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Research Paper

Patterns and drivers of plant biodiversity in Chinese university campuses

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ABSTRACT

Urban biodiversity is strongly correlated with human well-being and is quickly becoming a new research field. Most previous studies in this field focus on patterns of species richness but few consider species and trait compositions and how these are shaped by anthropogenic and environmental drivers. Such information, however, is critical for effective planning and management of urban species. We compiled published species lists from 71 Chinese university campuses. We also collected environmental data for each campus, including anthropogenic (campus age and area) and environmental variables (climate and topography), to explore the distribution patterns and the drivers of species richness, composition and traits. We found that university campuses in China maintain substantial plant diversity, including at least 1565 woody and 1614 herbaceous species. The distribution pattern of campus species richness was mostly driven by anthropogenic variables, being positively correlated with campus age and size. In contrast, campus species composition and leaf traits were mostly driven by climate variables. This was especially true for woody plants of which campus species composition and traits were more constrained by mean annual temperature than herb species. Our study provides a basic but diverse database for the selection of campus plants, which can benefit the management of urban ecosystems. Our results reveal that landscape design can influence urban species richness, species composition is still restricted by the natural environment. Hence, many endangered species can be protected in these human-friendly urban ecosystems if they have suitable traits adapted to local climatic conditions.

1. Introduction

Recently, scientists have pointed out the importance of urban biodiversity for the maintenance of ecosystem services and well-being of local citizens (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Miller, 2005; Zhang & Jim, 2014). However, although more than half the world's people live in cities (McKinney, 2002), ecological theories still have contributed relatively little to the management of city species because ecologists have shunned urban areas for most of the 20th century (Grimm et al., 2008). Therefore urban ecosystems provide an unexploited opportunity for ecological research (McDonnell & Pickett, 1990), especially on the management of urban species and the restoration of urban green ecosystems (Wang et al., 2014). How to translate biodiversity conservation theories into practical urban management is an important question today.

Cities can harbor high species richness, even in the most densely populated parts (Araújo, 2003; Luck, 2010). One reason for this could be that cities are generally located in resource rich environments that were already species rich before urbanization (Kuhn, Brandl, & Klotz, 2004; Luck, 2007). Another important reason could be that cities contain a large range of highly fragmented landscape elements of differing disturbance levels (Rebele 1994). Such diversity in environments can maintain high species richness (Wania, Kühn, & Klotz, 2006). On the other hand, urbanization also reduces green spaces and fragments existing habitats in smaller and smaller parcels, which in turn can cause local extinction of native species and replacement by alien species. Urbanization can therefore also be a major driver of biotic homogenization and species loss (Knapp, Kühn, Schweiger, & Klotz, 2008; McKinney, 2006). Even when high species richness is observed in cities, this diversity may represent a limited group of species with similar traits that are found across all cities (i.e., high alpha-diversity combined with low beta-diversity). For instance, although total dung beetle species richness does not decrease with urbanization intensity, species specialized for live in forests do decline or disappear completely (Magura, Lövei, & Tóthmérész, 2010). So cities can provide opportunities for surprisingly rich floras, but the species that survived in cities may be limited by their specific traits (Thompson & McCarthy, 2008). Therefore, understanding the patterns of biodiversity in urban ecosys-

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tems requires not only information on species richness but also species composition. Trait-based approaches may be especially useful to understand how species with different environmental affinities react to land use change (Knapp et al., 2009).

Understanding the mechanisms that explain species and trait composition in artificial ecosystems is essential for the development of efficient strategies that enhance the ecological and functional value of urban areas. Previous studies found that changes in plant species and trait composition in natural systems were affected mostly by climate and soil parameters (Ordoñez et al., 2009; Svenning & Skov, 2005). Given the large influence of anthropogenic factors, such as urbanization related land use changes and socio-economic factors (Andersson & Colding, 2014; Golding et al., 2010), this pattern is likely to be more complex in non-natural urban systems. For example, short-statured, small-seeded species are more likely to go extinct in cities (Duncan et al., 2011). To date, few studies have assessed the importance of local environmental conditions and anthropogenic factors in shaping plant species composition in urban areas, due to lack of basic field-based investigation.

We studied how anthropogenic factors (campus age, campus size) and environmental factors (climate, topography) affect plant diversity and composition on university campuses across China. University campuses provide useful systems to understand how urbanization affects plant species richness and composition for several reasons. Firstly, universities are home to many botanists who have an active interest in plant diversity (Moerman & Estabrook, 2006) which has led to many reliable campus plant surveys and most universities keeping good records of their campus plant diversity (e.g. Xiamen University: http://xmuplant.sinaapp.com/). Secondly, universities, because of their similar functions and relatively homogenous conditions are especially suitable for comparisons across large spatial and environmental scales. Thirdly, there are about 2000 universities in China, meaning that there is a wealth of data to be analyzed. Our study is the first to investigate the large-scale biodiversity patterns across university campuses in China.

This paper aims to disentangle the relative contributions of anthropogenic and environmental factors in explaining species diversity, composition and trait composition patterns across Chinese university campuses. Our main questions are: 1) how many species are there in China's university campuses? 2) What are the drivers of observed patterns in species richness, composition and trait composition? 3) Do these findings have any implications for biodiversity conservation in urban regions?

2. Methods

2.1. Campus plant lists

We searched the China National Knowledge Infrastructure website (http://www.cnki.net/), a database containing most papers published in China, on campus plants to find articles that published herbaceous and woody plant lists. We used only those lists with plants identified to species level. For articles about campus plants that did not publish the plant lists themselves we contacted the authors with the question to provide these lists. We tried to include at least one university campus from each province in China. We also performed a search on Baidu (www.baidu.com) and Google (www.google.com) to find online databases of campus plants (Supplementary information Table S1). In total, we found 71 campuses with woody plant species records, mostly from southern and eastern China. Forty-one of these also included herb species lists with more than 20 species (Fig. 1). We standardized the plant classification using APG III (2009). We focus only on seed plants, hence, records from bryophytes and ferns were removed from our analysis. Unfortunately, we were unable to differentiate between planted and naturally established plant species in the campuses due to the diverse methods used in each of the inventories. Species were grouped into different IUCN red list categories using the China species red list (Wang, 2004) and checked whether the species were native or exotic to China using the Chinese Database of Invasive Alien Species (http://www.chinaias.cn/wjPart/SpeciesSearch.aspx).

Leaf traits have been shown to be good indicators of plant performance and are widely used as a reflection of environmental conditions (Ordoñez et al., 2009; Wright et al., 2005). For example, leaf traits, such as leaf size, are routinely used to rebuild paleoclimates (Malhado et al., 2009; Royer, Wilf, Janesko, Kowalski, & Dilcher, 2005). Therefore, we used maximum leaf length and width as an index for our trait analysis. To do this, we extracted the maximum leaf length and width data of all studied species from the Flora of China (http://www.efloras.org/index.aspx). For species with compound leaves, we used the leaflets as measuring units. Leaf size was calculated with the equation from (Kraft, Valencia, & Ackerly, 2008) (Size = Length*Width*0.7).

2.2. Predictors of biodiversity patterns

We collected data for several environmental variables, including natural and anthropogenic factors that we thought might affect plant diversity on university campuses. We extracted latitude, longitude and elevation data for each campus using Google Earth. We retrieved climate variables (mean annual temperature, mean annual rainfall, minimum and maximum temperature) either from the records kept by the universities themselves (preferred) or using data from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/shishi/climate.jsp). We used campus descriptions to determine their area size (range from 5.87 to 400 ha) and age (range from 1 to 117 years) at the time when plants were surveyed (Table 1).

2.3. Data analysis

We conducted data analyses using the R software (Team, 2014), unless otherwise specified. We first constructed data for our response variables. Species richness is the total number of species recorded in the campus which we obtained directly from the species lists. To evaluate the pattern of species composition in relation to local environmental conditions, we performed detrended correspondence analysis based on presence/absence data in the *vegan* package (Oksanen et al., 2007), and used DCA1 (Eigenvalue: 0.601) as an index for species composition, as this represents the main floristic gradient. For plant functional traits, we calculated the average value of leaf length and width for herbs and woody species for each campus separately.

To check for the normality of the response variables, we used the Shapiro test and found that both the species richness and leaf traits composition data were not normally distributed. Log-transformation was used to make these variables normal. Afterwards we tested whether our data was spatially biased by using Moran's I in 'Spatial Analysis in Macroecology' software (Rangel, Diniz, & Bini, 2010). No spatial autocorrelation was detected in our study (Moran's I < 0.05).

We used ordinary least squares multiple regression to regress species richness, species composition and traits composition respectively against the site environmental predictors: mean annual temperature (MAT), mean annual rainfall (MAR), maximum temperature (MaxT) and minimum temperature (MinT), elevation and anthropogenic predictors (campus size, campus age) for the last 30 years. Regression models for all possible combinations of response and predictor variables were calculated after which the optimal models were selected based on the lowest AICc scores. We assessed the variation explained by environmental and anthropologic predictors using partial regression with Spatial Analysis in Macroecology software. We ran separate regression on woody plants and herbs. Graphical output was generated using "ggplot2" package (Wickham & Chang, 2012).