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Regional effects of plant diversity and biotic homogenization in urban greenspace – The case of university campuses across China

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ABSTRACT

The human introduction and spread of species in urban greenspace may lead to an increase in the similarity of plant species composition between distant areas. Univervsity campuses are an important element of greenspace in many cities, but we know little about the extent to which such biotic homogenization of plant species can be detected across different regions and plant growth forms. Here, we collected plant species occurrence data from 253 Chinese university campuses in 130 cities to explore patterns and drivers of plant diversity and biotic homogenizations across different geographical regions and growth forms. We found that native species richness was positively correlated to campus area at the national scale, while non-native species richness was significantly associated with mean annual temperature, precipitation seasonality, campus area and campus age. We found limited support for homogenization caused by non-native plants in most regions. For growth forms, tree species exhibited significant biotic homogenization at the national scale, with weak or no effect for shrubs or herbs. Plant compositional similarity varied among regions, and eastern China always had the highest similarity in species composition with other regions. Combined effects of mean annual temperature and geographic distance overshadowed the roles of other predictors in shaping compositional dissimilarity in most regions. These findings suggest that multi-region settings and plant growth forms should be considered in urban biodiversity management, with special attention towards avoiding homogenization in trees. Increasing native species with local characteristics and considering region-specific environmental and socio-economic conditions are beneficial to mitigate biotic homogenization in urban greenspace.

1. Introduction

As a primary anthropogenic process, urbanization affects species diversity patterns and also has profound effects on biotic homogenization (McKinney, 2006; Aronson et al., 2014). Biotic homogenization increases the similarity across spaces in species composition over time (McKinney and Lockwood, 1999; Olden and Rooney, 2006). There are two major processes driving variations in plant diversity and biotic homogenization in urban areas (Trentanovi et al., 2013; Yang et al., 2015; Lopez et al., 2018). First, the introduction of widespread species based on human preferences breaks down natural barriers of species distributions (Dehnen-Schmutz et al., 2007; Capinha et al., 2015). Second, relatively similar urban environments, with high anthropogenic disturbance and different urban climate and soil conditions compared to natural ecosystems, may favor species with particular traits (McKinney, 2006; Williams et al., 2015). Over time, urbanization processes are expected to underpin a common suite of urban-adapted biota worldwide, altering plant diversity and homogenizing species compositions of urban flora across large spatial scales (Williams et al., 2009).

Non-native species play important roles in driving urban plant

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diversity, but their effects on biotic homogenization are not yet clear (McKinney, 2006; La Sorte et al., 2014). For example, alien plants with long residence time promoted biotic homogenization in 32 cities in Central Europe (Lososová et al., 2016), while increased introduction rate of alien plants did not intensify biotic homogenization in 20 European cities (Ricotta et al., 2012). These inconsistent results of biotic homogenization also occur for different plant growth forms in human-managed habitats. For tree species, Yang et al. (2015) showed non-native trees were majorly constrained by climatic filter and played a limited role in promoting homogenization in 38 cities worldwide. For herbaceous plants, Padullés Cubino et al. (2019a) found that non-native grasses with similar traits homogenized cultivated and spontaneous yard floras across seven cities in the US. Different effects of biotic homogenization are partly related to complex ecological processes and human influences (e.g., human cultivation preference and management) of urban floras at different regions and growth forms. It is unclear whether or not, and to what extent, complex interplay of these factors in determining the biotic homogenizations in cities. Therefore, further research on biotic homogenization in urban floras based on a wide geographic range and different plant growth forms is urgently required.

University campuses, as an important component of urban greenspace, are closely associated with positive measures of the residents' health and well-being (Holt et al., 2019). Campuses also provide a unique opportunity to evaluate biodiversity variations and the effects of biotic homogenization under urbanization across regions. First, university campuses harbor rich species resources. For example, 3,179 plant species were recorded in 71 university campuses (Liu et al., 2017), and 393 bird species were found in 38 university campuses in China (Zhang et al. 2018). A large number of species spread into campuses through different anthropogenic activities, such as horticultural decorations and artificial cultivations, presenting a complex composition pattern of native and non-native plant species. Second, university campuses are home of botanists and ecologists, and comprehensive investigations in campuses could generate a large amount of high-quality data records (Liu et al., 2017). Third, university campuses are widely distributed around the world (Tzoulas et al., 2015), which means a wealth of data can get access to underpin biodiversity analyses across large scales. Therefore, a dataset generated by university campuses could facilitate assessment of the effects of biotic homogenization and identification of key factors that constrain these effects across a wide range of urban ecosystems.

China, one of the most species-diverse countries in the world, is experiencing a rapid urbanization in recent decades (Mi et al., 2021). Dramatic land use changes and a large amount of plant introductions have resulted in significant changes of species compositions in urban greenspace (Liu et al., 2005). Meanwhile, China spans a wide geographic range, and thus can be used to evaluate the regional effects of biotic homogenization along climatic and anthropogenic gradients in urban ecosystems.

In this study, we collected plant occurrence data from 253 university campuses in 130 cities across China and assessed the extent and mechanisms of biotic homogenization in this element of urban greenspace. Specifically, we addressed the following questions: (1) What drives plant diversity patterns on university campuses? (2) To what extent does the introduction of non-native plant species contribute to biotic homogenization across different geographic regions and plant growth forms? (3) How is biotic homogenization linked to climatic and anthropogenic factors?

2. Materials and methods

2.1. Plant data collection

To compile a relatively complete coverage of university campus floras in China, we first conducted a systematic literature search in the China National Knowledge Infrastructure (http://cnki.net) using the following key words in Chinese: *University* or *Campus* or *Academy of Sciences* or *College* and *plant*. One hundred and twenty papers containing campus plant list were identified. We also compiled plant checklists from 36 books, 37 online databases and 18 research reports of university campus plants and all these primary data sources can be found in Table A1 (Wang et al., 2021). Finally, we collected the campus flora data of 253 university campuses in 130 cities in China, ranging from 20 °N to 49 °N in latitude and from 81 °E to 129 °E in longitude. All cultivated and spontaneously occurring plants appearing in the plant list of each campus were included. We standardized taxonomic nomenclature using The Plant List v1.1 (http://www.theplantlist.org). For the species that cannot be found in The Plant List, we used Flora Reipublicae Popularis Sinicae (http://frps.iplant.cn) and iPlant's Taxonomic Name Resolution Service (http://tnrs.iplantcollaborative.org) to validate. Unknown species and genus- or family-level records were excluded. All varieties and subspecies were merged into species level for analysis to reduce the observer effect (i.e., the data of each locality were collected by the observers with different levels of plant identification skill). In addition, considering the high niche similarity of the subspecies and varieties of the same species, it should have a very limited influence on our result. Overall, there were 44,628 plant records containing 4,801 vascular plant species from 253 university campuses, belonging to 1,657 genera and 225 families (Fig. 1a).

To evaluate the regional differences of biotic homogenization, we classified the campuses into seven geographic regions, including eastern, southern, central, northern, northeastern, southwestern, and northwestern China respectively (Fig. 1a). These regions, to a certain extent, represent different climate zones (i.e., subtropical monsoon, tropical monsoon, temperate monsoon, plateau climate, and temperate continental climates) and different levels of socio-economic development (Zhu et al., 2019). We used the Flora of China (http://foc.iplant.cn/), the Database of Invasive Alien Species in China (http://www.chinaias.cn) and the catalogue of cultivate plants in China (Lin, 2018) to identify the nativeness status of species in each region. Species that occurred outside the regions of their native distributions were classified as non-native species (Padullés Cubino et al., 2019a; Avolio et al., 2020).

Plant species were classified into three plant growth forms (trees, shrubs, and herbs) according to the descriptions in the Flora of China and other literatures. Finally, 1,421 tree species, 839 shrub species, and 2,541 herb species were included in the dataset. To ensure data completeness of each campus, we excluded the campuses with only native plants in the species lists. Campuses with < 15 herbaceous species or with < 5 woody species were also removed based on the lowest species number among northernmost, westernmost, and highest elevation campuses in different growth forms reported in our data. In total, there were 1,550 tree species in 251 campuses, 910 shrub species in 244 campuses, and 2,631 herbaceous species in 154 campuses (Table A2). Across five major regions, the number of campuses ranged from 19 to 37, and the number of species ranged from 1,308 to 2,666 (Table A3).

2.2. Environmental variables

For each campus, geographic locations, campus area (AREA), and the years since the campus was established (AGE_Campus) were extracted from the original literature and the official homepages of these campuses. We extracted the locations from Google Earth if they were missing. The proportion of greenspace in each campus could be a good proxy for the campus environment. Considering that it is highly related to campus area and ages, we didn't include it in the current analysis. Bioclimatic variables and elevation were extracted from the WorldClim data at 2.5 arc-min spatial resolution (Hijmans et al., 2005). To eliminate multicollinearity among these variables, we removed variables with a Pearson's correlation coefficient greater than |0.7| before analyses (Dormann et al., 2013). Finally, we selected three bioclimatic variables and two anthropogenic drivers for this study, including mean annual temperature (MAT), precipitation seasonality (PREC_Season),

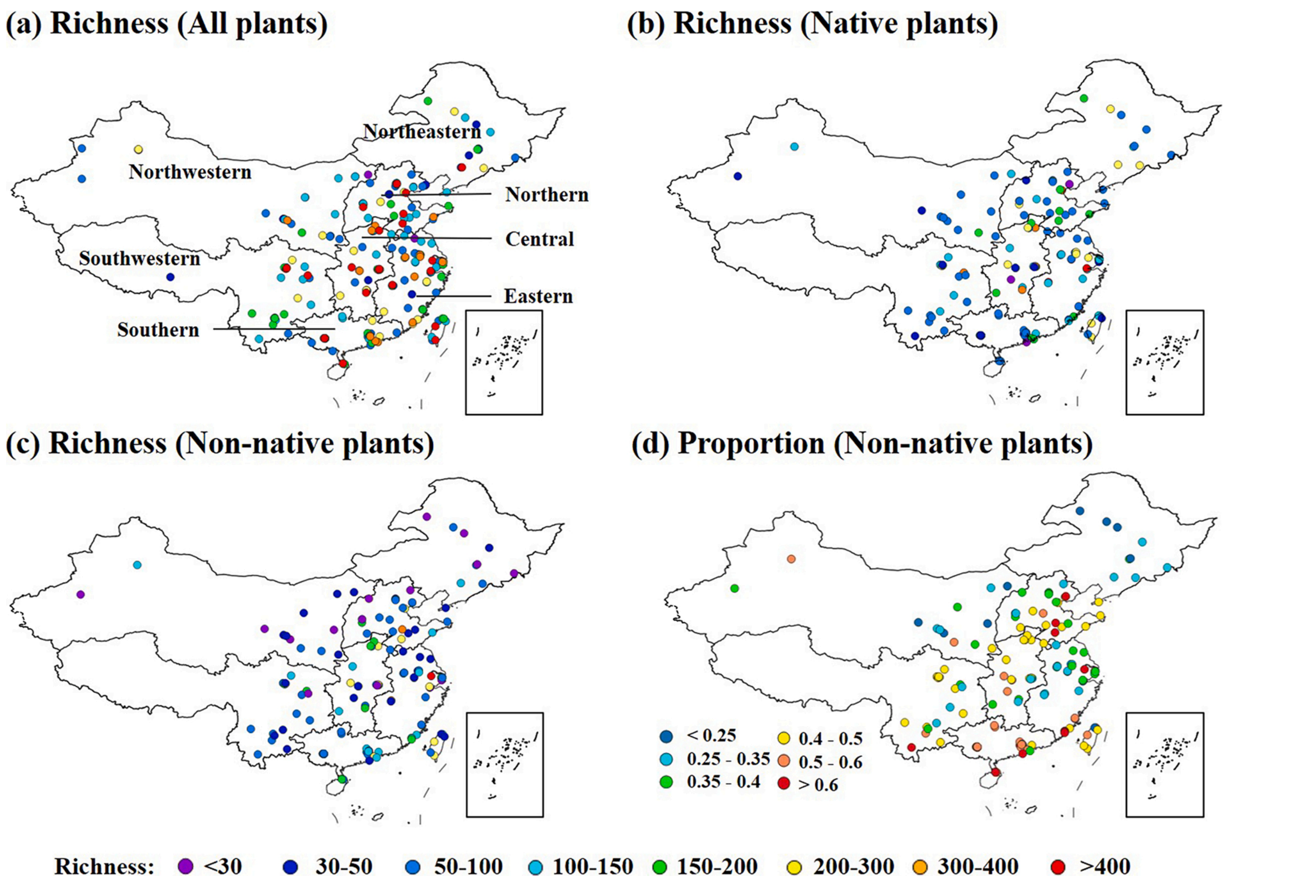

Fig. 1. The distribution of plant richness in 253 university campus (a), and the patterns of (b) native plant richness, (c) non-native plant richness and (d) the proportion of non-native plants in 154 campuses with well-sampled data in all three plant growth forms.

elevation (ELEV), AREA, and AGE_Campus. The climatic variables had large variations among these campuses, ranging from -0.70 to 24.30 °C in MAT. The elevation ranged from 0 to 2,322 m. The campus area varied from 4.2 to 683 ha, and the campus age ranged from 7 to 124 years (Table A3).

2.3. Beta diversity measure

To quantify the compositional dissimilarity variations among campuses and regions, we calculated the turnover component of beta diversity, β_{-3} index (Carvalho et al., 2012; Haider et al., 2018): $\beta_{-3} = 2 \times \min(b,c)/(a+b+c)$, where a is the number of species shared, $\min(b,c)$ is the lower number of unique species between two campuses or regions. The value approaches zero, indicating larger similarity in composition between campuses or regions.

2.4. Statistical analysis

To account for the influence of spatial autocorrelation on plant richness across the campuses, we used spatial simultaneous autoregressive error models (SARs) (Kissling and Carl, 2008) to assess relations to the potential drivers. Moran's I were used to assess spatial autocorrelation before and after performing the SARs (Rangel et al., 2010). For each data set, all the possible combinations of predictor variables were used to fit the models, and Akaike weight (w) representing the relative importance of all variables was calculated based on all possible combinations of the predictors (Zhang et al., 2013). The selection of the 'best' model was based on the minimization of Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002). The analysis was calculated using R package "*spdep*". Due to relatively low sample sizes (<15 campuses) in the northwestern and northeastern regions, we excluded them from these analyses to avoid statistical bias emerging from relatively low sample sizes. To improve the normality and linearity in our models, we log-transformed plant richness, PREC_Season, ELEV and AREA for all analyses. All predictors were standardized to have mean zero and standard deviation of one.

To identify the effects of biotic homogenization caused by non-native species across different regions and growth forms covering all regions, we used the exponential regression of compositional similarity on geographical distance for all pairs of campuses to compare the trends of distance decay between all species and native plants (Capinha et al., 2015). If non-native species have a homogenizing effect, the similarity of all species tends to be greater than that of native species. To assess the relative importance of environmental variables in shaping plant compositional variations, we applied generalized dissimilarity modelling (GDM), a nonlinear matrix regression approach (Ferrier et al., 2007). The default setting of three I-spline basis functions was used for all GDMs. We used maximum likelihood estimation to assess the coefficient for each predictor, representing the magnitude of turnover along each gradient when holding all other variables constant. The coefficient was calculated by summing the coefficients of three I-splines, which was equivalent to the maximum height obtained by the curve (Fitzpatrick et al., 2013). We rescaled these coefficients that their sum equals the deviance explained by the model (König et al., 2017). The GDM was implemented by R package "*gdm*" (Manion et al., 2018). All statistical analyses were carried out using R language v3.5.2 (R Core Team, 2018).

3. Results

3.1. Patterns and drivers of plant richness

A total of 4,801 plant species occurred on the 253 campuses, with 40 campuses from across China having $\geq$ 300 species (Fig. 1a). Among them, 69 campuses harbored $\geq$ 100 native species and 57 campuses had $\geq$ 100 non-native species (Fig. 1b-c). Campuses in northern and southern China as well as the coastal area of eastern China had high proportions (> 0.5) of non-native species (Fig. 1d). Ten species were widely distributed (occurred in more than 60 % of campuses), including *Salix babylonica, Juniperus chinensis, Prunus persica, Lagerstroemia indica, Platycladus orientalis*, *Ginkgo biloba*, *Styphnolobium japonicum*, *Osmanthus fragrans*, *Punica granatum*, and *Prunus cerasifera* (Fig. A1 and Table A4).

Native and non-native species richness was related to different predictors (Table 1). At the national scale, native species richness was strongly related to the campus area, while non-native species richness had significant correlations with mean annual temperature, precipitation seasonality, campus area, and age. At the regional scale, campus area was the most important variable for native species richness, and mean annual temperature showed significant effects on non-native species richness in eastern, southern, and northern China. Campus age strongly influenced non-native species richness in southern, central, and northern China, while precipitation seasonality and elevation had little effect in most regions. For different growth forms, campus area and age had positive effects on the richness of trees, shrubs, and herbs at the national scale. Mean annual temperature was significantly positively related to non-native species richness of each growth form, but the relations with native species varied among them.

3.2. Patterns of biotic homogenization

We detected similar trends of distance decay for native species (exponential decay rate of compositional similarity per 1000 km r_{1000} = -0.376, $P < 0.001$) and all species (r_{1000} = -0.351, $P < 0.001$) at the national scale (Fig. 2a). The trends were consistent in most regions (Fig. 2b-f), except for northern China where greater similarity of all species (r_{1000} = -0.382, $P < 0.050$) than that of native species (r_{1000} = -0.608, $P < 0.001$) was detected over 400 km apart (Fig. 2e). For various growth forms covering all regions, a strong effect of biotic homogenization was detected for trees (r_{1000} for all trees = -0.278, $P < 0.001$; r_{1000} for native trees = -0.391, $P < 0.001$), slightly homogenization effect for shrubs at the distance larger than 650 km, and no homogenization effect for herbs (Fig. 2g-i).

When comparing compositional similarity among regions by integrating plant list data of each region (Fig. 3), the compositional similarity of non-native species among regions was significantly larger than that of native species, especially for shrubs and herbs (Student's *t* test for all plants: $P < 0.01$; Trees: $P = 0.97$; Shrubs: $P < 0.05$; Herbs: $P < 0.001$). Eastern and southwestern China had the most similar species compositions for all native and non-native plants, while eastern and northeastern China had the highest similarity for native trees and shrubs as well as non-native trees.

3.3. Drivers of species compositional patterns

Mean annual temperature accounted for a major proportion of the compositional variations of all species and native species at the national scale (Fig. 4a). For southern and southwestern China, mean annual temperature and geographic distance explained most of compositional variation for native and non-native species. Campus area and age contributed to relatively small parts of the compositional variation, irrespective of native and non-native species (Figs. 4a and A2). For growth forms, mean annual temperature had the largest impact on the variation of all species and native species for trees and shrubs but had a relatively small effect on non-native trees and shrubs at the national scale. However, mean annual temperature contributed more to the variation of non-native herbs than that of native ones (Fig. 4b).

4. Discussions

4.1. Plant diversity in Chinese university campuses

Urban greenspace and the biodiversity contained serve as an essential connection between people and nature in the Anthropocene (Aronson et al., 2017). In our study, 253 university campuses across 130 cities in China contained a total of 4,801 plant species, indicating that the campuses play an important role in maintaining biodiversity in urban greenspace (Liu et al., 2017). The campuses with a high proportion of non-native species were mainly concentrated in regions with relatively intensive human activities (e.g., eastern and southern China). Variations of plant diversity among regions indicate that regional effects caused by socio-economic development and the intensity of human activity would affect plant diversity (Zhu et al., 2019).

At the national scale, we found that campus area contributed substantially to explain patterns of species richness, irrespective of native and non-native species. The importance of campus area is supported by the previous study in China and Turkey (Liu et al., 2017; Güler, 2019), as well as for other urban greenspaces, such as urban parks and botanical gardens (Golding et al., 2010; Nielsen et al., 2014). Urban greenspace with larger areas usually contains more heterogeneous microhabitats, providing diverse habitats to support different plant species in urban areas (Davies et al., 2005). The positive relationship between species richness and campus age in southern China suggests that ongoing planting activities and landscape decorations in campuses with longer history would facilitate the introduction and accumulation of new species with the time accumulation (Liu et al., 2017). In addition to the effects of anthropogenic drivers, mean annual temperature was significantly related to non-native species richness in eastern, southern, and northern China, reflecting warmer urban areas would have a larger horticultural pool of non-native species suitable for their climate. This finding also corresponds to several European studies which found that non-native species occurred more frequently in warmer urban regions (Simonová and Lososová, 2008; Lososová et al., 2012). It suggests that human-introduced non-native species adapted to warm cities would access more potential habitats and spread widely under future climate warming scenarios, increasing the spread of non-native species and the impact of biotic homogenizations in urban areas (Ricotta et al., 2012). Thus, urban managers should reduce the widespread planting of non-native species and replace them with native species which are well suited to specific local conditions.

4.2. Regional effects of biotic homogenization

Understanding the extent to which non-native species contribute to biotic homogenization across multiple regions is of great interest. Several previous studies have reported inconsistent homogenization effects of non-native species in urban ecosystems (Lososová et al., 2012; La Sorte et al., 2014), but little reported studies in highly managed urban greenspace such as university campuses, across different geographic regions. In this study, we compared the homogenization effects of university campuses in five geographic regions in China and found the effects of non-native species on biotic homogenization were limited in most regions. Similarly, Castro and Jaksic (2008) reported that non-native species did not contribute to biotic homogenization in Chile. There are three possible reasons for this. First, compositional variations of non-native species in these regions were controlled by geographic distance and temperature. That is, the campuses with large environmental differences would limit the homogenization effects of non-native species in these regions. Second, numerous range-expanding native species were widely used for urban greening, e.g., *Salix babylonica, Juniperus chinensis* and *Platycladus orientalis*, which would relatively weaken the homogenization effects of non-native species. In this case, landscape planners should also pay more attention to the impacts of widespread native species on compositional similarity, despite

Table 1
The relationships between plant richness and environmental variables across geographic regions and plant growth forms, as derived from spatial simultaneous autoregressive models (SAR). Standardized coefficients (Coef.) represented the relative importance of variables in the optimal model, and Akaike weight (*w*) for each variable was based on all possible combinations of predictor variables. Pseudo r^2 of each model was in bold. MAT: mean annual temperature; PREC_Season: precipitation seasonality; ELEV: elevation; AREA: campus area; AGE_Campus: the age of each campus since its establishment. Species richness, PREC_Season, ELEV, and AREA were log-transformed.

Species richness	Predictors	Regions												Growth forms					
		China		Eastern China		Southern China		Central China		Northern China		Southwestern China		Trees		Shrubs		Herbs	
		Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*	Coef.	*w*
Native plants	MAT	–	0.309	–	0.357	0.213	0.566	1.419***	0.838	0.335*	0.771	−0.410**	0.732	0.351***	1.000	–	0.281	−0.186**	0.843
	PREC_Season	–	0.273	–	0.290	–	0.294	1.543***	0.863	–	0.423	–	0.473	−0.104	0.495	–	0.374	–	0.299
	ELEV	–	0.302	0.255	0.687	–	0.319	–	0.412	–	0.344	−0.536***	0.851	0.099	0.521	–	0.294	–	0.282
	AREA	0.405***	1.000	0.295*	0.682	0.566***	0.996	–	0.476	0.480**	0.864	–	0.361	0.427***	1.000	0.351***	1.000	0.233**	0.976
	AGE_Campus	0.128	0.616	–	0.290	0.428**	0.919	–	0.381	–	0.390	–	0.393	0.173***	0.989	0.154**	0.920	0.125	0.584
	Pseudo r^2	**0.201**		**0.206**		**0.445**		**0.581**		**0.439**		**0.500**		**0.350**		**0.169**		**0.128**	
Non-native plants	MAT	0.534***	1.000	0.291**	0.855	0.376**	0.802	–	0.390	0.514***	0.999	–	0.362	0.699***	1.000	0.46***	1.000	0.223**	0.844
	PREC_Season	0.177*	0.853	–	0.336	–	0.398	–	0.442	−0.392***	0.925	0.442***	0.950	–	0.502	–	0.479	0.128	0.517
	ELEV	–	0.393	–	0.480	–	0.313	–	0.642	−0.278**	0.754	−0.304**	0.884	–	0.280	–	0.280	–	0.308
	AREA	0.265***	0.994	0.330*	0.769	0.553***	0.990	–	0.475	–	0.440	–	0.303	0.220***	1.000	0.254***	1.000	0.188*	0.814
	AGE_Campus	0.159*	0.841	–	0.307	0.430**	0.895	0.484*	0.544	0.547***	0.930	0.318	0.564	0.121**	0.948	0.149**	0.927	0.180*	0.870
	Pseudo r^2	**0.306**		**0.256**		**0.462**		**0.320**		**0.792**		**0.584**		**0.552**		**0.289**		**0.134**	

Significance:
*** $P < 0.001$.
** $P < 0.01$.
* $P < 0.05$.

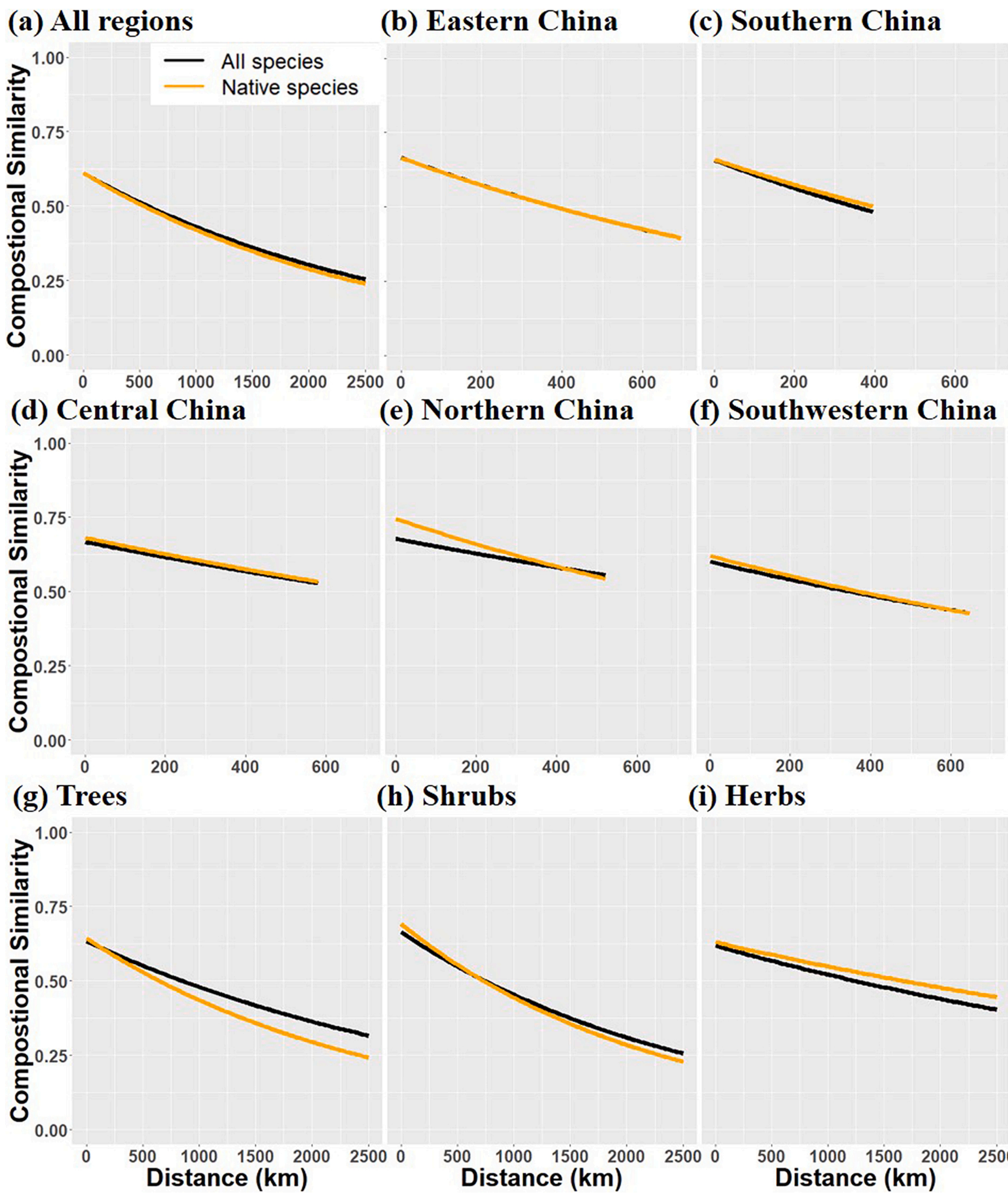

Fig. 2. Distance-decay curves of plant species compositional similarity at the national level (a), across five selected regions (b-f), and through three plant growth forms covering all regions (g-i). These curves were fitted by the exponential decay models of compositional similarity. The fitted curves represent the effects of native species only (yellow) and both native and non-native species (black). When the black curve is above the yellow one, it shows the signal of the homogenization effects of non-native species (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

non-native species in urban greenspace (McKinney, 2006). Third, this study only focused on plant occurrence records, though the effects of species abundance on biotic homogenization could be important. Regional assessment of biotic homogenization might be underestimated without considering species abundance (La Sorte and McKinney, 2007; Yang et al., 2015), which should be taken into account in future studies.

There is strong evidence that regional effect of biotic homogenization is affected by the socio-economic characteristics due to regional pairs with the most similar species compositions always include eastern China. Eastern China, characterized by high human population density and intensive commercial trades, represents the developed area (Wu et al., 2019). As reported by Avolio et al. (2020), urban managers tended to favor greening plants from local nurseries and nurseries offered a similar suite of species with ornamental traits, resulting in a homogeneous source pool. Accompanied by intensive trade activities and human-mediated species dispersal, species compositional similarity of developed regions would be higher compared with other regions (Capinha et al., 2015). To this end, rapid global urbanization with

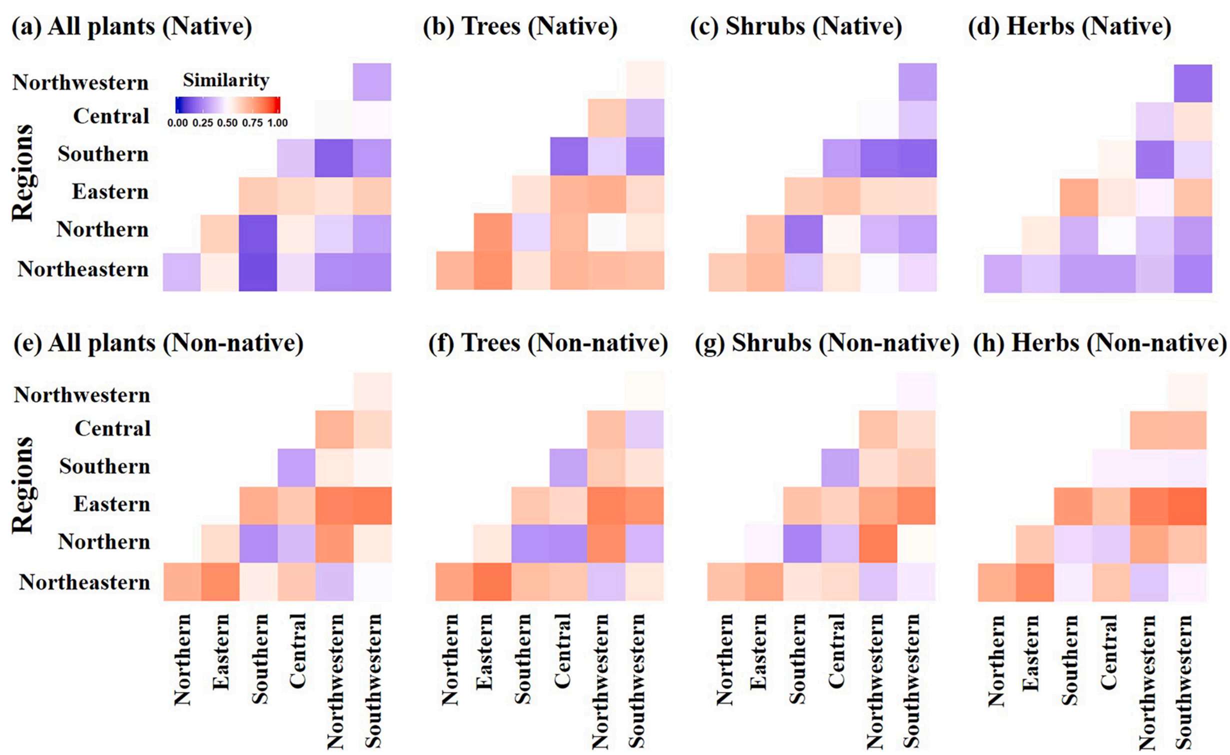

Fig. 3. The pairwise compositional similarity between native and non-native species among seven geographic regions after grouping all native and non-native species lists of each campus into seven regions.

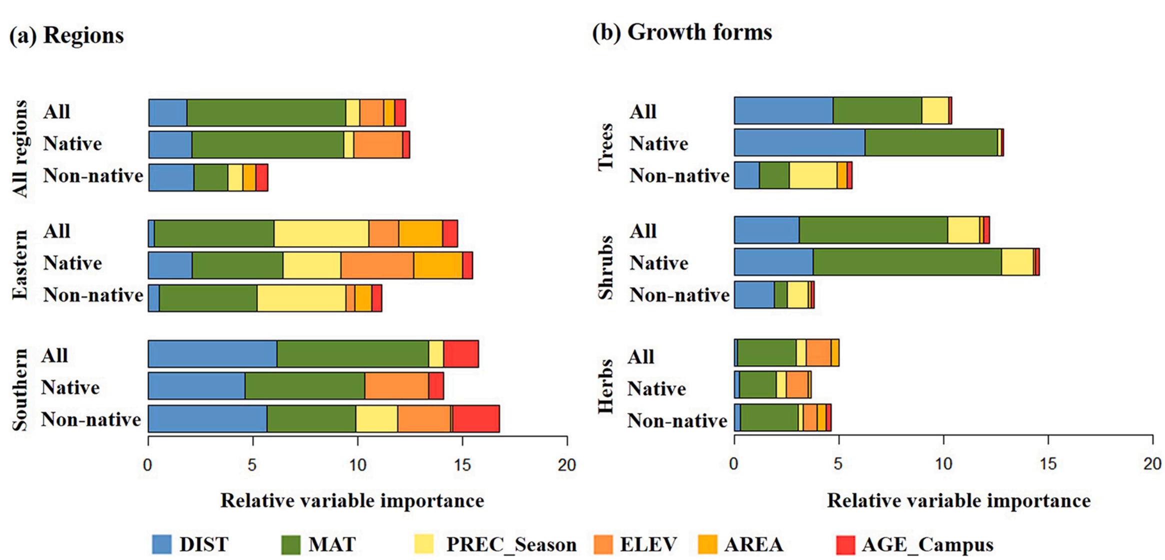

Fig. 4. Relative contributions of environmental variables in explained deviance of species turnover, using generalized dissimilarity modelling (GDM). The analyses were conducted for all species, native species and non-native species separately. Results are shown for different subsets of the entire datasets based on geographical regions and plant growth forms covering all regions. The variable importance was based on the height of GDM transformation functions. The results of two selected regions (eastern and southern China) are shown here. The results of other regions are shown in supporting information (Fig. A2). Different bar colors represent different predictors. DIST: geographic distance among campuses; MAT: mean annual temperature; PREC_Season: precipitation seasonality; ELEV: elevation; AREA: campus area; AGE_Campus: the age of each campus since its establishment.

extended trade networks would promote the introductions of widespread species and therefore increase the impacts of biotic homogenization at a global scale (La Sorte and McKinney, 2006).

The regional effects of biotic homogenization varied among different plant growth forms. Although previous studies majorly focused on trees or herbs (Yang et al., 2015; Padullés Cubino et al., 2019a), there was no comparative studies across different growth forms. Our analyses showed that non-native tree species covering all regions contributed biotic homogenization across Chinese university campuses, which coincides with the findings for urban greenspace in 11 cities in China (Qian et al., 2016). One reason for the homogenization in tree species would be that plant nurseries provide limited tree species based on residential preferences for shade and ornamental purposes in urban greenspace (Pincetl et al., 2013; Avolio et al., 2020). The result that eastern and northeastern China located in different regions had the most similar compositions for native and non-native trees also supports this point. It demonstrates that tree species distributions in campuses under anthropogenic interferences increase compositional similarities among distant regions. Planting rare and native tree species would be an effective way to mitigate the biotic homogenization in urban greenspace. For herbs, non-native species contributed little to biotic homogenization at the national scale, which could be related to stronger dispersal abilities for herbs and the differences of the human preference on different plant growth forms.

4.3. Drivers of biotic homogenization in urban greenspace

Our results clearly showed that different drivers had distinct powers to explain species compositional variations across different geographic regions. Mean annual temperature contributed substantially to explain the compositional variations for native and non-native species, suggesting that temperature still acts as a dominant filter on species compositions in urban greenspace. Strong effects of geographical distance were observed in southern and southwestern China, indicating that campuses over a long distance would be relatively isolated with fewer shared species. There may be related to the restriction on the spatial availability of plant species from nurseries since people prefer to choose the plants growing nearby (Nassauer et al., 2009). Plant composition was weakly constrained by the precipitation seasonality in southern, central, and southwestern China, reflecting high water availability in managed greenspace (Padullés Cubino et al., 2019b). Unlike plant richness, compositional variations were relatively less constrained by anthropogenic factors. This difference highlights the importance of comprehensive consideration of urban vegetation attributes (such as diversity and composition) in urban management and biodiversity maintenance.

For different growth forms, species compositions of woody plants in urban greenspace were majorly controlled by environmental variables rather than anthropogenic influences at the national scale, which was in accordance with one study of urban forests in 257 cities in China (Yan and Yang, 2017). Further, we found the constraints of temperature and geographical distance on non-native trees and shrubs was relatively weak at the national scale, while the composition of non-native herbs was more closely associated with temperature when comparing with native herbs. These results provide an explanation to support homogenization effects for non-native trees and shrubs.

Our study presented inconsistent effects of the drivers on the compositional variations of native and non-native assemblages and the generally low explained variation for non-native species in eastern and northern China. Those suggest that non-native species compositions are subject to complex drivers, such as various planting activities, human preferences for particular plants, and the commercial availability of species. Further research on the effects of non-native plants is needed to explore the linkages among environmental variables, regional social-economic settings, and various plant traits, which are related to human attitudes and preferences that promote biotic homogenization.

5. Conclusions

Using plant occurrence data of 4,801 species from 253 university campuses within 130 cities across seven geographic regions in China, we documented that the magnitude of biotic homogenization caused by non-native species was affected by specific region characters and different growth forms in human-managed urban greenspace. Our study indicates that the findings from trees in developed regions like eastern China may not be suitable for other plant growth forms in developing and underdeveloped regions. A better understanding of which plant species people prefer, why people select, and where the plants come from is necessary to further understand the causes and consequences of biotic homogenization for horticultural plants in urban greenspace. To reduce the effects of biotic homogenization in urban greenspace, urban land managers should consider region-specific environmental and socio-economic conditions and cultivate local plants with particular traits instead of widely distributed species.

Author statement

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ufug.2021.127170.

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