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Effects of urbanization intensity on forest structural-taxonomic attributes, landscape patterns and their associations in Changchun, Northeast China: Implications for urban green infrastructure planning

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ABSTRACT

Understanding the associations between urbanization intensity and urban forest structural-taxonomic attributes is a central theme of urban ecology, biodiversity conservation and forest management for maximizing ecological services to design proper urban green infrastructure. By selecting a typical provincial capital city of Changchun as an example, the effects of urbanization intensity (low, medium and heavy urbanization as measured by impervious surface area, ISA) on landscape patterns and structural-taxonomic attributes of urban forests were investigated in this study. The results showed that the urban forest Patch Density (PD), Landscape Shape Index (LSI), Interspersion & Juxtaposition Index (IJI), Tree Density (TD), Canopy Density (CD), Species Richness (SR) and Species Diversity (H' index) exhibited strictly monotonic increases with urbanization intensity, increasing by 162%, 60%, 44%, 37%, 50%, 85%, and 84% from low to heavy urbanization areas, respectively. In contrast, the forest Mean Euclidian Nearest Neighbor Distance (ENN-MN) and Health Condition grade (HC) monotonically decreased by 12% and 37%, respectively. Furthermore, regression analysis suggested that structural-taxonomic attributes were closely associated with forest-related landscape patterns, but urbanization intensity dramatically influenced these associations. Our findings highlight that the planning of urban green infrastructure, in particular, urban afforestation and associated management, should be different at different urbanization intensities. In low urbanization areas, low Total area (TA, forest area) requires construction of larger forest patches and the protection of large remnant trees, and TD and above ground biomass (AGB) could be increased by enhancing the Mean Fractal Dimension (FRAC-MN) and PD, respectively. In medium urbanization areas, the same increases in TD and AGB could be more effectively achieved by decreasing the IJI and Area-Weighted Mean Contiguity (CONTIG-MN). Moreover, in heavy urbanization areas, more attention should be paid to increasing forest patch aggregation and contiguity, and both tree diversity and evenness could be increased by enhancing the FRAC-MN index. Because these structural-taxonomic attributes are the basis of various forest ecological services, our findings indicate that regulation of some of these landscape metrics could improve urban forest services in Changchun.

1. Introduction

Urbanization is increasing. More than 50% of the global human population now live in cities, and the proportion is still growing (United Nations, 2014). Urban areas are sprawling even faster than they are adding people, swallowing up both farmland and wildlands (Wigginton et al., 2016). The change in land use as a product of the process of urbanization is considered one of the major drivers of climate change and environmental modification (Morelli et al., 2016; Wigginton et al., 2016). Urban forests can play an important role in delivering multiple services and functions in urban ecosystems (Dallimer et al., 2016). However, due to rapid urban growth, urban forest patches might become smaller or more segregated (Botzat et al., 2016), the structural and taxonomic attributes of forest and its services may correspondingly be dramatically altered. As the most important and fundamental components of urban ecological services provided, the dynamics of

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landscape patterns and structural-taxonomic attributes of urban forests cannot be ignored in the rapid urbanization progress, due to their functional role in regulating forest services (Li and Wu, 2004; Lv et al., 2016; Xiao et al., 2016). Understanding the variation tendency can be helpful in providing theoretical support for further urban planning and is of great significance for promoting urban ecology progress, including its accurate evaluation.

In forest management, landscape metrics have been mainly used to monitor changes and the effectiveness of management practices (Etheridge et al., 2006; Ribeiro and Lovett, 2009; Sano et al., 2009; Uuemaa et al., 2013). Screening of landscape heterogeneity metrics related to ecological functions is vital in configuring landscape patterns, processes, and ecological functions (Li and Wu, 2004). In urban ecosystems, much emphasis has been placed on quantifying the spatiotemporal patterns of landscapes in response to urbanization (Wu et al., 2011; Yeh and Huang, 2009) and the driving force of landscape heterogeneity in an urban region (Proulx and Fahrig, 2010), whereas studies about the effects of urbanization intensity on forest landscape patterns in the inner city remain largely open. As for urban forest structural attributes, previous studies have mainly focused on evaluating and assessing tree cover and three-dimensional forest structure by remote sensing (Giannico et al., 2016; Jiang et al., 2017; Lv et al., 2016; Ucar et al., 2016), developing allometric equations for major tree species (Kim and Lee, 2016), and analyzing the influences of environmental factors on forest attributes (Ghosh et al., 2016). Studies on the effects of urbanization intensity, as measured by impervious surface area (ISA, Hutyra et al., 2011), on the forest structural attributes of down-top inventory parameters [diameter at breast height (DBH), tree height, tree canopy density (CD)] are important for clarifying the underlying mechanisms of landscape regulation for forest ecological services. Moreover, relationships between urbanization and species diversity (Aronson et al., 2014; McDonald et al., 2008; McKinney, 2008; McKinney, 2002; Xiao et al., 2016) and species homogenization in urban areas (Kuhn and Klotz, 2006; McKinney, 2006; Yang et al., 2015) are necessary for describing taxonomic attributes of urban trees. A comprehensive study of the effects of urbanization intensity on landscape patterns and structural-taxonomic attributes of urban forests could extract the linkages among these characteristics and, accordingly, benefit the design of urban green infrastructure.

Consequently, the goals of this paper include the following: (1) identify the effects of urbanization intensity on landscape patterns and structural-taxonomic attributes of urban forests; (2) explore the associations between landscape patterns with structural-taxonomic attributes of urban forests; and (3) propose possible implications for maximizing urban forest services related to structural-taxonomic attributes via landscape pattern regulations. Systematic studies regarding these questions are urgently needed to assess the overall effects of human impact on urban forest services and then to support landscape-scale planning to improve urban ecosystem services.

2. Methods

2.1. Study area

Changchun is the capital city of Jilin Province in Northeast China. This region is characterized by a continental climate of the north temperate zone with clear variation of four seasons. The annual average temperature of the winter in the region is −14 °C, and the annual average temperature of the summer is 24 °C (Ren et al., 2015). In the past four decades, the main urban area of Changchun had increased from 90 km^2 in 1978–365 km^2 in 2010 (Huang et al., 2009; Li et al., 2012), which is a typical case of the fast urbanization processes in China. Our study area was located within the fifth ring road of Changchun city, with an area of 524 km^2 (125°07′ E–125°26′ E, 43°44′ N–44°02′N; Fig. 1) and a total population of 3.63 million. The forest types are mainly composed of coniferous and broad-leaved trees.

2.2. Urbanization intensity identification

In our study, a spectral mixture analysis was used to acquire the impervious surface area (ISA) of Changchun city. Ultimately, the mean Root Mean Square (RMS) of all pixels was less than 0.02, and the range of ISA was from 0 to 1 (Fig. 2). The study region was split into 2 km × 2 km grids (a total of 157 grids). We identified the urbanization intensity based on the ISA value for each grid (Fig. 2), which consisted of low urbanization areas (ISA < 0.5), medium urbanization areas (0.5 ≤ ISA ≤ 0.8), and heavy urbanization areas (ISA > 0.8) (Hutyra et al., 2011).

2.3. Survey and calculation of urban forest structural and taxonomic attributes

A stratified random sampling method was adopted to allocate plot numbers (Nowak et al., 2003). The plot number of each grid was determined according to the urban forest coverage (Liu and Li, 2012). Field surveys were conducted from July to October of 2012. Each plot was 400 m^2. The regularly shaped plots were 20 m wide and 20 m long. For the irregularly shaped plots, such as roadside forests, we adjusted the plot width and length to cover an area of 400 m^2. A total of 331 plots were surveyed, distributed into 109 grids: 29 grids for low urbanization areas, 63 grids for medium urbanization areas, and 17 grids for heavy urbanization areas. For each plot, the height and crown radius of shrubs were measured in four directions. Trees whose diameter at breast height (DBH) was higher than 2 cm were measured at 1.3 m above-ground level. The height and crown radius in four directions and the health condition (HC) of each measured tree were also recorded. Six grades of HC were included based on the proportion of dead branches in the crown of a tree (Nowak et al., 2003; Liu and Li, 2012). These grades were as follows: (1) excellent, no obvious dead branches inside the tree crown; (2) fair, < 25% of the crown was composed of dead branches; (3) poor, 26–50%; (4) critical, 51–75%; (5) dying, 76–99%; and (6) dead, 100%. To facilitate the statistical analysis, the HC grades of excellent, fair, poor, critical, dying and dead were reported as by 1, 2, 3, 4, 5, and 6, respectively. In addition, the woody plant species richness (SR) in each plot was recorded. The Shannon-Wiener species diversity index (H'), evenness index (J') and canopy density were calculated for each plot. The equations are as follows:

(Shannon and Weaver, 1963; Magurran, 1988)

$$\text{Shannon} - \text{Wiener index}: \ H' = -\sum_{i=1}^{S} RA_i \,(\ln RA_i) \tag{1}$$

(Pielou, 1966)

$$\text{Evenness index}: \ J' = \frac{H'}{\ln(s)} \tag{2}$$

where S is the total number of species in each plot, RA is the relative abundance, RA_i represents number of trees for species i/total number of trees.

$$\text{Canopy density (CD)}: CD = \frac{\sum_{i=1}^{n}\left(\frac{\sum_{j=1}^{4}\text{Crown radius}}{4}\right)^2 \times \Pi}{A} \tag{3}$$

where n is the total number of trees and shrubs in each plot; A is the plot area, and Π is the constant parameter 3.14.

Aboveground biomass(AGB) was estimated for each surveyed woody plant using biomass allometric equations obtained from the literature (Zhang et al., 2015). The values of forest structural attributes