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Urban green spaces and plant diversity at different spatial–temporal scales: A case study from Beijing, China

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Abstract

Urban green spaces and plant diversity at different spatial–temporal scales: A case study from Beijing, China.— Beijing, the capital city of China, is one of the largest and most rapidly-urbanizing cities in the world. In this work, we present the main results of one decade's research on urban vegetation and plant diversity changes in different urban structural units. Urban vegetation/plant diversity has been studied at two different levels: at the landscape level (greening percentage, fragmentation degree) and at the plant species level (structure, composition, and origin). Finally, concerns with the ability to study Beijing's plant urban ecology are discussed.

Key words: Beijing; China; green spaces; invasive species; land use; socio-economics; urban ecology.

Resumen

Espacios verdes urbanos y diversidad vegetal a diferentes escalas espacio-temporales: el ejemplo de Beijing, China.— Pekín, la capital de China, es una de las urbes más pobladas y a la vez con una de las tasas de expansión urbana más rápidas del mundo. En el presente trabajo, se presentan los principales resultados tras una década de estudio de los cambios en la vegetación y diversidad vegetal urbana a lo largo de las diferentes unidades estructurales urbanas. La vegetación y la diversidad vegetal urbana se han estudiado a dos niveles: a nivel de paisaje (porcentaje de zonas verdes, grado de fragmentación) y a nivel de especie (estructura, composición y origen). En último lugar se discuten algunos aspectos relacionados con la metodología de estudio de la ecología urbana en Pekín.

Palabras clave: Beijing; China; ecología urbana; espacios verdes; especies invasoras; socio-economía; usos del suelo.

摘要

不同时空尺度上的城市绿地和植物多样性：以北京市为例。— 中国的首都北京是世界上最大且发展最快的城市之一。本文展示了过去10余年间北京不同城市结构单元中城市绿地和植物多样性变化的主要研究结果。我们对城市绿地和植物多样性在两个不同的尺度上进行了研究：在景观尺度上（如绿化率，破碎化程度等）和植物群落尺度上（植物结构，组成和来源等）。最后，我们对未来城市植物学研究谈了几点看法。

关键词： 北京；中国； 绿地；入侵物种；土地利用；社会经济学；城市生态学。

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INTRODUCTION

Plants contribute to the spatial structure of urban systems not only through their presence in parks and reserves, but also via their occurrence throughout the entire urban mosaic. Understanding today's urban biodiversity will help us to predict future biodiversity and the ecological consequences of modern biodiversity changes (Cadotte *et al*., 2008). Urban green space has become one of the most extensively-researched topics in urban ecology because of the environmental, social and economic benefits of green space (Peckham *et al*., 2013). Urban vegetation acts as an effective noise and dust barrier, removes large quantities of atmospheric carbon dioxide, saves energy, and mitigates the Urban Heat Island (UHI) effect (i.e. when a metropolitan area is significantly warmer than its surrounding areas); in addition, urban vegetation has aesthetic and cultural values (McPherson *et al*., 1997; Tyrväinen *et al*., 2005). Nowadays, because the urban environment in developing countries is deteriorating (WHO, 2014), people living there frequently look toward urban green space for improving their living environment. For example, people living in Beijing often complain about air pollution, which has become especially serious in recent times (Fig. 1A, B; Wong, 2014). Increasing the number of green areas in Beijing as well as improving their quality may help to alleviate the problems derived from air pollution and other environmental risks to health. Recently some proposals, such as the greening of Beijing rooftops (there are *ca*. 100 million square metres of roof space suitable for setting up green roofs; Zhang, 2013) and the establishment of green "air corridors" (Wu & Zheng, 2014) have been put on the table.

Since the mid-2000s, we have explored the urban vegetation and plant diversity changes in different urban structural units (e.g. universities or similar work units) in order to promote urban vegetation ecological service functions. Taking Beijing as a case study (Fig. 2), we have surveyed urban vegetation/plant diversity at two different levels: firstly, we explored the effects of urbanization on urban green space/plant diversity at the landscape level (greening percentage, fragmentation degree; Fig. 3); secondly, we examined these effects at the plant species level (structure, composition, and origin) and their response mechanism (Fig. 4). Our final aim is to achieve a better incorporation of plant diversity and ecosystem services in Beijing's future urban planning and design.

BEIJING AS A CASE STUDY

Beijing has been the capital city of China for 800 years and has a three-millennium history as a human settlement. An eminently rural city until the middle of the 20th century (Haw, 2007), it has recently experienced an impressive demographic and economic growth. Today, Beijing is one of the largest cities in the world, with an estimated population of *ca*. 21 million inhabitants in the whole Municipality of Beijing, a number that represents a nearly sevenfold increase since the 1950s. The Municipality of Beijing occupies 16,807.8 km^2, and the central urban area confined within the fifth ring road (i.e. the region that can be considered the "downtown"; Fig. 2) is 652.2 km^2. In our studies, remote sensing images (*Satellite Pour l'Observation de la Terre*, SPOT-5, in 2002) of the fifth ring of Beijing were divided into 264 2 × 2 km grids (Fig. 2); 1–4 urban structural units (USUs, i.e. universities or similar work units) were selected in each grid based on uniformity and importance. Properties of an USU were defined by the designations in Gill *et al*. (2008) as well as by the Urban Forest Effects (UFORE) model. Each unit boundary was delineated using remote sensing images, and land cover was divided into impermeable ground (built-up land), forest land, grassland, mixed forest and grassland, agricultural land, and water bodies (water-covered areas). During our field work, we investigated at least one sampling plot in each USU with stratified sampling. In each sampling plot, we recorded height, diameter at breast height (DBH), and origin for the tree species; height, cover, and origin for the shrubs; and cover, abundance, and origin for the herbs. We also included other biophysical information (e.g. longitude, latitude, and distance to urban center).

At the landscape level, we have identified a total of 453 USUs belonging to 12 primary USU types and to 38 different secondary USU types (see Wang *et al*., 2013, for a detailed explanation on the types of USUs). The percentage of built-up, green, and water-covered areas varied across the different urban structural units (of the 38 secondary USU types,

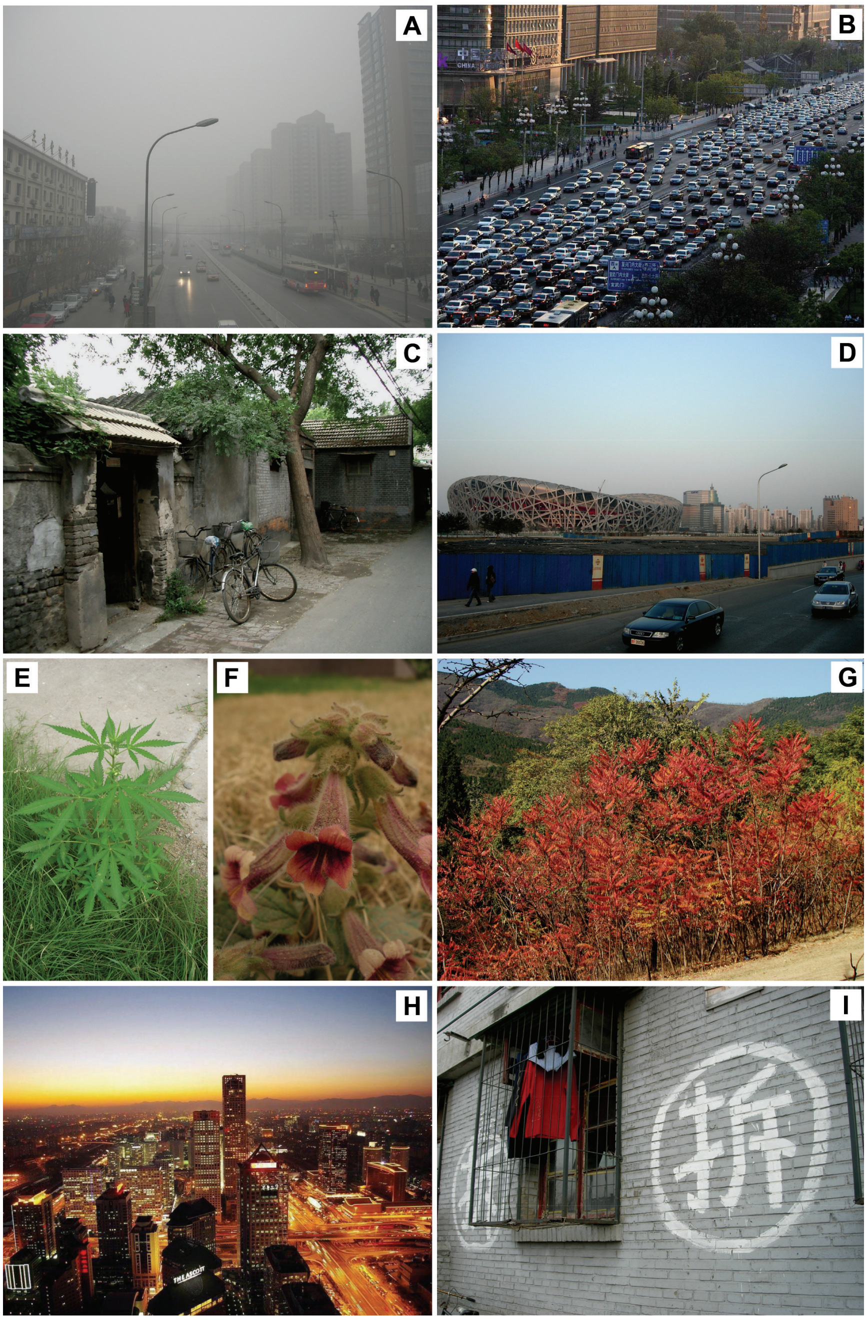

Figure 1. (A), smoggy day in Zhongguancun quarter, NW part of Beijing (photograph: J. López-Pujol); (B), traffic jam in Chang'an Avenue, central Beijing (photograph: http://en.wikipedia.org/wiki/Chang'an_Avenue#mediaviewer/File:Chang%27an_avenue_in_Beijing.jpg); the number of private cars has suffered a huge increase during the last 25 years (in 1987, Beijing had only 7000 private cars, at the end of 2011, the number of cars almost reached 4 million; BMBS, 2012); (C), *siheyuan* area, central Beijing (photograph: J. López-Pujol); (D), construction works in the Beijing Olympic Park, in early 2008 (photograph: J. López-Pujol); (E), *Cannabis sativa* L., a naturalized plant very common in all the districts of Beijing Municipality; this individual was growing in the pavement of a residential area near Beijing Botanical Garden (photograph: J. López-Pujol); (F), *Rehmannia glutinosa* (Gaertn.) Libosch. ex Fisch. & C. A. Mey., one of the most important plant species used in Traditional Chinese medicine (*Sheng Di Huang*, 生地黄); this individual was growing spontaneously in a residential area near Beijing Botanical Garden (photograph: J. López-Pujol); (G), individuals of *Rhus typhina*, an invasive species of North American origin, growing in mountainous areas of Beijing Municipality (photograph: H.-F. Wang); (H), skyline of Beijing Central Business District, Chaoyang District, eastern Beijing (photograph: http://en.wikipedia.org/wiki/Beijing#mediaviewer/File:BeijingCBD-2007-8.JPG); (I), the character chai (拆), which means "to demolish", it is a commonplace in Beijing and symbolizes the quickly evolution of the city (photograph: J. López-Pujol).

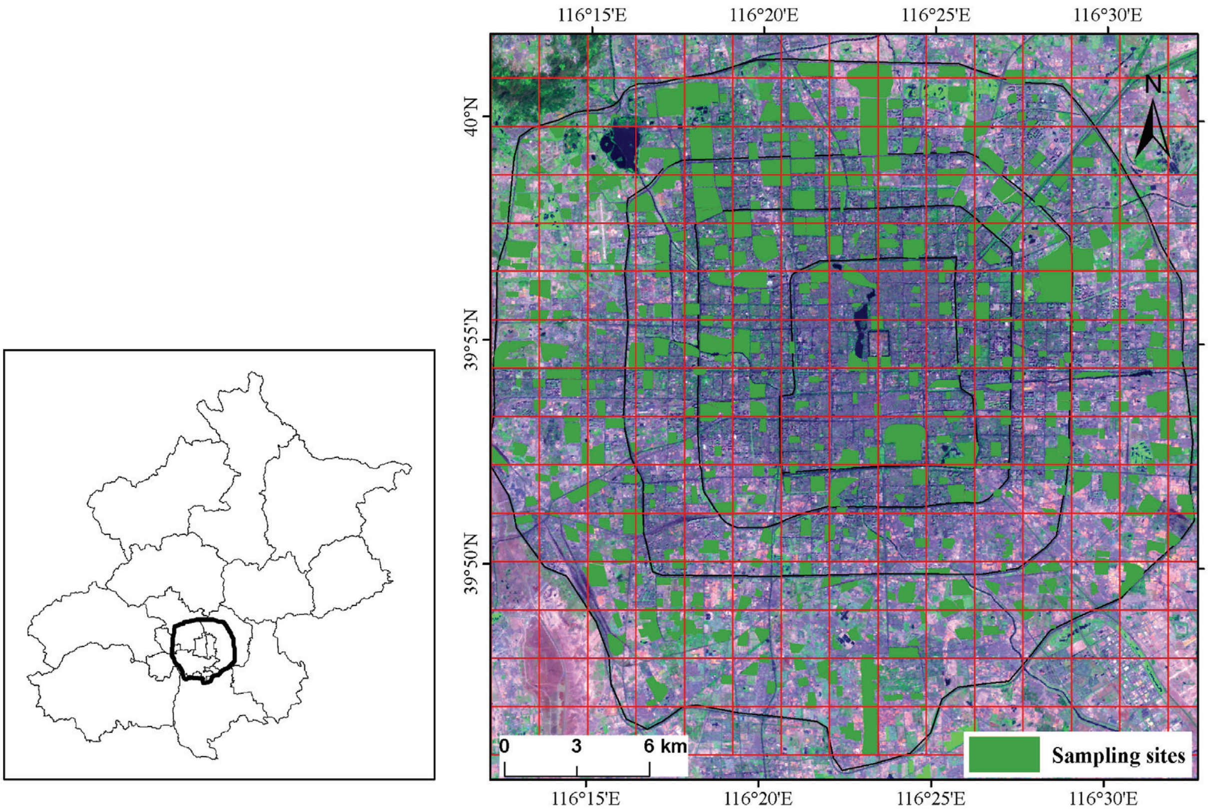

Figure 2. Sampling sites within the fifth ring of Beijing (remote sensing image: SPOT-5, *Satellite Pour l'Observation de la Terre*).

only 22 were used for our analyses; Fig. 3). The percentage of built-up area was highest in those regions with hotels (84.9%), and lowest in areas with primary and middle schools (16.4%). The percentage of woodland area was highest in primary and middle schools (69.4%), and lowest in entertainment plazas (7.2%). The percentage of grassland area was highest in farmland or orchards (22.7%), and lowest in *siheyuan* (0.4%; *siheyuan* are Beijing's historical courtyards; Fig. 1C). The percentage of mixed woodland and grassland was highest in public squares (16.1%), and lowest again in *siheyuan* (0.05%). The percentage of water-covered areas was highest in areas containing government properties (23.1%), although water-covered areas were totally absent in several types of urban structural units (Fig. 3). The percentage of agricultural land was highest in business/enterprise zones (6.1%), and totally absent in several types of urban structural units (Fig. 3). Finally, the percentage of green space (considering "green space" as the sum of woodland, grassland, and mixed woodland–grassland) was highest in primary and middle schools (82.8%), and lowest in areas with hotels (15.1%). There was no significant correlation between the percentage of green space and construction period in colleges/universities, parks and high-density residential areas (the USU types for which we had enough sample sizes to carry out statistical analysis). However, there was an "inverted-U curve" relationship between the housing price and green space percentage in residential areas, which can be described by the equation: $f = 17736.45 + 348.21x - 4.15x^2$, $p = 0.0022 < 0.05$. This relationship implies that socio-economic factors like housing prices may have a role in determining the pattern of urban ecosystems in Beijing (Wang *et al*., 2013).

At the plant species level, within the fifth ring road we found 551 plant species of 313 genera and 103 families, of which 118 were trees, 99 shrubs, and 296 herbs. Nearly half (48.3%) of the total plant species were aliens, and these predominated in the shrub/tree layers (68.4%) but not in the herb layer (31.1%). Only 7.7 and 1.9% of the plant genera found in Beijing urban areas were endemic to East Asia and to China, respectively. Species richness

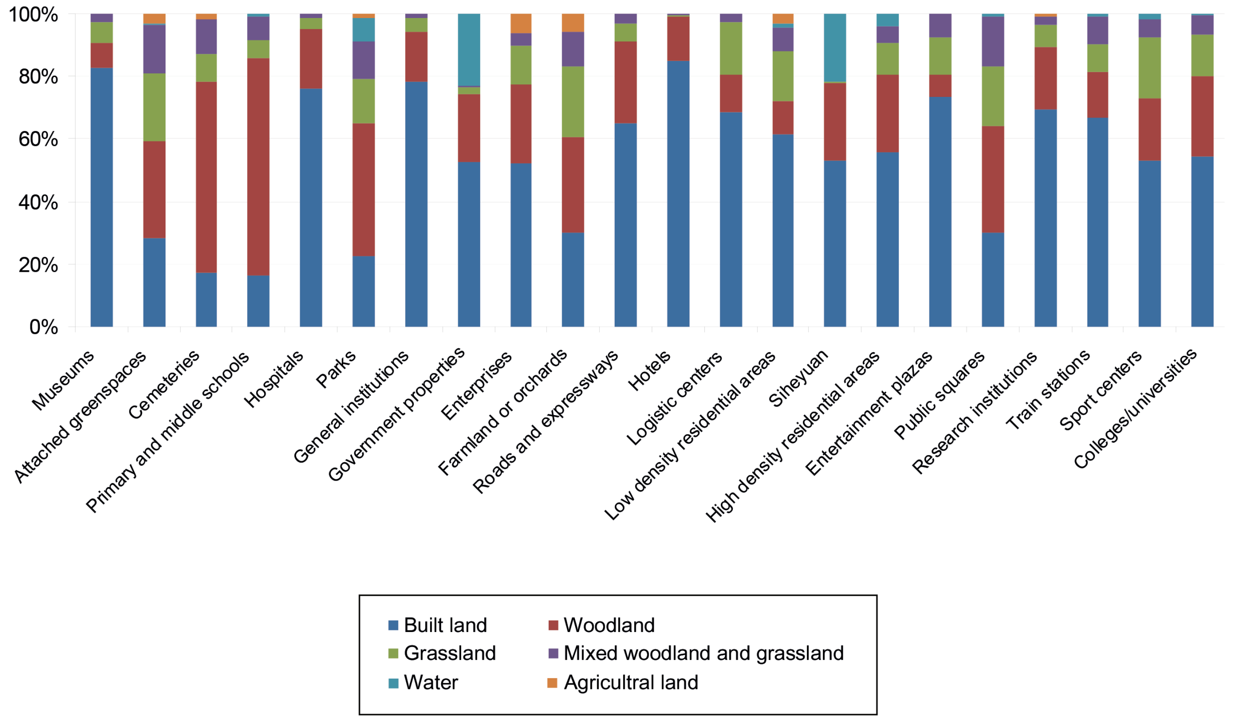

Figure 3. Percentage of each kind of land cover area in the 22 secondary urban structural units of Beijing (for more details, see Wang *et al*., 2013).

and density were positively correlated both for tree/shrub and herb taxa. This correlation may indicate that, although some species predominate in our study area (such as some tree species widely planted along the city streets, e.g. *Populus tomentosa* Carrière var. *tomentosa*, *Magnolia denudata* Desr., and *Juniperus chinensis* L.), there is an important array of species in relation to their densities. Most of the socio-economic variables studied were related to at least one of the four plant diversity variables (herb richness, herb density, tree/shrub richness, and tree/shrub density). Land use showed a significant relationship in all four cases, which generally had lower values in cultural and educational institute-dominated areas (areas that in Beijing are generally characterized by large extensions of urbanized land). Notably, tree/shrub density values were significantly higher in residential areas, which is at least partly due to traditional beliefs: for example, some trees such as *Juniperus chinensis*, *Pinus tabuliformis* Carrière var. *tabuliformis*, and *Platycladus orientalis* (L.) Franco are commonly planted in *siheyuan* areas because of their traditional association with longevity (Profous, 1992). The year of a given area's establishment was also largely related to plant diversity, with higher diversity indices in more recently developed areas. This result was expected given the dynamics of the urban development of Beijing during the last 60 years: intense "urban sprawling" (peaking during the 1980 and the 1990s), followed by more environmentally-friendly urbanization practices during the 2000s related to the greening of the city for the 2008 Olympic Games (Fig. 1D; Wang *et al*., 2012).

Also at the plant species level, we have made a detailed study of the patterns of biological invasions in Beijing, which was carried out not only for the city center but also throughout the entire Municipality. We compiled a comprehensive list of naturalized and invasive species and their associate traits (distribution, habit, life form, habitat, geographic origin, and mode of introduction). One hundred and twelve naturalized (including 48 invasive) plants were identified within the Beijing Municipality. Although these numbers can be regarded as "modest" compared to other large Asian cities such as Shanghai, Hong Kong, or Singapore (see Table 3 in Wang *et al*., 2011), they represent a significant fraction of the alien species richness reported for the entire country: namely, up to one-quarter of the total naturalized flora of China (420 to 861 species; Wu *et al*., 2010; Jiang *et al*., 2011) and one-fifth of

Figure 4. Different scenes taken during fieldwork of Hua-Feng Wang in Beijing (China). (A), residential area of the 1980s; (B), residential area of the 1990s; (C), residential area of the 2010s; (D), Hua-Feng Wang is working in the field (Photographs: H-F. Wang).

the invasive flora of China (270 to 488 plant species; Weber *et al*., 2008; Xu *et al*., 2012). Moreover, finding 112 naturalized species represents a *ca.* 23% increase from the previous report of Liu *et al*. (2002), suggesting that biological invasions in Beijing have increased over the last decade. Some of the invasive species observed by us are among the most noxious invaders in China, such as *Alternanthera philoxeroides* (Mart.) Griseb., *Ambrosia trifida* L., *Lolium temulentum* L., *Solidago canadensis* L., and *Sorghum halepense* (L.) Pers. Most of the naturalized and invasive plants belonged to six families (Asteraceae, Poaceae, Amaranthaceae, Euphorbiaceae, Brassicaceae, and Fabaceae) and are annual herbs that preferentially grow in disturbed sites (e.g. roadsides and waste places). North and South America were the main sources of the naturalized and invasive flora of Beijing (with almost half of the species having this origin; Fig. 1G). Beijing districts that have recently experienced the highest human population growth, the greatest urban expansion (to cope with the huge demand for new housing, as the inner districts have been completely urbanized since the 1960s), and the largest economic growth were also those with the highest number of naturalized and invasive species. Managed green spaces in urban districts (i.e. street trees, lawns, urban and residential gardens, and parks) would have a major role for the growing number of naturalized plants in Beijing. Green areas substantially increased in number during recent years to prepare the city to host the 2008 Olympic Games (during the period 2001–2007, over 700 spaces were built in the downtown—an increase of nearly 9000 ha; UNEP, 2009).

CONCLUSIONS AND RECOMMENDATIONS

After a decade of uninterrupted study of Beijing's urban flora, we have two main concerns about China's future urban green space and plant diversity research. First, as a subdivision of modern ecology, urban ecology is also focused on the relationships between biological organisms and their surrounding environment. In urban ecosystems, the main biological organisms are the same as those in other settings, with the notable exception of humans, who obviously play a very important role in the urban ecosystem. Conversely, the environment in the urban ecosystem is comparatively more fragmented and heterogeneous than other ecosystems such as agricultural or grassland ecosystems. One of the main obstacles that urban studies typically face is the limited access to data for some of main driving variables, especially those related to socio-economic features of urban areas (e.g. household income, race, education level, population density, etc.). In contrast, physical variables are usually readily determined, as these are typically collected within the ecosystem (e.g. rainfall, temperature, and soil properties). In American urban ecology studies, researchers can get high resolution socio-economic variables from the National Aeronautics and Space Administration (NASA) (Fink *et al*., 2003) or companies such as Nielsen and its PRIZM geo-demographic segments for the United States (Grove *et al*., 2006). However, in Chinese cities, researchers cannot access high resolution socio-economic data at present, due to a series of shortcomings on the frequency of censuses (every ten years at best), on the quality of statistics collected by government agencies, and on the reliability of official statistics. For instance, we can acquire basic data, such as information about the population of each district in Beijing from the Beijing Statistic Yearbook series, but we cannot get more useful statistics at a finer scale; e.g. there is no way to know how many people are living in a given community, how many of them are foreigners, how old they are, what their education level is, what their income is, and so on. These factors, as demonstrated elsewhere (reviewed in Table 2 of Wang *et al*., 2012) can affect urban vegetation/plant structure, composition and origin, among other variables. Therefore, China's future urban ecology studies still have a long way to go to understand how human (socio-economic) drivers have molded biodiversity patterns in urban areas.

Second, urban ecology is a relatively new discipline in China. In 1978, China was a rural country (only 20% of the population lived in cities in that time); however, between 1978 and 2012 China's urban population increased by more than a half billion people (today, the percentage of urbanization has reached 52%), and the urban population is expected to increase by about 250 million more over the next two decades (World Bank, 2014). Thus, field data are badly needed in order to reveal the patterns of urban ecology in China as well as the drivers that give rise to those patterns. Urban ecologists usually do "plant sampling" in cities in the same manner as forest ecologists do "vegetation sampling" in forests. However, the heterogeneity of the Chinese urban matrix is very high; in Beijing, for example, very ancient one-story *siheyuan* areas from the Ming Dynasty coexist with late-19th century districts and some of the most modern high-rise buildings in the world; Fig. 1H). As a result, it is challenging to find enough 20 × 20 m sampling sites in urban settings. In our opinion, the position and size of plots in urban plant sampling should take the land use features into consideration, and urban ecologists should adopt flexible standards for sampling comprehensively and representatively. Moreover, urban ecology also needs long-term, continuous monitoring data to support its hypotheses and this, again, is of particularly significance in China, whose cities evolve so quickly.

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REFERENCES

BMBS (Beijing Municipal Bureau of Statistics) 2012. 2012 年北京统计年鉴 [*Statistical yearbook of Beijing 2012*]. China Statistics Press, Beijing [in Chinese].

Cadotte, M. W., Cardinale, B. J. & Oakley, T. H. 2008. Evolutionary history and the effect of biodiversity on plant productivity. *Proceedings of the National Academy of Sciences of the United States of America* 105: 17012–17017. http://dx.doi.org/10.1073/pnas.0805962105

Fink, J., Steiner, F., Grimm, N. B. & Redman, C. L. 2003. Greater Phoenix 2100: building a national urban environmental research agenda. In: Heiken, G., Fakundiny, R. & Sutter, J.

(Eds.), *Earth science in the city: A reader*. American Geophysical Union, Washington, DC: 413–426. http://dx.doi.org/10.1029/sp056p0413

Gill, S. E., Handley, J. F., Ennos, A. R., Pauleit, S., Theuray, N. & Lindley, S. J. 2008. Characterising the urban environment of UK cities and towns: A template for landscape planning. *Landscape and Urban Planning* 87: 210–222. http://dx.doi.org/10.1016/j.landurbplan.2008.06.008

Grove, J. M., Cadenasso, M. L., Burch Jr., W. R. *et al*. 2006. Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. *Society and Natural Resources* 19: 117–136. http://dx.doi.org/10.1080/08941920500394501

Haw, S. G. 2007. *Beijing – a concise history*. Routledge, Oxon.

Jiang, H., Fan, Q., Li, J.-T., Shi, S., Li, S.-P., Liao, W.-B. & Shu, W.-S. 2011 Naturalization of alien plants in China. *Biodiversity and Conservation* 20: 1545–1556. http://dx.doi.org/10.1007/s10531-011-0044-x

Liu, Q. R., Yu, M. & Zhou Y. 2002. 北京地区外来入侵植物的初步研究 [A preliminary study on the invasive plants in Beijing]. *Journal of Beijing Normal University (Natural Science)* 38: 399–404 [in Chinese].

McPherson, E. G., Nowak, D., Heisler, G., Grimmond S., Souch C., Grant, R. & Rowntree, R. 1997. Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems* 1: 49–61. http://dx.doi.org/10.1023/A:1014350822458

Peckham, S. C., Duinker, P. N. & Ordóñez, C. 2013. Urban forest values in Canada: Views of citizens in Calgary and Halifax. *Urban Forestry & Urban Greening* 12: 154–162. http://dx.doi.org/10.1016/j.ufug.2013.01.001

Profous, G. V. 1992. Trees and urban forestry in Beijing, China. *Journal of Arboriculture* 18: 145–154.

Tyrväinen, L., Pauleit, S., Seeland, K. & Vries, S. de 2005. Benefits and uses of urban forests and trees. In: Konijnendijk, C., Nilsson, K., Randrup, T. & Schipperijn, J. (Eds.), *Urban forests and trees – A reference book*. Springer, Berlin & Heidelberg: 81–114. http://dx.doi.org/10.1007/3-540-27684-X_5

UNEP (United Nations Environment Programme) 2009. *Independent environmental assessment Beijing 2008 Olympic Games*. UNEP, Nairobi.

Wang, H.-F., López Pujol, J., Meyerson, L. A., Qiu, J.-X., Wang, X.-K. & Ouyang, Z.-Y. 2011. Biological invasions in rapidly urbanizing areas: a case study of Beijing, China. *Biodiversity and Conservation* 20: 2483–2509. http://dx.doi.org/10.1007/s10531-011-9999-x

Wang, H.-F., MacGregor-Fors, I. & López-Pujol, J. 2012. Warm-temperate, immense, and sprawling: Plant diversity drivers in urban Beijing, China. *Plant Ecology* 213: 967–992. http://dx.doi.org/10.1007/s11258-012-0058-9

Wang, H.-F., Qiu, J.-X., Breuste, J., Ross Friedman, C., Zhou, W.-Q. & Wang, X.-K. 2013. Variations of urban greenness across urban structural units in Beijing, China. *Urban Forestry & Urban Greening* 12: 554–561. http://dx.doi.org/10.1016/j.ufug.2013.05.004

Weber, E., Sun, S. G. & Li, B. 2008. Invasive alien plants in China: diversity and ecological insights. *Biological Invasions* 10: 1411–1429. http://dx.doi.org/10.1007/s10530-008-9216-3

WHO (World Health Organization) 2014. *WHO's Ambient Air Pollution database – Update 2014*. WHO, Geneva. Retrieved November 7, 2014, from http://www.who.int/phe/health_topics/outdoorair/databases/AAP_database_results_2014.pdf?ua=1

Wong, E. 2014. 'Airpocalypse' smog hits Beijing at dangerous levels. *The New York Times*, January 16, 2014. Retrieved November 7, 2014, from http://sinosphere.blogs.nytimes.com/2014/01/16/airpocalypse-smog-hits-beijing-at-dangerous-levels/?_php=true&_type=blogs&_php=true&_type=blogs&_r=1

World Bank 2014. *Urban China: Toward efficient, inclusive, and sustainable urbanization*. World Bank, Washington, DC.

Wu, S.-H., Sun, H.-T., Teng, Y.-C., Rejmánek, M., Chaw, S.-M., Yang, T.-Y. A. & Hsieh, C.-F. 2010. Patterns of plant invasions in China: taxonomic, biogeographic, climatic approaches and anthropogenic effects. *Biological Invasions* 12: 2179–2206. http://dx.doi.org/10.1007/s10530-009-9620-3

Wu, W. & Zheng, X. 2014. Beijing considers 'air corridors' to reduce pollution. *China Daily*, August 4, 2014. Retrieved November 14, 2011, from http://www.chinadaily.com.cn/china/2014-08/04/content_18240394.htm

Xu, H., Qiang, S. & Genovesi, P. *et al*. 2012. An inventory of invasive alien species in China. *NeoBiota* 15: 1–26. http://dx.doi.org/10.3897/neobiota.15.3575

Zhang, J. 2013. Greening Beijing's rooftops. *China Daily*, October 22, 2013. Retrieved November 14, 2011, from http://www.chinadaily.com.cn/opinion/2013-10/22/content_17049480.htm