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Analysis and Prediction of Coupled Coordination Development between Ecological Environment and Tourism Economy in the Pearl River Basin

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Abstract. The tourism economy and ecological environment constitute a structurally complex interactive coupled open system, and correctly understanding and handling the relationship between them is key to sustainable development. Based on data from six provinces in the Pearl River Basin from 2018 to 2020, this study explores the spatiotemporal coupling characteristics of the tourism economy and ecological environment systems in the Pearl River Basin and predicts the coupling coordination degree for the next three years using a coupled coordination model and a grey G.M(1,1) prediction model. The results indicate that the comprehensive level of the two systems is declining overall, with significant spatial differentiation. The evaluation index of the tourism economy can be divided into two stages, with an overall upward trend from 2018 to 2019 and a downward trend in 2020, showing an east-high and west-low spatial distribution pattern. The ecological environment exhibits various trend changes such as V-shaped, inverted V-shaped, and increasing trends, with the lagging system mainly in the form of tourism lag. Most provinces are in a high-level coupling stage, with the coupling coordination degree showing a downward trend and the coordination level not high, presenting a spatial distribution pattern of "high downstream, low upstream." In the coming years, the coupling coordination degree of most provinces in the Pearl River Basin will slowly rise, but it will take a long time to achieve an upward shift in coordination level.

Keywords: Pearl River Basin, coupled coordination, tourism economy, ecological environment, G.M (1,1)

1. Introduction

The tourism industry has become an important source of income for China's economy, but it has also brought about some ecological problems, such as the destruction of animal and plant species, waste management issues, and emissions of pollutants. A good ecological environment promotes the growth of the tourism economy, and there is a clear coupled coordination effect between the two. Foreign scholars initially conducted research on the tourism economy and ecological environment from an ecological perspective, first proposing the concept of tourism carrying capacity, and then mainly studying the relationship between the two, including research on the limitations of environmental factors on economic growth and the coordinated development of the environment and the economy [1]. Wang [2] et al. (2018) investigated the impact of outbound tourism demand on the ecological environment, while Bella G [3] used the Environmental Kuznets Curve to study the relationship between tourists and pollution emissions, providing recommendations for the development of the tourism economy in France. Research on the coupled coordination of the tourism economy and ecological systems in China started relatively late. Ma Hongtao [4] used a coupled coordination model to explore the relationship between the economy, environment, and tourism in the Yellow River Basin; Wu Qian [5] used GIS spatial technology to explore the development laws of the coupling coordination among tourism, economy, and environment in Guangdong Province from both temporal and spatial dimensions; Han Chenchen [6], based on calculating the coupling coordination of the ecological environment and tourism economy in Anhui Province, deeply explored the factors influencing the development of the two systems; Liu Manfeng et al. [7] calculated the economic-environmental development efficiency of 30 provinces and cities in China and analyzed its variation law. Zhao Hulan [8] used a coupling model to evaluate

the three major systems of tourism, ecology, and economy in Xinjiang, and combined with the grey prediction model to analyze future development. Currently, domestic scholars use various methods such as coordination development degree model, Environmental Kuznets Curve, grey correlation model, system dynamics model, etc., to explore the tourism economy and ecological environment [9]. The research objects are mainly focused on national [10-11], regional [12-15], and provincial [16-18] levels. Research achievements on river basins are concentrated in the Yellow River Basin [19-21], Yangtze River Basin [22-23], with relatively few studies on the Pearl River Basin. Therefore, this study takes six provinces in the Pearl River Basin as the research objects, investigates the spatiotemporal coupled coordination development relationship between the tourism economy and ecological environment from 2018 to 2020, and predicts the future development of coordination using the grey prediction model, providing reference for the high-quality sustainable development of the tourism economy and ecological environment in the Pearl River Basin.

2. Research Area and Data Sources

2.1. Overview of the Study Area

The Pearl River Basin is located between 102°14′–115°53′E and 21°31′–26°49′N, spanning six provinces and regions in China, namely Yunnan, Guangxi, Guizhou, Guangdong, Hunan, and Jiangxi, with a total area of 452,600 km² and a population of approximately 124 million. It is an important region for China's economic and ecological development [24]. The Yungui Plateau is situated in the northwest of the basin, with elevations ranging from 1000 to 3000 meters, while the eastern part consists of the hills of Guangdong and Guangxi, with an average elevation of about 500 meters. The eastern part of the basin is characterized by high population density and rapid economic development, particularly in the Pearl River Delta. The Pearl River Basin ranks second in China in terms of runoff volume and is prone to flood and drought disasters, with ecological efficiency at a medium to low level [25]. The tourism economy in the Pearl River Basin has grown rapidly, while the ecological environment remains fragile. Since the 18th National Congress of the Communist Party of China, with Comrade Xi Jinping at its core, the Party Central Committee has strengthened the overall leadership of the Party in ecological civilization construction and promoted the construction of a beautiful China as the foundation of sustainable development. After the Yellow River and Yangtze River basins were elevated to national strategies, the promotion of ecological protection and economic development in the Pearl River Basin was formally proposed by members of the National People's Congress and the Chinese People's Political Consultative Conference in 2020 to achieve coordinated development and protection in the basin. Therefore, the coupling study of the ecological environment and tourism economy in the six provinces and regions of the Pearl River Basin is particularly important.

2.2. Data Sources

This study focuses on the Pearl River Basin and calculates the coupling coordination of two types of data: tourism economy and ecological environment systems. Data for this article were sourced from the "China Environmental Yearbook," "China Statistical Yearbook," "China Tourism Yearbook," and statistical yearbooks of Yunnan, Guizhou, Guangdong, and other provinces and regions, as well as announcements released on official websites. The time range selected was from 2018 to 2020. In cases of individual missing data, the weighted average method was used for imputation.

3. Research Design

3.1. Construction of Indicator System

Following the principles of scientificity, reliability, and comprehensiveness, and drawing on relevant existing research [26-27], the evaluation index system of the tourism economy in the Pearl River Basin was established from three aspects: tourist numbers, tourism revenue, and tourism resources. The evaluation index system for the ecological environment was established based on the Pressure-State-Response (PSR) model [30]. The constructed indicator system consists of 16 secondary indicators, where "+" indicates a positive effect indicator, with larger values promoting system development, and "-" indicates a negative effect indicator (Table 1).

Table 1. Evaluation Indicator System for Tourism Economy and Ecological Environment

Subsystems	Primary Indicators	Secondary Indicators	Unit	Weight	Type
Tourism Economy Subsystem	Tourist Numbers	Inbound Tourist Arrivals	10,000 person-times	0.1626	+
		Domestic Tourist Arrivals	10,000 person-times	0.0227	+
	Tourism Revenue	Domestic Tourism Revenue	100 million yuan	0.0365	+
		Foreign Exchange Tourism Revenue	100 million US dollars	0.1920	+

Table 1. Continued

Subsystems	Primary Indicators	Secondary Indicators	Unit	Weight	Type
Ecological Environment Subsystem	Tourism Resources	Number of Star-rated Hotels	Units	0.0662	+
		Number of Travel Agencies	Units	0.0689	+
	Environmental Pressure	Industrial Wastewater Discharge	10,000 tons	0.0324	-
		Industrial Emission of Waste Gases	10,000 tons	0.0246	-
		Industrial Solid Waste Discharge	10,000 tons	0.0235	-
	Environmental Status	Per Capita Water Resources	m^3	0.0340	+
		Forest Coverage Rate	%	0.0487	+
		Per Capita Park Green Area	m^2	0.0535	+
		Urban Greening Rate	%	0.0503	+
	Environmental Response	Total Investment in Industrial Pollution Control	10,000 yuan	0.0792	+
		Investment in Geological Disaster Prevention and Control	10,000 yuan	0.0829	+
		Harmless Treatment Rate of Domestic Waste	%	0.0220	+

3.2. Research Method

3.2.1. Entropy Method

Step 1: To ensure the accuracy of the indicator data, standardization processing is performed according to the nature of each indicator [31].
For positive indicators:

$$X_{ij} = (X_{ij} - X_{ijmin})/(X_{ijmax} - X_{ijmin}) \quad (1)$$

For negative indicators:

$$X_{ij} = (X_{ijmax} - X_{ij})/(X_{ijmax} - X_{ijmin}) \quad (2)$$

Where xij is the standardized value; Xijmax and Xijmin are the maximum and minimum values of the j-th indicator for the i-th object. To avoid meaningless calculation results, add 0.0001 to data standardized to 0.

Step 2: Normalization processing, calculate the weight of each indicator:

$$P_{ij} = \frac{x'_{ij}}{\sum_{j=1}^{n} x'_{ij}} \quad (3)$$

Step 3: Calculate entropy:

$$E_j = -k \sum_{i=1}^{n} P_{ij} \ln(P_{ij}), k = \frac{1}{\ln n} > 0 \quad (4)$$

Step 4: Calculate the coefficient of variation of the indicators:

$$G_j = 1 - E_j \quad (5)$$

Step 5: Calculate the weights of the indicators:

$$w_j = \frac{G_j}{\sum_{j=1}^{m} G_j} \quad (6)$$

Where x'ij is the indicator value after standardization and translation; Pij is the indicator value after normalization; Ej is the coefficient of variation of each indicator; Gj is the difference in entropy values of the indicators.

3.2.2. Comprehensive Level Evaluation Model

Using the method of weighted sum of weights and indicators, calculate Ui:

$$U_i = \sum_{i=1}^{m} w_j x_{ij} \quad (7)$$

Where I =1, 2; U1 is the comprehensive evaluation index of the tourism economy, and U2 is the comprehensive evaluation index of the ecological environment.

3.2.3. Coupling Degree and Coupling Coordination Model

The coupling degree model representing the interaction between the tourism economy and the ecological environment system is expressed as:

$$C = \sqrt{\frac{U_1 \times U_2}{\left(\frac{U_1+U_2}{2}\right)^2}} \quad (8)$$

Where C represents the coupling degree. A larger C value indicates a better coupling degree between the systems, and vice versa (Table 2).

Table 2. Coupling Degree Classification

C	0-0.3	0.3-0.5	0.5-0.8	0.8-1.0
Coupling Level	Low-level Coupling Stage	Antagonistic Stage	Coordinated Stage	High-level Coupling Stage

The formula for calculating the coordination degree of the coupling between the ecological environment and tourism economy is as follows:

$$D=\sqrt{(C\times T)} \quad (9)$$

$$T = \alpha U_1 + \beta U_2 \quad (10)$$

Where D represents the level of coupling coordination; T represents the comprehensive evaluation index of the system; α and β are undetermined coefficients. Considering the equal importance of the two systems, the values of α and β are set to 0.5. To reflect the coupling relationship more clearly, referring to the research results of Liao Zhongbin [22], the coupling coordination level of each province in the Pearl River Basin is classified (Table 3). 0≤D≤1, and the higher the value of D, the better the coordination between the systems.

Table 3. Classification Criteria for Coupling Coordination between Ecological Environment and Tourism Economy

Range of D Values	Type
[0.000, 0.100]	Extremely Disordered Decline Type
[0.100, 0.200]	Serious Disordered Decline Type
[0.200, 0.300]	Moderate Disordered Decline Type
[0.300, 0.400]	Slight Disordered Decline Type
[0.400, 0.500]	Borderline Disordered Decline Type
[0.500, 0.600]	Barely Coordinated Development Type
[0.600, 0.700]	Primary Coordinated Development Type
[0.700, 0.800]	Intermediate Coordinated Development Type
[0.800, 0.900]	Good Coordinated Development Type
[0.900, 1.000]	High-quality Coordinated Development Type

3.2.4. Grey G.M(1,1) Prediction Model

Referring to the methods of scholars such as Zhou Cheng and Liu Xiaoming [26-27], the specific values of the coupling coordination between the ecological environment and tourism economy in future time periods are predicted using a sequence prediction method.

1) The new sequence R1 is generated by cumulating the original time series R0.

2) Obtain the corresponding GM (1,1) model differential equation:

$$\mu = \frac{dR_1}{d_t} + cR_1$$

(Where c is the development gray number, μ is the endogenous control gray number).

3) Solve by cumulative reduction:

$$r_1^T \widehat{R_1}(k+1) = \left[r_0(1) - \frac{\mu}{c}\right] e^{-ck} + \frac{\mu}{c}, \textit{ where k=1, 2, ...n.}$$

4) Calculate the posterior ratio of residuals C and the small error probability P, as shown in Table 4.

Table 4. Precision Evaluation Criteria for GM (1,1) Model

Precision Level	P	C
Good	>0.95	<0.35
Eligible	>0.80	<0.5
Basic eligiblity	>0.70	<0.65
Disqualification	≥0.70	≤0.65

4. Analysis of Temporal and Spatial Characteristics of Tourism Economy-Ecological Environment System in the Pearl River Basin

4.1. Comprehensive Development Level Analysis

By calculating the comprehensive evaluation index of tourism economy and ecological environment for the six provinces and regions in the Pearl River Basin from 2018 to 2020 using equation (7) (see Figure 1).

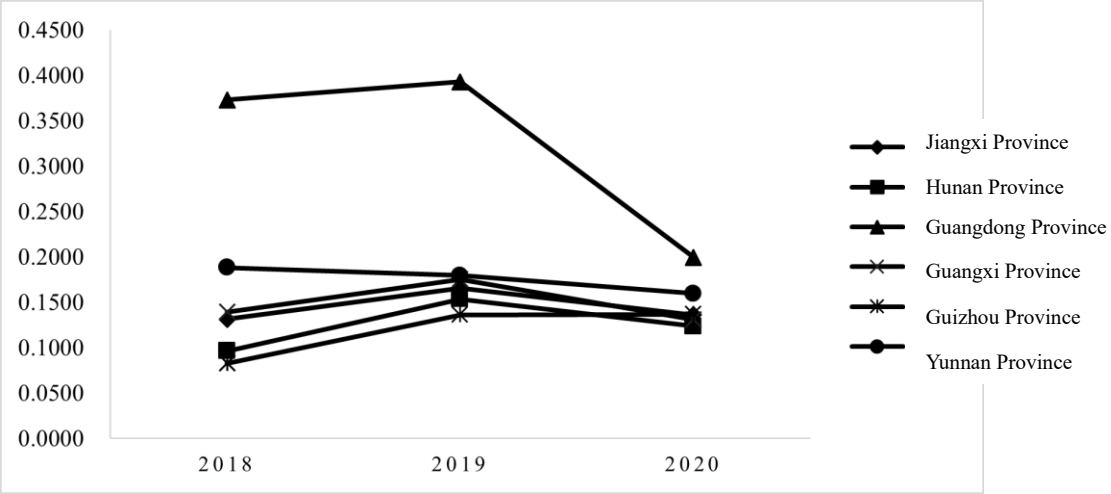

Figure 1. Trends in Comprehensive Index of Tourism Economy and Ecological Environment in the Pearl River Basin

The comprehensive development level of the tourism economy and ecological environment in the Pearl River Basin exhibits significant uneven stratification. Guangdong has the highest comprehensive development level, with significant gaps between its development level and the other five provinces and regions. The main reason is that the karst rocky desertification control area is located in the upper reaches of the Pearl River, where the ecological environment is extremely fragile and the economic development model is extensive [35], leading to a relatively low comprehensive development level. Guangdong, situated in the southern coastal area of China, enjoys unique development advantages in terms of economic development and tourism industry compared to other provinces and regions in the Pearl River Basin. Secondly, there is a lack of comprehensive development in the two systems of the Pearl River Basin. The most serious is Guizhou, with comprehensive index values between 0.083 and 0.137, and the comprehensive evaluation indexes of Jiangxi, Hunan, Guangxi, and Yunnan are all below 0.3, indicating a relatively low level of development. Overall, the development trend of tourism and ecology in the Pearl River Basin in recent years is not optimistic, and the development status of different provinces and regions will not change in the short term. Improving the development of tourism economy and ecological quality in the Pearl River Basin in the future requires adhering to the concept of high-quality and coordinated development, prioritizing environmental protection, and improving the comprehensive development level of both systems.

4.2. Analysis of Temporal Characteristics of Subsystems

Based on the entropy method to obtain the weight coefficients of various indicators of the two major systems in the Pearl River Basin, the proximity of the two systems is calculated as the evaluation index of each subsystem (see Table 5, Figure 2). Overall, from 2018 to 2019, the tourism economy index of each province and region in the Pearl River Basin showed an overall upward trend, but the outbreak of the COVID-19 pandemic in 2020 dealt a severe blow to the highly vulnerable tourism industry, resulting in a cliff-like decline in the tourism economy index. In terms of values, the tourism economy evaluation index of Guangdong Province has been the highest from 2018 to 2020, while that of Guizhou Province has been the lowest. In terms of growth rate,

from 2018 to 2019, Guizhou had the highest growth rate, with a year-on-year increase of 47.87%, while Guangdong had the lowest growth rate, with a year-on-year increase of 3.45%. In 2020, the tourism economy development of each province and region showed negative growth. In summary, the comprehensive level of tourism economy development in Guangdong still leads other provinces and regions, but there is a trend of slow narrowing of regional disparities. The development of ecological environment in each province and region of the Pearl River Basin from 2018 to 2020 varies. The ecological environment evaluation indexes of Guangdong, Jiangxi, Guangxi, and Hunan provinces and regions show an inverted V-shaped change with an initial increase followed by a decrease; Yunnan shows a V-shaped change with an initial decrease followed by an increase; Guizhou shows an increasing trend. The ecological environment quality of Guizhou improves year by year, while other provinces and regions show a downward trend. It can be seen that the development level of ecological environment in each province and region of the Pearl River Basin is unstable and requires strengthened ecological governance and protection.

Table 5. Lag Types of Tourism Economy and Ecological Environment in the Pearl River Basin

Province	2018			2019			2020		
	U_1	U_2	Lagging System	U_1	U_2	Lagging System	U_1	U_2	Lagging System
Jiangxi	0.0636	0.1994	Tourism	0.0796	0.2512	Tourism	0.0399	0.2323	Tourism
Hunan	0.0939	0.0987	Tourism	0.1086	0.1982	Tourism	0.0589	0.1886	Tourism
Guangdong	0.5100	0.2360	Ecology	0.5276	0.2585	Ecology	0.1689	0.2300	Tourism
Guangxi	0.1125	0.1664	Tourism	0.1370	0.2135	Tourism	0.0648	0.1971	Tourism
Guizhou	0.0476	0.1181	Tourism	0.0704	0.2021	Tourism	0.0223	0.2516	Tourism
Yunnan	0.1905	0.1861	Ecology	0.2016	0.1573	Ecology	0.0731	0.2465	Tourism

Based on the calculation results, comparing the sizes of U1 and U2, the lagging systems in the Pearl River Basin from 2018 to 2020 are determined [36] (Table 5). Through comparison, it is found that the lagging system type in the Pearl River Basin is mostly tourism lagging. Specifically, in 2018-2019, Guangdong Province and Yunnan Province showed ecological lagging, indicating that during this period, the level of tourism economic development exceeded the level of ecological environmental governance. The other provinces and regions showed tourism economic lagging, indicating that the level of tourism economic development was lower than the improvement in ecological quality. In 2020, all provinces and regions in the Pearl River Basin exhibited tourism economic lagging. Therefore, although the lagging systems in each province in 2020 were all related to tourism economy, the pace of tourism economic development was slow. It is evident that in the future, the Pearl River Basin should focus on releasing the potential of tourism economy while emphasizing the protection of the ecological environment to promote the coordinated development of the two major systems.

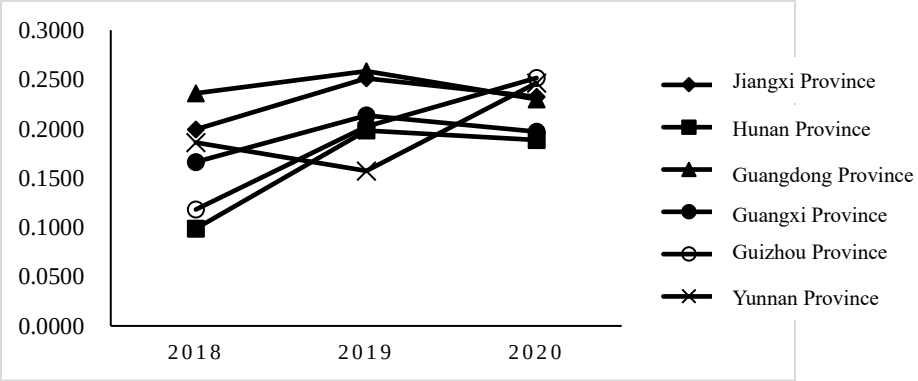

Figure 2. Trend of Ecological System Index in the Pearl River Basin

4.3. Spatial Characteristics Analysis of Subsystems

The tourism economic index of each province in the Pearl River Basin shows an east-high-west-low pattern with minimal fluctuations, indicating a significant polarization phenomenon (Table 5). From 2018 to 2020, the spatial pattern of tourism economic development remained stable, with the index rankings in all years being Guangdong, Yunnan, Guangxi, Hunan, Jiangxi, and Guizhou. The average tourism economic evaluation index in Guangdong was 0.4022, 8.6 times that of Guizhou and 6.6 times that of Jiangxi. High-value areas of tourism economic index in the Pearl River Basin are polarized in the east (Guangdong), while low-value areas are polarized in the west (Guizhou), showing an east-high-west-low distribution pattern with an increasing trend from west to east. The development status of the ecological environment in each province of the Pearl River Basin showed significant spatial pattern changes in different years, and was highly unstable. In 2018, the ecological environment evaluation index was ranked in descending order as Guangxi, Guangdong, Guizhou, Hunan, Jiangxi, and Yunnan, with Guangxi having the highest index and Yunnan the lowest, with a maximum value 2.4 times the minimum. In 2019, the spatial pattern changed to Guangxi, Guangdong, Hunan, Jiangxi, Yunnan, and Guizhou, with Guangxi maintaining the first position and Guizhou ranking last. In 2020, there was a significant change in the spatial pattern, with rankings as follows: Jiangxi, Guizhou, Guangdong, Guangxi, Hunan, and Yunnan, indicating an improvement in the ecological environment quality in Jiangxi to the top position and Yunnan returning to the lowest. It can be seen that the distribution of tourism economic development in the Pearl River Basin is east-high-west-low, with significant spatial polarization and relatively stable distribution patterns, while the development level of the ecological environment is highly variable and unstable.

5. Coupling Degree and Coupling Coordination Feature Analysis

5.1. Temporal Characteristics of Coupling Degree and Coupling Coordination

5.1.1. Temporal Analysis of Coupling Degree

Based on formulas (8) to (9), the calculation results of the coupling degree of the two systems in each province of the Pearl River Basin are obtained. Combining Table 6 and Table 2, it can be observed that from 2018 to 2019, the coupling degree of tourism economy and ecological environment in the six provinces was mainly in the range of (0.80, 1.00], indicating that their coupling degree has consistently been at a high level. During this period, the development levels of tourism economy and ecological environment in the six provinces grew synchronously, and the gap gradually narrowed, thus the coupling degree level was in a growing state. In 2020, Jiangxi and Guizhou saw a decrease in coupling value to the phase of coordination, while the coupling degree values of the other provinces ranged from 0.8400 to 0.9882, showing a downward trend, but with a minor change in magnitude. During this period, the development levels of tourism economy and ecological environment in each province showed a decreasing trend, but still remained at a high level of coupling. It can be foreseen that with the gradual advancement of ecological civilization construction, the relationship between tourism economy and ecological environment will become even closer.

Table 6. Coupling Degree of Tourism Economy and Ecological Environment in the Pearl River Basin

Region	2018			2019			2020		
	C	D	Coordination Level	C	D	Coupling Coordination Evaluation	C	D	Coordination Evaluation
Jiangxi	0.8563	0.3356	Slightly Imbalanced	0.8549	0.3760	Slightly Imbalanced	0.7071	0.3102	Slightly Imbalanced
Hunan	0.9997	0.3103	Slightly Imbalanced	0.9564	0.3830	Slightly Imbalanced	0.8516	0.3246	Slightly Imbalanced
Guangdong	0.9301	0.5890	Barely Coordinated	0.9396	0.6077	Primary Coordinated	0.9882	0.4439	On the Verge of Imbalance
Guangxi	0.9811	0.3699	Slightly Imbalanced	0.9759	0.4136	On the Verge of Imbalance	0.8630	0.3362	Slightly Imbalanced
Guizhou	0.9050	0.2738	Moderately Imbalanced	0.8754	0.3454	Moderately Imbalanced	0.5465	0.2735	Moderately Imbalanced
Yunnan	0.9999	0.4339	On the Verge of Imbalance	0.9923	0.4220	On the Verge of Imbalance	0.8400	0.3664	Slightly Imbalanced

5.1.2. Coupling Coordination Degree Time Series Analysis

Combining with Table 6, an analysis is conducted on the coupling coordination degree of tourism economy and ecological environment in each province of the Pearl River Basin from 2018 to 2020. Regarding the changes in rankings, there are minimal variations in the rankings of coupling coordination degree from 2018 to 2020. The top three positions, Guangdong, Yunnan, and

Guangxi, remain unchanged throughout the period, with only Hunan rising from fifth place in 2018 to fourth place in 2020. In terms of coupling coordination types, Guangxi and Yunnan are between being on the verge of imbalance and slightly imbalanced, while Guizhou has long been in a state of moderate imbalance. Hunan and Jiangxi have been in a state of slight imbalance for a long time, with only Guangdong experiencing stages of barely coordination and primary coordination. This also indicates that while promoting the protection of the ecological environment in the Pearl River Basin, the improvement of coupling coordination between the two systems should not be neglected. Looking at the future trend, the coupling coordination degree of each province is showing a downward trend. Overall, there is considerable development space for the transformation of coupling coordination types in various provinces.

5.2. Coupling Degree and Coupling Coordination Degree Spatial Characteristics

5.2.1. Coupling Degree Spatial Analysis

From 2018 to 2020, the level of coupling degree between tourism economy and ecological environment in various regions of the Pearl River Basin generally remained at a high-level coupling stage. Only Jiangxi and Guizhou occasionally reached the coordination stage, showing a spatial pattern characterized by overall balance and concentrated distribution, with minimal fluctuations in spatial evolution. In terms of geographical distribution, the coupling degree in the downstream area of the Pearl River was significantly higher, with Guangdong scoring as high as 0.95. Comparatively, the overall level of coupling degree in the upstream region was slightly lower, with Jiangxi and Guizhou averaging scores of 0.8061 and 0.7756, respectively. It is worth noting that Guangxi in the midstream region scored 0.94, ranking third among all provinces.

5.2.2. Coupling Coordination Degree Spatial Analysis

Table 6 delineates the stages of coupling coordination degree for different provinces during each period, reflecting the spatial changes in the coupling coordination degree between tourism economy and ecological environment in the Pearl River Basin. Overall, the coupling coordination degree between tourism economy and ecological environment in the Pearl River Basin is not high, mainly falling within the range of [0.20, 0.5), belonging to the categories of moderate, slight, and imminent imbalance. Spatially, there is a pattern of low-upstream and high-downstream distribution, with significant differentiation and uneven regional development. In terms of stages, Guangdong remained in a coordinated development stage during the first two periods, transitioning to an imminent imbalance stage in the last period, indicating a weakening of coupling degree between the two systems. However, as the province with the highest coupling coordination degree in the Pearl River Basin, Guangdong is also positively influenced by factors such as tourism resources, tourism revenue, and ecological environment status, showing tremendous potential for upward transition development. Over the three periods, Guangxi experienced a repeated process from slight imbalance to imminent imbalance and back to slight imbalance, while Yunnan transitioned from an imminent imbalance stage to a slight imbalance stage, indicating varying degrees of weakening in the coupling coordination degree of these two provinces. Jiangxi, Hunan, and Guizhou have long been in a state of slight or moderate imbalance, with coupling coordination degree at a low level, indicating that the coordination relationship between tourism economy and ecological environment in these three provinces has remained relatively stable. It is evident that achieving high-quality integration between tourism economy and ecological environment in each province will require long-term efforts.

6. Predicting the Coordinated Development of Tourism Economy and Ecological Environment Systems

Based on the grey GM (1,1) prediction model and utilizing DPS9.50 analysis software to calculate the future coupling coordination degree of the two major systems, the prediction results of the coupling coordination degree for the next three years were obtained through five iterations of residual modeling. From Figure 3, it can be observed that the development trend of the coupling coordination degree of the two systems in the coming years. Jiangxi, Hunan, Guizhou, and Guangxi will experience a slight upward trend, with Guizhou's system transitioning from moderate imbalance to slight imbalance, and Jiangxi transitioning from slight imbalance to imminent imbalance. Although the coupling coordination levels of the remaining provinces remain unchanged from 2020, the coupling coordination values of Guangdong and Yunnan have decreased from 0.0439 and 0.3664 to 0.4172 and 0.3033, respectively, indicating a tendency towards lower levels. The prediction results indicate that the coupling coordination degree of the two major systems in the Pearl River Basin will increase over the next three years, but the rate of development in their coupling levels is relatively slow. Achieving good coordinated development will require a long time, and each province should break through the main constraints in future development to enhance the level of coordinated development between tourism economy and ecological environment.

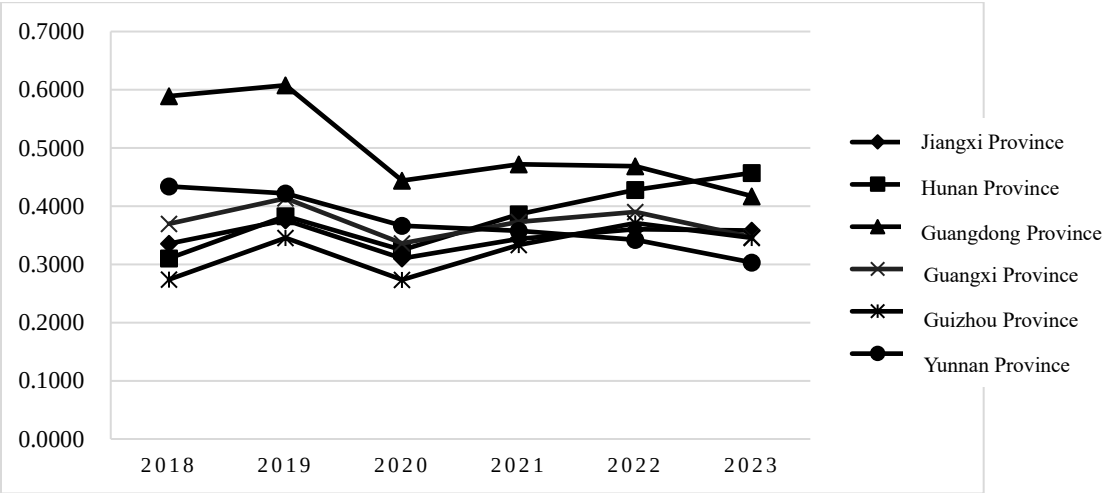

Figure 3. Evolution of Coupling Coordination Degree in the Pearl River Basin

7. Conclusion and Recommendations

7.1. Conclusion

Through the analysis of the relevant indicators of tourism economy and ecological environment development in the six provinces of the Pearl River Basin from 2018 to 2020, the coupling degree and coupling coordination degree of the two were calculated. The development rules were analyzed from two dimensions: horizontal spatial differentiation and vertical temporal evolution. Finally, the grey system model was used to predict the future three years' coupling coordination degree, and the following conclusions were drawn:

Firstly, the comprehensive level of the tourism economy-ecological environment system in the Pearl River Basin is showing a downward trend, with prominent spatial differentiation. The six provinces exhibit hierarchical and insufficient development phenomena, with Guangdong Province leading in development, while the comprehensive development level of the remaining provinces is not high. The pattern of significant regional differences in development is unlikely to change in the short term.

Secondly, the spatial distribution pattern of the evaluation indices of the two systems in the Pearl River Basin varies, with the tourism lagging type being dominant. Overall, from 2018 to 2019, the tourism economy indices of various provinces generally increased, while in 2020, they showed a downward trend. The changes in ecological environment indices in various provinces are complex, showing trends such as V-shaped, inverted V-shaped, and incremental changes. The lagging type is mainly the tourism system lagging type. From the spatial evolution results, the spatial polarization of tourism economic evaluation indices is significant, with an east-high and west-low distribution pattern that is stable. However, the ecological environment quality fluctuates greatly, and spatial evolution is irregular. The ecological environment is the foundation of tourism industry development, and only a good ecological environment can promote the sustainable development of tourism economy. However, the ecological environment indices are showing a declining trend. If the promotion of tourism economy development continues at the cost of consuming the ecological environment, the development of the two systems will lose balance and stagnate.

Thirdly, from the overall development and evolution of coupling degree, most provinces were in a high-level coupling stage from 2018 to 2020, with strong interaction and mutual promotion among the elements of the two systems. In terms of spatial differences, the spatial evolution characteristics exhibit overall balance and concentrated distribution. The top three provinces in terms of coupling degree are Guangdong, Yunnan, and Guangxi. From the overall development and evolution of coupling coordination degree, from 2018 to 2020, most provinces in the Pearl River Basin had coupling coordination degree levels between moderate imbalance and slight imbalance, with an overall low level of coupling coordination. In terms of development trends, the coupling coordination degree of most provinces is declining. Spatial difference results show that the Pearl River Basin exhibits a spatial pattern of "high in the downstream, low in the upstream". Downstream provinces generally have a higher but unstable coupling coordination degree between tourism industry and ecological environment development, while upstream and midstream coupling coordination levels are relatively stable but at lower levels, all below the level of moderate imbalance.

Fourthly, the use of the grey GM (1,1) model to predict the future coupling coordination degree of the two major systems revealed that the coupling coordination degree of most provinces and regions is slowly increasing, and achieving an upward shift in coordination level will require a long time. However, due to the limitations of data acquisition and the randomness of the prediction model sequence, there may be some impact on the results.

7.2. Recommendations

Firstly, continue to maintain the dominant position of the ecological environment. With the goal of sustainable development in the Pearl River Basin, adhere to the core guiding ideology of "harmonious coexistence between humans and nature," enhance ecological governance capabilities, and comprehensively enhance the integrated value of ecological environment construction and tourism economy construction in the Pearl River Basin. Governments at all levels should strengthen cooperation, explore the establishment of an overall plan for ecological protection in the Pearl River Basin, formulate relevant regulations for the development of ecological tourism, regulate and guarantee from a holistic perspective, and improve the ecological compensation mechanism for developing the tourism economy.

Secondly, innovate the development of ecological tourism routes. In the post-pandemic era, the new demand for pursuing health and wellness is driving the development of ecological tourism. For example, the construction of green ecological corridors, along the main streams of the West River, Beijiang River, Dongjiang River, and other tributaries, establish protective green belts and riparian landscape belts to create riverside landscapes with local cultural themes and green ecology, promote the overall improvement of the aquatic ecological environment. On the other hand, enrich and meet the diverse needs of different groups for ecological tourism, integrate ecological tourism with sports, culture, medical care, and other industries. For regions like Teagarden in Guizhou, which have local specialty agricultural industries such as oil tea, white tea, and golden tips, it is essential to develop and cultivate eco-tourism economic pilot projects while ensuring the preservation of ecological barriers. Simultaneously, efforts should be made to explore tourism market demand, thus creating highly distinctive "Pearl River Series" eco-tourism new projects.

Finally, stimulate new dynamics for the development of the tourism economy. The tourism economic index saw a significant decrease in 2020. Governments should establish mechanisms to drive industrial development in the downstream areas of the Pearl River, leveraging the leading role of Guangdong, to provide financial support for the development of ecological tourism construction in upstream areas, and achieve coordinated development across the entire basin. On the other hand, increase the supply of high-quality ecological tourism products. The quality of tourism products often affects consumer purchasing decisions. Tourism operators should strengthen their ability to understand tourism market trends, as the key to stimulating the development of the tourism economy lies in high-quality tourism products.

Funding Project

Mechanism and Empirical Study on Sustainable Income Increase of Farmers in Ethnic Villages through Rural Tourism (71964010).

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