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Analysis of Landscape Pattern Characteristics of Urban Forests in Beijing' s Main Urban Area (Postprint)

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Abstract

Urban forests constitute a crucial component of urban ecological civilization construction. This study investigates urban forests within Beijing' s Fifth Ring Road, utilizing GF-2 remote sensing imagery acquired on September 16, 2016 as the data source. Based on landscape and ecological service functions, urban forests were classified into four types: ancillary courtyard aesthetic forests, road and riparian protective forests, urban park recreational forests, and urban-rural fringe excursion forests. An object-oriented approach was employed to extract information on different urban forest types and generate thematic maps. Fragstats 4.2 software was utilized to calculate metrics including landscape patch number and composition, fragmentation index, fractal dimension, Simpson' s diversity index, Simpson' s evenness index, and aggregation index. Results demonstrate that high-resolution imagery offers advantages in urban forest information extraction, achieving an overall classification accuracy of 90.36% and a Kappa coefficient of 0.88. The total area of urban forests in Beijing' s main urban district is 22,514.79 hm^2, with a forest coverage rate of 32.35%. Urban forest patches exhibit uneven distribution: large and extra-large patches account for only 13.62% of the total number but comprise 73.20% of the total area, indicating that the ecological value of small and medium-sized patches warrants further exploration. Distinct characteristics exist among different urban forest types: ancillary courtyard aesthetic forests and road and riparian protective forests represent the dominant landscape types, yet both exhibit high fragmentation, poor aggregation, and scattered distribution. Urban park recreational forests and urban-rural fringe excursion forests occupy relatively smaller proportions, with park construction in southern urban areas particularly deficient. Urban forest landscape indices demonstrate regular patterns along the urban expansion gradient, with landscape fragmentation decreasing progressively from the city center outward, reaching as high as 183.50 within the Second Ring Road. Based on these findings, we recommend that Beijing strengthen resource integration of small and medium-sized patches and increase the construction of pocket parks; enhance the development of road and riparian protective forests to connect large patches such as urban park recreational forests and urban-rural fringe excursion forests, while simultaneously strengthening park construction in southern urban areas; and intensify overall spatial regulation of urban forests through supplementary planting in old districts within the Third Ring Road and optimizing management techniques for urban forests beyond the Third Ring Road, thereby enhancing overall urban forest coverage and quality.

Full Text

Landscape Pattern Analysis of Urban Forest in Central Beijing

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Abstract

Urban forests constitute a critical component of urban ecological civilization construction. This study examines urban forests within Beijing' s Fifth Ring Road using GF-2 remote sensing imagery from September 16, 2016. Based on landscape and ecological service functions, urban forests were classified into four types: affiliated landscaping forest, road-river shelter forest, urban park leisure forest, and suburban recreation forest. Object-oriented classification was employed to extract information for different urban forest types and generate thematic maps. Landscape metrics including patch number and composition, fragmentation index, fractal dimension, Simpson' s diversity index, Simpson' s evenness index, and aggregation index were calculated using Fragstats 4.2 software. Results demonstrate the advantages of high-resolution imagery for urban forest information extraction, with an overall classification accuracy of 90.36% and a Kappa coefficient of 0.88. The total area of urban forest in central Beijing is 22,514.79 ha, representing a forest coverage rate of 32.35%. Patch distribution is highly uneven: large and extra-large patches account for only 13.62% of total patch numbers but comprise 73.20% of total area, while the ecological value of small and medium patches remains underutilized. Different urban forest types exhibit distinct characteristics. Affiliated landscaping forest and road-river shelter forest are the dominant landscape types, yet both suffer from high fragmentation and poor aggregation, with scattered distributions. Urban park leisure forest and suburban recreation forest occupy relatively smaller proportions, with park construction particularly weak in southern Beijing. Landscape indices show regular patterns along urban expansion gradients, with fragmentation decreasing outward from the city center and reaching 183.50 within the Second Ring Road. Based on these findings, we recommend strengthening integration of small and medium patches through pocket park construction, enhanc-

ing road-river shelter forest development to connect large patches, improving park construction in southern Beijing, and implementing comprehensive spatial regulation to increase both coverage and quality of urban forests.

Keywords: urban forest, landscape pattern, remote sensing, central Beijing, spatial optimization

Introduction

While a unified definition of urban forest remains elusive, most scholars agree that urban forests differ from urban green spaces in that they should be dominated by trees, cover areas greater than 0.5 ha, and maintain canopy coverage between 10% and 30%, representing an organic integration of urban and forest ecosystems (Liu Changfu, 2003). As the "green lungs" of cities, urban forests play vital roles in environmental beautification, soil and water conservation, and water source protection, forming an essential component of urban ecological civilization construction (Kendal, 2014; Wang Cheng, 2016). As China' s capital, Beijing serves as a national model for ecological civilization. The *Beijing Urban Master Plan (2016-2035)*, released in September 2017, provides explicit guidance for the city' s green space structure. Optimizing Beijing' s urban forest landscape pattern is thus crucial for establishing a sound municipal green space system and building a world-class harmonious and livable city.

"3S" technologies (RS, GIS, GPS) have become important tools for urban landscape pattern research (Wang Ye, 2014). Frank & Palmer (1999) used Landsat TM imagery to analyze landscape heterogeneity changes in South Africa' s Eastern Cape River Basin. Chinese scholars have applied TM imagery to analyze Beijing' s landscape fragmentation over two decades (Fu Gang et al., 2017), employed remote sensing for urban green space landscape pattern studies (Jiang Min, 2013; Chen Yang et al., 2015), and investigated urban forest landscape patterns in Anhui and Shenzhen (Wang Yuan, 2006; Li Zhihua et al., 2017). However, comprehensive studies on Beijing' s urban forest landscape pattern remain relatively scarce, and most existing research relies on low-resolution TM imagery.

This study utilizes higher-resolution GF-2 remote sensing imagery to classify urban forests within Beijing' s main urban area according to landscape and ecological functions. By quantitatively analyzing characteristics of different urban forest types, patch composition, and landscape patterns across different ring roads and directional zones, this research reveals the current status and existing problems of Beijing' s urban forest construction and proposes optimization recommendations.

Study Area and Data Sources

The study area encompasses the region within Beijing' s Fifth Ring Road, covering the core districts of Dongcheng and Xicheng, as well as portions of the functional expansion zones in Haidian, Chaoyang, Fengtai, and Shijingshan, with a total area of 652.20 km².

Remote sensing data consist of GF-2 satellite imagery from September 16, 2016, at sensor-corrected level, characterized by cloud-free, noise-free, and unbiased conditions. GF-2 imagery includes four multispectral bands with 2 m spatial resolution and one panchromatic band with 0.80 m resolution. Field surveys collected data on forest locations, areas, vegetation composition, canopy density, and site conditions around major parks, residential areas, roads, and rivers within the study area. Supplementary data include Beijing' s 1:10,000 topographic maps and the NASA Socio-Economic Data and Application Center Human Influence Index Dataset (http://dx.doi.org/10.7927/H4BP00QC).

Research Content and Methods

2.1 Classification of Urban Forest Landscape Types

China currently lacks explicit standards for urban forest classification. Following the principles and criteria proposed by He Xingyuan et al. (2004), this study classifies urban forests within the Fifth Ring Road into four types based on landscape and ecological functions, combined with Beijing' s urban characteristics and current forest construction status (He Xingyuan et al., 2004):

1. **Affiliated Landscaping Forest**: Primarily for courtyard beautification, with secondary functions in disease prevention, environmental sanitation improvement, and microclimate regulation. Distributed around buildings in residential areas, institutions, and university campuses, with tree coverage of 10%-30%.

2. **Road-River Shelter Forest**: Primarily for dust and noise reduction and traffic safety, with secondary functions in cityscape beautification and urban heat island mitigation. Distributed along roads and rivers as street trees and median strips, with tree coverage above 30% and width no less than 3 m.

3. **Urban Park Leisure Forest**: Provides outdoor recreation space through landscape design, with secondary functions in soil and water conservation and urban heat island reduction. Located within various urban parks including historic gardens, comprehensive parks, and community parks, with tree coverage above 30%.

4. **Suburban Recreation Forest**: Meets diverse public recreation needs and provides urban greenbelt isolation functions. Distributed near the Fourth and Fifth Ring Roads within country parks developed from former shelter forests and nurseries, with tree coverage above 30%.

2.2 Remote Sensing Image Processing and Urban Forest Information Extraction

Due to sensor-related factors, remote sensing imagery often experiences geometric and radiometric distortion during acquisition. ENVI 5.3 software was used for radiometric correction, geometric correction, histogram matching, grayscale adjustment, mosaicking, cloud removal, and image fusion of GF-2 imagery, followed by clipping and stitching according to the study area boundaries. Object-oriented image classification technology was then applied to extract information for different urban forest types in Beijing (Chen Yang et al., 2015), with classification accuracy validated using field survey data.

2.3.1 Patch Composition

Different patch size classes exhibit distinct ecological functions. Based on Beijing' s urban forest characteristics and following Li Yang (2010), patches were classified into five size categories: small (<0.1 ha), small-medium (0.1-0.4 ha), medium (0.4-1 ha), large (1-10 ha), and extra-large (>10 ha). Overlay analysis with the human influence factor distribution map was conducted to analyze patch class distribution characteristics under varying human influence intensities.

2.3.2 Selection of Landscape Pattern Indices

Landscape pattern indices effectively condense landscape information into simple quantitative metrics reflecting structural composition and spatial configuration (Schumaker, 1996). This study selected the following indices:

1. **Patch Density (PD)**: Measures the number of patches per unit area. Formula variables: NP = total number of patches for a landscape element; A = total landscape area.
2. **Fractal Dimension (FRAC)**: Quantifies patch shape complexity. Formula variables: Ei = perimeter of patch i; Ai = area of patch i.
3. **Simpson's Diversity Index (SIDI)**: Measures landscape diversity. Formula variables: Pi = proportion of total patch area occupied by landscape element i.
4. **Simpson' s Evenness Index (SIEI)**: Measures distribution uniformity among landscape elements. Formula variables: H = Simpson' s diversity index; n = total number of landscape element types.
5. **Aggregation Index (AI)**: Measures degree of patch aggregation. Formula variables: gii = number of adjacencies between pixels of a landscape type; maxgii = maximum possible number of adjacencies.

The main urban area was divided into four ring zones (Second Ring Road to Fifth Ring Road) and four directional zones (along the central axis and Chang' an Avenue). Fragstats 4.2 software was used to analyze urban forest landscape indices across these zones.

Results

3.1 Urban Forest Type Characteristics and Analysis

Object-oriented classification extracted urban forest information within Beijing's Fifth Ring Road, achieving an overall accuracy of 90.36% (>85%) and Kappa coefficient of 0.88 (>0.8), confirming reliable classification results (Zhang Anding, 2016; Yue Ruihong, 2010). Statistics show 27,494 urban forest patches covering 22,514.79 ha, with an overall forest coverage rate of 32.35% (Table 1).

Affiliated landscaping forest comprises 14,000 patches (49.32% of total) covering 13,011.66 ha (57.79% of total area), representing the dominant type in both number and area. These patches are scattered uniformly around buildings within the Fifth Ring Road, appearing as small fragmented blocks. Road-river shelter forest ranks second in area at 4,663.17 ha (20.71% of total). Suburban recreation forest covers 3,196.11 ha (14.20%), with more distribution in the south than north (Figure 1 [Figure 1: see original paper]), likely because slower urbanization in the south has preserved large artificial greenbelt shelter forests. Urban park leisure forest is the smallest component at 1,643.85 ha (7.30%), showing a north-south disparity with southern Beijing' s total area of only 386.82 ha—less than one-third of the northern area—indicating relatively weak park construction in southern districts (Fengtai, Daxing). These results align with Wu Lijuan (2006), though this study adds the suburban recreation forest category, which has emerged with rapid expansion of first-tier cities like Beijing and Shanghai to protect suburban environments and prevent uncontrolled urban sprawl while providing recreation space.

3.2.1 Patch Composition Analysis

Within Beijing' s Fifth Ring Road, small and small-medium patches total 19,138 (69.61% of patches) but account for only 13.73% of area. Conversely, large and extra-large patches number 3,745 (13.62%) but comprise 73.20% of total area (Table 2), consistent with Wang Juan et al. (2010) and confirming that large patches constitute the primary ecological functional units. Except for historic parks like Temple of Heaven and Yuyuantan, large and extra-large patches are mainly distributed in outer ring areas with lower human influence factors, indicating severe degradation of urban forests in old city areas (Figure 2 [Figure 2: see original paper]).

3.2.2 Urban Forest Landscape Pattern Analysis

Fragmentation decreases progressively from the Second to Fifth Ring Road, with the highest fragmentation (PD = 183.50) within the Second Ring Road, demonstrating significant impacts of central urban construction on forest landscapes

(Fu Gang, 2017). SIDI and SIEI decrease from the Second to Fourth Ring Roads but increase dramatically at the Fifth Ring Road to maximum values of 0.63 and 0.84, respectively, likely due to the addition of suburban recreation forests and large comprehensive parks like the Old Summer Palace and Olympic Park that increase landscape diversity. AI increases gradually from inner to outer rings, peaking at 57.90% between the Fourth and Fifth Ring Roads where large artificial shelter forests are concentrated. FRAC shows minimal variation across ring zones (approximately 1.57), indicating similar patch shape complexity (Table 3).

Across forest types, affiliated landscaping forest and road-river shelter forest are dominant. Affiliated landscaping forest exhibits the highest PD and FRAC values, indicating maximum fragmentation and most complex patch shapes. Road-river shelter forest shows the lowest aggregation with AI values around 40%, demonstrating the most scattered distribution. Urban park leisure forest has the lowest PD and highest AI across all ring zones (79.65% within the Second Ring Road), consistent with Mao Xiaogang (2012), attributable to large historic parks like Temple of Heaven and Jingshan within the inner ring. Suburban recreation forest shows relatively high aggregation and low fragmentation with parameters similar to urban park leisure forest. Both types have FRAC values below 1.50, indicating relatively regular patch shapes (Table 4).

Directionally, southern Beijing exhibits higher fragmentation than northern areas, with the southwest showing the maximum PD (155.92), suggesting that Fengtai District' s ongoing urbanization has inadequately protected ecological spaces. Northern areas show higher aggregation, with the northwest reaching maximum AI (57.04%), consistent with Yue Depeng et al. (2009), likely due to large forest patches like the Summer Palace, Old Summer Palace, and university campuses in Haidian District. Landscape diversity and evenness show east-west differences, with higher values in the east, possibly because Xicheng District' s numerous parks create dominant large-patch advantages. FRAC values show minimal variation across ring zones and directions (approximately 1.55) (Table 5).

Conclusions and Recommendations

Based on GF-2 imagery, this study extracted urban forest information within Beijing' s Fifth Ring Road with an overall accuracy of 90.36% and Kappa coefficient of 0.88, demonstrating the advantages of high-resolution imagery for urban forest extraction. Quantitative analysis of Beijing' s urban forest landscape patterns yielded the following conclusions and recommendations:

Total urban forest area within the Fifth Ring Road is 22,514.79 ha with 32.35% coverage. Patch distribution is highly uneven: large and extra-large patches constitute only 13.62% of patch numbers but 73.20% of area, predominantly distributed in outer ring areas with limited presence in old city districts. While the *Beijing Urban Master Plan* proposes "strengthening urban repair to create excellent human habitats," current small and medium patches are scattered and their ecological value underutilized. We recommend: (1) protecting large and extra-large patches to safeguard urban ecological space, and (2) integrating small and medium patches by gradually opening enclosed residential compounds and institutional yards to create pocket parks (Chen Tingting et al., 2017; Liu Xin & Ju Yueshi, 2017), particularly in high human-impact areas like southeastern Haidian and western Chaoyang, to establish foundations for quality human habitats.

Different urban forest types show distinct characteristics. Affiliated landscaping forest and road-river shelter forest are dominant types, comprising 57.79% and 20.71% of area, respectively, but both exhibit high fragmentation and poor aggregation. Affiliated landscaping forest within the Second Ring Road shows extreme fragmentation (PD = 124.55), while road-river shelter forest maintains AI around 40% across all rings. Urban park leisure forest and suburban recreation forest occupy only 21.50% of total area, with weak park construction in southern Beijing (Fengtai, Daxing)—the southern urban park area of 386.82 ha is less than one-third of the northern area. This indicates the "second greenbelt country park ring" mentioned in the municipal green space layout plan remains underdeveloped. We recommend strengthening suburban recreation forest construction, particularly in southern Fengtai and Daxing, by transforming existing shelter forests and nurseries into country parks to expand recreation space, protect suburban environments, and prevent uncontrolled urban sprawl (Tian Yuan & Wang Shudong, 2013). Additionally, the plan' s proposal to "construct a recreation green space system interwoven with parks and greenways" can be realized by enhancing road-river shelter forest development to improve the urban forest network and connect large patches of urban park leisure forest and suburban recreation forest, thereby maximizing ecological value.

Urban forest patterns change systematically with urban expansion, with fragmentation decreasing outward from the city center. Areas within the Third Ring Road with high human influence factors show greater fragmentation (PD = 183.50 within the Second Ring Road), while areas between the Fourth and Fifth Ring Roads with lower human influence show reduced fragmentation (PD = 110.63). The master plan proposes "building a forest city and increasing municipal forest coverage." Therefore, we recommend comprehensive spatial regulation: within the Third Ring Road, implement "land banking for greening" through gap-filling planting and vertical greening; outside the Third Ring Road, apply optimized management techniques to improve overall urban forest coverage and quality, promoting harmonious and orderly urban-forest development.

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