the 1960s). These districts also harbor two-thirds of the factories in the municipality (Tian et al. 2010) and some of the main transport infrastructures (e.g., three of the orbital expressways and the international airport) reflected in the loss of agricultural land over the last two decades (Table 1).

Managed green spaces in urban districts (i.e., street trees, lawns, urban and residential gardens, and parks) may also account for the growing number of naturalized plants in

Beijing. These green areas substantially increased in large part to prepare the city to host the 2008 Olympic Games. During the period 2001–2007, over 700 spaces were built downtown, an increase of nearly 9,000 Ha (United Nations Environment Programme (UNEP) 2009). Today, green space totals nearly 60 thousand Ha (Table 1) and this will increase in the future (Yan 2009). This trend is especially significant as urban gardens and parks often contain many alien species planted as ornamentals which may escape and can become sources for invasions (Kowarik 2005; Botham et al. 2008). This is the case for Europe where the majority of plant invaders were introduced as ornamentals (Hulme 2007). In Beijing, over 50% of the plant species grown in urban green spaces are of alien origin (Zhao et al. 2010), likely setting the stage for future invasions. One of the most notorious cases is the massive planting of *Rhus typhina* throughout the municipality, including the Olympic Park (Ji 2009). Regrettably, this shrub native to North America was one of the main species used for afforesting Beijing and today has become a serious invader (Wang et al. 2008).

Haidian district has the largest number of naturalized and invasive species in the Beijing Municipality (Fig. 2). It also has the highest GDP and the largest GDP growth as well as one of the fastest population growth rates (Table 1). In addition, Haidian has several botanical gardens, including the Beijing Botanical Garden (one of the largest in China) and the botanical garden of the Institute of Botany (Chinese Academy of Sciences). Botanical gardens are intentionally managed to accommodate alien plants and are often foci for their spread and escape (Reichard and White 2001; Dawson et al. 2008). For example, *Euphorbia dentata*, a serious invasive in Beijing, was first naturalized in the botanical garden of the Institute of Botany (Ma and Liu 2003; Li et al. 2008).

## Profile of the naturalized and invasive flora

Although the number of invasive species in Beijing is relatively low at present, this number represents a significant fraction of the species richness reported for the entire country: up to one-quarter of the total naturalized flora of China (~420 species; Wu et al. 2010) and ~one-fifth of the invasive flora of China (270 plant species; Weber et al. 2008). Some of the invasive species listed in the Appendix 1 (Table 4) are among the most noxious invaders in China, such as *Alternanthera philoxeroides*, *Ambrosia trifida*, *Lolium temulentum*, *Sorghum halepense*, and *Solidago canadensis* (Huang et al. 2009; Feng and Zhu 2010).

Only six families (Asteraceae, Poaceae, Amaranthaceae, Euphorbiaceae, Brassicaceae, and Fabaceae) accounted for almost two-thirds of the naturalized and invasive flora of Beijing, which is not surprising as these families, together with Solanaceae, are the main contributors to the alien floras not only of Asian cities and regions, but also worldwide (e.g., Pyšek 1998; Ng and Corlett 2002; Wu et al. 2004, 2010; Kil et al. 2004; Zerbe et al. 2004; Weber et al. 2008; Chong et al. 2009; Shi et al. 2009). The large numbers of species of Amaranthaceae and Euphorbiaceae (common in tropical or warm climates; Heywood et al. 2007; Wu et al. 2010) are remarkable in the flora of Beijing which is typical of the Northern Hemisphere having strong continental characteristics (Ma and Liu 2003). Why these species thrive in Beijing is an issue that deserves further investigation, but it may be related to the "urban heat island effect" (Ricotta et al. 2009).

Annual herbs are by far the most predominant life strategy of both the naturalized and invasive plant species of Beijing. Few invasive plants have long generation cycles (i.e., perennials), as is expected for highly disturbed urban environments (Zerbe et al. 2004; Pyšek and Richardson 2007; Kowarik 2008). Although Beijing has still many natural areas, these have not yet been significantly invaded by long-lived perennials such as shrubs and

trees which often invade natural and semi-natural environments (Cadotte and Lovett-Doust 2001; Vilà et al. 2008) possibly reflecting that large-scale introductions in Beijing are still in an early phase (Pyšek et al. 2003; Pyšek and Richardson 2007; Huang et al. 2010).

The Americas are the main contributors to the naturalized and invasive flora of Beijing, a pattern also found at national level (Liu et al. 2006; Xu et al. 2006; Weber et al. 2008; Wu et al. 2010), as well as for other several Chinese provinces and cities (Ng and Corlett 2002; Wu et al. 2004; Jiang et al. 2008; Yang and Chen 2009), and Singapore (Corlett 1988). The increase of international trade between Asia and America, as well as biogeographical affinities have been proposed as reasons for the predominance of American elements in the alien floras of China and neighboring regions (Corlett 1988; Wu et al. 2004; Liu et al. 2006; Weber et al. 2008). A particularity of this study is the larger weight of species native to the temperate areas of North America, a foreseeable result considering the high latitude of Beijing.

## Conclusions, prospects, and recommendations

Beijing is one of the fastest developing cities in the world, and urban expansion is predicted to continue in the future (Tang and Kunzmann 2008) fueled by economic growth and the immigration of rural people into the urban areas (Anonymous 2007). Therefore, more invasions are expected into a flora that still has a relatively low proportion of alien species (e.g., Ma and Liu 2003; Weber and Li 2008). In addition to growing urbanization, the mountainous districts already suffering from pollution, wetland loss, and severe soil erosion (Wang et al. 2007) are expected to become more invaded. Rural tourism, which has boomed in recent years, may be an additional driver for invasions by enhancing urbanization and infrastructure development (Wang et al. 2007).

The current wave of urbanization and ecological degradation urgently necessitate the development and implementation of an appropriate management strategy to minimize further invasions, including enforcing quarantines and inspection procedures. It is essential to strengthen risk assessment procedures to manage the deliberate introduction of alien species to prevent ill-conceived introductions such as the massive planting of the invasive shrub *R. typhina*. Using more native species rather than alien species should be the norm, and not the exception, when designing new green areas (Zhao et al. 2010). Nonetheless, any management or regulation measure will fail if public awareness and further scientific research are not included as in a comprehensive action plan. This study should be regarded only as the baseline for launching more ambitious surveys on biological invasions to address at a minimum the following: (i) estimates of species frequency in each district; (ii) identification of the historical process of invasions within the municipality; (iii) identification of the most aggressive invaders; and (iv) estimates of the economic and environmental impacts of the introduced species.

**Acknowledgments** The authors are grateful to Zhi-Xin Zhu and Xiao-Min Ma for the help with providing several articles. We also thank the two anonymous reviewers for valuable comments and suggestions. This study was funded by NSF of China (41030744), the National Basic Research Program of China (973 program 2006CB403400), and the Knowledge Innovation Project of Chinese Academy of Sciences (KZCX2-YW-422).

## Appendix 1

See Table 4.

**Table 4** Catalog of naturalized plant species occurring at present in Beijing Municipality. The invasive species are in boldface

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| ***Acanthospermum australe*** | Asteraceae | Xicheng | A | H | 1, 5 | S America | Yes/yes | Unknown |
| ***Ageratum conyzoides*** | Asteraceae | Haidian, Pinggu, Xicheng | A | H | 1, 2, 3, 4, 5 | Neotropics | Yes/yes | Unknown |
| *Alopecurus japonicus* | Poaceae | Miyun, Xicheng | A | H | 2, 5 | E Asia [China?] | No/yes | Unknown |
| ***Alternanthera philoxeroides*** | Amaranthaceae | Chaoyang, Fengtai, Haidian, Huairou, Pinggu, Xicheng | P | H | 1, 2, 5 | S America | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002; Yang et al. 2009) |
| *Alternanthera sessilis* | Amaranthaceae | Chaoyang, Daxing, Fengtai, Haidian | A | H | 1, 2, 5 | Asia [China] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Amaranthus blitoides* | Amaranthaceae | Xicheng | A | H | 1, 2 | N America | Yes/yes | A (by importation of foods) (Liu et al. 2002) |
| *Amaranthus cruentus* | Amaranthaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | N & C America | No/yes | Unknown |
| *Amaranthus palmeri* | Amaranthaceae | Fengtai | A | H | 1, 2, 5 | N America | No/yes | Unknown |
| ***Amaranthus polygonoides*** | Amaranthaceae | Chaoyang, Daxing, Fengtai, Haidian, Huairou, Pinggu, Xicheng | A | H | 1 | N & C America | Yes/yes | Unknown |
| ***Amaranthus retroflexus* var. *retroflexus*** | Amaranthaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 5 | N America | Yes/yes* | A (by importation of foods) (Liu et al. 2002; Yang et al. 2009) |
| *Amaranthus retroflexus* var. *delilei* | Amaranthaceae | Fengtai | A | H | 1 | N America | Yes/yes* | Unknown |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| ***Amaranthus spinosus*** | Amaranthaceae | Changping, Mentougou, Miyun | A | H | 1, 2 | Neotropics | Yes/yes | A (by importation of foods) (Liu et al. 2002) |
| *Amaranthus tricolor* | Amaranthaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | Tropical Asia | Yes/yes | D (as vegetable) (Liu et al. 2002) |
| ***Amaranthus viridis*** | Amaranthaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | S America | Yes/yes | A (by importation of foods) (Liu et al. 2002) |
| ***Ambrosia artemisiifolia*** | Asteraceae | Changping, Fengtai, Haidian, Miyun, Mentougou, Shunyi | A | H | 1, 2, 4 | N America | Yes/yes | A (by transportation of luggage) (Liu et al. 2002; Yang et al. 2009) |
| ***Ambrosia trifida*** | Asteraceae | Changping, Fengtai, Haidian, Miyun, Mentougou, Shunyi | A | H | 1, 2, 4 | N America | Yes/yes | A (by transportation of luggage) (Liu et al. 2002) |
| *Ammannia coccinea* | Lythraceae | Changping, Chaoyang, Haidian | A | H | 2, 5 | N, C & S America | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Ammannia multiflora* | Lythraceae | Changping, Haidian | A | H | 2, 5 | Africa, Asia [China?], Australia | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Amorpha fruticosa* | Fabaceae | Present in all the districts and counties of Beijing | P | S | 5 | N America | No/yes | D (as street tree) (Liu et al. 2002) |
| ***Aster subulatus*** | Asteraceae | Tongzhou | A | H | 1, 2 | N America | Yes/yes | Unknown |
| *Asystasiella neesiana* | Acanthaceae | Fengtai | P | H | 4, 5 | Asia [China?] | No/no | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Avena fatua*** | Poaceae | Haidian | A | H | 1, 2, 3 | N Africa, Asia, Europe | Yes/yes | Unknown |
| ***Bidens pilosa*** | Asteraceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 4, 5 | Neotropics | Yes/yes | Unknown |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Bromus japonicus* | Poaceae | Present in all the districts and counties of suburban and exurban Beijing | A | H | 1, 4, 5 | N Africa, Asia [China], Europe | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Buchloe dactyloides* | Poaceae | Haidian | P | H | 1, 3 | N America | Yes/yes | D (as turf grass) (Liu et al. 2002) |
| *Cannabis sativa* | Cannabaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 4 | C Asia | Yes/yes | D (as medicinal plant) (Liu et al. 2002; Yang et al. 2009) |
| *Cardamine flexuosa* | Brassicaceae | Chaoyang, Daxing, Fengtai, Haidian, Huairou, Pinggu, Xicheng | A/B | H | 1, 2, 3, 4, 5 | Europe | No/yes | Unknown |
| *Cardamine hirsuta* | Brassicaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 5 | Africa, Asia [China], Europe | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Cayratia japonica* | Vitaceae | Present in all the districts and counties of Beijing | P | H | 1, 2, 3, 4 | Asia [China], Australia | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Cenchrus echinatus*** | Poaceae | Xicheng | A | H | 1, 6 | Neotropics | Yes/yes | Unknown |
| ***Chenopodium hybridum*** | Chenopodiaceae | Huairou, Mentougou, Miyun, Yanqing | A | H | 1, 3, 4 | Asia, Europe | Yes/yes | Unknown |
| ***Conyza bonariensis*** | Asteraceae | Haidian | A | H | 1, 2, 4 | Neotropics | Yes/yes | Unknown |
| ***Conyza canadensis*** | Asteraceae | Haidian, Pinggu | A | H | 1, 2, 3, 5 | N & C America | Yes/yes | A (by transportation of luggage) (Liu et al. 2002; Yang et al. 2009) |
| *Coronilla varia* | Fabaceae | Present in all the districts and counties of Beijing | P | H | 1, 2, 3, 4, 5 | W & C Asia, Europe | No/yes | Unknown |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| ***Coronopus didymus*** | Brassicaceae | Haidian | A/B | H | 1, 2, 4 | S America | Yes/yes | Unknown |
| ***Crassocephalum crepidioides*** | Asteraceae | Chaoyang, Haidian | A | H | 1, 3, 5 | Africa | Yes/yes | D (as ornamental) (Yang et al. 2009) |
| ***Cyperus rotundus*** | Cyperaceae | Daxing | P | H | 1, 2, 3, 4, 5 | Pantropical | Yes/yes | Unknown |
| *Dactyloctenium aegyptium* | Poaceae | Xicheng | A | H | 1, 2, 6 | Africa, Asia [China] | No/yes | Unknown |
| ***Datura stramonium*** | Solanaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3 | N America | Yes/yes | Unknown |
| *Dodartia orientalis* | Scrophulariaceae | Fengtai | P | H | 1, 2, 5, 6 | Asia [China?] | No/yes | Unknown |
| ***Eleusine indica*** | Poaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | Paleotropics | Yes/yes | Unknown |
| *Emilia sonchifolia* | Asteraceae | Fengtai, Haidian, Xicheng | A | H | 1, 2, 3 | S Asia [China?] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Erigeron annuus*** | Asteraceae | Chaoyang, Haidian | A/B | H | 1, 2, 4 | N America | Yes/yes | A (by transportation of luggage) (Yang et al. 2009) |
| *Eruca vesicaria* subsp. *sativa* | Brassicaceae | Changping, Yanqing | A | H | 1, 2, 3 | N Africa, Asia [China?], Europe | No/yes | D (as vegetable) (Liu et al. 2002; Yang et al. 2009) |
| ***Euphorbia dentata*** | Euphorbiaceae | Haidian | A | H | 1, 2, 3 | N America | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Euphorbia helioscopia* | Euphorbiaceae | Haidian | A | H | 1, 2, 3, 4 | N Africa, Asia, Europe | Yes/yes | Unknown |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| ***Euphorbia hirta*** | Euphorbiaceae | Fengtai, Haidian, Xicheng | A | H | 1, 2, 3, 4 | Neotropics | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Euphorbia hypericifolia* | Euphorbiaceae | Changping | A | H | 1, 2, 3 | Neotropics | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Euphorbia maculata*** | Euphorbiaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3 | N America | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Euphorbia nutans* | Euphorbiaceae | Fangshan, Fengtai, Xicheng | A | H | 1, 2 | N & C America | Yes/yes | Unknown |
| *Euphorbia prostrata* | Euphorbiaceae | Fengtai | A | H | 1, 2, 3 | Neotropics | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Euphorbia serpens* | Euphorbiaceae | Fengtai | A | H | 1, 2, 5 | N, C & S America | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Fagopyrum esculentum* | Polygonaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | China | No/yes | D (for forage or feed) (Liu et al. 2002) |
| ***Galinsoga parviflora*** | Asteraceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 4, 5 | Neotropics | Yes/yes | A (by luggage of tourists) (Liu et al. 2002; Yang et al. 2009) |
| *Gaura parviflora* | Onagraceae | Haidian | A/B | H | 1, 2 | N America | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Gnaphalium polycaulon* | Asteraceae | Chaoyang, Fengtai, Haidian | A | H | 1, 2, 3 | Unknown | No/yes | Unknown |
| *Hedyotis corymbosa* | Rubiaceae | Daxing, Haidian, Xicheng, | A | H | 1, 2, 3, 4, 5 | Africa, Tropical Asia | No/yes | Unknown |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Helianthus tuberosus* | Asteraceae | Present in all the districts and counties of Beijing | P | H | 1, 2, 4, 5 | N America | Yes/yes | D (for forage or feed) (Liu et al. 2002) |
| ***Hibiscus trionum*** | Malvaceae | Haidian, Mentougou | A | H | 1, 2, 4 | Africa, Asia, Europe | Yes/yes | Unknown |
| *Hydrocotyle sibthorpioides* | Apiaceae | Chaoyang, Fengtai, Haidian, Huairou, Pinggu | P | H | 3, 4, 5 | Africa, Asia [China] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Impatiens balsamina* | Balsaminaceae | Present in all the districts and counties of Beijing | A | H | 1 | Tropical Asia | No/yes | D (as ornamental plant) (Liu et al. 2002) |
| *Ipomoea hederacea* | Convolvulaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | Neotropics | Yes/yes | D (as ornamental plant) (Liu et al. 2002) |
| *Ipomoea nil* | Convolvulaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3 | Pantropical | Yes/yes | D (as ornamental plant) (Liu et al. 2002; Yang et al. 2009) |
| ***Ipomoea purpurea*** | Convolvulaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 4, 5 | Neotropics | Yes/yes | D (as ornamental plant) (Liu et al. 2002) |
| *Leptochloa chinensis* | Poaceae | Chaoyang, Daxing, Fengtai, Haidian, Xicheng | A | H | 1, 2, 5 | Africa, Asia [China] | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Leptochloa panicea* | Poaceae | Chaoyang, Daxing, Fengtai, Haidian, Xicheng | A | H | 1, 2, 5 | Africa, N, C & S America, Asia [China], Australia | No/yes | Unknown |
| *Lolium multiflorum* | Poaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3 | N Africa, W & S Asia, Europe | Yes/yes | D (as turf grass) (Liu et al. 2002) |
| *Lolium perenne* | Poaceae | Present in all the districts and counties of Beijing | P | H | 1, 3, 4 | N Africa, Asia, Europe | Yes/yes | D (for forage or feed) (Liu et al. 2002) |
| *Lolium persicum* | Poaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 5 | Asia | Yes/yes | Unknown |
| ***Lolium temulentum*** | Poaceae | Fengtai, Haidian, Xicheng | A | H | 1, 2 | Europe | Yes/yes | A (by importation of foods) (Yang et al. 2009) |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Ludwigia hyssopifolia* | Onagraceae | Changping, Haidian, Yanqing | A | H | 1, 2, 4, 5 | Africa, Asia [China], Australia, Neotropics | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Ludwigia prostrata* | Onagraceae | Changping, Haidian, Yanqing | A | H | 2, 5 | Asia [China?] | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Lysimachia candida* | Primulaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 5 | E & SE Asia [China?] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Macleaya cordata* | Papaveraceae | Chaoyang | P | H | 3, 4, 5 | E Asia [China] | No/yes | Unknown |
| *Medicago sativa* | Fabaceae | Present in all the districts and counties of Beijing | P | H | 1, 2, 3, 5 | W Asia, Europe | Yes/yes | D (for forage or feed) (Liu et al. 2002) |
| ***Melilotus albus*** | Fabaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 5 | N Africa, Asia, Europe | Yes/yes | Unknown |
| ***Mirabilis jalapa*** | Nyctaginaceae | Mentougou | A/P | H | 1 | Neotropics | Yes/yes | D (as ornamental plant) (Liu et al. 2002; Yang et al. 2009) |
| *Mitracarpus villosus* | Rubiaceae | Xicheng | A | H | 1, 2 | Neotropics | No/yes | Unknown |
| *Mollugo stricta* | Molluginaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 6 | China | No/yes | Unknown |
| *Nasturtium officinale* | Brassicaceae | Changping, Haidian, Mentougou, Yanqing | P | H | 5 | Africa, Asia, Europe | Yes/yes | Unknown |
| *Oenothera biennis* | Onagraceae | Mentougou | B | H | 1, 2, 5 | N America | No/yes | D (as ornamental plant) (Liu et al. 2002) |
| ***Oxalis corymbosa*** | Oxalidaceae | Chaoyang, Fengtai, Haidian, Pinggu, Xicheng | P | H | 1, 2, 4 | S America | Yes/yes | D (as ornamental plant) (Yang et al. 2009) |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Paederia scandens* | Rubiaceae | Haidian | P | H | 1, 3, 4, 5 | Asia [China] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Panicum bisulcatum* | Poaceae | Fengtai | A | H | 4, 5 | Asia [China], Australia | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| ***Paspalum conjugatum*** | Poaceae | Xicheng | P | H | 1, 2, 4, 5 | Pantropical | Yes/yes | Unknown |
| ***Peperomia pellucida*** | Piperaceae | Chaoyang, Fengtai, Haidian, Huairou, Pinggu, Xicheng | A | H | 2, 4, 6 | Neotropics | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002; Yang et al. 2009) |
| ***Phytolacca americana*** | Phytolaccaceae | Chaoyang, Haidian | P | H | 1, 3, 4 | N America | Yes/yes | Unknown |
| ***Pilea microphylla*** | Urticaceae | Chaoyang, Fengtai, Haidian, Huairou, Pinggu, Xicheng | A | H | 1, 2, 4, 6 | Neotropics | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002; Yang et al. 2009) |
| ***Rhus typhina*** | Anacardiaceae | Present in all the districts and counties of Beijing | P | S | 1, 3, 4 | N America | Yes/yes | D (as street tree) (Liu et al. 2002; Yang et al. 2009) |
| *Richardia scabra* | Rubiaceae | Xicheng | A | H | 1, 2, 3 | N, C & S America | No/yes | Unknown |
| ***Ricinus communis*** | Euphorbiaceae | Present in all the districts and counties of Beijing | A | H | 1, 4, 5 | Africa | Yes/yes | D (as medicinal plant and industrial lubricant) (Liu et al. 2002; Yang et al. 2009) |
| *Robinia pseudoacacia* | Fabaceae | Present in all the districts and counties of Beijing | P | T | 1, 3, 4, 5 | N America | Yes/yes | D (as street tree) (Liu et al. 2002) |
| *Rorippa cantoniensis* | Brassicaceae | Fengtai, Haidian | A | H | 1, 2, 5 | E & SE Asia [China?] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Rostellularia procumbens* | Acanthaceae | Present in all the districts and counties of Beijing | A | H | 1, 2, 3, 5 | Asia [China] | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Rotala indica* | Lythraceae | Fengtai, Haidian, Yanqing | A | H | 2, 5 | Tropical Asia | No/yes | A (by introduction of crop seeds) (Liu et al. 2002) |
| *Rumex japonicus* | Polygonaceae | Xuanwu | P | H | 2, 5 | E Asia [China?] | No/yes | D (as medicinal plant) (Liu et al. 2002) |
| *Saxifraga stolonifera* | Saxifragaceae | Chaoyang, Haidian | P | H | 3, 4, 6 | E Asia [China] | No/yes | Unknown |
| ***Scoparia dulcis*** | Scrophulariaceae | Haidian | A | H | 1, 2, 3, 4 | Neotropics | Yes/yes | Unknown |
| *Secale cereale* | Poaceae | Present in all the districts and counties of Beijing | A | H | 2 | Asia, Europe | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Senecio dubitabilis*** | Asteraceae | Haidian | A | H | 2, 6 | Asia | Yes/no | Unknown |
| ***Solanum rostratum*** | Solanaceae | Yanqing | A | H | 1, 2, 3 | N America | Yes/yes | Unknown |
| ***Solidago canadensis*** | Asteraceae | Changping | P | H | 1, 2, 3, 4 | N America | Yes/yes | Unknown |
| ***Sorghum halepense*** | Poaceae | Fengtai, Haidian | P | H | 1, 2, 5 | N Africa, Asia, Europe | Yes/yes | A (by importation of foods) (Liu et al. 2002; Yang et al. 2009) |
| *Spermacoce stricta* | Rubiaceae | Chaoyang, Haidian | A | H | 3, 4 | Tropical Africa, Asia [China?] | No/yes | Unknown |
| ***Vaccaria hispanica*** | Caryophyllaceae | Present in all the districts and counties of Beijing | A | H | 1, 2 | N Africa, W & C Asia, Europe | Yes/yes | D (as medicinal plant) (Liu et al. 2002) |

**Table 4** continued

| Species | Family | Distribution | Habit | Life form | Habitat | Native range[a] | Invasive in China[b]/ invasive in other parts of the world[c] | Way of introduction (and reference) |
|---|---|---|---|---|---|---|---|---|
| *Vernonia cinerea* | Asteraceae | Fengtai | A | H | 1, 2, 3 | Africa, Asia [China], Australia | No/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Veronica arvensis* | Scrophulariaceae | Chongwen, Haidian | A | H | 1, 2, 3, 4 | N Africa, Asia, Europe | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| *Veronica peregrina* | Scrophulariaceae | Xuanwu | A | H | 1, 2, 4, 5 | N, C & S America | Yes/yes | A (by importation of garden and landscape plants) (Liu et al. 2002) |
| ***Veronica persica*** | Scrophulariaceae | Chaoyang, Chongwen, Haidian | A/B | H | 1, 2 | SW Asia | Yes/yes | Unknown |
| ***Xanthium glabratum*** | Asteraceae | Changping, Miyun, Tongzhou | A | H | 1, 2, 5 | N America | Yes/yes | Unknown |
| ***Xanthium italicum*** | Asteraceae | Changping, Fangshan, Miyun, Shijingshan | A | H | 1, 2, 5 | N America | Yes/yes | A (by importation of livestock products) (Liu et al. 2002; Yang et al. 2009) |
| ***Xanthium spinosum*** | Asteraceae | Fengtai | A | H | 1, 2, 4, 5 | S America | Yes/yes | A (by importation of livestock products) (Liu et al. 2002) |

Habit: *A* annual, *B* biennial, *P* perennial. Life form: *H* herb, *S* shrub, *T* tree. Habitat type: *1* ruderal habitats (roadsides, disturbed places, etc.), urban areas (including urban parks and gardens); *2* agricultural areas (cultivated fields, orchards, etc.); *3* grasslands, shrublands; *4* forests or forest margins; *5* wet places (wetlands, marshes, riverbanks, streamsides, lakeshores, etc.) or water bodies (rivers, lakes, ponds, reservoirs, irrigation canals); *6* other (rocky outcrops, sandy places, etc.). Way of introduction: *D* deliberate or intentional, *A* accidental or unintentional. Reasons for their deliberate introduction and details of their accidental introduction are given between parentheses

* Information at species level (*A. retroflexus*)

[a] [China] means that China is included within the native range of the considered species

[b] At national level (that is, if listed in any of the reports on invasive species for China, such as those of Liu et al. (2005), Lin et al. (2007), Weber et al. (2008), Fang and Wan (2009) or Feng and Zhu (2010)

[c] When listed in (i) authoritative lists or compendiums, such as the Global Invasive Species Database (www.issg.org/database/) or the Global Compendium of Weeds (http://www.hear.org/gcw/), or (ii) scientific articles and technical reports

## References


Anonymous (2007) Beijing's population to top 21.4 m by 2020. China Daily, Beijing, 10 Dec 2007. http://www.chinadaily.com.cn/china/2007-12/10/content_6308561.htm. Accessed 24 Apr 2010

BMBS (Beijing Municipal Bureau of Statistics, NBS Survey Office in Beijing) (2008) Beijing statistical yearbook 2008. China Statistics Press, Beijing (in Chinese)

BMBS (Beijing Municipal Bureau of Statistics, NBS Survey Office in Beijing) (2009) Beijing statistical yearbook 2009. China Statistics Press, Beijing (in Chinese)

Botham MS, Rothery P, Hulme PE, Hill MO, Preston CD, Roy DB (2008) Do urban areas act as foci for the spread of alien plant species? An assessment of temporal trends in the UK. Divers Distrib 15:338–345

Cadotte MW, Lovett-Doust J (2001) Ecological and taxonomic differences between native and introduced plants of southwestern Ontario. Ecoscience 8:230–238

Chong KY, Tan HTW, Corlett RT (2009) A checklist of the total vascular plant flora of Singapore: native naturalised and cultivated species. Raffles Museum of Biodiversity Research, National University of Singapore, Singapore

Corlett RT (1988) The naturalized flora of Singapore. J Biogeogr 15:657–663

Dawson W, Mndolwa AS, Burslem DFRP, Hulme PE (2008) Assessing the risks of plant invasions arising from collections in tropical botanical gardens. Biodivers Conserv 17:1979–1995

Ding J, Mack RN, Lu P, Ren M, Huang H (2008) China's booming economy is sparking and accelerating biological invasions. Bioscience 58:317–324

Fang J, Wan F (2009) Invasive species and their impacts on endemic ecosystems in China. In: Kohli RK, Jose S, Singh HP, Batish DR (eds) Invasive plants and forest ecosystems. CRC Press, Boca Raton, pp 157–175

Feng J, Zhu Y (2010) Alien invasive plants in China: risk assessment and spatial patterns. Biodivers Conserv 19:3489–3497

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, Briggs JM (2008) Global change and the ecology of cities. Science 319:756–760

Guézou A, Pozo P, Buddenhagen C (2007) Preventing establishment: an inventory of introduced plants in Puerto Villamil, Isabela Island, Galapagos. PLoS One 2(10):e1042

Haw SG (2007) Beijing—a concise history. Routledge, Oxon

Heywood VH, Brummit RK, Culham A, Seberg O (2007) Flowering plant families of the world. Royal Botanic Gardens, Kew

Huang QQ, Wu JM, Bai YY, Zhou L, Wang GX (2009) Identifying the most noxious invasive plants in China: role of geographical origin, life form and means of introduction. Biodivers Conserv 18:305–316

Huang QQ, Qian C, Wang Y, Jia X, Dai XF, Zhang H, He F, Peng SL, Wang GX (2010) Determinants of the geographical extent of invasive plants in China: effects of biogeographical origin, life cycle and time since introduction. Biodivers Conserv 19:1251–1259

Hulme PE (2007) Biological invasions in Europe: drivers, pressures, states, impacts and responses. In: Hester RE, Harrison RM (eds) Biodiversity under threat—issues in environmental science and technology, no. 25. The Royal Society of Chemistry, Cambridge, pp 56–80

IUCN (International Union for the Conservation of Nature) (1999) IUCN guidelines for the prevention of biodiversity loss due to biological invasion. Species 31–32:28–42

Ji Y (2009) We feel the green landscapes when we enter the Olympic Forest Park. Gard Mag 10:23–27 (in Chinese)

Jiang Q, Lin Z, Li L, He X (2008) An investigation on the invasive plants in Zhongshan, Guangdong Province. Guangdong Forest Sci Technol 24:54–58 (In Chinese)

Jiménez A, Pauchard A, Cavieres LA, Marticorena A, Bustamante RO (2008) Do climatically similar regions contain similar alien floras? A comparison between the Mediterranean areas of central Chile and California. J Biogeogr 35:614–624

Jing T-H, Liang T-G, Zhang Y (2004) Migration and clustering: the Beijing population dynamic image. Beijing City Plan Constr Rev 4:8–10

Kil JH, Shim KC, Park SH, Koh KS, Suh MH, Ku YB, Suh SU, Oh HK, Kong HY (2004) Distributions of naturalized alien plants in South Korea. Weed Technol 18:1493–1495

Kowarik I (2005) Urban ornamentals escaped from cultivation. In: Gressel J (ed) Crop ferality and volunteerism. CRC Press, Boca Raton, pp 97–122

Kowarik I (2008) On the role of alien species in urban flora and vegetation. In: Marzluff JM, Shulenberger E, Endlicher W, Alberti M, Bradley G, Ryan C, Simon U, ZumBrunnen C (eds) Urban ecology—an international perspective on the interaction between humans and nature. Springer-Verlag, New York, pp 321–338

Li J (2004) The controversial greening of Beijing. China Internet Information Center. http://english1.china.org.cn/english/2004/Jul/101225.htm. Accessed 12 March 2010
Li ZY, Xie Y (2002) Invasive alien species in China. Chinese Forestry Press, Beijing (in Chinese)
Li B, Qiu H, Ma J, Zhu H, Gilbert MG, Esser HJ, Dressler S, Hoffmann P, Gillespie LJ, Vorontsova M, McPherson GD (2008) Euphorbiaceae. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 11, Oxalidaceae through Aceraceae. Science Press, Beijing and Missouri Botanical Garden Press, St. Louis, pp 163–314
Lin W, Zhou G, Cheng X, Xu R (2007) Fast economic development accelerates biological invasions in China. PLoS One 2:e1208
Liu QR, 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)
Liu J, Liang SC, Liu FH, Wang RQ, Dong M (2005) Invasive alien plant species in China: regional distribution patterns. Divers Distrib 11:341–347
Liu J, Dong M, Miao SL, Li ZY, Song MH, Wang RQ (2006) Invasive alien plants in China: role of clonality and geographical origin. Biol Invasions 8:1461–1470
Ma J, Liu Q (2003) Flora of Beijing: an overview and suggestions for future research. Urban Habitats 1:30–44
Maatsch S, Monden R, Stockmann D (2009) ISL comment. Shipp Stat Mark Rev 53(5/6):5–17
Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689–710
McNeely JA, Mooney HA, Neville LE, Schei P, Waage JK (eds) (2001) A global strategy on invasive alien species. IUCN Gland, Switzerland
Meng XS, Ouyang ZY, Cui GF, Li WF, Zheng H (2004) Composition of plant species and their distribution patterns in Beijing urban ecosystem. Acta Ecol Sin 24:2200–2206 (in Chinese)
Mu FY, Zhang ZX, Chi YB, Liu B, Zhou QB, Wang CY, Tan WB (2007) Dynamic monitoring of built-up area in Beijing during 1973–2005 based on multi-original remote sensed images. J Remote Sens 11:257–268 (in Chinese)
Ng SC, Corlett R (2002) The bad biodiversity: alien plant species in Hong Kong. Biodivers Sci 10:109–118 (in Chinese)
Pyšek P (1998) Is there a taxonomic pattern to plant invasions? Oikos 82:282–294
Pyšek P, Richardson DM (2007) Traits associated with invasiveness in alien plants: where do we stand? In: Nentwig W (ed) Biological invasions, ecological studies 193. Springer-Verlag, Berlin, pp 97–126
Pyšek P, Sádlo J, Mandák B, Jarošik V (2003) Czech alien flora and the historical pattern of its formation: what came first to Central Europe? Oecologia 135:122–130
Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J (2004) Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. Taxon 53:131–143
Qin XS, Zhang RJ, Chen HF, Yan YH, Zheng XL, Xing FW (2008) Alien plants in limestone regions of Hainan Island, China. Chin J Ecol 27:1861–1868 (in Chinese)
Qiu Y-X, Peng Z-H, Wu Y, Bo N-L (2007) Characteristic of plant landscape of Liuzhou. N Hort 12:155–157 (in Chinese)
Reichard SH, White P (2001) Horticulture as a pathway of invasive plant introductions in the United States. Bioscience 51:103–113
Rejmánek M (2000) Invasive plants: approaches and predictions. Aust Ecol 25:497–506
Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. Divers Distrib 6:93–107
Ricotta C, La Sorte FA, Pyšek P, Rapson GL, Celesti-Grapow L, Thompson K (2009) Phyloecology of urban alien floras. J Ecol 97:1243–1251
Shi LC, Shi G, Yi QL, Qin YC, Dong ZD, Huang GZ (2009) The countermeasure researches for investigation and eradication of alien invasive plants in Liuzhou. J Guangxi Acad Sci 25:178–182 (in Chinese)
Tang Y, Kunzmann KR (2008) The evolution of spatial planning for Beijing. Inform Raumentwicklung 2008:457–470
Tian G, Wu J, Yang Z (2010) Spatial pattern of urban functions in the Beijing metropolitan region. Habitat Int 34:249–255
UNEP (United Nations Environment Programme) (2009) Independent environmental assessment Beijing 2008 Olympic Games. UNEP, Nairobi
Vilà M, Valladares F, Traveset A, Santamaria L, Castro P (eds) (2008) Invasiones biológicas. Consejo Superior de Investigaciones Científicas (CSIC), Madrid

Von der Lippe M, Kowarik I (2008) Do cities export biodiversity? Traffic as dispersal vector across urban-rural gradients. Divers Distrib 14:18–25
Wan FH, Zheng XB, Guo JY (2005) Biology and management of invasive alien species in agriculture and forestry. Science Press, Beijing
Wang GM, Jiang GM, Zhou Y, Liu Q, Ji Y, Wang S, Chen S, Liu H (2007) Biodiversity conservation in a fast-growing metropolitan area in China: a case study of plant diversity in Beijing. Biodivers Conserv 16:4025–4038
Wang GM, Jiang GM, Yu SL, Li YH, Liu H (2008) Invasion possibility and potential effects of *Rhus typhina* on Beijing Municipality. J Integr Plant Biol 50:522–530
Weber E, Li B (2008) Plant invasions in China: what is to be expected in the wake of economic development? Bioscience 58:437–444
Weber E, Sun SG, Li B (2008) Invasive alien plants in China: diversity and ecological insights. Biol Invasions 10:1411–1429
Wiersema JH, León B (1999) World economic plants: a standard reference. CRC Press, Boca Raton
Wittig R (2004) The origin and development of the urban flora of Central Europe. Urban Ecosyst 7:323–339
Wu SH, Hsieh CF, Chaw SM, Rejmánek M (2004) Plant invasions in Taiwan: insights from the flora of casual and naturalized alien species. Divers Distrib 10:349–362
Wu Q, Li HQ, Wang RS, Paulussen J, He Y, Wang M, Wang BH, Wang Z (2006) Monitoring and predicting land use change in Beijing using remote sensing and GIS. Landscape Urban Plan 78:322–333
Wu SH, Sun HT, Teng YC, Rejmánek M, Chaw SM, Yang TA, Hsieh CF (2010) Patterns of plant invasions in China: taxonomic, biogeographic, climatic approaches and anthropogenic effects. Biol Invasions 12:2179–2206
Xinhua (2007) Nearly half the world's new buildings built in China. Xinhua News Agency. http://www.sh.xinhuanet.com/2007-08/24/content_10953578.htm. Accessed 20 May 2010
Xu BS (1999) Flora of Shanghai. Shanghai Science and Technology Publishing House, Shanghai (in Chinese)
Xu HG, Qiang S (2004) Inventory: invasive alien species in China. Chinese Environment Science Press, Beijing
Xu H, Qiang S, Han Z, Guo J, Huang Z, Sun H, He S, Ding H, Wu H, Wan F (2006) The status and causes of alien species invasion in China. Biodivers Conserv 15:2893–2904
Yan J (2009) 3910' concept guides Green Beijing Action Plan. Beijing This Month [online], 13 Nov 2009. http://www.btmbeijing.com/contents/en/business/2010-01/coverstory/Article.2010-01-19.7848206798. Accessed 7 Dec 2010
Yang J, Chen HB (2009) A preliminary study on alien invasive plants in Fujian Province. Subtrop Plant Sci 38:47–52 (in Chinese)
Yang J, Wang G, Jiang C, Zhao H, Zhang Z (2009) Ecological characters and distribution of invasive plants under the influence of urbanization in Beijing, China. Ecol Environ Sci 18:1857–1862 (in Chinese)
Yusuf S, Saich T (eds) (2008) China urbanizes—consequences, strategies, and policies. The World Bank, Washington
Zerbe S, Choi IK, Kowarik I (2004) Characteristics and habitats of non-native plant species in the city of Chonju, southern Korea. Ecol Res 19:91–98
Zhao J, Ouyang ZY, Zheng H, Zhou W, Wang X, Xu W, Ni Y (2010) Plant species composition in green spaces within the built-up areas of Beijing, China. Plant Ecol 209:189–204