Interannual Variation of Social-Ecological System Resilience and Its Influencing Factors in Arid Region Cultural Tourism Destinations: A Case Study of Dunhuang City, Gansu Province (Postprint)

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Abstract

In the context of culture-tourism integration, analyzing the interannual variation and influencing factors of social-ecological system resilience in cultural tourism destinations can provide sound theoretical and practical guidance for their sustainable development. Taking Dunhuang City as a typical case study area, this study constructs an evaluation index system for social-ecological system resilience of cultural tourism destinations from four dimensions: social, economic, cultural, and ecological environment. Using methods such as grey relational TOPSIS, coupling coordination degree model, and BP neural network, it explores the temporal variation and influencing factors of social-ecological system resilience in the case area from 2007 to 2018. The results show that: (1) From 2007 to 2018, the social-ecological system resilience of Dunhuang City was in a relatively favorable state and could be divided into fluctuation, slow growth, and rapid ascent stages. (2) The cultural and ecological environment subsystems played a dominant role in determining the level of social-ecological system resilience in Dunhuang City. (3) Both the coupling degree and coordination degree between the social-ecological system and its subsystems exhibited an upward trend, with inter-subsystem coordination generally exerting a positive driving effect on overall system coordination, and the intensity of this effect increasing over time. (4) The contribution rates of various factors were ranked as follows: Dunhuang Baidu Index > number of graduate students at Dunhuang Research Academy > various types of cultural heritage protection units > total carbon emissions from tourism > cultural industry operating units.

Full Text

Preamble

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Abstract: Against the backdrop of culture-tourism integration, analyzing the interannual variation and influencing factors of social-ecological system resilience in cultural tourism destinations can provide valuable theoretical and practical guidance for their sustainable development. Taking Dunhuang City as a typical case study area, this paper constructs an evaluation index system for the resilience of cultural tourism destination social-ecological systems from four dimensions: social, economic, cultural, and ecological environment. Using grey correlation TOPSIS, coupling coordination degree models, and BP neural network methods, we investigate the temporal changes and influencing factors of the social-ecological system resilience in the study area from 2007 to 2018. The results show that: (1) The social-ecological system resilience of Dunhuang City was in a relatively good state and can be divided into fluctuating, slow-growth, and rapid-rise stages. (2) The cultural and ecological environment subsystems play a dominant role in determining the degree of social-ecological system resilience in Dunhuang City. (3) The coupling degree and coordination degree between the social-ecological system and its subsystems both show upward trends, with subsystems generally exerting positive 推动作用 on the overall system coordination, and the intensity of this effect increases over time. (4) The contribution rates of various factors rank as follows: Dunhuang Baidu Index > number of graduate students at Dunhuang Research Academy > various cultural relic protection units > total carbon emissions from tourism > cultural industry operating units.

Keywords: arid area; cultural tourism destination; social-ecological system; Dunhuang City

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1. Introduction

Under the new era background, culture-tourism integration has emerged to meet people's needs for a better life. Cultural tourism destinations represent typical examples of culture-tourism integration practice. However, as social-ecological systems, cultural tourism destinations exhibit obvious vulnerability, and high-intensity tourism development activities increasingly disturb and damage these

systems, drawing significant attention from relevant authorities who have introduced measures to promote culture-tourism integration while strengthening cultural and ecological protection of heritage resources. The concept of resilience was introduced into ecology by Holling, and resilience research has expanded from purely ecological systems to social-ecological systems. Tourism destination social-ecological system resilience research has focused on two main aspects: (1) Basic theories of tourism destination social-ecological system resilience, primarily clarifying concepts and relationships among vulnerability, resilience, adaptability, and sustainability; and (2) Measurement and influencing factors of tourism destination social-ecological system resilience, where scholars have constructed frameworks and assessed resilience by examining climate disturbances or pressures and their impacts on tourism activities.

Cultural tourism destination social-ecological systems are complex adaptive systems where social, economic, cultural, and ecological environment subsystems interact, with coordination among subsystems being essential for healthy tourism development. In recent years, resilience has become a new concept and paradigm for sustainable tourism development, emerging as a research hotspot in geography and tourism management. Although scholars have conducted extensive research on tourism destination social-ecological system resilience, existing studies in China have primarily focused on natural scenic destinations in eastern regions, with less attention paid to cultural tourism destinations in western arid areas. Research content has often involved single subsystem resilience or overall resilience, with limited attention to the multi-interaction processes among subsystems from a coupling perspective. Additionally, while sustainable development of cultural tourism is another popular research topic, studies have mostly focused on potential, competitiveness evaluation, and coordinated development between cultural resources and tourism industries, rarely examining cultural tourism sustainability from the perspective of social-ecological system resilience across different region types.

Dunhuang City, located in a typical arid climate zone, represents an area with both ecological vulnerability and active cultural tourism development. It is rich in cultural tourism resources, with 266 cultural heritage sites, including 3 world cultural heritages, 9 national key cultural relics protection units, and 32 provincial-level protection units. In recent years, the Dunhuang Research Academy has vigorously promoted the cultural tourism industry, earning the "2019 China Cultural Tourism Annual Contribution Award" for its "Digital Dunhuang" and "Creative Dunhuang" initiatives. Moreover, Dunhuang culture holds irreplaceable cultural value for inheriting excellent traditional Chinese culture and enhancing social cohesion and national soft power. However, due to global climate change and ecological interference from tourism development, its ecological environment vulnerability continues to increase. Therefore, selecting Dunhuang City as a case study area is highly representative.

Given this context, this paper takes Dunhuang City, a cultural tourism destination in an arid region with abundant resources, as a case study. We construct a

resilience evaluation index system from four aspects (social, economic, cultural, and ecological environment) and two dimensions (vulnerability and coping capacity), and analyze the interannual variation and influencing factors of social-ecological system resilience in arid region cultural tourism destinations. This research expands the perspective of cultural tourism destination studies and provides reference for the sustainable and healthy development of such destinations in arid regions.

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2. Analysis Framework for Social-Ecological System Resilience in Arid Region Cultural Tourism Destinations

Tourism and culture have an interdependent and mutually beneficial relationship—culture is the soul of tourism development, while tourism serves as an important medium for cultural resource transmission. The essence of cultural tourism lies in the uniqueness and authenticity of cultural resources. However, as tourism development deepens, tourism inevitably produces negative effects while activating culture, threatening the sustainable development of cultural tourism destinations and prompting scholars to reflect on the balance between cultural protection and tourism development. Scholars believe that cultural protection and utilization are complementary, and that cultural tourism development should be premised on protection.

Arid regions are inland areas with dry climates, water shortages, and sensitive responses to global climate change. Although industrial development conditions and ecological environments are harsh, these regions possess distinctive cultural tourism resources. Moreover, the tourism industry has high relevance, can enhance economic strength, and provides financial support for cultural tourism resource protection, making tourism development an effective pathway for both resource protection and economic promotion in arid regions. When tourism development is introduced as an exogenous variable, cultural tourism destinations become spaces where cultural tourism resources and tourism activities coexist through the culturalization and capitalization of resources. In this social-ecological system, tourism development, cultural tourism resource protection, vulnerability, and coping capacity undergo interactive evolution.

From a resource and development perspective, cultural tourism resources in arid regions, as tourism attractions, are endowed with economic value. However, due to their fragility and external diseconomies, tourism development inevitably imposes stress on both cultural resources and the ecological environment, increasing vulnerability and affecting the destination's survival state. From a dissemination and protection perspective, as historical material carriers, cultural tourism resources gain new vitality while conveying cultural values to tourists and reinforcing human existence and identity meanings. Stakeholders, aiming to reduce vulnerability, take measures to protect cultural tourism resources and enhance coping capacity, thereby implementing protective development.

3. Data and Methods

3.1 Data Sources

Ecological environment data: Vegetation index data were obtained from the Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn/). Precipitation, temperature, relative humidity, and sunshine hours were sourced from the China Meteorological Data Sharing Service System's annual surface meteorological dataset (http://data.cma.cn/). Due to difficulty obtaining long-term meteorological data for Dunhuang City, we used Jiuquan City meteorological data instead, as Dunhuang is under its jurisdiction. Dang River runoff and annual temperature differences were obtained from the Dunhuang Meteorological Bureau. Natural disaster data came from the Dunhuang Emergency Management Bureau. Total carbon emissions from tourism were derived from reference [35]; data for 2007-2015 were directly cited, while 2016-2018 data were calculated using the same methodology.

Socioeconomic and cultural data: These were primarily obtained from the Gansu Statistical Yearbook, Dunhuang Research Academy Yearbook, Dunhuang City 12th Five-Year Statistical Yearbook, Gansu Urban Statistical Yearbook, and China Urban Construction Statistical Yearbook. The Dunhuang Baidu Index was calculated annually based on daily Baidu Index data retrieved from the Baidu Index website. The public welfare activity funds of the China Dunhuang Grottoes Protection Research Foundation were obtained from information published on the Dunhuang Research Academy website (http://public.dha.ac.cn/). Missing data were filled using interpolation methods. To ensure objectivity, we used the entropy weight method to determine indicator weights, with specific calculation steps detailed in reference [36].

3.2 Methods

3.2.1 Grey Correlation TOPSIS TOPSIS is a common method in multi-objective decision analysis that determines the relative merits of evaluation objects by measuring their proximity to positive and negative ideal solutions. Grey correlation TOPSIS improves the accuracy of TOPSIS evaluation by incorporating the advantages of grey correlation degree in curve pattern analysis. Specific calculation steps are detailed in reference [37].

3.2.2 Coupling Coordination Degree Model We introduced the coupling coordination degree model to better reflect the resilience development status of cultural tourism destination social-ecological systems in arid regions. The calculation models are as follows:

For a three-element system:

$$C = \frac{3\sqrt[3]{u_1 u_2 u_3}}{u_1 + u_2 + u_3}, \quad T = \alpha u_1 + \beta u_2 + \delta u_3$$

For a four-element system based on the three-element coupling mechanism:

$$C_4 = \frac{4\sqrt[4]{u_1 u_2 u_3 u_4}}{u_1 + u_2 + u_3 + u_4}, \quad T_4 = \alpha u_1 + \beta u_2 + \delta u_3 + \varepsilon u_4$$

$$D = \sqrt{C \times T}, \quad D_4 = \sqrt{C_4 \times T_4}$$

Where: D and D_4 are the coupling coordination degrees; C and C_4 are the coupling degrees; T and T_4 are the comprehensive coordination indices; α, β, δ, and ε are undetermined weights; and u_1, u_2, u_3, and u_4 represent the resilience of social, economic, cultural, and ecological environment subsystems, respectively.

3.2.3 BP Neural Network We used the BP neural network to calculate the contribution rates of influencing factors to resilience. After training the neural network and obtaining weights between input and output layers, we calculated the contribution rates. The BP neural network model's input layer, hidden layer, and output layer nodes are interconnected, generating connection weights. We used the neural network's connection weights to calculate the impact of input parameters on output parameters, with the mathematical calculation method as follows [38]:

$$I_j = \frac{\sum_{m=1}^{N_h} \left| \sum_{k=1}^{N_i} w_{1km} w_{2mn} \right|}{\sum_{j=1}^{N_i} \sum_{m=1}^{N_h} \left| \sum_{k=1}^{N_i} w_{1km} w_{2mn} \right|}$$

Where: I_j is the impact weight of the jth input parameter on the nth output parameter. A larger I_j value indicates greater influence of the input variable on the output variable. N_i and N_h are the numbers of input layer and hidden layer nodes, respectively; w_1 is the connection weight from input layer to hidden layer; w_2 is the connection weight from hidden layer to output layer; j, k, m, and n represent neurons (e.g., w_{1jm} is the connection weight between the jth neuron and the mth neuron in the hidden layer).

3.3 Indicator System

Yu Zhongyuan et al. [33] consider social-ecological systems as complex giant systems comprising natural environment, economy, culture, governance, and consciousness. Cultural tourism destinations, centered on cultural tourism resource development and protection, generate elements intertwined with social

and economic subsystems. Accordingly, the structure of cultural tourism destination social-ecological systems should include a "cultural subsystem" in addition to the social, economic, and natural subsystems found in natural tourism destinations. Therefore, cultural tourism destination social-ecological systems comprise four subsystems: social, economic, cultural, and ecological environment. A sustainable arid region cultural tourism destination social-ecological system should result from the interaction and mutual influence of social stability, healthy economic development, cultural activation and inheritance, and ecological balance.

Based on this understanding and drawing on existing research [34], combined with Dunhuang City's actual conditions, we constructed an evaluation index system for arid region cultural tourism destination social-ecological system resilience using factors related to tourism development as vulnerability indicators and factors reflecting system response to disturbances as coping capacity indicators. The system follows principles of scientific rigor, systematicity, operability, and data availability (Table 1). Resilience is divided into three levels (Table 2), where higher resilience indices indicate better resilience in cultural tourism destinations.

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4. Results

4.1 Interannual Variation of Dunhuang City's Social-Ecological System Resilience

Based on grey correlation TOPSIS calculations, the social-ecological system resilience, vulnerability, and coping capacity of Dunhuang City from 2007 to 2018 show the following (Figure 3): (1) The social-ecological system resilience index increased from 0.413 to 0.759, reaching the medium-high level, indicating that Dunhuang City's social-ecological system resilience is in a relatively good state. (2) From 2007 to 2018, vulnerability, coping capacity, and resilience all showed steady upward trends, with balanced development among the three.

We used regression analysis to further explore relationships among vulnerability, coping capacity, and resilience:

$$E = 0.413 + 0.542A - 0.227V$$

Where E, V, and A represent resilience value, vulnerability value, and coping capacity value, respectively. When coping capacity increases by 1 unit, resilience increases by 0.542 units; when vulnerability increases by 1 unit, resilience increases by 0.227 units. This shows that vulnerability has a more prominent impact on Dunhuang City's social-ecological system resilience than coping capacity.

Further analysis reveals that resilience, vulnerability, and coping capacity can be divided into three stages: 2007-2010 as a fluctuation stage, 2011-2015 as a slow-growth stage, and 2016-2018 as a rapid-rise stage. The large fluctuations in the 2007-2010 curve were mainly due to the global financial crisis, H1N1 influenza, and the Xinjiang "7.5" terrorist incident, which caused sharp declines in tourist numbers. The rapid rise in 2016-2018 was primarily policy-related, as the Dunhuang municipal government strengthened tourism promotion while vigorously introducing cultural industries and cultural tourism projects, actively promoting the construction of Dunhuang as an international cultural tourism city and transforming tourism products into cultural-tourism composite types.

4.2 Interannual Variation of Subsystem Resilience in Dunhuang City

Using the least squares method, we examined the influence relationships between subsystems and overall social-ecological system resilience. Table 3 shows the regression results: the adjusted R^2 is 0.999, F value is 5157.520, and $P < 0.05$, indicating good model fit. All subsystem coefficients are positive, showing that each subsystem positively impacts social-ecological system resilience. In terms of influence magnitude: cultural subsystem (0.314) > ecological environment subsystem (0.303) > economic subsystem (0.301) > social subsystem (0.282).

From 2007 to 2018, the coefficient of variation and growth rate of resilience values for social, economic, cultural, and ecological environment subsystems were 9.93% and 5.46%, 7.75% and 2.75%, 11.26% and 7.65%, and 5.00% and -2.27%, respectively. This indicates that social and ecological environment subsystems had smaller dispersion, while economic and cultural subsystems showed larger variation. In terms of growth rate, ecological environment subsystem resilience was negative, while social, economic, and cultural subsystems showed faster growth.

The social subsystem resilience curve shows a "fluctuating rise" pattern, with the 2010 peak primarily due to improved social security. Economic subsystem resilience shows a "slow growth - slow decline" trend, with the slow decline after 2015 due to slowing cultural industry growth. Cultural subsystem resilience shows a fluctuating upward trend, with the rapid rise in 2016-2018 benefiting from series of cultural protection policies. Ecological environment subsystem resilience fluctuates within a small range around 0.5 (Figure 4), related to Dunhuang's ecological baseline conditions as a northwestern region with arid climate, extensive Gobi desert, and weak ecological self-purification capacity.

4.3 Coupling Coordination Characteristics of Dunhuang City's Social-Ecological System

To further reflect the resilience development status of cultural tourism destination social-ecological systems, we introduced the coupling coordination degree model based on subsystem coupling to explore multi-interaction processes among subsystems. The "social-economic-cultural-ecological environment" re-

silience coupling coordination reflects the overall coupling coordination level of the tourism social-ecological system.

The results show that both coupling degree and coordination degree between the social-ecological system and its subsystems show upward trends, with coordination level lower than coupling level but the gap gradually narrowing, indicating strengthened interactions among subsystems. (1) From the coupling degree perspective, the mean coupling degree of "social-economic-cultural" reached 0.971, while other subsystem combinations averaged 0.743, indicating that the four subsystems interact strongly and are in an orderly development state. (2) From the coordination degree trend perspective, the overall system coordination degree showed steady growth during the study period, with continuously improving coordination among subsystems. The overall system coordination degree increased from 0.501 to 0.593, a growth rate of 18.36%. The mean coordination degrees of "social-economic," "social-cultural," "social-ecological environment," "economic-cultural," "economic-ecological environment," and "cultural-ecological environment" were 0.560, 0.576, 0.558, 0.572, 0.554, and 0.571, respectively, with growth rates of 11.26%, 5.00%, 1.21%, 7.65%, 2.75%, and 5.46%.

To analyze how inter-subsystem coordination affects overall coupling coordination, we constructed a coordination influence index following Wang Shaojian et al. [39]. Overall, inter-subsystem coordination positively drives the system's overall coordination degree, with increasing intensity over time (Figure 6).

4.4 Influencing Factors

We introduced multiple linear stepwise regression and BP neural network methods to analyze influencing factors of cultural tourism destination social-ecological system resilience. Multiple linear stepwise regression was used to screen key influencing factors, while BP neural network calculated factor contribution rates. The process was: (1) Conduct Pearson correlation analysis between 20 indicators and resilience to exclude non-significant factors; (2) Use multiple linear stepwise regression to identify key influencing factors, employing pairwise cross-regression by subsystem to avoid omissions; (3) The final selected factors were Dunhuang Baidu Index, cultural industry operating units, various cultural relic protection units, number of graduate students at Dunhuang Research Academy, and total carbon emissions from tourism; (4) Use BP neural network's nonlinear mapping capability to train data in MATLAB R2018b and calculate contribution rates using formula (5).

Results show factor contribution rates rank as: Dunhuang Baidu Index (32.42%) > number of graduate students at Dunhuang Research Academy (25.91%) > various cultural relic protection units (20.53%) > total carbon emissions from tourism (15.43%) > cultural industry operating units (5.71%). The Dunhuang Baidu Index is the key factor affecting resilience, reflecting potential tourist demand for Dunhuang.

Dunhuang's famous tourist attractions are mostly near built-up areas, creating

prominent land supply-demand conflicts and limited population carrying capacity. With intensifying tourism development, large numbers of tourists flock to Dunhuang, causing excessive population aggregation, traffic congestion, declining living environment quality, and increased resource consumption (especially water), thereby increasing ecological environment stress. Cultural industry operating units provide sustained momentum for improving system resilience. Their increase enhances economic strength, promotes economic structure transformation, strengthens investment, and improves infrastructure, providing financial and technical support for ecological environment management and cultural relic restoration, thereby effectively reducing system vulnerability and enhancing coping capacity.

Various cultural relic protection units and graduate student numbers at Dunhuang Research Academy are driving forces for improving system resilience. Cultural tourism resources are the prerequisite for Dunhuang's tourism survival and development. Increases in graduate student numbers and protection units not only strengthen cultural relic protection and enhance coping capacity but also create an atmosphere for protection and raise awareness, thereby reducing system vulnerability. Total carbon emissions from tourism are a limiting factor for system resilience. Increased emissions intensify ecological pressure and accelerate cultural relic oxidation, while a good ecological environment is essential for tourism economic development. Therefore, increased carbon emissions constrain coping capacity improvement and limit resilience development.

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5. Discussion

Cultural tourism destinations, as typical representatives of culture-tourism integration, are complex adaptive systems involving tourism supply-demand relationships and multiple stakeholders. Their sustainable and healthy development helps meet people's needs for a better life. This paper selected Dunhuang City as a typical case study, constructing an indicator system and analytical framework from the "cultural subsystem" dimension to analyze temporal variation and influencing factors of social-ecological system resilience in arid region cultural tourism destinations, expanding research perspectives and providing references for sustainable development.

Empirical research found that the cultural subsystem has the greatest impact on Dunhuang's social-ecological system resilience, while the ecological environment subsystem's impact exceeds that of social and economic subsystems. This differs from non-arid region social-ecological system resilience research results, possibly due to arid region ecological baseline conditions where ecological systems are more sensitive to external interference and have higher vulnerability. Influencing factors are mainly tourism development and related factors, consistent with previous research.

However, due to limitations in cultural data availability, the cultural subsys-

tem focuses on material cultural indicators and fails to incorporate difficult-to-quantify indicators such as cultural interpretation and cultural authenticity. Future research needs to improve the evaluation index system and explore interactions between macro and micro factors. Additionally, future studies should embed the evolution stages of cultural tourism destinations into the adaptive cycle of social-ecological systems to explore evolution processes or use multi-criteria algorithms based on different stakeholder preferences to simulate or predict resilience in arid region cultural tourism destination social-ecological systems.

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6. Conclusion

This paper uses grey correlation TOPSIS, coupling coordination models, and BP neural networks to study the temporal variation, coordination degree, and influencing factors of social-ecological system resilience in arid region cultural tourism destinations from 2007 to 2018. The main conclusions are:

1. Based on existing research and characteristics of cultural tourism destinations, we constructed an index system and analytical framework for social-ecological system resilience in arid region cultural tourism destinations from social, economic, cultural, and ecological environment dimensions.

2. Compared with endogenous variables, social-ecological systems in arid region cultural tourism destinations respond strongly to exogenous variables. The overall resilience is at a medium-high level and can be divided into fluctuating, slow-growth, and rapid-rise stages, with significant volatility in each subsystem's resilience.

3. Subsystems exert different influences on social-ecological system resilience in arid region cultural tourism destinations. Cultural and ecological environment subsystems have more prominent impacts, with all subsystems jointly promoting improved overall system coupling coordination.

4. Influencing factors of social-ecological system resilience in arid region cultural tourism destinations are related to tourism and cultural industries. Factor contribution rates rank as: Dunhuang Baidu Index > number of graduate students at Dunhuang Research Academy > various cultural relic protection units > total carbon emissions from tourism > cultural industry operating units.

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Note: Figure translations are in progress. See original paper for figures.