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

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

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

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ABSTRACT

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

1. Introduction

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

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

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

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

1.2. Socio-economic forces behind urban plant diversity

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

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

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

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

1.4. Aims of this study

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

2. Methodology

2.1. Study area

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

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