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, Brändl, & 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 florals, 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-
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 & Golding, 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.sinapp.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.chinaaias.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 inMacroecology’ 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).
3. Results

3.1. How many plant species are there in Chinese universities?

In total, 3179 species were found in 71 campuses (Supplementary information Table S2), among which 1565 species were woody species and 1614 herbaceous species (12 ferns, 96 lianas and 2 vine species were excluded from our analysis). The most frequent species were *Salix babylonica* and *Lagerstroemia indica* (shown in 53 campuses) (Table 1). Among the 1345 genera the most common were *Acer, Ficus, Phyllostachys* and *Rhododendron*. The most diverse campus inventoried was Northwest Agriculture & Forestry University (454 woody species and 589 herbaceous species). Most campuses had an average species richness of about 100 species for both woody (average: 91.6, range from 17 to 454) and herbaceous (average: 107.6, range from 19 to 585) plants. Thirty of the listed species were present in the China Red List, with 1 species rated critically endangered, 7 rated endangered, and 22 rated vulnerable. Chinese universities also hosted numerous alien plant species (140 herbaceous species and 25 woody species).

There was a positive relationship between the number of species and the number of genera with a very steep slope of about one new genus recorded for every 1.5 species (Genus richness = 0.62*Species + 28.72, n = 41, \( r^2 = 0.97 \)). Additionally, species richness of woody plants was significantly correlated with richness of herbs (n = 41, \( r^2 = 0.25, p < 0.001 \)).

3.2. Patterns and drivers of species richness, composition and traits composition

Species richness of herbs and woody plants combined, was completely driven by anthropogenic factors (Table 2). Regression analysis showed that most of this was explained by campus age (Pearson’s test, n = 41, \( r = 0.536, p < 0.001 \)) and marginally by campus size (\( r = 0.301, p = 0.053 \)) (Fig. 2). There was a negative trend between species richness and elevation (\( r = -0.259, p = 0.100 \)).

When woody plants and herbs were analyzed separately, environmental conditions became more prominent (Table 2). There was a positive relationship between species richness of woody plants and mean annual temperature (n = 71, \( r = 0.415, p < 0.001 \)). However, environmental factors had only limited effect on richness of herbaceous plants, which remained mostly driven by campus age (n = 41, \( r = 0.456, p = 0.003 \)).

Species composition (indicated by DCA1) of herbs and woody plants combined was mostly associated with environmental variables (total variation explained: 0.864, Table 2). DCA1 was strongly positively correlated with mean annual temperature both for woody and herbaceous species.

![Studied university campuses in China](image)

**Fig. 1.** Locations of the studied university campuses. Stars indicate the campuses that had species lists that included both woody plants and herb, white dots indicate campuses where species lists included only woody plants.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Woody plants</th>
<th>Herbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studied sites</td>
<td>71</td>
<td>41</td>
</tr>
<tr>
<td>Campus age (year)</td>
<td>1–117</td>
<td>1–117</td>
</tr>
<tr>
<td>Campus size (ha)</td>
<td>5.87–400</td>
<td>5.87–366.36</td>
</tr>
<tr>
<td>Elevation range (m)</td>
<td>4–3650</td>
<td>4–2317</td>
</tr>
<tr>
<td>MAT range (°C)</td>
<td>3.2–23.8</td>
<td>3.2–23.8</td>
</tr>
<tr>
<td>Number of records</td>
<td>8025</td>
<td>4451</td>
</tr>
<tr>
<td>Number of species</td>
<td>1565</td>
<td>1614</td>
</tr>
<tr>
<td>Top 5 species</td>
<td><em>Lagerstroemia indica, Salix babylonica, Rosa chinensis, Ginkgo biloba, Osmanthus fragrans</em></td>
<td><em>Salvia splendens, Caesalpinia indica, Oxalis corniculata, Nymphaea tetragona, Capella bursa-pastoris</em></td>
</tr>
<tr>
<td>Leaf length range (cm)</td>
<td>0–300</td>
<td>0–300</td>
</tr>
<tr>
<td>Leaf width range (cm)</td>
<td>0–70</td>
<td>0–200</td>
</tr>
</tbody>
</table>

**Table 1**

Summarized information of the campuses in China used in this study. MAT = Mean Annual Temperature.
eous plants (Fig. 3), rather than anthropogenic factors (Table 2). When herbs and woody plants were analyzed separately, the amount of compositional change explained by the environment was higher for woody plants (0.878) than for herbaceous plants (0.431) (Table 2).

Leaf length of herbs was longer than that of woody plants (t test: $t = -5.111$, $n = 41$, df = 48.184, $p < 0.001$), but leaf width did not differ ($t = 0.638$, df = 46.039, $p = 0.527$). Both the community weighted leaf value of length and width were more driven by environmental factors than by anthropogenic factors (Table 2). Specifically, leaves were significantly longer and wider in areas with higher mean annual temperature (Fig. 4). For woody plants, both leaf width ($n = 71$, $r = -0.409$, $p < 0.001$) and length ($n = 71$, $r = -0.251$, $p = 0.035$) decreased significantly with elevation, but no relationship was found between leaf traits and elevation for herbs ($n = 41$, $p > 0.05$). Leaf size was also mostly affected by climate variables, with little influence of campus age for woody plants (Table 2). Again, traits of woody plants were more sensitive to climate than herb species were (Table 2).

### Table 2

<table>
<thead>
<tr>
<th>Type</th>
<th>n</th>
<th>Best model</th>
<th>$r^2$</th>
<th>Explained variation by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Environmental</td>
</tr>
<tr>
<td>Woody plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species richness</td>
<td>71</td>
<td>Area**+(0.126) + Age**+(0.145) - Elev (ns) + MAT**+(0.172)</td>
<td>0.38</td>
<td>0.213</td>
</tr>
<tr>
<td>DCA1</td>
<td>71</td>
<td>MAT(0.854***) + MinT(0.803***) - Age(ns)</td>
<td>0.894</td>
<td>0.878</td>
</tr>
<tr>
<td>Length</td>
<td>71</td>
<td>MAT(0.658***) - Elev(ns)</td>
<td>0.658</td>
<td>0.658</td>
</tr>
<tr>
<td>Width</td>
<td>71</td>
<td>MAT(0.31***) - Elev(0.168**)</td>
<td>0.369</td>
<td>0.369</td>
</tr>
<tr>
<td>Leaf size</td>
<td>71</td>
<td>MAT(0.532***) - Age(ns)</td>
<td>0.593</td>
<td>0.532</td>
</tr>
<tr>
<td>Herbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species richness</td>
<td>41</td>
<td>MAT(ns) + Age(0.208***)</td>
<td>0.233</td>
<td>0.025</td>
</tr>
<tr>
<td>DCA1</td>
<td>41</td>
<td>MAT(0.431***)</td>
<td>0.431</td>
<td>0.431</td>
</tr>
<tr>
<td>Length</td>
<td>41</td>
<td>MAT(0.256***)</td>
<td>0.256</td>
<td>0.256</td>
</tr>
<tr>
<td>Width</td>
<td>41</td>
<td>MAT(0.169***)</td>
<td>0.169</td>
<td>0.169</td>
</tr>
<tr>
<td>Leaf size</td>
<td>41</td>
<td>MAR(0.123**)</td>
<td>0.123</td>
<td>0.123</td>
</tr>
<tr>
<td>Woody plants + Herbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LogSpecies</td>
<td>41</td>
<td>Area(0.263***) + Age(ns)</td>
<td>0.323</td>
<td>0</td>
</tr>
<tr>
<td>DCA1</td>
<td>41</td>
<td>Age(0.008*) + MAT(0.855***) - MinT(ns)</td>
<td>0.88</td>
<td>0.864</td>
</tr>
</tbody>
</table>

Fig. 2. The relationship between total species richness, and campus area and age. Solid lines represent the model fit and shaded areas represent 95% confidence intervals.

Fig. 3. The relationship between DCA axis 1 and mean annual temperature for woody and herbaceous species.

### 4. Discussion

#### 4.1. Conservation value of university campuses

An increasing number of studies have recognized the importance of urban ecosystems in the maintenance of biodiversity. Green infrastructure such as green roofs (Williams, Lundholm, & Maclvor, 2014), backyards (Knapp et al., 2012) and public parks (Li, Ouyang, Meng, & Wang, 2006) can support the habitats for many species including beetles, birds and bats. We emphasize the important role of university campuses, which not only provide educational and enjoyment benefits for especially students living there but also provide considerable biodiversity benefits. We found high species richness in these university campuses. Although our study area was less than 0.0008% of China’s...
total surface area, about 10% of China’s vascular plant species were found, indicating that campuses can maintain high species richness, and even contain some endangered species listed on China’s Red list. On average, there are about 100 woody plant species in each campus, with some universities having more than 500 woody species. These results highlight the conservation value of university campuses, which may therefore play a similar role in the maintenance of plant diversity as botanical gardens (Pautasso & Parmentier, 2007). In addition, universities are home to many botanists who have an active interest in plant diversity (Moerman & Estabrook, 2006). The high species richness in university campuses provide an ideal starting point for environmental education and the increase of human well-being in these artificial landscapes (Fuller et al., 2007; Havens et al., 2006).

4.2. Drivers of species richness

Plant species richness in university campuses was mainly driven by anthropogenic factors, specifically, diversity increased with campus age and size. This corresponds to results found by a global study which revealed that the species–area relationship is congruent between cities and regional assemblages (Ferenc et al., 2014). Another study based on a global comparison of botanical gardens also found positive relationship between specie richness and garden area and age (Pautasso & Parmentier, 2007). The relationship between species richness and campus age suggests that at the initial stages of urban greening, most of the investment only contributes to high urban green coverage but does not foster high plant diversity (Wang et al., 2014). With accumulation of time and diversification of habitats, species richness and abundance may then increase (Pautasso & Parmentier, 2007). Hence, larger and older campuses generally support more species than smaller or younger ones.

However, our models for species richness only explained 32.3% of its total variation (Table 2), which is similar to the result observed from a global database (30%) (Aronson et al., 2014), indicating that other factors such as land use change, householder knowledge and socioeconomic factors may play important roles as well (Andersson & Colding, 2014; Golding et al., 2010; van Heezik, Freeman, Porter, & Dickinson, 2013). On the other hand, although anthropogenic factors played a dominant role in explaining plant species richness in campuses, our study showed that even in these highly managed circumstances, climate continuous to affect species richness patterns as well (Kuhn et al., 2004).

4.3. Drivers of species composition

Unlike species richness, species composition was mainly driven by climate rather than anthropogenic variables in campus systems. Specifically, plant composition was strongly correlated with mean annual temperature. Although gardeners may prefer to choose species for beauty, greening and culture to satisfy multiple recreational requirements (Kendal, Williams, & Williams, 2012), climate will constrain this plant choice. In natural systems, there are a lot of studies showing a change of species composition along environmental gradients, where climate is especially important at large scales (Ordoñez et al., 2009; Svenning & Skov, 2005). Similarly, a study in three Swiss cities found that urban community composition was mainly influenced by local environmental variables (Sattler et al., 2010). Therefore, plant species composition in urban areas are affected by same climate factors that also shape wild land plant communities (Ramage, Roman, & Dukes, 2013). This pattern is true for both native and alien species (Ricotta et al., 2014).

Our study disentangles the effects that anthropogenic and environmental variables have on species composition in university campuses. The drivers of species composition patterns in university campuses differ from those that drive species richness both in our study and in Aronson et al. (2014), and indicate that anthropogenic factors are especially important for diversity patterns, while local climate especially affects species composition. This is important for the management of urban species, as environments in cities may change due to global change. Since, species composition is likely to change with changing environmental conditions (Feeley et al., 2011), species with traits that cannot tolerate future expected environmental conditions may go extinct without additional conservation measures, even in an urban setting (Duncan et al., 2011).

4.4. Drivers of plant traits

Many studies have reported that plant traits are strongly influenced
by multiple (a)biotic and disturbance effects associated with urbanization at local scales (Williams, Habs, & Veski, 2014). Species with tolerant traits cope with urban conditions better and are even be more frequent in cities than in the countryside (Knopp, Kühn, Stolle, & Klotz, 2010). However, we detected a strong influence of climate variables on the mean value of leaf length, width and size in each campus. In relatively cold areas, smaller leaves are an adaptation to dry and cold conditions (Malhado et al., 2009). Although species with large leaves and flowers are preferred by local gardeners (Knopp et al., 2010), they may go extinct in stressful cold environments. Additionally, the local environment also affects preferences and expectations for certain tree attributes in local citizens, as people are more familiar with local plant species (Avolio et al., 2015). Therefore, most plants found in the university campuses were native and unique to each city with adaptable features to survive in urban ecosystems (La Sorte et al., 2014). For example, broad-leaved species such as figs (Ficus spp.) are common in south Chinese universities, while needle-leaved species are common in the north. Hence, at large scales, we found that leaf traits are strongly influenced by environmental conditions in urban areas, just as they are in natural systems (Wright et al., 2004). More traits are still required to be analyzed because different traits can have various responses to anthropogenic and environmental factors (Williams, Habs et al., 2014).

At present, urbanization causes biotic homogenization due to proliferation of the same set of alien species (McKinney, 2006; McKinney & Lockwood, 1999), most of which are fast growing pioneer species with high tolerance to disturbance. To counter this, species selection in urban landscapes should be based on native species that have traits suitable for the local climate. Selection of local, possibly endemic species may build diverse landscapes among different cities and minimize the homogenization effect (Wang et al., 2014). Our study, which provides a basic but diverse database for the selection of campus plants, can benefit the management of urban ecosystems.

4.5. Woody plants versus herb species

We found a positive species-area/time relationship in our study which mirrors that found for botanical gardens and for succession in natural systems (Pautasso & Parmentier, 2007; Rosenzweig, 1995). However, this relationship was considerably stronger for woody plants than for herbs. Environmental drivers of species composition and traits composition were also stronger for woody plants than herbs. This difference may be related to the lifespan difference between woody plants and herbs. Woody plants generally have a longer lifespan, bigger size and lower reproductive rate than herbs, so they have to be able to tolerate severe environmental conditions such as freezing and drought for many years, making them susceptible to damage sustained over long time periods and for rare, but extreme conditions (Díaz, Fargione, Chapin, & Tilman, 2006). In contrast, many of the herbaceous species have short life spans and smaller plant size, having their seeds or meristems stored belowground for survival during unfavorable periods (Klimelková & Klimeš, 2007). Therefore, woody plants, given their importance as keystone species in urban areas and their high sensitivity to the environment, will need more conservation concern and should be protected carefully in urban settings (Staggil et al., 2012).

University campuses turned out to play similar role as botanical gardens in terms of maintaining high plant diversity and should be used for biodiversity conservation and environmental education. For example, botanists can use these plants as materials for environmental education for millions of students in the universities. We also recommend that the maintenance of especially old and large urban ecosystems is vital for biodiversity conservation in the cities. In addition, city planners should be more aware of the value of these urban green areas and adapt their planting strategies in such a way that they maximize this refugia potential, taking into consideration that they should preferably use local plants, and especially threatened species (obtained from nurseries, not from the wild) which are already adapted to the local climate. If such a strategy could be applied nationwide, a considerable proportion of the Chinese flora could be protected within urban settings.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2017.04.008.

References


