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Original Research

Assessing Near-Naturalness of Plant Communities in Urban Green Spaces Using Comprehensive Index and Random Forest Methods: A Case Study in Hefei, China

Dong Dong[1, 2], Mingxin Chen[1], Fengquan Ji[1, 2, *], Tieqiao Xiao[1, 2], Xin Wen[1], Qing Li[1]

[1]School of Architecture and Planning, Anhui Jianzhu University, Hefei 230022, China
[2]Anhui Institute of Territory Spatial Planning and Ecology, Hefei 230022, China

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Abstract

As urbanization rapidly progresses, the ecological resilience and health of urban parks and green spaces face significant threats, underscoring the crucial need for effective ecological quality assessments. This study developed a comprehensive evaluation system, uniquely designed with sixteen indicators across four dimensions – community composition, structure, succession, and disturbance – to systematically assess the near-naturalness of 87 urban park plant communities in central Hefei and to explore the influencing factors. Employing comprehensive index and random forest algorithms, we find the near-naturalness index ranging from 0.135 to 0.752, categorizing only 18.39% of samples as 'near-natural' or 'semi-natural,' while a majority, 81.61%, fell into 'far-natural' or 'artificial' categories. Ideal near-natural conditions emerged in settings with 5 to 10 dead plants, litter cover of 10 to 30%, 10 to 15 species, and mild natural disturbances. Our findings indicate that the overall near-naturalness in Hefei's urban green spaces is moderate to low, suggesting a need for focused enhancements in community succession and structural adjustments. This research establishes a novel framework for advancing urban green space ecological planning and sustainable development, providing fresh insights and a robust scientific basis for enhancing the ecological quality of urban parks and green spaces.

Keywords: near-natural garden, urban green space, plant landscape management, near-naturalness assessment

*e-mail: finela@126.com;
Tel.: +86-138-6611-8825;
Fax: +86-0551-6352-1383

Introduction

Rising living standards, coupled with societal and economic advancements, have fueled public interest in ecological urban development as urbanization progresses. Urban garden greenery, a unique ecological component within cities, plays a crucial role in enhancing urban environmental quality and maintaining ecological balance [1]. Currently, expectations for urban garden greenery have evolved beyond its traditional recreational and aesthetic roles to include preserving ecological balance, protecting biodiversity, and mirroring natural environments. This shift has sparked significant interest among scholars in and outside China in the concept of near-natural gardens, which emulate natural zonal plant communities by combining human-engineered techniques with the natural growth patterns of plants [2, 3]. This approach notably enhances the scientific and artistic qualities of plant communities, thereby fully capturing the essence of regional characteristics [4, 5]. It effectively maintains ecosystem stability, enhances biodiversity in green areas, and promotes ecosystem self-regulation [6, 7]. The concept has recently become a key focus in the research of plant landscape design in green spaces [8] and is increasingly seen as vital for addressing challenges in urban green space plant community development [9, 10]. Consequently, the construction of near-natural gardens is poised for widespread future application.

International studies on near-natural gardens can be traced back to Gayer's 1869 concept of close-to-nature forestry, which emphasizes sustainable forest utilization [11]. This has led to the development of theories such as potential natural vegetation [12] and Miyawaki forestry methods [13, 14], which have significantly enhanced regional biodiversity and ecosystems [15–17]. The concept of near-natural gardens in China has its roots in the philosophy of classical gardens, which embody the notion of being "created by humans yet appearing as if crafted by nature." This concept emerged in the context of the urbanization wave in the late 20th century when Qi Xinhua, along with others, pioneered the near-natural garden concept, drawing inspiration from the core principles of near-natural forestry [18]. Over recent years, Chinese researchers have intensively pursued theoretical studies and practical applications of near-natural gardens. Their work has primarily focused on developing research on models [19, 20] and methods [21, 22] for constructing near-natural communities. Assessing the degree of naturalness is crucial for evaluating the quality of plant communities in near-natural gardens and for the high-quality development of urban garden greenery. Originating in forest management, such assessments typically result in zoning forest areas and exploring diverse management models for different vegetation states. This method is widely used to assess the natural conservation value, current forest states, and develop forest management plans [23, 24]. Evaluation techniques range from qualitative and quantitative to a combination of both. Initial studies on forest naturalness primarily focused on qualitative evaluations, often lacking criteria selection and evaluation frameworks [25]. Popular methods include the comprehensive index method [26], the analytical hierarchy process [27, 28], and grey relational analysis [29], each differing in focus, scale, and criteria selection. Subsequently, quantitative methods were introduced [30], primarily involving the calculation of a composite number by assigning indicator weights to assess the naturalness of forests [31, 32]. Scholars have explored combining qualitative and quantitative evaluations by initially using quantitative methods to calculate a naturalness index, and then classifying grades based on this index [33, 34]. Current studies assessing naturalness primarily focus on protected areas, such as extensive forest vegetation zones [35] and nature reserves [36, 37]. However, research on the naturalness of urban forests, particularly in urban green spaces where human interference is significant, remains scarce.

Hefei, designated as one of China's first National Garden Cities, is undergoing rapid urbanization. Its development into a National Park City reflects not only modern urban growth trends but also aligns deeply with China's commitment to ecological civilization. Recent achievements have significantly advanced this vision. Statistics show that the green coverage in urban areas of Hefei now exceeds 40% [38], with wetlands expanding to cover 11.82 thousand hectares. By 2025, Hefei aims to establish more than 500 urban parks, signaling progress in green development. However, challenges such as the loss and fragmentation of green spaces have emerged amidst rapid urbanization. According to a study by Yao et al., Hefei's green space area decreased by 516.59 km^2 from 1994 to 2020, while non-vegetated areas increased by 255.5 km^2 [39]. This change has impacted the city's ecosystem services and could potentially affect its urban resilience and health. Enhancing the near-naturalness of plant communities in urban green spaces can improve their stability and recovery, thus enhancing the quality and sustainability of these spaces and their ecosystem services [40]. Drawing on forest naturalness assessment methods, this study combines qualitative and quantitative approaches in field surveys and data collection across 27 urban green spaces in Hefei, involving 87 quadrats. A comprehensive evaluation indicator system was established to cover the composition, structure, succession, and disturbance level of plant communities in urban green spaces of Hefei. Principal component analysis, entropy weight method, and comprehensive index method were utilized for the comprehensive evaluation of the plant communities. Near-naturalness grades were classified through cluster analysis, and the relationship with key indicators was explored using the random forest algorithm. This investigation seeks to address two primary questions: (1) What is the level of near-naturalness of plant communities in urban green spaces of Hefei? (2) What factors have the most significant impact on the near-naturalness of these plant communities? By systematically assessing the near-naturalness of plant communities in Hefei's urban green spaces, this study explores the effects of urbanization on urban ecosystems. It provides fresh insights and actionable strategies for enhancing urban garden quality, serving as a valuable resource and guide for Hefei's garden greening initiatives.

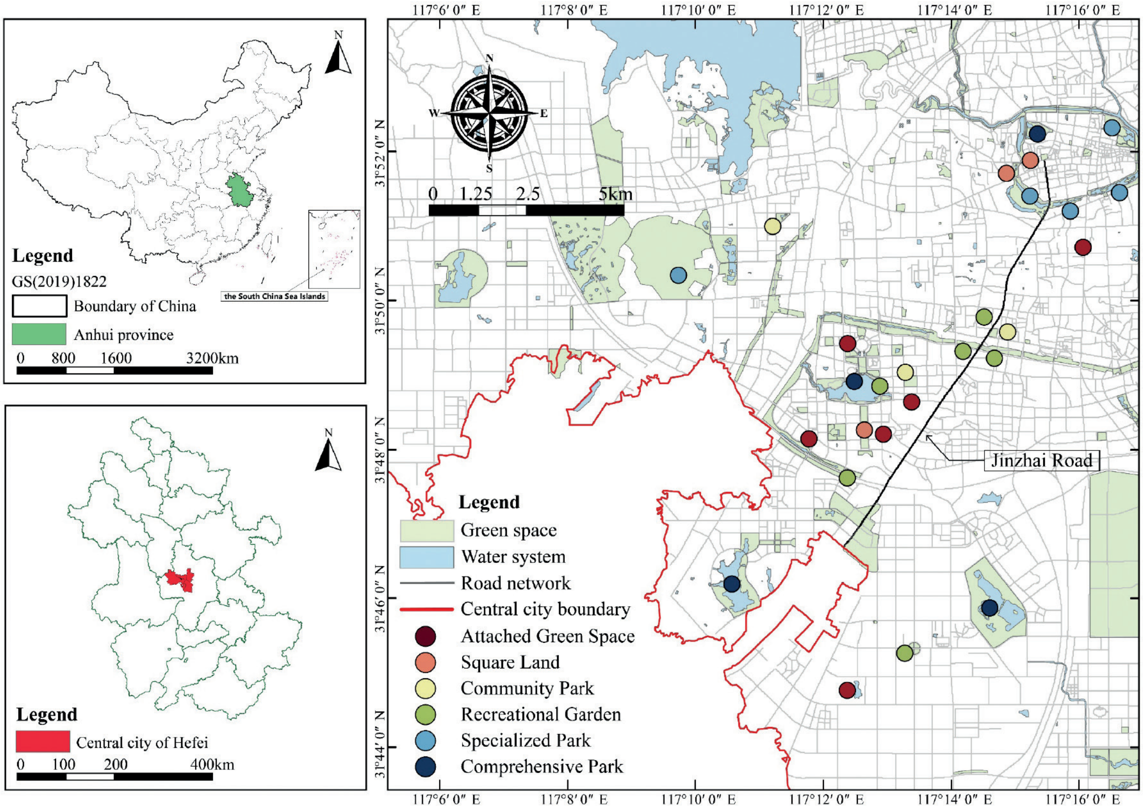

Fig. 1. Location of study area and sample sites.

Materials and Methods

Study Area and Sampling Site Configuration

Overview of Study Area

Hefei, located in the mid-latitude region (Fig. 1), is situated at the center of Anhui Province (N31°49′21.30″, E117°13′18.25″), between the Yangtze and Huai rivers. It is also adjacent to Chaohu Lake and connected to the Yangtze River via the Nanfei River. This strategic position connects the East and West, links the Central Plains, and spans from north to south, offering a unique locational advantage. Hefei's urban area spans 838.52 square kilometers, of which 360 square kilometers are built-up. The region experiences a subtropical humid monsoon climate, transitioning from warm temperate to subtropical conditions. This climate results in hot summers and cold winters, with mild and brief spring and autumn seasons, offering a moderate climate with distinct seasons. The combination of favorable climatic conditions and Hefei's unique geographical position creates an ideal environment for developing garden greenery landscapes. The region is home to a wide variety of plant species, including robust native plants and a favorable environment for high-quality exotic landscape species. Statistically, Hefei has 71 families, 184 genera, and 377 species (including variants) of local trees, which consist of 4 families, 7 genera, and 7 gymnosperm species, as well as 67 families, 177 genera, and 370 angiosperm species [41].

Sampling Site Establishment and Investigation

This study employed a systematic site selection approach on both sides of Jinzhai Road in Hefei City, with a focus on urban garden green spaces that are emblematic of the area. Jinzhai Road, a crucial thoroughfare that cuts through Hefei's central district, connects different urban sectors, such as the Economic and Technological Development Zone, the Administrative New District, and the old Lu Yang District. This roadway was chosen because its adjacent areas include a diverse array of green spaces, showcasing plant communities that are representative of different epochs in Hefei's development. This provides an ideal baseline for sampling. The site selection process commenced with a preliminary survey to pinpoint potential locations, followed by employing stratified random sampling to ensure the inclusivity of green space categories as defined by the latest "Urban Green Space Classification Standard" (CJJ/T85-2017) [42]. On this basis, green spaces that serve recreational, leisure, and entertainment purposes were selected as the main focus of this study. These include park green spaces, attached green spaces, and square lands. Park green spaces were further subdivided into comprehensive parks, community parks, specialized parks, and recreational gardens for detailed study. Regional green spaces and protective green spaces often have responsibilities, such as ensuring the integrity of the landscape pattern, maintaining facility safety, and providing protective isolation. Their land use is independent and not suitable for visitor access [43], and they are not within the scope of this study. This research employed a fixed plot approach to examine plant communities within the green spaces of Hefei. For the arboreal plots, each measured 20 m × 20 m, with recordings of species names, counts, diameter at breast height (DBH), heights, crown spreads, growth conditions, canopy densities, strata affiliations, and presence of regeneration. Shrub plots, covering 2 m × 2 m, included recordings of species names, counts, heights, widths, coverages, growth stages, and regeneration indicators. Herbaceous plots, each measuring 1 m × 1 m, were used to record species names, counts/clumps, heights, coverages, and growth conditions [44]. Furthermore, data on human disturbances within these plots was also documented. Diameters at breast height (DBH) for trees were measured at 1.3 meters above ground using a diameter tape, achieving a precision of 0.1 cm. Tree and shrub heights were measured

Table 1. Basic information of sample sites.

Green Space Type	Serial Number	Site Name (completion year)	Quadrat Quantity	Latitude	Longitude
Attached Green Space	1	Anhui Jianzhu University (2012)	3	31°44’51’’N	117°13’39’’E
	2	Municipal Government Affairs Center (2005)	2	31°49’39’’N	117°13’52’’E
	3	Kaixuanmen Estate (2012)	4	31°48’28’’N	117°14’12’’E
	4	Tianehu moma Estate (2020)	2	31°48’58’’N	117°14’49’’E
	5	Shuian Mingdu Estate (2012)	3	31°48’17’’N	117°13’26’’E
	6	Lvyuan Estate (2000)	2	31°50’32’’N	117°17’27’’E
Square Land	7	Lvzhou Park (2016)	5	31°48’25’’N	117°14’05’’E
	8	Hupotan Scenic Spot (1991)	2	31°52’03’’N	117°16’29’’E
	9	Heichiba Scenic Spot (1984)	3	31°52’07’’N	117°16’35’’E
Community Park	10	Laodong Park (2020)	6	31°49’50’’N	117°16’04’’E
	11	Shitai Road Park (2021)	6	31°49’14’’N	117°14’47’’E
	12	Tianle Park (1993)	4	31°51’24’’N	117°12’46’’E
Recreational Garden	13	Jinxiu Avenue Garden (2002)	2	31°45’34’’N	117°14’20’’E
	14	Kuang River Garden (2022)	3	31°48’01’’N	117°13’43’’E
	15	Dugang Garden (2012)	1	31°49’37’’N	117°15’48’’E
	16	Changqing Sports Park (2020)	4	31°49’36’’N	117°15’57’’E
	17	1958 Bearing Garden (2022)	2	31°49’51’’N	117°15’31’’E
	18	Qimen Road Garden (2011)	2	31°48’57’’N	117°14’22’’E
Specialized Park	19	Shushan Forest Park (1954)	2	31°51’05’’N	117°11’20’’E
	20	Xishan Scenic Spot (1984)	3	31°51’27’’N	117°16’54’’E
	21	Xiaoyaojin Park (1949)	2	31°52’21’’N	117°18’04’’E
	22	Lord Bao Park (1984)	4	31°51’51’’N	117°18’22’’E
	23	Yinhe Scenic Spot (1984)	3	31°51’35’’N	117°17’24’’E
Comprehensive Park	24	Nanyan Lake Park (2016)	4	31°46’27’’N	117°15’48’’E
	25	Tian’e Lake Park (2011)	3	31°49’05’’N	117°13’28’’E
	26	Feicui Lake Park (2006)	4	31°46’24’’N	117°12’10’’E
	27	Xinghua Park (1997)	6	31°52’31’’N	117°16’59’’E

using a hypsometer, with accuracy levels of 0.1 meters for trees and 0.5 meters for shrubs, respectively. The crown widths of shrubs were recorded in both east-west and north-south directions using a steel measuring tape, achieving a precision of 0.1 cm; an average of these measurements was calculated. Similarly, the heights and crown widths of herbaceous plants were assessed, with measurements averaged from both directions. Tree canopy closure was determined using the Hemiview canopy analysis system. Shrub and herbaceous layer coverage was calculated using the formula: Coverage = (East-West crown width × North-South crown width) divided by the plot area. The locations and number of plots were established based on the scale of the sites and the characteristics of plant distribution. The investigation was primarily conducted in July 2023. Ultimately, the green spaces surveyed included Tian'e Lake Park, Feicui Lake Park, Nanyan Lake Park, Shushan Forest Park, Xinghua Park, among others, totaling 27 locations with 87 plots in total (refer to Fig. 1 and Table 1).

Evaluation Indicators for the Near-Naturalness of Plant Communities

Evaluation Indicator System

Combining qualitative and quantitative evaluation methods, and informed by national, regional, and industrial standards and research, we developed an indicator framework to evaluate the near-naturalness of plant communities in green spaces [31, 45, 46]. This framework comprises indicators that reflect plant community characteristics across multiple dimensions. Due to the varying meanings, magnitudes, and dimensions of these indicators, standardizing each to a [0, 1] range is essential for comparability and distinctiveness. We collected and calculated values for indicators such as native plant proportion, species richness, community layers, tree canopy density, understory and herb layer coverage, dead plant numbers, and litter coverage (Fig. 2). For structural analysis and succession assessment, indices such as community layers, DBH classes, and counts of natural regeneration seedlings were calculated using specific methods. Disturbance degree in Criterion Layer B_4, a qualitative indicator, was primarily quantified through expert scoring and value assignment.

Indicator Survey and Data Collection

(1) Community Composition (B_1): Record the species count (C_2) in each tree, shrub, and herb layer within the sample plot, along with the plot's native plant species proportion (C_1) [48]. Compute the plot's Simpson index (C_3) and Shannon-Wiener index (C_4) [49] for species diversity and evenness. The Pielou index (C_5) evaluates the ratio of actual to theoretical maximum diversity, assessing community-level similarity.

(2) Community Structure (B_2): Document the number of layers in plant communities, including trees, shrubs, herbs, and ground cover, for each sample plot (C_6). Measure trees with a DBH over 4 cm to calculate the DBH class index (C_7). Classify trees by DBH into categories with corresponding values and calculate the index as the product of each category's proportion and value [50]. Record canopy closure (C_8), underwood, and herb cover in the plot (C_9 and C_{10}).

(3) Community Succession (B_3): Use the M. E. Tikhomirov method [51] to count naturally regenerating seedlings (C_{11}). Assign values to healthy and weak seedlings to calculate regenerating seedlings per hectare. Classify regeneration based on seedling count per hectare with assigned values. Also, record dead plant numbers (C_{12}) and ground litter coverage (C_{13}) in the sample plot.

(4) Disturbance Degree (B_4): Assess and categorize human disturbance (C_{14}), natural disturbance (C_{15}), and management intensity (C_{16}). Quantification is based on assigned values in Table 2 [52].

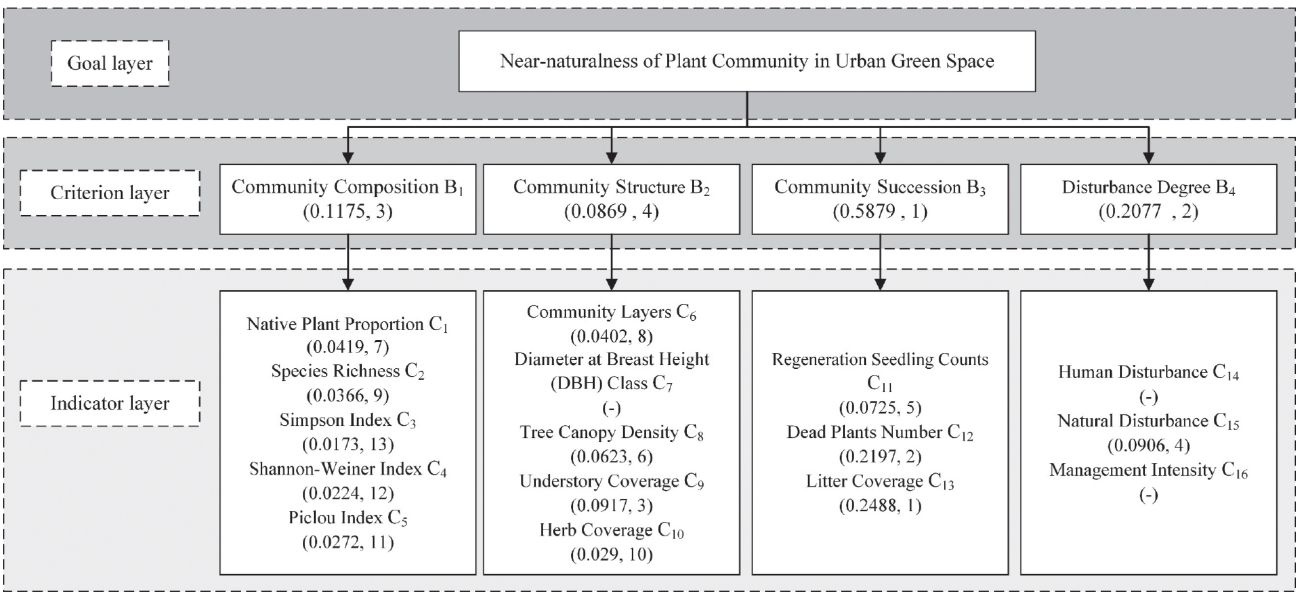

Fig. 2. Evaluation indicator system for near-naturalness of plant communities in Hefei's green spaces.

Table 2. The assignment table of disturbance degree index.

Index	Disturbance Intensity	Classification	Assigned Value
Human Disturbance C_{14}	None	No artificial disturbance, no residential areas or roads nearby.	1.0
	Mild	Slight human disturbance, occasional trampling at a distance from residential areas and roads.	0.8
	Moderate	Significant human disturbance, including trampling and picking, with proximity to residential areas and roads.	0.6
	Severe	Frequent human activities causing damage, repeated branch breakage, trampling, and picking, directly adjacent to residential areas and roads.	0.4
Natural Disturbance C_{15}	None	No diseases or pests, no fire, no wind disasters, no soil erosion, no frost damage, no constituting disturbance.	1.0
	Mild	The plant community ecosystem can self-regulate, and the disturbance intensity is within its own regulatory range.	0.4
	Moderate	Causes significant harm to the plant community, with disturbance intensity exceeding its own regulatory capacity.	0.2
	Severe	Humans employ moderate-intensity logging, vine removal, pruning, transplanting, and replanting measures in forest communities, resulting in more noticeable positive effects.	0.4
Management Intensity C_{16}	None	None management measure	1.0
	Mild	Humans employ relatively light-intensity logging, vine removal, pruning, transplanting, and replanting measures in forest communities, resulting in positive effects.	0.6
	Moderate	Humans employ moderate-intensity logging, vine removal, pruning, transplanting, and replanting measures in forest communities, resulting in more noticeable positive effects.	0.4
	Severe	Humans employ relatively high-intensity logging, vine removal, pruning, transplanting, and replanting measures in forest communities, resulting in clear positive effects.	0.2

Statistical Methods and Evaluation Framework

Evaluation Indicator Selection

Principal Component Analysis (PCA), a multivariate statistical method, uses linear combinations of original variables to reveal the covariance structure of multidimensional variables by creating principal components [53]. PCA is frequently used in scenarios with numerous interrelated indicators [54]. We used the `prcomp` function in R to perform PCA on near-naturalness evaluation indicators, aiding in their selection and simplification [55]. Principal component analysis involves several key steps: 1) Construct the observation data matrix and standardize it to ensure the accuracy of the analysis. 2) Generate the correlation coefficient matrix and compute its eigenvalues and eigenvectors to identify the principal components of the data. 3) Utilize the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity to assess the suitability of the data for PCA. 4) Determine the number of principal components based on the cumulative contribution rate. 5) Calculate the scores of the principal components.

Evaluation Indicator Weights

After determining the assessment objects, differences among indicators lead to variations in the information entropy of each, affecting the information they provide. Indicators with lower information entropy are more informative and thus assigned higher weights [56]. Our weighting approach employed the entropy weight method (EWM), grounded in objective statistical indicators [57]. The method comprises the following calculation steps:

1. Build the judgment matrix: Use sample data and evaluation indicators from Hefei's green spaces, we form a matrix with n samples and m evaluation indicators. In this matrix, x_{ij} denotes the j_{th} indicator's value for the i_{th} sample.
2. Standardize the indicators: Standardize the indicators using the range transformation method to ensure fairness in comparison between different indicators. Positive indicators are calculated using formula (6), while negative indicators follow formula (7).

$$y_{ij} = \frac{x_{ij} - min\, x_{ij}}{max\, x_{ij} - min\, x_{ij}} \tag{6}$$

$$y_{ij} = \frac{max\ x_{ij} - x_{ij}}{max\ x_{ij} - min\ x_{ij}} \tag{7}$$

3. Calculate the proportion and entropy of indicators: Determine the importance of each indicator in the evaluation system by calculating the proportion (F_{ij}) and entropy value (G_j) of the indicators, providing a quantitative basis for comprehensive evaluation.

$$F_{ij} = y_{ij} / \sum_{i=1}^{n} y_{ij} \text{ (i = 1, 2, …, } n\text{; j = 1, 2, …, } m\text{)} \tag{8}$$

$$G_j = -\frac{1}{\ln n} \sum_{i=1}^{n} F_{ij} / \ln F_{ij} \tag{9}$$

4. Calculate indicator weights (W_j): Compute the weight of each indicator, reflecting the contribution of different indicators to the evaluation of near-naturalness.

$$W_j = (1 - G_j) / \sum_{i=1}^{m} G_j \tag{10}$$

Plant Community Near-Naturalness Evaluation Model

The Near-Naturalness Index (NNI) evaluation model for plant communities was constructed by combining the standardized values and weights of the evaluation indicators. The corresponding formula is:

$$NNI = \sum_{i=1}^{m} W_j y_{ij} \text{ (j = 1, 2, …, } m\text{)} \tag{11}$$

Grading of Plant Communities for Near-Naturalness

For a more precise assessment and categorization of near-naturalness in Hefei's green spaces, we conducted a cluster analysis (CA) on the NNI of 87 plant communities using the R language [58]. Near-naturalness grades were scientifically determined based on the number of clusters identified. Initially, we processed the near-naturalness indices of each plant community using the 'hclust' function in R, and then performed clustering analysis using Ward's method. Subsequently, we utilized the 'ggtree' function for a graphical representation of the clustering results, which aided in the classification of near-naturalness grades in each plant community. Finally, we evaluated the near-naturalness of each sample based on these classified near-naturalness grades.

Regression Analysis between Near-Naturalness and Feature Indicators

Developed by Breiman in 2001, Random Forest (RF) is an ensemble learning method that utilizes multiple decision trees, suitable for classification and regression tasks [59]. Results visualization employs the ggplot2 package. The RF method utilizes Bootstrap sampling to create multiple datasets from the original data. It builds various decision trees and combines their outcomes for final predictions using either voting or averaging. RF is known for its resilience to data anomalies and noise, as well as its effectiveness in handling multivariate data. It is widely applied in fields such as medicine [60], ecology [61], and geography [62, 63]. This study utilizes the regression capability of the Random Forest algorithm to analyze the intricate relationship between plant community naturalness and various indicators. Utilizing the Random Forest package in the R programming language, a regression model was developed. It incorporated 16 metrics from four hierarchical levels of analysis: community composition, structure, succession, and disturbance intensity. These metrics were used as independent variables against the NNI for the sample plots, with random forest regression employed to analyze the relationship. The model's accuracy depends on two crucial parameters: the number of decision trees (ntree) and the maximum features considered at each split (mtry). Optimal model performance is achieved by using a minimal ntree value when additional trees do not improve prediction accuracy, with mtry usually set to one-third of the total number of variables. Variable significance is determined by the increase in Mean Square Error (IncMSE), where higher IncMSE values signify greater variable importance [64]. Partial dependence plots are used to clarify the nonlinear interactions between independent variables and the NNI, providing insights into complex ecological dynamics. Notably, the robustness of the random forest algorithm to variations in data scale and unit eliminates the need for normalization, simplifying data preparation processes for ecological modeling [65].

Results and Analysis

Results of the Evaluation Indicators Selection

Sixteen initial indicators of forest near-naturalness are used to construct an evaluation indicator matrix for principal component analysis. Results (Fig. 3) indicate that the first five components' cumulative variance contribution rate exceeds 70%, with a KMO measure of 0.714 and a P-value of 0 (Fig. 3), confirming the sample data's suitability for principal component analysis. The principal component factor loading matrix (Fig. 3) revealed high loadings on the first principal component for the Shannon-Weiner index, Simpson index, community layers, species richness, and Piclou index. The second principal component had high loadings for dead plants number, litter coverage, and natural disturbances; the third for understory and herb coverage; the fourth for tree canopy density and regeneration seedlings counts; and the fifth for native plant proportion. Indicators with loadings above 0.6 were selected (Fig. 3), yielding 13 evaluation indicators: native plant proportion (C_1), species richness (C_2), Simpson index (C_3), Shannon-Weiner index (C_4), Piclou index (C_5), community layers (C_6), canopy density (C_8), underwood coverage (C_9), herb coverage (C_{10}), regeneration seedlings count (C_{11}), dead plants number (C_{12}), litter coverage (C_{13}), and natural disturbance (C_{15}).

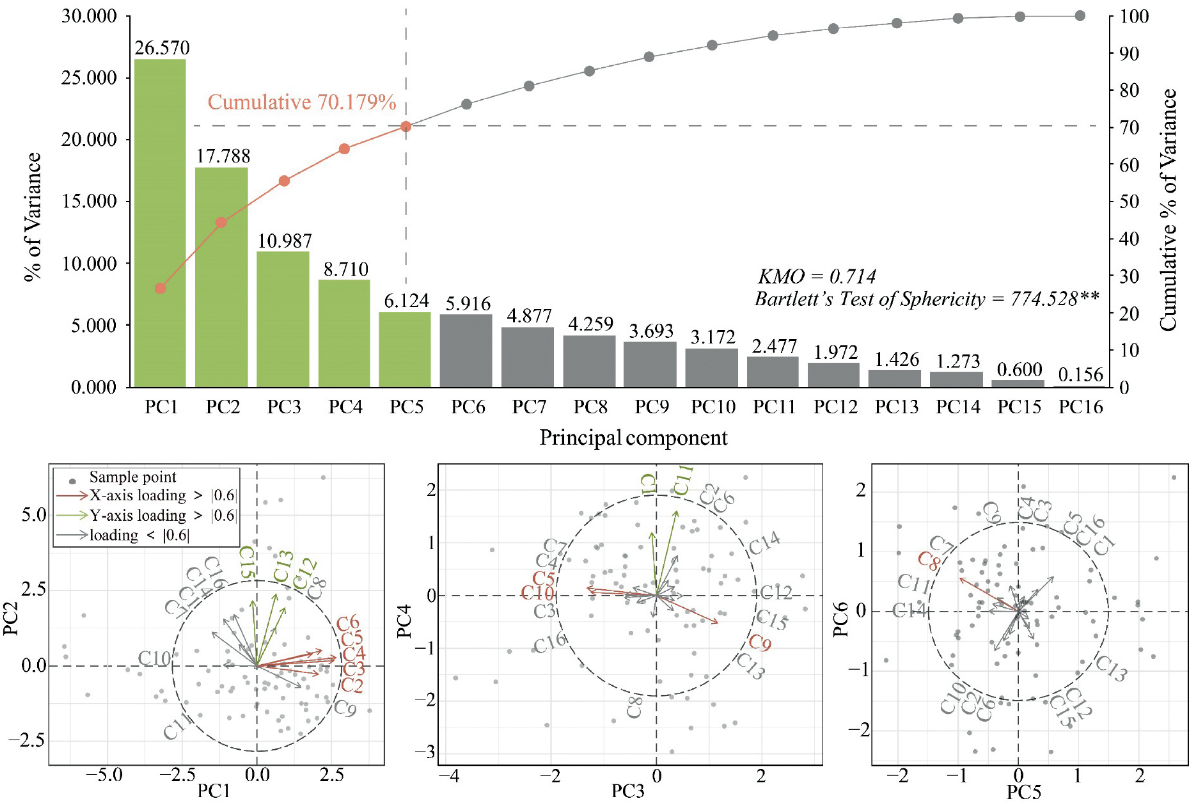

Fig. 3. Principal component analysis (PCA) of the near-naturalness evaluation indicators for plant communities in Hefei's urban green spaces: explained variance and principal component loadings.

Computation of Evaluation Indicator Weights

Thirteen indicators identified through principal component analysis serve as the foundation for a matrix, with their weight coefficients determined via the entropy weight method, as depicted in Fig. 2, spanning from 0.0173 to 0.2488. In the evaluation of indicator weights, litter coverage (C_{13}, 0.2488) has the highest weight, followed by the number of dead plants (C_{12}, 0.2197), understory coverage (C_9, 0.0917), natural disturbances (C_{15}, 0.0906), and natural regeneration seedling counts (C_{11}, 0.0725), with the remaining indicators having weight coefficients less than 0.05. The biodiversity indices, including the Simpson index (C_3, 0.0173), Shannon-Weiner index (C_4, 0.0224), and Piclou index (C_5, 0.0272), carry relatively lesser weights. Nevertheless, to prevent the loss of information and enhance the detail of ecological evaluation, these indices are maintained, ensuring the objectivity of further analysis.

Comprehensive Evaluation Results of Near-Naturalness

The assessment of the NNI for plant communities within 87 green spaces in Hefei's central urban district is depicted in Fig. 4, with NNI values spanning from 0.135 to 0.752. The frequency distribution graph (Fig. 4a) demonstrates a skewness in the NNI distribution, with the density curve peaking not at the center but skewed towards lower NNI values. This suggests that the majority of green spaces have plant communities with near-naturalness levels on the medium to low side, although a notable portion boasts higher near-naturalness levels. Specifically, the distribution (Table 3) reveals that 15 plots fall within an NNI range of 0.1 to 0.2, representing 17.24% of the total; 36 plots fall within 0.2 to 0.3 (41.38%); 22 plots within 0.3 to 0.4 (25.29%); 7 plots within 0.4 to 0.5 (8.05%); 4 plots within 0.5 to 0.6 (4.60%); and 3 plots within 0.6 to 0.7 (3.45%).

The box plot analysis (Fig. 4b) reveals that specialized parks have the highest median near-naturalness, with attached green spaces, recreational gardens, and comprehensive parks in the middle, and community parks and square green spaces at the lowest median. This suggests that specialized parks possess a higher level of near-naturalness, whereas community parks and square land exhibit lower levels. The interquartile ranges for community parks, recreational gardens, and comprehensive parks are narrower, showing a more concentrated distribution of near-naturalness levels in these green spaces, albeit not high on average. In contrast, attached green spaces, specialized parks, and square green spaces exhibit wider interquartile

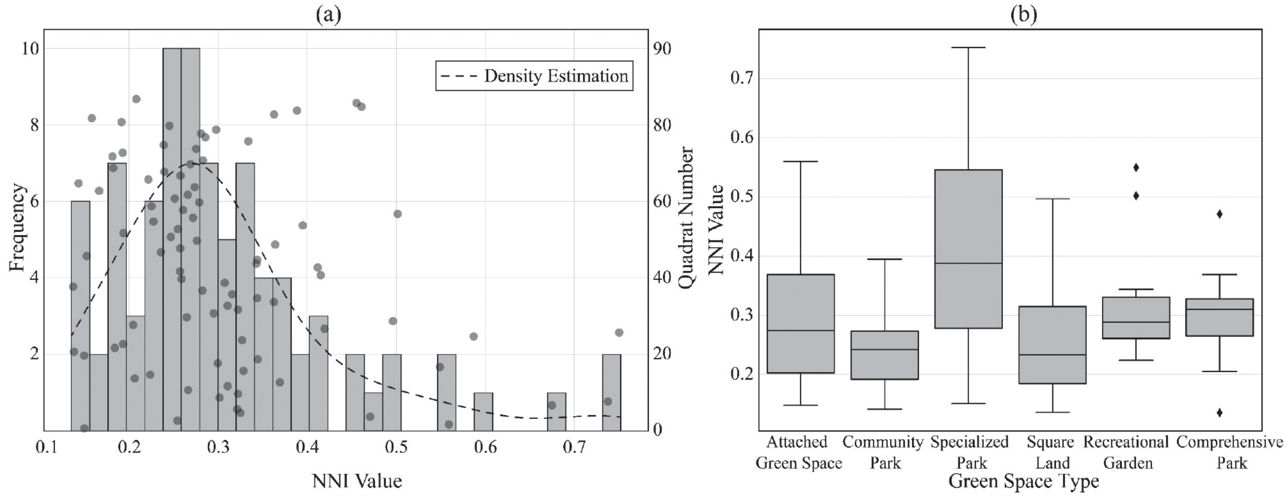

Fig. 4. The near-naturalness index for 87 plant community sampling plots in Hefei's urban green spaces: (a) frequency distribution and (b) boxplots for six categories of green spaces.

Table 3. Numerical distribution of near-naturalness index of 87 plant community quadrats in Hefei's green spaces.

NNI Value Range	Count	Percentage (%)	Quadrat Number
0.1–0.2	15	17.24	1, 20, 21, 22, 23, 38, 46, 52, 63, 65, 69, 72, 73, 81, 82
0.2–0.3	36	41.38	3, 11, 14, 15, 18, 28, 30, 31, 37, 40, 42, 47, 48, 50, 51, 53, 55, 56, 58, 59, 60, 61, 62, 64, 66, 67, 68, 70, 71, 74, 75, 77, 78, 79, 80, 87
0.3–0.4	22	25.29	5, 6, 9, 10, 12, 13, 16, 19, 24, 32, 33, 34, 35, 36, 39, 44, 45, 49, 54, 76, 83, 84
0.4–0.5	7	8.05	4, 27, 29, 41, 43, 85, 86
0.5–0.6	4	4.60	2, 17, 25, 57
0.6–0.7	3	3.45	7, 8, 26

ranges, reflecting greater variability in near-naturalness across different sections of these green spaces. Notably, recreational gardens and comprehensive parks include outliers, signifying the presence of a few plant communities with exceptionally high or low near-naturalness.

Specifically, the highest NNI was recorded in Plot 26, scoring 0.752, situated in the Xishan Scenic Spot of the Encircling City Park. This plot is distinguished by its diversity of tree species, including those with high canopy closure and undergrowth, showcasing a complex structure, evident succession, extensive grass coverage, and minimal human interference, contributing to its high near-naturalness. Following closely, Plot 8, with a score of 0.740, located in Shushan Forest Park, is characterized by its dominance of sweetgum trees taller than ten meters, high canopy closure, and significant litter coverage. The lowest scores of naturalness were observed in Plots 38 and 21, with scores of 0.135 and 0.136, respectively, found in the Palm Grove of Xinghua Park and the Cedar Forest of Lvzhou Park. These plots feature a simplistic structure primarily consisting of trees and lawns, with an absence of shrubbery.

Classification of Near-Naturalness Grade

The NNI for plant communities undergoes Ward clustering analysis and is depicted through a circular dendrogram (Fig. 5). The analysis delineates 87 plots into four distinct clusters, each symbolizing a specific grade of near-naturalness. In alignment with the German system for assessing near-naturalness [66] and methodologies pertinent to the naturalness evaluation of urban forests in China [45, 50], four distinct clusters are categorized as near-natural (I), semi-natural (II), far-natural (III), and artificial (IV). To be specific, Grade I encompasses three plots (numbers: 7, 8, 26), with NNI values spanning from 0.676 to 0.752, representing 3.45% of the total plots (refer to Fig. 5 and Table 4). Predominantly, these plots are situated in specialized parks, like Xishan Scenic Spot and Shushan Forest Park, and resemble almost natural communities. These areas, characterized by abundant native trees, diverse species, and a complete structure, showcase mature ecosystems with minimal human interference, strong resilience, and stability. They play a crucial role in preserving urban biodiversity

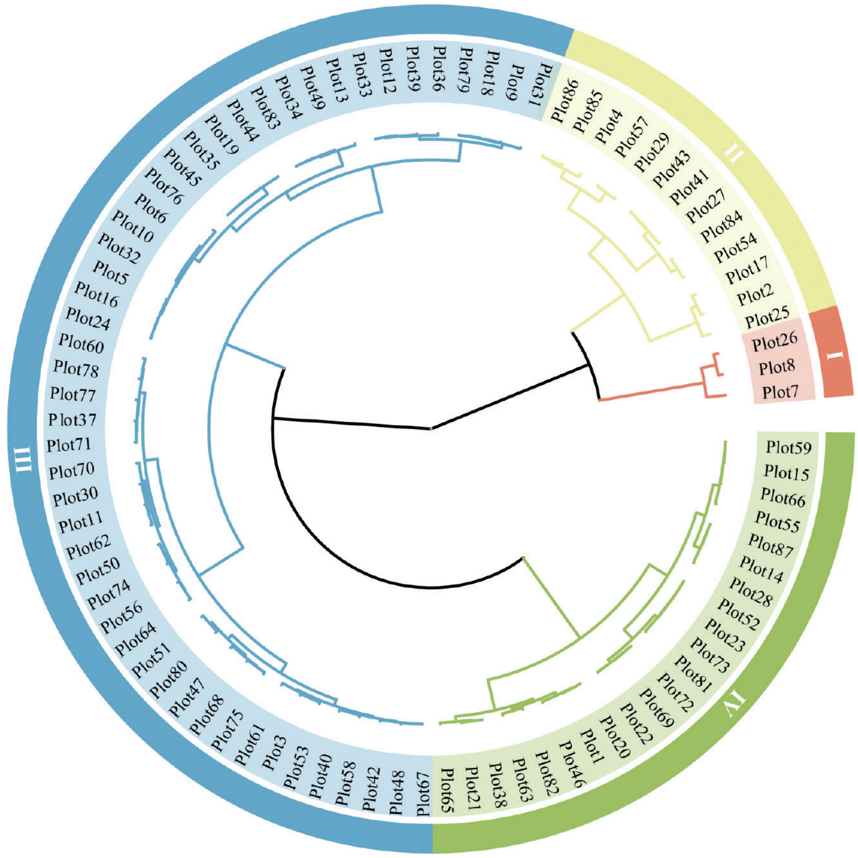

Fig. 5. Classification of near-naturalness clustering of 87 plant community quadrats in Hefei's green spaces.

and ecological balance. Grade II is comprised of 13 plots (numbers: 2, 4, 17, 25, 27, 29, 41, 43, 54, 57, 84, 85, 86), with NNI values between 0.388 and 0.588, constituting 14.94% of the aggregate, mainly located in specialized parks and attached green spaces, with a minority situated in various other green spaces. These areas demonstrate moderate Simpson and Shannon-Weiner indices. Despite high species richness and native tree proportion, these spaces could benefit from enhanced ecosystem complexity and stability. These spaces feature moderate species diversity and a balanced community structure. Grade III includes 49 plots, with NNI values ranging from 0.369 to 0.234, accounting for 56.32%, with the principal green space types being recreational and comprehensive parks that display ecological complexity but have simpler structures. These areas have a lower proportion of native trees and are affected by human activities, resulting in diminished ecosystem functions. Grade IV consists of 22 plots, with NNI values from 0.135 to 0.226, making up 25.29% of the total, primarily found in square lands and community parks are primarily pure forests, shaped hedges, and floral covers, with low species richness, native tree proportion, and Simpson and Shannon-Weiner indices, marked by low tree canopy closure and high herb coverage. These areas could benefit from increased biodiversity and reduced hard paving to enhance ecological characteristics.

In terms of green space types, attached green spaces have the highest proportion of Grade III near-naturalness at 43.75%, followed by Grade IV at 31.25% (Table 4). These spaces include areas in public services, residential zones, and campuses. Near-naturalness in square lands is generally low. Grade IV near-naturalness, which is the most prevalent at 50%, includes locations like Lvzhou Park, Heichiba Scenic Spot, and Hupotan Scenic Spot. Community parks primarily feature near-naturalness in Grades III and IV, cumulatively accounting for 93.75%. Recreational gardens predominantly exhibit near-naturalness at Grade III (78.57%), with lesser extents in Grade II (14.29%) and IV (7.14%). Specialized parks display near-naturalness at 21.43% in Grade I and 28.57% in Grade II, constituting 50% – the highest combined proportion of higher near-naturalness grades. Comprehensive parks mainly exhibit near-naturalness at Grade III, comprising 76.47% of their total. Additionally, attached green spaces and square lands usually exhibit

Table 4. The proportion of near-naturalness grade of different types of green space plant communities in Hefei City.

Green Space Type	Grade I		Grade II		Grade III		Grade IV	
	Quadrat quantity	percent-age/%	Quadrat quantity	percent-age/%	Quadrat quantity	percent-age/%	Quadrat quantity	percent-age/%
Attached Green Space	0	0.00%	4	25.00%	7	43.75%	5	31.25%
Square Land	0	0.00%	1	10.00%	4	40.00%	5	50.00%
Community Park	0	0.00%	1	6.25%	8	50.00%	7	43.75%
Recreational Garden	0	0.00%	2	14.29%	11	78.57%	1	7.14%
Specialized Park	3	21.43%	4	28.57%	6	42.86%	1	7.14%
Comprehen-sive Park	0	0.00%	1	5.88%	13	76.47%	3	17.65%
Sum Total	3	3.45%	13	14.94%	49	56.32%	22	25.29%

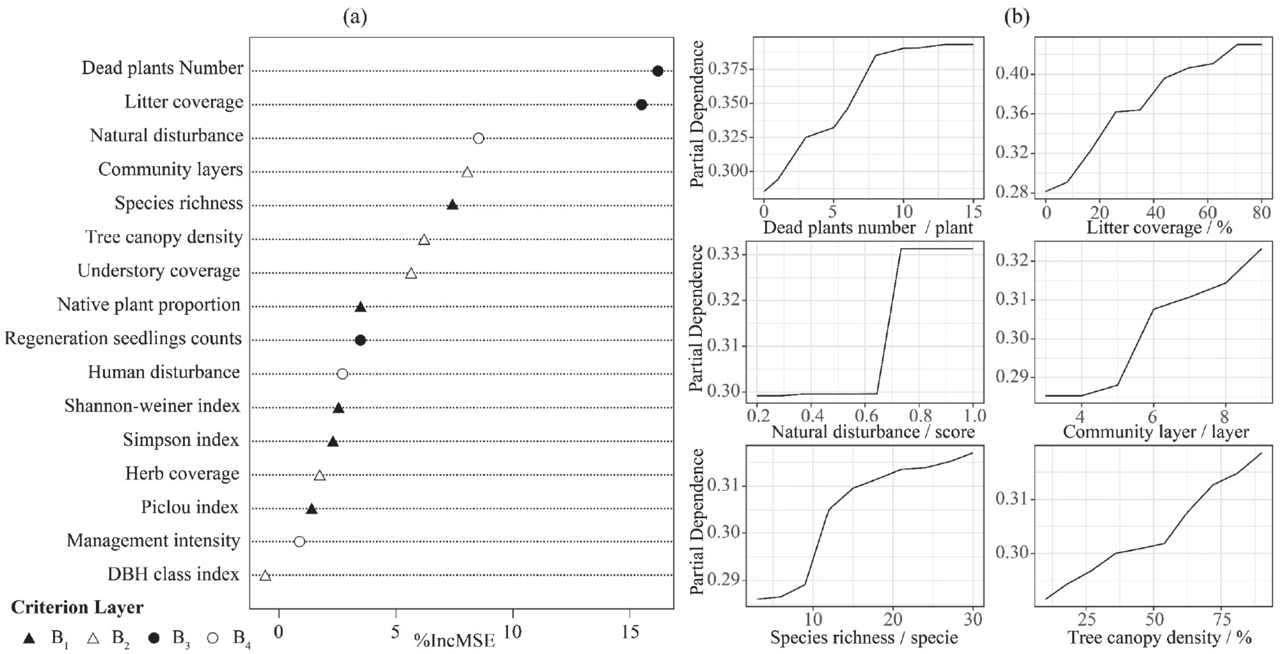

Fig. 6. (a) Ranking of importance for near-naturalness feature indicators. (b) Influence of the top 6 feature indicators on near-naturalness.

lower near-naturalness, likely due to higher human disturbance. Specialized parks often retain more natural features due to their specific ecological or cultural themes. Comprehensive parks balance multifunctional needs while preserving ecological and natural characteristics.

Overall, the near-naturalness of plant communities in Hefei's gardens and green spaces is at a medium to low level. Plots rated as "near-natural" and "semi-natural" account for 18.39% of the total surveyed plots, mainly distributed in specialized parks, represented by the Xishan Scenic Spot and Shushan Forest Park, with other types of green spaces accounting for a smaller proportion; plots rated as "far-natural" and "artificial" make up 81.61% of the total plots, mainly located in community parks and comprehensive parks.

The Random Forest Regression Relationships of Near-Naturalness Feature Indicators

The creation of a training set with the initial 16 indicators to determine optimal trial parameters reveals that the ideal parameters for the random forest model are mtry = 5 and ntree = 500 (Appendix Fig. 8). At these settings, the model achieves peak performance and the lowest error rates. Consequently, a random forest regression model is developed, incorporating graphs that illustrate the importance of the indicators and provide partial dependence plots.

In the random forest regression model, factor importance is typically measured by the increase in mean square error (Inc MSE value), where a larger Inc MSE value signifies

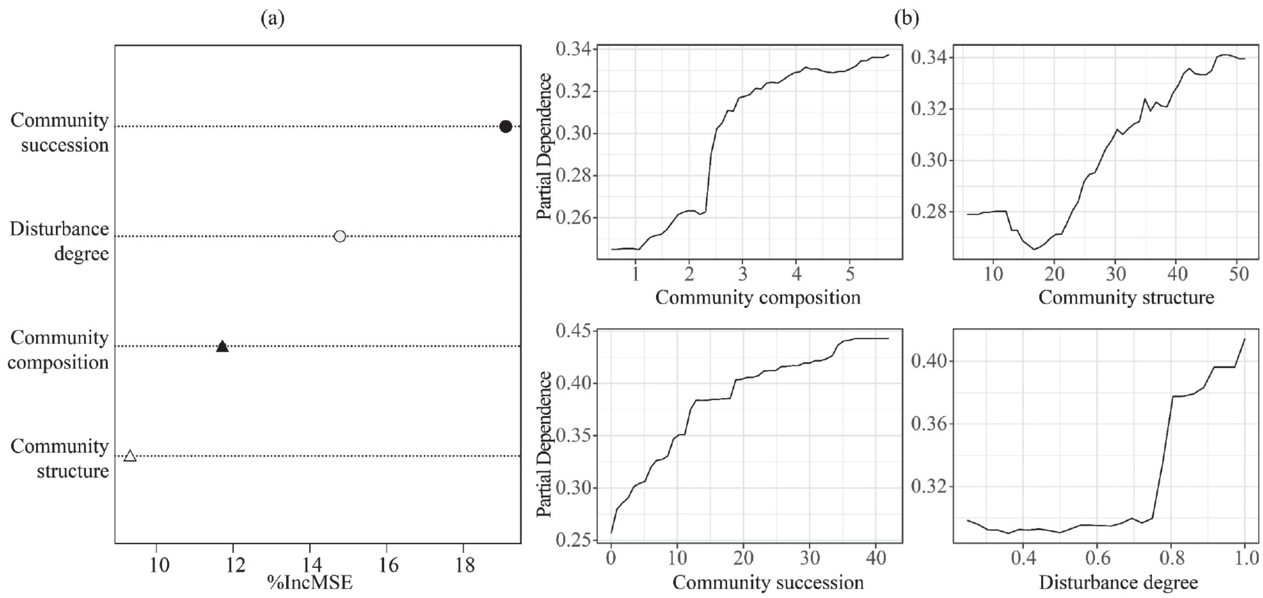

Fig. 7. (a) Ranking of criterion layer indicators' importance relative to near-naturalness. (b) Influence of criterion layer indicators on near-naturalness.

a more important factor. The ranking of indicator importance in Fig. 6(a) shows that the primary indicators affecting NNI are the number of dead plants (16.2%) and litter coverage (15.9%). Following these, other indicators such as natural disturbance (8.54%), community layers (8.05%), species richness (7.41%), and tree canopy density (6.20%) impact NNI, with the least influence from management intensity (0.87%) and a negative impact from DBH class index (-0.59%). The cumulative importance of indicators within each criterion layer is distributed as: community succession (34.42%), community structure (21.05%), community composition (17.15%), and degree of disturbance (12.13%). The model effectively uncovers the non-linear impacts of feature indicators, utilizing partial dependence plots to demonstrate their varied influences on NNI. Diagrams in Fig. 6(b) are created using the six most significant indicators (C_{12}, C_{13}, C_{15}, C_6, C_2, C_8) to illustrate their effects. Generally, the response of plant community near-naturalness varies among different key feature indicators. All indicators exhibit a non-linear increasing trend, with natural disturbance acting as a qualitative scoring factor. Specifically, the number of dead plants, litter coverage, and species richness show a non-linear trend of rapid increase followed by stabilization. A significant increase in plant community NNI is observed with 5–10 dead plants, 10-30% litter coverage, and a species richness of 10–15 species. The qualitative indicator of natural disturbance scores between 0.6 and 0.8, indicating that mild or lesser natural disturbances correspond to a similar trend in NNI. The impact of community layers and tree canopy density on NNI is also notably significant.

Employing the same methodology, the analysis further explores the relationship between the four criterion layers and NNI, focusing on the synergistic effects among the indicators. The data for the 16 indicators is first normalized and then processed using the entropy weight method, establishing their respective weights in each criterion layer. This enables weighted computations for the original data of each layer in the random forest regression, with the criterion layer (B) set as the independent variable against the NNI, and optimal parameters identified as ntree = 500 and mtry = 1 (Appendix Fig. 8). Fig. 7(a) and (b) present the ranking of criterion layer indicators' importance to near-naturalness: community succession (19.11%) ranks the highest, followed by disturbance degree (14.77%), community composition (11.72%), and community structure (9.31%). These four indicators exhibit a fluctuating yet rising non-linear trend, demonstrating their significant impact on near-naturalness.

Discussion

Selection of Near-Naturalness Indicators for Plant Communities in Urban Green Spaces

Assessing the near-naturalness of urban green space plant communities aids in understanding their growth status and facilitates the timely repair of damaged areas. This assessment forms a fundamental aspect of urban green space management and maintenance [67]. This assessment is particularly crucial for monitoring and managing urban plant communities, which often face significant human disturbances. Implementing effective near-naturalness assessment methods and appropriate measures to enhance community naturalness is vital for the stability and sustainable development of urban green spaces. Earlier studies on near-naturalness assessment primarily focused on one or two indicators [30, 33]. Subsequent research, increasingly incorporating numerous indicators [47], suggests that the near-naturalness of plant communities requires a composite evaluation using multiple indicators. Consequently, this study developed an evaluation model incorporating four dimensions and 16 indicators (Fig. 2). However, soil physical properties, which are crucial for near-naturalness assessment [47, 68], were not included in this study. This exclusion stemmed from the limited distribution of sample points in the study area, all located in low-altitude plains, where soil characteristics displayed no significant local geographical differences. Consequently, variables that could not accurately reveal differences in plant community characteristics or that introduced uncertainty to the assessment were excluded. Additionally, as near-naturalness evaluation methods evolve, it becomes crucial to consider indicators of both natural attributes and human disturbance. Therefore, the degree of disturbance, including human, natural, and management intensity, was included as a qualitative dimension in constructing the near-naturalness evaluation index system (Table 2).

Analysis of Near-Naturalness and Feature Indicators of Plant Communities in Hefei's Urban Green Spaces

An in-depth analysis focused on the near-naturalness of plant communities in Hefei's green spaces. The evaluation of near-naturalness indices for 87 sample plots revealed significant differences in these spaces. The regression analysis using the random forest algorithm highlighted the significance of dead plants and litter coverage in near-naturalness (Fig. 6a), contributing 16.20% and 15.5% respectively. These two indicators reflect the process of natural succession and the integrity of the ecological cycle and are important indicators for evaluating the naturalness of communities. This is consistent with the findings of scholars such as Kunttu [33] and Korhonen [69]. Litter plays a vital role in the ecological cycle by recycling nutrients. Near-naturalness increases notably with 5-10 dead plants and 10-30% litter coverage. Additionally, natural disturbance ranks third in importance at 8.54%. Mild natural disturbances improve near-naturalness without exceeding the plant community's self-regulation capacity. In addition to common disturbances such as pest infestations, windstorms, and frost damage, research by Baskent et al. [70] indicates that communities prone to soil erosion and poor nutrient development, leading to soil and water loss, are considered to have lower near-naturalness than communities with good soil conditions.

Community succession and disturbance degree emerge as the top two indicators in criterion layer analysis (Fig. 7a), underscoring the importance of ecosystem integrity. The overall importance ranking of feature indicators shows a consistent significance for community succession, with variations in the importance of other criterion layers compared to their weighted significance. For instance, community composition's weighted outcome surpasses its aggregate result, suggesting the necessity of multi-indicator analysis. The research by Strong et al. [71] indicates that the Shannon-Wiener index of a community needs to be considered in conjunction with both species richness and evenness. In summary, indicators like dead plant count, litter coverage, natural disturbance, community layers, species richness, and canopy density are crucial for assessing near-naturalness in Hefei City's green spaces. The importance of criterion layer indicators is ranked as: community succession, disturbance degree, community composition, and community structure, with community succession being the most influential on near-naturalness.

Features and Improvement Measures of Hefei's Green Spaces Plant Communities with Different Near-Naturalness Grade

This study proposes various recommendations for the near-natural development and management of Hefei's green spaces at different community layers. Firstly, in high near-natural green spaces ("Near-natural" Grade), maintaining and enhancing natural traits, preserving natural succession dynamics, and minimizing human intervention are essential. Emphasize the protection and augmentation of rare and endangered species to foster biodiversity, and utilize these spaces for environmental education and public science activities, thereby boosting public appreciation and respect for nature [72]. Secondly, in medium near-natural green spaces ("Semi-natural" and "Far-natural" Grade), enhancing naturalness through the gradual introduction of native plants and minimizing human management activities like pruning and fertilizing is vital. Implement ecological restoration in damaged ecosystems, focusing on aquatic ecology restoration and soil condition improvement [73]. Additionally, integrate fragmented green spaces into ecological corridors to connect various ecological areas, facilitating species migration and interaction [74]. Thirdly, in low near-natural green spaces ("Artificial" Grade), transform existing plant communities to increase native plant representation and enhance structural complexity [75]. Furthermore, create diverse microhabitats, like water bodies, rocks, and dead wood, to increase habitat diversity, reduce hard ground paving, improve permeable paving and green areas, and enhance surface water infiltration and soil ecological functions [76, 77]. In essence, during the near-natural restoration of garden and green space communities, it's crucial to engage in proactive structural adjustments to foster the natural succession of these communities. Moreover, when managing communities with varying structural types, an understanding of the natural progression of community succession, the extent of variation between vegetation under disturbance and natural vegetation, along with implementing appropriate management actions tailored to the specific site conditions, is essential for scientifically facilitating the transformation of plant communities back to their natural state.

Advantages, Disadvantages, and Prospects of the Research Method and Evaluation Model

Drawing on urban forest naturalness assessment methods, this study offers a practical approach for evaluating green space plant communities' near-naturalness, providing a reference for similar urban area assessments. However, the lack of a universally accepted quantitative method for assessing near-naturalness suggests the need for further validation of this model [78]. Principal component analysis, commonly used in forest naturalness assessments [79, 80], addresses the challenges of large datasets and complex weight calculations due to numerous indicators. Firstly, this study initially utilizes principal component analysis for selecting indicators. Secondly, this study uses the entropy weight method for calculating the weights of near-naturalness evaluation indicators, improving the objectivity and accuracy of evaluations [81]. Thirdly, the study adopts a comprehensive index method for the quantitative evaluation of green space plant communities' near-naturalness, providing operational ease and relatively reliable outcomes. However, the method's large-scale implementation is limited by the extensive data collection workload at field sampling points. Fourthly, the study employs Ward's method for cluster analysis to categorize near-naturalness grades. This method's strength is in its variance minimization principle, clustering samples based on near-naturalness distance, ensuring intra-cluster similarity and inter-cluster distinction in terms of evaluation indicators [82]. This approach not only guarantees internal consistency in near-naturalness within each plant community, aiding in the clear differentiation of clusters [27], but also aligns with the concept of near-naturalness.

The Random Forest (RF) algorithm shows superior accuracy and efficiency in data classification, sample regression, and model prediction tasks [83]. It outperforms other regression models by showing insensitivity to multicollinearity, offering stable performance with missing or unbalanced data, and delivering higher execution efficiency [84]. In our study, due to the Simpson index and the Shannon-Weiner index having similar computational logics, a predisposition towards collinearity among indicators was observed. The random forest regression algorithm effectively mitigates these collinearity issues, facilitating a comprehensive analysis of the interconnections among various indicators. Furthermore, there is redundancy between the variable importance outcomes of RF and the assessment indicator weights. This redundancy stems from the entropy weight method-derived indicator weighting, offering an objective foundation for the initial construction of the evaluation model within a systematic and quantifiable framework. Conversely, RF's application in assessing the importance of variables introduces an empirical viewpoint, accentuating the dynamic influence of each indicator on the accuracy of model predictions within the context of complex environmental data interrelations. This empirical evaluation allows for the theoretical framework to be substantiated with empirical evidence, ensuring the model's robustness and its suitability for real-world data. The concurrence of these findings validates the reliability of the selection and weighting of indicators, offering further insights into the non-linear and interactive effects among them [85]. This enhances our comprehension of the intricate factors influencing the near-naturalness of urban green spaces.

While this study strives for a comprehensive evaluation indicator system, it acknowledges limitations in fully encompassing all factors impacting green spaces' ecological quality, like soil conditions and microclimate factors. Future studies should consider these elements for a more holistic assessment of plant communities' near-naturalness, fostering deeper insights and improved management approaches. Additionally, based on data collected in summer, this research may not fully account for seasonal variations' influence on plant communities' naturalness, highlighting an area for future study.

Conclusions

Amid the accelerating global urbanization, the ecological quality of urban green spaces is crucial for maintaining the health and stability of urban ecosystems. This study developed a new comprehensive evaluation system, applying multiple statistical methods including principal component analysis, entropy weight method, comprehensive index methods, cluster analysis, and random forest algorithms, to systematically assess the near-natural state of 87 park plant communities in Hefei, and to identify the influencing factors. The evaluation system, incorporating sixteen indicators across four dimensions (community composition, structure, succession, and disturbance level), offers a cutting-edge tool for urban planners and environmental managers to prioritize interventions that significantly improve urban green environments.

The findings indicate that the near-naturalness of Hefei's plant communities in the green spaces is medium to low, scoring between 0.135 and 0.752. with only 18.39% of areas classified as 'near-natural' or 'semi-natural'. The vast majority, 81.61%, fall into 'far-natural' or 'artificial' categories. Crucially, the ideal state for near-naturalness – characterized by 5–10 dead plants, 10–30% litter cover, 10–15 species, and mild natural disturbances – highlights the sensitive balance required to foster more natural urban habitats. The influence hierarchy of the criteria – community succession, disturbance degree, community composition, and community structure – provides a clear guideline for targeted ecological interventions. Therefore, beyond merely enhancing structural diversity and reducing human disturbances, our study underscores the necessity of managing organic debris and promoting natural regeneration processes tailored to specific site conditions. By doing so, urban green spaces can evolve more naturally, enhancing their resilience and ecological functions. Ultimately, this research not only contributes

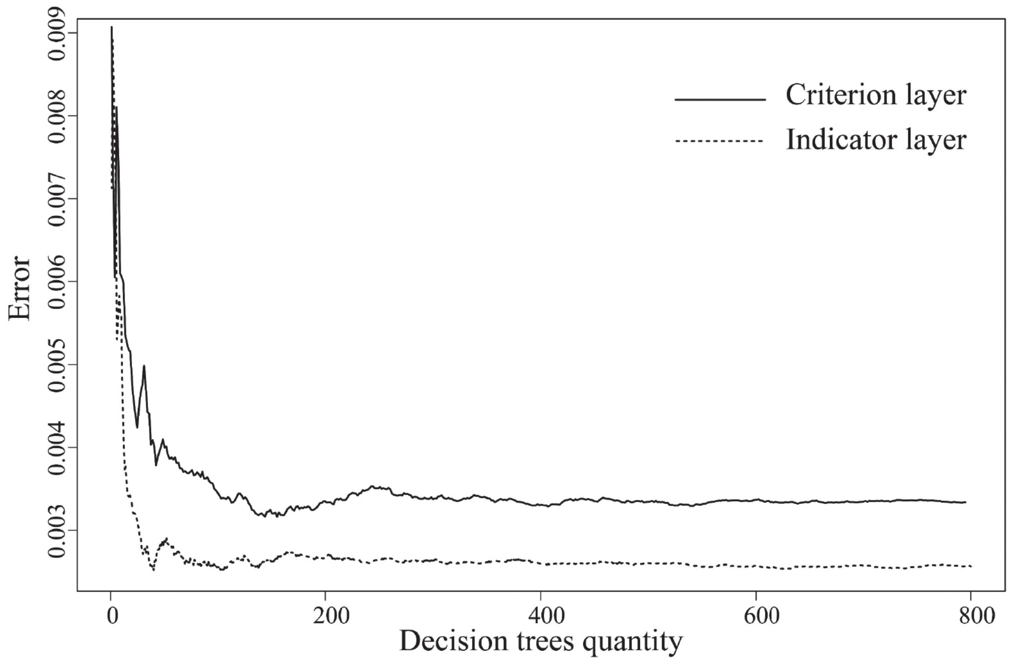

Fig. 8. The correlation between error and quantity of decision trees at criterion and indicator layer in near-naturalness of Hefei city's plant communities.

valuable evidence-based strategies for ecological urban design but also lays a foundational framework for ongoing research into the sustainable development of urban green spaces. This work serves as a cornerstone for the naturalistic transformation and resilience enhancement of urban environments, offering actionable insights that can drive future innovation in urban ecological management.

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Conflict of Interest

The authors declare no conflict of interest.

Appendix

The correlation between error and quantity of decision trees at criterion and indicator layer in near-naturalness of Hefei city's plant communities is shown in Fig. 8.

References

1. FENG C.Y., SUN Z.Y., XU X.Q. Application of close-to-nature concept to landscaping. World Forestry Research, **26** (03), 58, **2013** [In Chinese].
2. YANG Y.P., ZHOU Z.X. Theoretical basis and construction methods of urban nature-approximating landscape architecture. Chinese Journal of Ecology, **28** (03), 516, **2009** [In Chinese].
3. REN R.B., LI S.H., YIN L.F., XU Z.Q. Planting design developed by simulating natural plant communities of Changshu. Scientia Silvae Sinicae, **45** (12), 139, **2009** [In Chinese].
4. WILDE H.D., GANDHI K.J., COLSON G. State of the science and challenges of breeding landscape plants with ecological function. Horticulture Research, **2**, 14069, **2015**.
5. QIAN S., QI M., HUANG L., ZHAO L., LIN D., YANG Y. Biotic homogenization of China's urban greening: A meta-analysis on woody species. Urban Forestry & Urban Greening, **18**, 25, **2016**.
6. MIYAWAKI A. Restoration of urban green environments based on the theories of vegetation ecology. Ecological Engineering, **11**, 157, **1998**.
7. MIYAWAKI A. Creative ecology restoration of native forests by native trees. Plant Biotechnology, **16**, 15, **1999**.
8. HO K.V., KRÖEL-DULAY G., TÖLGYESI C., BÁTORI Z., TANÁCS E., KERTÉSZ M., TÖRÖK P., ERDŐS L. Non-native tree plantations are weak substitutes for near-natural forests regarding plant diversity and ecological value. Forest Ecology and Management, **531**, 120789, **2023**.
9. TEOBALDELLI M., CONA F., STINCA A., SAULINO L., ANZANO E., GIORDANO D., MIGLIOZZI A., BONANOMI G., D'URSO G., MAZZOLENI S. Improving resilience of an old-growth urban forest in Southern Italy:

Lesson(s) from a stand-replacing windstorm. Urban Forestry & Urban Greening, **47**, 126521, **2020**.
10. PIRNAT J., HLADNIK D. The concept of landscape structure, forest continuum and connectivity as a support in urban forest management and landscape planning. Forests, **9** (10), 584, **2018**.
11. SHAO Q. A boom of "nature-approximating forestry" in Middle Europe. World Forestry Research, **4**, 8, **1991**.
12. TUXEN R. Die heutige potentielle naturliche Vegetation als Gegenstand der Vegetationskartierung. Beriche Zur Deutschen Landeskunde, **19**, 200, **1957**.
13. SCHIRONE B., SALIS A., VESSELLA F. Effectiveness of the Miyawaki method in Mediterranean forest restoration programs. Landscape and Ecological Engineering, **7**, 81, **2011**.
14. WANG R., FUJIWARA K., YOU H. Theory and practices for forest vegetation restoration: Native forest with native trees-introduction of the Miyawaki's method for reconstruction of. Chinese Journal of Plant Ecology, **26**, 133, **2002**.
15. SANDEEP R., SHARMA P., MODI N. Development of tree plantation through Miyawaki method at Sabarmati Riverfront Development Corporation Limited-a research. International Association of Biologicals and Computational Digest, **1** (1), 163, **2022**.
16. GU L., WANG C. Experiences and revelations of urban forest development in Hong Kong and Taiwan. World Forestry Research, **25** (03), 50, **2012** [In Chinese].
17. SIKORSKA D., CIĘŻKOWSKI W., BABAŃCZYK P., CHORMAŃSKI J., SIKORSKI P. Intended wilderness as a nature-based solution: Status, identification and management of urban spontaneous vegetation in cities. Urban Forestry & Urban Greening, **62**, 127155, **2021**.
18. QI X.H., CHEN L., HONG W., CHENG Y., CHEN M.J. Researches on nature-approximating landscape architecture. Architectural Journal, **8** (08), 53, **2005** [In Chinese].
19. FOO C.H. Linking forest naturalness and human wellbeing-a study on public's experiential connection to remnant forests within a highly urbanized region in Malaysia. Urban Forestry & Urban Greening, **16**, 13, **2016**.
20. SHEN L.Y., HAN Y.J. Construction of urban forest system in Shanghai with close-to-nature forestry management ideas. Journal of Nanjing Forestry University (humanities and Social Sciences Edition), 1, 93, **2007** [In Chinese].
21. HITCHMOUGH J. Exotic plants and plantings in the sustainable, designed urban landscape. Landscape and Urban Planning, **100** (4), 380, **2011**.
22. REN B.B., SHANG R., LI F., LI W., WANG J.H., LI G., LIU Q. Close-to-nature plant community construction in urban greenspace of Beijing. Chinese Journal of Ecology, **38** (10), 2911, **2019** [In Chinese].
23. LIU G., LU Y.C., STURM K., NING J.K., LEI X.D. Application of near-nature estimation method for forest management in Beijing. Journal of Northeast Forestry University, **37** (05), 114, **2009** [In Chinese].
24. GIMMI U., RADELOFF V.C. Assessing naturalness in Northern Great Lakes forests based on historical land-cover and vegetation changes. Environmental Management, **52**, 481, **2013**.
25. HE Z.L., ZHANG Y.X., GUO J.P. Research progress on management technology and effect evaluation of near-natural forestry management in China. Journal of Shanxi Agricultural Sciences, **45** (09), 1566, 1582, **2017** [In Chinese].
26. KORJUS H., KIVISTE A., KANGUR A., PALUOTS T., LAARMANN D., PÕLDVEER E. Dataset on stand structural indices and forest ecosystem naturalness in Hemiboreal forests. Data in Brief, **29**, 105387, **2020**.
27. FENG J., WANG J., YAO S., DING L. Dynamic assessment of forest resources quality at the provincial level using AHP and cluster analysis. Computers and Electronics in Agriculture, **124**, 184, **2016**.
28. ZHAO Z., HUI G. Forest naturalness evaluation method based on stand state characters: A case study of Gansu Xiaolongshan forests. Scientia Silvae Sinicae, **47** (12), 9, **2011**.
29. ÖZKAYA G., ERDIN C. Evaluation of the forest quantity, quality, and management through Gray relational analysis method. Eurasian Journal of Forest Science, **10**, 27 (2), **2022**.
30. BONČINA A., KLOPČIČ M., SIMONČIČ T., DAKSKOBLER I., FICKO A., ROZMAN A. A general framework to describe the alteration of natural tree species composition as an indicator of forest naturalness. Ecological Indicators, **77**, 194, **2017**.
31. OLIVEIRA L.Z., VIBRANS A.C. An approach to illustrate the naturalness of the Brazilian Araucaria forest. Canadian Journal of Forest Research, **50** (1), 32, **2020**.
32. MCROBERTS R.E., WINTER S., CHIRICI G., LAPOINT E. Assessing forest naturalness. Forest Science, **58** (3), 294, **2012**.
33. KUNTTU P., JUNNINEN K., KOUKI J. Dead wood as an indicator of forest naturalness: A comparison of methods. Forest Ecology and Management, **353**, 30, **2015**.
34. HUANG X., TENG M., ZHOU Z., WANG P., DIAN Y., WU C. Linking naturalness and quality improvement of monoculture plantations in urban area: A case study in Wuhan City, China. Urban Forestry & Urban Greening, **59**, 126911, **2021**.
35. SCHERRER D., BALTENSWEILER A., BÜRGI M., FISCHER C., STADELMANN G., WOHLGEMUTH T. Low naturalness of Swiss broadleaf forests increases their susceptibility to disturbances. Forest Ecology and Management, **532**, 120827, **2023**.
36. MERGANIČ J., MERGANIČOVÁ K., MORAVČÍK M., MARUŠÁK R. Objective evaluation of forest naturalness: Case study in Slovak nature reserve. Polish Journal of Environmental Studies, **21** (5), **2012**.
37. JAROSZEWICZ B., CHOLEWIŃSKA O., GUTOWSKI J.M., SAMOJLIK T., ZIMNY M., LATAŁOWA M. Białowieża Forest – a relic of the high naturalness of European forests. Forests, **10** (10), 849, **2019**.
38. ANHUI PROVINCIAL BUREAU OF STATISTICS. Anhui Statistical Yearbook, 2022 ed., China Statistical Publishing House: Beijing, China, pp. 283, **2022** [In Chinese]**.**
39. YAO X.M., CHEN Y.Y., OU C., ZHANG Q.Y., YAO X.J. Spatio-temporal evolution and ecological benefits of urban green space: Takes Hefei Municipal Area as an example. Resources and Environment in the Yangtze Basin, **32** (01), 51, **2023** [In Chinese].
40. YAN P., YANG J. Species diversity of urban forests in China. Urban Forestry & Urban Greening, **28** (02), 160, **2017**.
41. WANG J.N., ZHAO D.X., LIU H., LV Z.K., WANG H.X. Selection of tree species in an urban green space by local participants. Journal of Zhejiang A & F University, **34** (06), 1120, **2017** [In Chinese].
42. MINISTRY OF HOUSING AND URBAN-RURAL DEVELOPMENT OF THE PEOPLE'S REPUBLIC OF CHINA. Urban green space classification standard, CJJ/T

85-2017, China Architecture & Building Press: Beijing, China, **2018** [In Chinese].
43. WANG J.N., WANG H. An analysis of the new standard for classification of urban green space. Chinese Landscape Architecture, **35** (04), 92, **2019** [In Chinese].
44. LIU H., ZHU J., WANG J.N., WANG Z.C., CAO X.J. Dynamic change of plant community structure in the Ring Park around Hefei City. Ecology and Environmental Sciences, **26** (08), 1284, **2017** [In Chinese].
45. STANDOVÁR T., SZMORAD F., KOVÁCS B., KELEMEN K., PLATTNER M., ROTH T., PATAKI Z. A novel forest state assessment methodology to support conservation and forest management planning. Community Ecology, **17** (2), 167, **2016**.
46. CÔTÉ S., BÉLANGER L., BEAUREGARD R., THIFFAULT É., MARGNI M. A conceptual model for forest naturalness assessment and application in Quebec's boreal forest. Forests, **10** (4), 325, **2019**.
47. YAO X.J. Study on native tree species in Hefei. Master, Anhui Agriculture University, Hefei, **2008** [In Chinese].
48. FAKHAR IZADI N., KESHTKAR H. Investigating the effects of distribution patterns on ecological indices of plant species in a simulated environment. Desert, **25** (2), 201, **2020**.
49. XU M.S., ZHENG L.T., YE S.F., LIU X.Y., YAN E.R. Evaluation of vegetation naturalness across 10 islands in Eastern China. Acta Ecologica Sinica, **41** (09), 3713, **2021** [In Chinese].
50. ZHOU Z.X. Garden ecology experimental practice guide book, 1st ed., China Agricultural Publishing House: Beijing, China, pp. 76, **2003** [In Chinese].
51. CUI H.S., JIANG Y., LIN M.Z., JIANG T., JI S.T. Forest naturalness evaluation in Baiyun Mountain of Guangzhou. Journal of Subtropical Resources and Environment, **10** (01), 18, **2015** [In Chinese].
52. GREENACRE M., GROENEN P.J., HASTIE T., D'ENZA A.I., MARKOS A., TUZHILINA E. Principal component analysis. Nature Reviews Methods Primers, **2** (1), 100, **2022**.
53. RICCIOLI F., FRATINI R., MARONE E., FAGARAZZI C., CALDERISI M., BRUNIALTI G. Indicators of sustainable forest management to evaluate the socio-economic functions of coppice in Tuscany, Italy. Socio-economic Planning Sciences, **70**, 100732, **2020**.
54. BUZZARD V., MICHALETZ S.T., DENG Y., HE Z., NING D., SHEN L., TU Q., VAN NOSTRAND J.D., VOORDECKERS J.W., WANG J. Continental scale structuring of forest and soil diversity via functional traits. Nature Ecology & Evolution, **3** (9), 1298, **2019**.
55. WU R.M., ZHANG Z., YAN W., FAN J., GOU J., LIU B., GIDE E., SOAR J., SHEN B., FAZAL-E-HASAN S. A comparative analysis of the principal component analysis and entropy weight methods to establish the indexing measurement. Plos One, **17** (1), e0262261, **2022**.
56. LUO H., ZHAO Q., ZHANG L., GAO C., WU X., NIE Y. Landscape health assessment of suburban forest park: A case study based on multiple sampling units and functional characteristics. Forests, **14** (11), 2237, **2023**.
57. LIUBACHYNA A., BUBBICO A., SECCO L., PETTENELLA D. Management goals and performance: Clustering state forest management organizations in Europe with multivariate statistics. Forests, **8** (12), 504, **2017**.
58. JEVŠENAK J., SKUDNIK M. A Random Forest model for basal area increment predictions from national forest inventory data. Forest Ecology and Management, **479**, 118601, **2021**.
59. XU Z., SHEN D., NIE T., KOU Y. A hybrid sampling algorithm combining M-smote and ENN based on random forest for medical imbalanced data. Journal of Biomedical Informatics, **107**, 103465, **2020**.
60. NIU L., GUO Y., LI Y., WANG C., HU Q., FAN L., WANG L., YANG N. Degradation of river ecological quality in Tibet Plateau with overgrazing: A quantitative assessment using biotic integrity index improved by Random Forest. Ecological Indicators, **120**, 106948, **2021**.
61. GEORGANOS S., GRIPPA T., NIANG GADIAGA A., LINARD C., LENNERT M., VANHUYSSE S., MBOGA N., WOLFF E., KALOGIROU S. Geographical Random Forests: A spatial extension of the random forest algorithm to address spatial heterogeneity in remote sensing and population modelling. Geocarto International, **36** (2), 121, **2021**.
62. WANG F., WANG Y., ZHANG K., HU M., WENG Q., ZHANG H. Spatial heterogeneity modeling of water quality based on Random Forest regression and model interpretation. Environmental Research, **202**, 111660, **2021**.
63. CHEN S., YAO S. Evaluation of forestry ecological efficiency: A spatiotemporal empirical study based on China's provinces. Forests, **12** (2), 142, **2021**.
64. PHAM B.T., PRADHAN B., BUI D.T., PRAKASH I., DHOLAKIA M. A comparative study of different machine learning methods for landslide susceptibility assessment: A case study of Uttarakhand area (India). Environmental Modelling & Software, **84**, 240, **2016**.
65. COLAK A., ROTHERHAM I., CALIKOGLU M. Combining 'naturalness concepts' with close-to-nature silviculture. Forstwissenschaftliches Centralblatt, **122** (6), 421, **2003**.
66. WANG Q.L., WANG W.Y., LIN S., CAO Z., CHEN Q., HE K.N. Stand structure adjustment based on the near-natural management of plantation ecological public forests in Eastern Qinghai. Acta Ecologica Sinica, **41 (**12), 5004, **2021** [In Chinese].
67. HANNA E., BRUNO D., COMÍN F.A. Evaluating naturalness and functioning of urban green infrastructure. Urban Forestry & Urban Greening, **80**, 127825, **2023**.
68. HORVÁTH M., BEČVÁROVÁ P.H., ŠARAPATKA B., VENCÁLEK O., ZOUHAR V. Potential relationships of selected abiotic variables, chemical elements and stand characteristics with soil organic carbon in spruce and beech stands. iForest-Biogeosciences and Forestry, **14** (4), 320, **2021**.
69. KORHONEN A., SIITONEN J., KOTZE D.J., IMMONEN A., HAMBERG L. Stand characteristics and dead wood in urban forests: Potential biodiversity hotspots in managed boreal landscapes. Landscape and Urban Planning, **201**, 103855, **2020**.
70. BASKENT E.Z. A framework for characterizing and regulating ecosystem services in a management planning context. Forests, **11** (1), 102, **2020**.
71. STRONG W. Biased richness and evenness relationships within Shannon–Wiener index values. Ecological Indicators, **67**, 703, **2016**.
72. SIMMONDS J.S., SUAREZ-CASTRO A.F., RESIDE A.E., WATSON J.E., ALLAN J.R., ATKINSON S.C., BORRELLI P., DUDLEY N., EDWARDS S., FULLER R.A. Retaining natural vegetation to safeguard biodiversity and humanity. Conservation Biology, **37** (3), e14040, **2023**.
73. FORERO L.E., KULMATISKI A., GRENZER J., NORTON J.M. Plant-soil feedbacks help explain biodiversity-productivity relationships. Communications Biology, **4** (1), 789, **2021**.

74. ANDERSON E.C., MINOR E.S. Assessing four methods for establishing native plants on urban vacant land. Ambio, **50** (3), 695, **2021**.
75. BERTHON K., THOMAS F., BEKESSY S. The role of 'nativeness' in urban greening to support animal biodiversity. Landscape and Urban Planning, **205**, 103959, **2021**.
76. JOHNSON T., CAMERON D., MOORE G., BRIEN C. Ground movement in a moderately expansive soil subject to rainfall infiltration through pervious paving. Ecological Engineering, **158**, 106022, **2020**.
77. LIU Y., MIAO H., CHANG X., WU G. Higher species diversity improves soil water infiltration capacity by increasing soil organic matter content in semiarid grasslands. Land Degradation & Development, **30** (13), 1599, **2019**.
78. LIU X.Z., MA S., LU Y.C. Research of forest naturalness assessment. Journal of Southwest Forestry University, **35** (04), 99, **2015** [In Chinese].
79. BORGHI C., FRANCINI S., MCROBERTS R.E., PARISI F., LOMBARDI F., NOCENTINI S., MALTONI A., TRAVAGLINI D., CHIRICI G. Country-wide assessment of biodiversity, naturalness, and old-growth status using national forest inventory data. European Journal of Forest Research, 1, **2023**.
80. DI FILIPPO A., BIONDI F., PIOVESAN G., ZIACO E. Tree ring-based metrics for assessing old-growth forest naturalness. Journal of Applied Ecology, **54** (3), 737, **2017**.
81. LIANG X., YANG T., NIU J., ZHANG L., WANG D., HUANG J., YANG Z., BERNDTSSON R. Quality assessment and rehabilitation of mountain forest in the Chongli Winter Olympic Games area, China. Forests, **13** (5), 783, **2022**.
82. FICKO A., LIDESTAV G., DHUBHÁIN Á.N., KARPPINEN H., ZIVOJINOVIC I., WESTIN K. European private forest owner typologies: A review of methods and use. Forest Policy and Economics, **99**, 21, **2019**.
83. BOATENG E.Y., OTOO J., ABAYE D.A. Basic tenets of classification algorithms K-nearest-neighbor, support vector machine, random forest, and neural network: A review. Journal of Data Analysis and Information Processing, **8** (4), 341, **2020**.
84. GONG Y., LI X., LV L., ZHANG B., XUAN J., DU H. Using UAV lidar intensity frequency and hyperspectral features to improve the accuracy of urban tree species classification. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, **17**, **2023**.
85. GENUER R., POGGI J., TULEAU-MALOT C. Variable selection using Random Forests. Pattern Recognition Letters, **31** (14), 2225, **2010**.