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Evaluation of Green Space Ecological Service Value and Ecological Pattern Optimization in Xi'an Daming Palace Relic Park

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Abstract. As a complex space that integrates historical culture and ecological functions, the assessment of green space ecosystem service values and the optimization of spatial patterns in urban heritage parks are key issues for the coordinated development of urban ecological construction and cultural heritage conservation. Taking Xi'an Daming Palace Relic Park as the study area, this paper adopts remote sensing interpretation, GIS spatial analysis, the equivalent factor method, landscape metrics, and the minimum cumulative resistance model to systematically evaluate four categories of ecosystem services---supply, regulation, support, and culture---provided by the park's green spaces. It also analyzes the current status and core problems of the ecological pattern and proposes targeted optimization strategies. The results show that the total ecosystem service value of green spaces in Daming Palace Relic Park exhibits strong spatial heterogeneity, with cultural and regulatory services as the main contributors. The park's green spaces face issues such as patch fragmentation, insufficient corridor connectivity, and unbalanced structural composition. Accordingly, optimization strategies are put forward from four aspects: core patch improvement, ecological corridor construction, green space structure adjustment, and coordinated layout of heritage and ecological zones. After optimization, the ecosystem service values of the park's green spaces are expected to rise significantly, and the rationality of the ecological pattern and compatibility with heritage conservation will be effectively enhanced. This study provides a practical basis for ecological protection and sustainable management of Daming Palace Relic Park, and also offers a reference for evaluating ecosystem service values and optimizing spatial patterns in similar urban heritage parks.

Keywords: Daming Palace Relic Park, green space ecosystem service value, value assessment, ecological pattern optimization, GIS technology

1. Introduction

Xi'an is located in a warm temperate semi-arid zone with a continental monsoon climate. The dominant wind direction is northeast, and the secondary prevailing wind is southwest. The region has four distinct seasons, a mild climate, sufficient sunshine, and relatively abundant rainfall. The annual average temperature is 13.5℃, the accumulated temperature above 10℃ reaches 4626℃, the

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average annual precipitation is 559.7 mm, the frost-free period lasts 208 days, and annual sunshine duration totals 2436 hours, which are beneficial to agricultural production. Nevertheless, precipitation is unevenly distributed, concentrating in July, August, and September. Droughts often occur in spring and summer, while short but intense rainstorms in summer frequently trigger severe soil erosion.

Urban heritage parks represent a fusion of cultural heritage conservation and urban ecological space development. They not only undertake cultural functions such as inheriting historical context and displaying archaeological achievements but also deliver a variety of ecosystem services---including water conservation, air purification, and recreational opportunities---through green space systems, making them important components of urban ecological and cultural systems. Against the background of new-type urbanization, the coordinated realization of the dual values of urban heritage parks has become an important approach to balancing urban cultural protection and ecological restoration. The quantification of ecosystem service functions and spatial pattern optimization have become research hotspots in urban planning. Green spaces serve as the core carrier of urban ecosystems, and the services they supply are essential for improving the quality of urban living environments. The assessment of green space ecosystem service values translates ecological benefits into quantifiable and comparable indicators, offering a scientific foundation for urban green space planning, ecological compensation mechanisms, and decision-making in urban ecological construction. At present, China's urban ecological development has shifted from quantitative expansion to quality improvement and efficiency enhancement, and precise evaluation of ecosystem service values has become an important tool to guide spatial optimization and improve service capacity [1-3].

Xi'an Daming Palace Relic Park is a national archaeological park built on the ruins of the Tang Dynasty Daming Palace, covering approximately 3.2 km^2 [4]. It serves as a major ecological green space and cultural landmark in northern Xi'an. In recent years, with the deepening operation of the park and accelerated urban expansion, the area faces the dual demands of strict heritage protection and improved ecosystem services. On the one hand, heritage protection zones impose strict spatial constraints on green space development [1]; on the other hand, residents in surrounding areas have growing needs for recreation, cooling, humidification, and other ecological benefits. At present, the ecosystem service values of the park's green space system have not been systematically quantified, and the compatibility between the ecological pattern and heritage conservation needs to be improved. Therefore, carrying out targeted value assessment and pattern optimization is of urgent practical importance.

The park is situated in Weiyang District, Xi'an, on the eastern side of the city's northern central axis, with geographic coordinates ranging from 108°56′15″E to 108°57′30″E and 34°18′40″N to 34°19′50″N. It is bordered by Jianzhang Road to the west, Taihua Road to the east, Xuanwu Road to the north, and Danfengmen Square to the south, with a total area of about 320 hectares. Located in the central Guanzhong Plain, the study area has a warm temperate semi-humid continental monsoon climate, with an annual average temperature of 13.3 ℃ and average annual precipitation of about 580 mm, mostly concentrated from July to September. The four seasons are clearly separated, and rainfall coincides with high temperatures. The soil is mainly Lou soil, characterized by deep layers and medium fertility, suitable for temperate deciduous broad-leaved trees and herbaceous plants. The park is surrounded by the core built-up area of Weiyang District, with a dense residential population and convenient transportation. The average annual number of visitors has exceeded 3 million in the past five years [4], making it an important venue for daily recreation for local residents and cultural experiences for tourists.

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The Daming Palace ruins are a national key cultural relic protection unit and a candidate site for the World Heritage List [1]. The park's heritage protection zones are divided into core protection areas, buffer zones, and exhibition and utilization areas. The core protection areas are mainly distributed in the central part of the park, covering key ruins such as Hanyuan Hall, Linde Hall, and Taiye Pool, where strict limits are imposed on green space construction and terrain modification. Buffer zones surround the core areas and allow moderate ecological greening and low-intensity recreational facilities. Exhibition and utilization areas are mainly located on the park's periphery, where ecological green space development and cultural tourism support facilities can be constructed. The total green space area of Daming Palace Relic Park is about 216 hectares, accounting for 67.5% of the total park area, forming the main landscape matrix. Based on vegetation structure and function, the park's green spaces are classified into four types: arbor forest, shrub land, lawn, and wetland green space. Arbor forest covers the largest area---about 108 hectares, 50% of total green space---dominated by native temperate trees such as Sophora japonica, Platanus acerifolia, and Fraxinus chinensis, mainly concentrated in the peripheral exhibition zones. Shrub land covers about 32.4 hectares (15%), dominated by flowering shrubs, and is mostly distributed along the edges of heritage buffer zones. Lawns cover about 64.8 hectares (30%), concentrated around core heritage areas, using low herbaceous plants to reduce disturbance to ruins. Wetland green space covers about 10.8 hectares (5%), mainly distributed around Taiye Pool, forming waterfront landscapes integrated with water bodies. Overall, the spatial distribution of green spaces is closely related to heritage protection zoning, with low-disturbance lawns in core zones and complex arbor forests in peripheral areas, showing obvious spatial differentiation.

This study used four types of data: basic spatial data, natural environmental data, socioeconomic data, and field survey data. Basic spatial data included 2024 GF-2 high-resolution remote sensing images (0.8 m resolution), 1:1000 topographic maps of Xi'an, boundary vectors of Daming Palace Relic Park, and heritage protection zone vectors. Natural environmental data included meteorological data of Weiyang District from 2019 to 2024, as well as soil type and fertility data. Socioeconomic data included annual visitor numbers, tourism revenue, and resident population statistics from 2019 to 2024 [4]. Field survey data included vegetation community structure, temperature and humidity, and soil organic matter measured in July and August 2024. Data preprocessing included remote sensing image correction, green space classification and vectorization, data standardization, and database establishment. The main research methods included ecosystem service value assessment and ecological pattern analysis and optimization. The former was based on the equivalent factor table of terrestrial ecosystem service values in China [2], revised according to the natural conditions and green space types of Daming Palace Relic Park, combined with the market value method, shadow project approach, and travel cost method to quantify regulation and cultural services. The latter adopted landscape metrics [5], the minimum cumulative resistance model [6], GIS spatial analysis [7] and pattern optimization based on the patch-corridor-matrix theory of landscape ecology [5,6].

2. Literature review

Foreign research on the assessment of green space ecosystem service values began relatively early. The conceptual framework of ecosystem services was systematically elaborated by Daily [7], and the valuation framework established by Costanza et al. [8] laid a foundation for later studies. Subsequently, scholars gradually improved methods including the market value method, travel cost method, and contingent valuation method, shifting from qualitative description to quantitative measurement. In recent years, international research has focused on multi-method integration and

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spatial heterogeneity analysis, using GIS technology [7] to achieve spatial visualization of ecosystem service values.

Domestic research started in the early 21st century. Based on the characteristics of China's terrestrial ecosystems, Xie et al. [2] established an equivalent factor table for ecosystem service values, which has become a core method for regional green space value assessment and has been widely applied in urban parks, green space systems, and scenic areas [1,3]. With further research, Chinese scholars have gradually revised equivalent factors according to regional characteristics, integrated multiple valuation methods to improve accuracy, and analyzed differences in ecosystem service values among green space types and spatial scales. Generally, domestic assessment methods have become increasingly mature, but research on special green spaces restricted by cultural protection---such as heritage parks---still needs to be deepened.

Foreign studies on heritage parks focus on the coordination between heritage conservation and ecological restoration, emphasizing ecological spatial planning that meets protection requirements and applying landscape ecology principles to build adaptive ecological patterns. Domestic research on ecological patterns of heritage parks started later but has grown rapidly in recent years. Most studies take landscape ecology as a theoretical foundation, using landscape metrics [5] and GIS [7] to analyze the characteristics and problems of green space patterns. Some studies use the minimum cumulative resistance model [6] and circuit theory to identify ecological sources and key corridors, proposing targeted optimization schemes. Studies on the Old Summer Palace and Luoyang Sui-Tang City Relic Botanical Garden [9,10] have provided references for ecological space construction in heritage parks. However, most existing studies focus on structural analysis, and few combine ecosystem service valuation with pattern optimization to enhance service values.

A comprehensive review of current research reveals three main limitations. First, assessments for heritage parks rarely fully consider the spatial constraints of heritage protection [1], and the adaptability of indicators and methods needs improvement. Second, ecological pattern optimization mostly emphasizes structural adjustment rather than value enhancement, reducing the scientificity and applicability of schemes. Third, the coordination mechanism between heritage protection and ecosystem service supply is insufficiently studied, and an integrated pattern optimization system has not yet been formed. Accordingly, this study takes Daming Palace Relic Park as the case area, integrates heritage protection constraints into value assessment and pattern optimization, uses the equivalent factor method [2] and GIS [7] to quantify and map ecosystem service values, applies landscape metrics [5] and the minimum cumulative resistance model [6] to diagnose pattern problems, and finally proposes an optimization strategy that improves service values while balancing heritage protection and ecological functions. This research fills the existing gaps [2,5,6,8,11] and provides a reference for similar heritage parks.

3. Results

Following the principles of scientificity, systematicness, operability, and pertinence, and combining the green space characteristics and heritage protection requirements of Daming Palace Relic Park with the national standard Specifications for Ecosystem Service Assessment (GB/T 38582-2020), an evaluation index system for the park's green space ecosystem service values was constructed. Based on indicator quantification, the equivalent factor table was adjusted at regional and type levels according to the natural environmental conditions of Weiyang District [2].

The results indicate that the total annual ecosystem service value of green spaces in Daming Palace Relic Park in 2024 was 258 million yuan, with a unit area value of 1.1944 million yuan per hectare per year. Among green space types, arbor forest contributed the highest total value, wetland

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green space had the highest unit area value, and lawn had the lowest total value. Wetland green space provides outstanding biodiversity conservation and water retention benefits due to its combination of water and vegetation. Arbor forest contributes the most to total value owing to its large area and complex structure. Lawns have relatively weak ecological functions due to simple vegetation structure. In terms of service categories, regulation services rank first, followed by cultural services, support services, and supply services, which is highly consistent with the cultural identity of the heritage park and urban recreational demand.

The total value of the park's green spaces is relatively high, and the unit area value exceeds the average level of urban green spaces in Xi'an, providing strong support for the urban ecosystem. The combined proportion of cultural and regulation services is high, reflecting the integrated "ecology + culture" value of the heritage park. Spatially, ecosystem service values show a pattern of "high in the periphery, low in the center", which is closely correlated with heritage protection zoning [1]. Protection constraints are the main factor causing spatial heterogeneity.

Based on landscape ecology theory [5] and research needs, 10 core landscape indicators were selected from three dimensions---landscape composition, structure, and function---to evaluate the ecological pattern. The park's green spaces are dominated by arbor forest and lawn, showing a dual-structure feature with insufficient diversity. The landscape structure is "aggregated in the periphery, fragmented in the center", with high fragmentation in core heritage zones. Landscape functions differ significantly between the core and peripheral areas due to spatial distribution and patch structure.

The main ecological pattern problems are as follows: first, green space patches are highly fragmented, especially lawns in core zones, weakening ecological functions; second, ecological corridors lack connectivity, resulting in poor landscape continuity and blocked ecological flows; third, the green space structure is unbalanced, with low diversity and stability, reducing the ecosystem's resistance to disturbance; fourth, spatial coordination between heritage protection [1] and ecological construction is insufficient, requiring better integration of green space development and heritage display.

4. Discussion

Based on the patch-corridor-matrix theory of landscape ecology [5,6], combined with the ecosystem service value characteristics, ecological pattern problems, and heritage protection requirements of the park, and following the principles of ecology priority, protection first, coordinated development, and practical feasibility, targeted optimization strategies are proposed from four aspects, and the effects are predicted and evaluated.

The goal of core patch optimization is to expand high-quality patches, restore degraded patches, and improve overall quality. Guided by heritage protection zoning [1], differentiated improvements are implemented: high-quality arbor forest and wetland patches are expanded; degraded lawns and scattered shrubs are restored; and vegetation structure is upgraded to enhance patch quality. All optimization follows the principle of not harming heritage sites, aiming to improve ecological functions while reducing fragmentation and enhancing the integrity and aggregation of the green space pattern.

Based on the minimum cumulative resistance model [6], an ecological corridor network of "one core, two axes, and multiple corridors" is established. Key ecological sources are identified, and primary and secondary corridors are constructed according to resistance values. Existing corridors are upgraded, and ecological nodes are set at critical connections to realize effective linkage among

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core sources. The corridor network improves connectivity and continuity, facilitates ecological flows, and strengthens material and energy exchange among patches.

Focusing on enhancing diversity, optimizing spatial layout, and adapting to heritage protection, the area ratio and distribution of each green space type are adjusted to form a structure dominated by arbor forest, supplemented by shrubs and wetlands, with rationally distributed lawns, using native species as a priority. This structural adjustment resolves the imbalance of green space composition, improves ecosystem diversity and stability, and enhances anti-interference capacity while complying with protection rules [1].

Centered on the concept of "ecological protection adapting to heritage conservation and ecological construction supporting heritage display", a three-layer spatial structure is built: core heritage zone, ecological buffer zone, and ecological exhibition zone. Landscape sightlines among layers are coordinated; low-impact ecological methods are used in core and buffer zones; and appropriate greening and tourism facilities are developed in the exhibition zone to achieve spatial harmony between protection and ecology. This coordinated layout effectively improves integration and promotes the synergistic development of cultural protection and ecological services.

After optimization, the total ecosystem service value of the park's green spaces is expected to increase significantly, along with unit area value. Regulation, cultural, and support services will be notably improved, while supply services remain stable. Spatial heterogeneity will be greatly reduced, achieving overall improvement in ecosystem service values. Landscape indicators will be significantly enhanced: fragmentation decreases, integrity and aggregation rise; connectivity and continuity strengthen; patch shapes become more complex, and ecological functions improve, effectively raising the rationality of the ecological pattern.

The optimization scheme can achieve coordinated improvements in ecological, social, economic, and cultural benefits: it better satisfies recreational needs, enhances the urban living environment; boosts tourism income and reduces maintenance costs; enriches cultural experience and improves the taste of the heritage park; and strengthens the communication and influence of cultural heritage.

5. Conclusions

The total and per-unit-area ecosystem service values of green spaces in Xi'an Daming Palace Relic Park are relatively high, with strong ecological service capacity. They show the structural features of "wetland green space having the highest unit value and arbor forest the largest total value" and the functional features of "regulation and cultural services as the core". Spatially, values are distributed heterogeneously as "high in the periphery, low in the center", closely related to heritage protection zoning [1].

The ecological pattern of the park's green spaces is characterized by peripheral aggregation and central fragmentation, insufficient connectivity, and obvious functional differentiation. The core problems include patch fragmentation, weak corridor connectivity, unbalanced structure, and inadequate coordination between heritage protection and ecological construction, which are closely related to spatial constraints and planning coordination.

This study proposes four optimization strategies: core patch improvement, ecological corridor construction, green space structure adjustment, and coordinated layout of heritage and ecological zones. It establishes a "one core, two axes, multiple corridors" network and a three-layer spatial system. After optimization, ecosystem service values and pattern rationality are significantly improved, and ecological, social, economic, and cultural benefits grow simultaneously. This study provides a practical basis for ecological protection and sustainable management of Daming Palace

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Relic Park and a reference for value assessment and pattern optimization in similar urban heritage parks.

This study has several limitations. First, the number of field survey plots is limited, leaving room for higher data accuracy. Second, the assessment mainly relies on the equivalent factor method [2], and some service quantifications involve subjectivity. Third, the research is static, lacking dynamic temporal analysis, so it cannot reflect long-term changes in values and patterns.

In the future, long-term dynamic monitoring of green spaces in Daming Palace Relic Park can be conducted, and multi-model integration can be used to achieve refined dynamic assessment, allowing accurate understanding of changing trends.

Multi-scenario simulations can be carried out to design different optimization schemes under varying protection intensity and service demand, providing more flexible decision support. The methodological framework of this study can be extended to other urban heritage parks in China, especially those in warm temperate semi-arid and semi-humid regions, forming a more complete technical system and supporting the coordinated development of cultural heritage protection and ecological construction.

In addition, countermeasures for ecological protection and sustainable utilization are proposed: establish a green space ecological monitoring system, implement ecological restoration projects, and build a dynamic value evaluation mechanism to continuously improve service capacity; integrate the optimization scheme into overall park planning, formulate coordinated management regulations for heritage protection and ecology, and strengthen green space maintenance to ensure stable functions; increase policy and financial support, set up a diversified investment mechanism, enhance public awareness and participation, and strengthen scientific cooperation to provide technical and theoretical support for the park's sustainable development.

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