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Study on Coordination Effect and Interactive Stress between Tourism Economy and Eco-environment —— Taking Pearl River Delta for an Example

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Abstract: A coupling coordination degree model and an interactive stress model of tourism economy and eco-environment in Pearl River Delta are established to analyze the dynamic coordinated relationship of 9 cities in Pearl River Delta from 2007 to 2018. Results show that in the time series, coupling coordination of the tourism economy and the eco-environment in 9 cities shows a steady upward trend; in the spatial pattern, the coupling coordination of coastal areas is generally better than non-coastal areas; dynamic coordinated relationship's spatial distribution about the two systems exists in all cities in Pearl River Delta. Besides, according to the interactive stress model, there is a strong interactive stress between tourism economy and the eco-environment. And the level of tourism economy is higher in economically developed areas, and the possibility of deterioration of the eco-environment in economically backward areas is greater. With the interactive stress of the tourism economy and eco-environment, advice should be proposed to adjust the relationship between them, in order to coordinate smooth and optimized development.

Keywords: Pearl River Delta; Tourism economy; Eco-environment; Coupling coordination; Interactive stress

1 Introduction

Tourism is an important part of the tertiary industry, and is a "sunrise industry" for social and economic development[1]. Therefore, promoting the upgrading of the tourism industry structure and tourism economy is conducive to promoting the national economy. The development of the tourism economy should be within the scope of the eco-environment to sustainable development. The tourism industry's characteristics of environmental dependence and resource consumption determine its interaction with the eco-environment. A high-quality eco-environment is the foundation of the tourism economy, and the tourism economy's development will harm the local eco-environment[2]. With the development of the social economy, tourism has gradually become more dynamic. While the pace of the tourism industry's development is accelerating, issues about

ecology have become increasingly serious, becoming an obstacle to sustainable development[3]. Therefore, under the guidance of sustainable development and green concepts, focusing on the coordinated development between eco-environment system and tourism economy system is a value orientation of harmonious coexistence between human and nature. The way of achieving coupling coordination between the two systems is the key to sustainable development.

As early as the 1920s, scholars began to analyze the relationship between tourism activities and eco-environment elements. For example, Stehhen started from a number of tourism cases and studied the positive and negative effects of tourism activities on the eco-environment of tourist destinations [4]; Lacitignola et al. constructed a minimal descriptive model of socio-ecological systems from the perspectives of tourists, ecosystem goods and service quality, and capital to effectively support the sustainable development of tourist destinations [5]. Since then, many scholars have become interested in tourism's ecological safety, eco-environment threshold and tourism's carrying capacity. For example, Trista et al. explored the environmental management of the tourism industry through the ecological footprint method[6]; Taking Pattaya beach and Chalatat beach as examples, Nidhinarangkoon conducted research on the carrying capacity of beach tourists and found that due to the influence of beach areas, correction factors, and management capacity, the area of Pattaya beach is smaller than half of Chalatat beach, but its effective carrying capacity is far greater than Chalatat beach[7]. With the advent of the tourism era, research on the relationship between tourism economy and eco-environment has gradually become the important points that people focus on. At present, researches on tourism economy and eco-environment mainly focus on the following three aspects:

(1) One is to study the development of the tourism field from a single dimension of governance and protection of the eco-environment, including the relationship between environmental pollution, air quality, land use and the tourism industry. Anna et al. analyzed eco-tourism from a dynamic perspective and showed that the development of eco-tourism contributes to the sustainable development of the eco-environment[8]. Dong et al. used a Regression Discontinuity Design (RDD) to control endogeneity and estimated air pollution how to work on China's inbound tourism. The results showed that air pollution is positively related to total consumption of tourists, but tourists in areas with severe air pollution tend to spend more money[9]. Lorena et al. assessed the suitability of land in the basins of Uruguay's coastal lagoons, and used the multi-attributed model developed by the geographic information system to reduce conflicts with land use, to establish a harmonious distribution of land which suitable for tourism, agriculture, and animal husbandry[10].

(2) The second type explores the evolution of the eco-environment from various perspectives of the tourism industry, including the relationship between tourism resources, tourist flow, and the eco-environment. Anser et al. used different regression estimates and found that inbound tourism, population density, international trade, and eco-environment are highly correlated, and inbound tourism is the main negative factor of global environmental conditions that cause the "ecological footprint". Besides, there is an "inverted U-shaped" relationship between inbound tourism and eco-environment [11]. Paglia et al. carried out landscape information collection from Tremiti

Islands, a tourist resort with biodiversity and special geomorphology, and established tools to see the link between landscape and natural heritage, to afford ecological protection convenience for local tourism [12]. Wu analyzed the value and functions of geology parks with natural heritage attributes, and emphasized the importance of eco-tourism and geological resources [13].

(3) The third type is the study about coupling of tourism economy and eco-environment. Through the combination of empirical analysis and theoretical research, the coordination relationship and coupling mechanism between the two are revealed, and model evaluation and model for simulated prediction are established. Based on Southeast Asian tourism data, Brahmasrene et al. conducted research on the interaction between tourism and environmental quality through a panel regression method [14]. Wang et al. studied the coupling coordination degree between the tourism industry and the local environment in the four neighboring provinces and municipality of Hunan, Hubei, Guizhou and Chongqing, and found that the overall level of the degree between the two is low [15]. Zhang et al. established a coupling coordination model which is similar to Wang for Turpan in China, analyzing the spatio-temporal evolution of local coupling degree [16].

Existing literature shows that there are many studies on the correlation between the tourism domain and the eco-environment, but most of them focus on the order of coupling and coordination in time dimensions. They have a low grasp of spatial pattern's characteristics and lack dynamic concepts. Moreover, there is insufficient research on whether there is an interactive stress connection between the tourism economy and eco-environment. Based on this, this paper selects relevant tourism and eco-environment data of 9 cities in Pearl River Delta from 2007 to 2018, establishes a coupling and coordination evaluation model to explore the dynamic coupling and coordination degree of Pearl River Delta's tourism economy and eco-environment from two dimensions of time and space and verifies whether there is interactive stress between the tourism economy and eco-environment, to enrich current tourism economy and eco-environment coupling related research. Through the quantitative and qualitative research on the link about coupling and coordination, policies and suggestions for the coordinated development of Pearl River Delta's tourism industry and eco-environment system are put forward.

2 Data and methods

2.1 Overview of study area and index system design

2.1.1 Overview of study area

Pearl River Delta is located in south-central part of Guangdong Province, covering 9 cities including Guangzhou, Shenzhen, Zhuhai, Zhaoqing, Foshan, Dongguan, Huizhou, Zhongshan, and Jiangmen. Pearl River Delta is at the forefront of reform and opening up. It is a region with great vitality, a developed economy, and open culture. The 9 cities in Pearl River Delta cover an area of about 55,000 square kilometers, accounting for about 1/3 of the area of Guangdong Province, and amass 79.67% of Guangdong Province's total economic output. Pearl River Delta is

adjacent to Hong Kong and Macao, and its excellent geographical location and economic special zone's advantages have enabled the rapid development of tourism and have become an important tourism development destination in my country. The rapid development of the tourism economy has caused a certain impact on the eco-environment, making the contradiction between the tourism industry's development and the eco-environment more acute. Also, rapid development trend of Yangtze River Delta has affected the status of Pearl River Delta. Coordinating tourism and ecology in Pearl River Delta is significant to promote sustainable development of Pearl River Delta and enhance its comprehensive competitiveness. There are many kinds of research on tourism in Pearl River Delta, but few pieces of research have been conducted on coupling coordination and interactive stress between tourism and eco-environment. Therefore, studying coupling coordination characteristics of the two systems in time and space and formulating an effective eco-tourism strategy is of great significance to promoting stable and sustainable development of Pearl River Delta's tourism industry.

2.1.2 Data sources and index system design

Tourism and eco-environment data of 9 cities in Pearl River Delta from 2007 to 2018 are mainly derived from Guangdong Statistical Yearbook, municipal statistical yearbooks, and municipal statistical bulletin of national economic and social development of 9 cities. Some of the data come from local tourism departments and ecology department's professional statistical bulletins and historical statistical data. A very small part of missing data is calculated and filled by means, interpolation, and analogy.

To accurately evaluate the relationship between the tourism economy and eco-environment, this paper refers to related research results [17-20], from three aspects of tourism benefits, tourism infrastructure, and tourist flow, as well as three aspects of ecological protection, ecological load, and ecological governance of the eco-environment system to select 15 evaluation indicators, to establish a coupled evaluation index system for tourism economy and eco-environment, as shown in Table 1. To observe a degree of coordination between the tourism economic system and the eco-environment system objectively, entropy method is used to determine second-class index weight, and the second-class index weights summarized to obtain first-class index weight.

Tab.1 Evaluation index system for coupling tourism economy and eco-environment

Target	Subsystem layer	First-class Index	Second-class Index	Weight	Index Type
Coupling of tourism economy and eco-environment	Tourism and Economy	Tourism benefits	Total tourism revenue	0.025	+
			Foreign exchange income from international tourism	0.147	+
			Proportion of total tourism revenue to GDP	0.057	+

Tourism infrastructure		Number of travel agency companies	0.129	+
		Number of tourist star hotels	0.028	+
		Number of domestic tourists	0.037	+
Tourist flow		Number of outbound tourists	0.155	+
		Number of overnight tourists received by the city	0.093	+
Ecological protection		Green coverage rate of built-up area	0.057	+
		Per capita park green area	0.028	+
		Total waste water discharge	0.083	-
Ecological Environment	Ecological load	Total industrial waste gas emissions	0.065	-
		General industrial solid waste generation	0.048	-
Ecological governance		Sewage treatment rate	0.003	+
		Harmless treatment rate of domestic garbage	0.043	+

Due to different units and positive and negative effects of each index, extremum method is used to standardize the acquired raw data. The specific formula is shown in (1) (2). When an index has a positive effect, the larger the index value is, the better, and formula (1) is used for processing; when an index has a negative effect, the smaller the index value is, the better, and formula (2) is used for processing.

$$y_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

Among them, x_{ij} , \max_{ij} , and \min_{ij} represent the raw data of the j -th index, the maximum and minimum values of the j -th index in the i -th year, and y_{ij} represents the j -th standardized data in

the i-th year.

2.2 Coupling coordination degree model

Coupling is a physical concept that represents the phenomenon of two or more systems interacting under systems' internal and external influence; and coupling degree is a measurement of the degree of correlation between systems, used to express the interaction between systems [21]. Based on the significant similarity of the interaction coupling relationship between system and system, the coupling degree model is widely used to analyze the interaction coupling mechanism between tourism economy and eco-environment system. Specific calculation steps of the coupling degree are as follows:

$$C = \left\{ \frac{U_1 * U_2}{[(U_1 + U_2) / 2]^2} \right\}^{\frac{1}{2}} \quad (3)$$

In formula (3), U_1 and U_2 respectively represent the evaluation index of the tourism economic system and an eco-environment system; C represents the coupling degree of the tourism economic system and eco-environment system, and C takes a value of 0~1.

However, coupling degree cannot judge the absolute level between tourism economy and eco-environment system. Therefore, the coupling coordination degree model between the two is further established [22], namely:

$$D = (C * T)^{\frac{1}{2}}, \text{其中 } T = \alpha U_1 + \beta U_2 \quad (4)$$

In formula (4), T represents a comprehensive coordination index between the tourism economy and the eco-environment. Referring to existing research [22,23], this paper sets α and β as 0.6 and 0.4, respectively. And D represents coupling coordination degree, reflecting their degree of coordination between the two systems.

If the value of D is larger, it means a degree of coupling coordination between the two systems is higher; if value of D is smaller, it means that the two systems have failed in coordination. Drawing lessons from related research [22-25], coordinated development of the tourism economy and eco-environment are divided into 6 types, see Table 2 for details.

Tab.2 Classification of coordination types of tourism economy and eco-environment system

D	Development Stages
0.0-0.3	Severely dysfunctional recession
0.3-0.4	Mild dysfunctional recession
0.4-0.5	On the verge of imbalanced recession
0.5-0.6	Low-level coordinated development

0.6-0.7	Medium-level coordinated development
0.7-1.0	High-level coordinated development

2.3 Interactive stress model

Based on system dynamics theory, two subsystems of tourism economy and eco-environment are combined to analyze the internal stress relationship. According to the existing literature [11,26], it can be known that the relationship between economic development and eco-environment follows an inverted U-shaped curve, and there is a logarithmic curve relationship between tourism economic and economic development level, namely:

$$\begin{cases} Z = m - n(x - p)^2 \\ y = a \lg x + b \end{cases} \quad (5)$$

In formula (5), Z represents a degree of ecological degradation, x , y respectively represent per capita GDP and tourism economy level, and m , n , p , a , b are non-negative parameters. According to formula (5), the formula can be simplified to the following double-exponential function:

$$Z = m - n[10^{\frac{y-b}{a}} - p]^2 \quad (6)$$

It can be seen from equation (6) that at that time of $10^{\frac{y-b}{a}} < p$, eco-environment deteriorates with the improvement of tourism economy; at that time of $10^{\frac{y-b}{a}} = p$, state of eco-environment reaches a minimum; at that time of $10^{\frac{y-b}{a}} > p$, eco-environment is optimized with the improvement of tourism economy.

3 Results

3.1 Results of the coupling coordination degree

3.1.1 Time series analysis

As shown in Figure 1, the curve in the figure represents the coupling coordination degree of tourism economy and eco-environment, the comprehensive value of tourism economy, and the comprehensive value of eco-environment in Pearl River Delta from top to bottom. During 2007-2018, three curves developed steadily upwards. Among them, the coupling coordination degree curve fluctuates slightly during the period from 2008 to 2011, and the coupling coordination degree's values are between [0.3, 0.5], of which 2008 and 2009 are mild dysfunctional recession, and 2010 and 2011 are on the verge of imbalanced recession. Beginning

in 2012, the coupling coordination degree has shifted from dysfunctional recession to coordinated development. The coordination category includes three stages of low-level, medium-level and high-level coordinated development. Among them, the values in the low-level coordinated development state from 2012 to 2016 are 0.506, 0.518, 0.541, 0.561 and 0.595; Since 2017, the coupling coordination degree of tourism economy and eco-environment in Pearl River Delta has been at medium-level coordinated development.

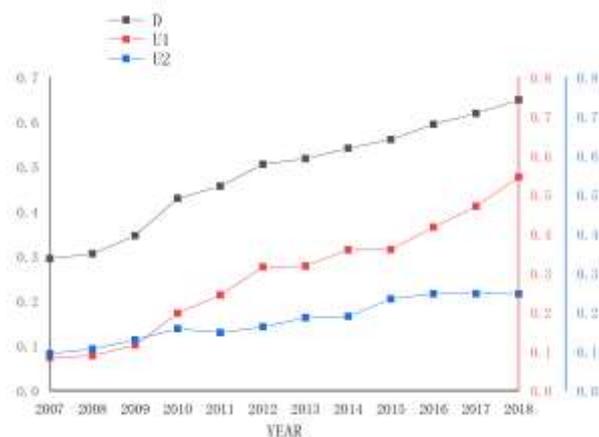


Fig.1 Variations of the coordination between tourism economy and eco-environment in Pearl River Deltain from 2007 to 2018

It can be seen from Figure 1 that the comprehensive value curve of the tourism economy and the comprehensive value curve of the eco-environment both show a steady upward trend, and the former is generally higher than the latter. Before 2010, the comprehensive value of the eco-environment in Pearl River Delta region is lower than the tourism economy. In the past 12 years, the comprehensive indicators of the eco-environment fluctuated little, with steady growth every year, while the tourism economic indicators have grown rapidly since 2008. The reason is that domestic tourists have increased sharply while inbound tourists remain unchanged. As an important port, Pearl River Delta is close to Hong Kong and Macao. Besides, Taiwanese tourists also prefer the Macao-Zhuhai route when entering. Therefore, even if the financial crisis occurred in 2008, it did not have much impact on the tourism economy of Pearl River Delta. In 2010, due to the hosting of the Asian Games and the Asian Paralympic Games and the opening of Wuhan-Guangzhou high-speed rail, these opportunities quickly radiated to Guangzhou, Shenzhen, Zhuhai, and other cities in Pearl River Delta, which greatly increased tourist attractions and promoted the development of tourism economy. From 2010 to 2015, the growth rates of the two curves of the tourism economy and the eco-environment first increased and then stabilized; after 2015, the tourism economy index has developed rapidly, and the eco-environment index has stabilized, so the growth rates' gap between the two curves has gradually widened. In 2013, Pearl River Delta launched a new plan for reform and development, which proposed a work plan to realize the "Great Leap in the Year of the Ox" to accelerate the integration process of Pearl River Delta. It requires the improvement of tourism cooperation mechanisms, strengthening of tourism marketing, and further deepening of cross-border tourism cooperation, strengthening tourism

standardization and informational construction. Therefore, since 2013, the tourism economy in Pearl River Delta region has begun to grow steadily and rapidly.

In the eco-environment system, the ecological load's index is the highest, and the ecological governance's index is the lowest, as shown in Figure 2. At the beginning of the study period, the ecological load's index is 0.060, and at the end of the study period, it has reached 0.135. The ecological load subsystem includes total wastewater discharge, total industrial waste gas discharge, and general industrial solid waste generation. These indicators are negative indicators, which the larger the value, the greater the ecological pressure. In recent years, although the tourism economy and eco-environment indicators have continued to rise, the gap between the two systems has been widening after fluctuations, indicating that the improvement of Pearl River Delta's eco-environment has not kept up with the pace of the tourism economy. It is still necessary to speed up the coordination of the contradiction between ecological load and ecological governance and optimize the eco-environment.

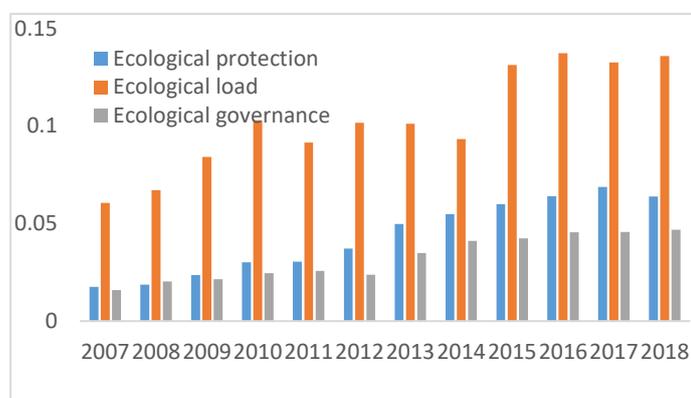


Fig.2 Eco-environment subsystem index in Pearl River Delta from 2007 to 2018

3.1.2 Spatial analysis

Selecting 2007, 2013, and 2018 as the representative years, the spatial pattern evolution analysis of the coupling coordination degree of 9 cities in Pearl River Delta is carried out. As shown in Figure 3(a), in 2007, the coupling coordination degrees of Guangzhou, Dongguan, Zhaoqing, Shenzhen, Huizhou, and Zhongshan are all in severely dysfunctional recession, and their coupling coordination degrees are 0.295, 0.275, 0.264, 0.222, 0.219, 0.253, respectively. The coupling coordination degree of Foshan and Jiangmen is between 0.3 and 0.4, which is in mild dysfunctional recession; only one city Zhuhai is in a state of low-level coordinated development. In 2013, as shown in Figure 3(b), the overall coordination of the tourism economy and eco-environment has improved, except for a few cities, all of them have changed from imbalanced types to coordinated types. Among them, Zhongshan and Zhuhai are in mild dysfunctional recession type and on the verge of imbalanced recession type, with coupling coordination degrees of 0.386 and 0.499 respectively; the rest of the cities are in the coordination types. Five of them are low-level coordinated development, namely Guangzhou, Foshan, Shenzhen, Huizhou, and Jiangmen; Dongguan and Zhaoqing have entered medium-level coordinated development ahead of

schedule. In 2018, as shown in Figure 3(c), all cities are moving towards deeper coordination. There are 4 cities in medium-level coordinated development and high-level coordinated development respectively. Among them, Zhuhai, Dongguan, Foshan, and Zhaoqing are medium-level coordinated development types, and Guangzhou, Shenzhen, Huizhou, and Jiangmen have entered high-level coordinated development types. The remaining Zhongshan is still in low-level coordinated development type.

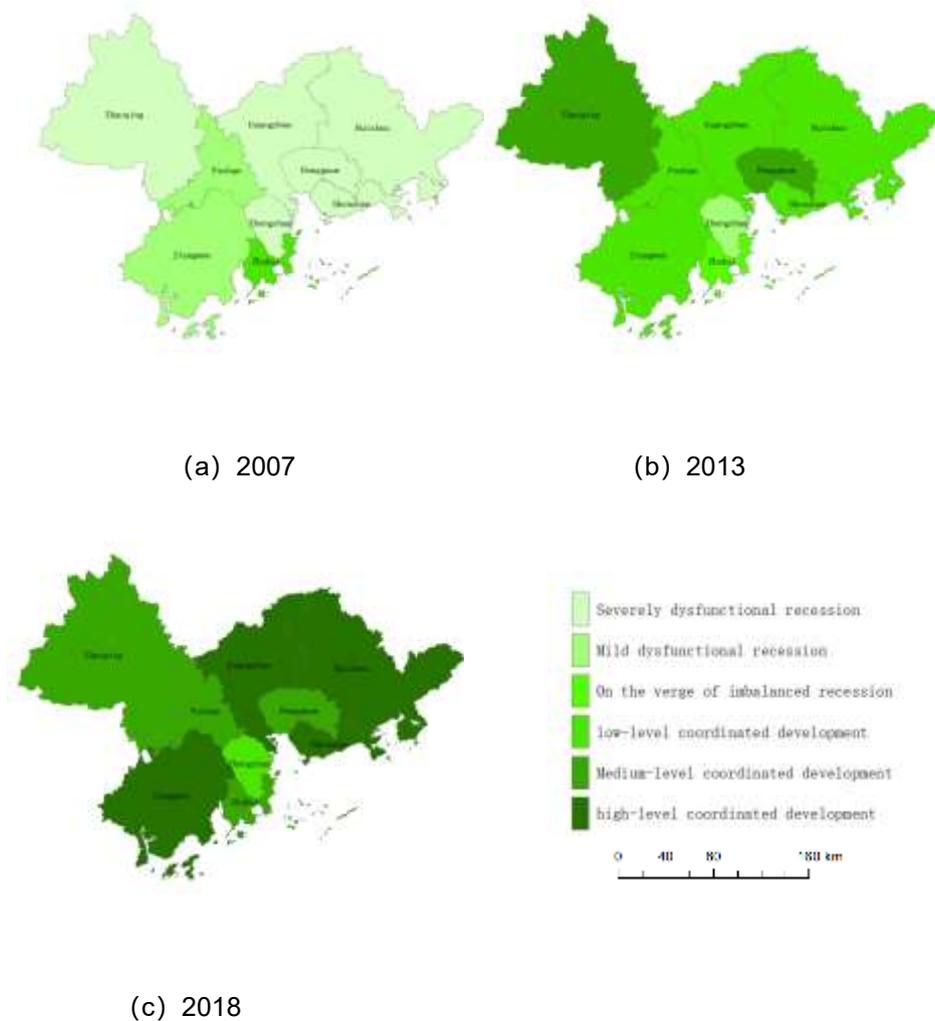


Fig.3 Spatial pattern of the coupling coordination between tourism economy and eco-environment of cites in Pearl River Delta from 2007 2013 and 2018

(Note: The map is based on the standard map with the approval number GS(2019)3333 downloaded from the standard map service website of the Ministry of Natural Resources. The base map has not been modified.)

From an overall point of view, the spatially coupled and coordinated development of the tourism economy and the eco-environment in Pearl River Delta has obvious regional characteristics, showing a pattern of "slow coordination in the northwest and rapid coordination in the southeast". Compared with the beginning of the study period, the overall coordination of the tourism economy and eco-environment has been continuously optimized. As of 2018, Guangzhou has the highest degree of coordination among cities, with a coordination degree of 0.801, which is

in a high-level coordinated development state; the degree of lowest is Zhongshan, with a coordination degree of 0.543, which is in a low-level coordinated development state. From the perspective of the three representative years, the degree of coupling and coordination of each city has slightly fluctuated, but the overall optimization trend remains unchanged. Guangzhou, Shenzhen, Huizhou and Jiangmen ranks in the forefront of the coordination assessment in 2018, especially Guangzhou and Shenzhen, their coordination degree is the first and second respectively. This is inseparable from the city's industrial structure and economic infrastructure. And Zhongshan and Zhaoqing are in backward cities at the end of the study period. The reason is that the eco-environment index could not be adjusted during the rising period of the tourism economy index, resulting in a significant gap between the tourism economy index and the eco-environment index.

Pearl River Delta is divided into coastal areas (Jiangmen, Zhuhai, Shenzhen, Dongguan, Guangzhou) and non-coastal areas (Foshan, Zhongshan, Zhaoqing, Huizhou) according to its natural geographical location. And analyzing coupling coordination degree from the two major areas. Since 2007-2018, the coupling of the tourism economy and eco-environment in the two major regions has following characteristics. The coupling coordination degree of the two major regions is showing a steady upward trend, especially in the coastal cities, where the tourism economic development and eco-environmental protection are developed rapidly, and the coupling coordination degree is also stronger than that of non-coastal areas. In 2007, 2013, and 2018, the average degree of cities in coastal areas is higher than that in non-coastal areas. In 2007, the average degree of cities in coastal areas is 0.0689 ahead of non-coupling areas. After 5 years, the gap in coupling degree between the two regions has narrowed to 0.0194 in 2013. But in 2018, the gap has expanded to 0.0689. The main reasons for the backward tourism and ecological development in non-coastal areas are that the economic base is lower than that of coastal areas, and population loss is higher than that of coastal areas. By 2013, all cities except Zhongshan have entered the category of coupled and coordinated development. The development characteristics of the degree of coupling and coordination between the two regions are similar to their economic development. The article uses the entropy method to comprehensively evaluate the tourism economy and eco-environment. Starting from the calculation results of the entropy method, the index weights of tourism benefits, tourism infrastructure and tourist flow are 0.341, 0.233, and 0.426 respectively, that is, tourism benefits and tourist flow account for about 77% of the total tourism economy system. This directly affects the evaluation results of tourism economic development. Guangzhou, Zhuhai, Shenzhen, Dongguan, and Jiangmen, which are located in the coastal areas, have good geographical locations at ports and a solid economic foundation, so the regional coordination is relatively high. On the contrary, non-coastal cities with slightly inferior geographical locations and less tourist flow have a lower degree of coupling and coordination.

3.2 Results of the relationship of interactive stress

In this paper, using Matlab software, combined with the construction of an interactive stress model, curve fitting was performed on tourism economic system and eco-environment system of 9 cities in Pearl River Delta from 2007 to 2018 (Table 3). At the same time, the paper draws the

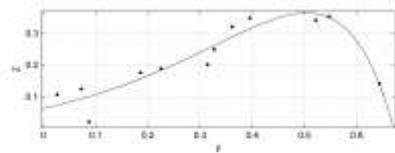
corresponding fitting diagram according to the fitting result of the double-exponential function (Figure 4). From the variance and R^2 coefficient of the calculation results, it can be seen that the cities in Pearl River Delta have a good fit for the function. In the double-exponential function, m represents the degradation degree of Pearl River Delta's eco-environment when the function curve appears at an inflection point; n reflects the degree of change of Pearl River Delta's eco-environment with the development rate of the tourism economic system. The larger the value of n , the faster the tourism economy of Pearl River Delta will develop, and the faster the eco-environment will deteriorate. And b represents the ordinate of the inflection point of the double-exponential curve. The larger the value of b , the higher the level of tourism economic development when the inflection point appears [30].

It can be seen from Table 3 that the order of the value of m is: Guangzhou>Zhongshan>Huizhou>Dongguan>Shenzhen>Zhuhai>Jiangmen>Foshan>Zhaoqing. It reflects that when the double-exponential curve of tourism economy and eco-environment in Pearl River Delta reaches an inflection point, the ecological load of cities with higher m values such as Guangzhou and Zhongshan is higher than that of cities with lower m values such as Zhaoqing and Foshan. Moreover, the cities with heavier ecological load at the turning point are mainly concentrated in Pearl River coastal area. And the economic development of this area is more developed, and the natural resources are also more abundant. The n -values of the 9 cities from large to small are Zhuhai, Huizhou, Dongguan, Zhongshan, Shenzhen, Guangzhou, Jiangmen, Foshan, and Zhaoqing. That means the faster the tourism economy of Zhuhai develops, the faster the eco-environment deteriorates. Huizhou's influence is closely followed by Zhuhai, while the deterioration of Zhaoqing's eco-environment is least affected by the development of tourism economy. The b reflects the level of tourism economic development at the turning point. From Table 3, it can be seen that at the turning point, the tourism economic development level is higher in non-coastal areas such as Huizhou and Foshan, while the tourism economic development level is lower in coastal cities such as Shenzhen and Zhuhai. It shows that in Pearl River Delta, the b -value of the turning point is related to the tourism economy and socioeconomic level of the place, and the b value is lower in regions with high tourism economy and socioeconomic level. Combined with Figure 4, according to the double-exponential coupling function curve of tourism economy and eco-environment of 9 cities, it can be concluded that the developing trajectory of tourism economy and eco-environment has spatial imbalance and hierarchy, which are mainly manifested as: the economic development rate of the coastal areas of Pearl River Delta is relatively fast, and when the curve reaches the turning point, these areas' tourism economy level is relatively high; the economic development of non-coastal areas is lagging and the eco-environment problems are more serious. Before the turning point, the direction of the development trajectory of tourism economy and eco-environment is the same, that is, tourism economic growths, the eco-environment will be more affected by the tourism economy; after the turning point, the relationship between the two systems is reversed, that is, when the level of tourism economic development rises, the eco-environment will be lesser affected. The evolution trajectory shows that the fitting diagram of the double-exponential function of tourism economy and eco-environment conforms to the evolution of the nonlinear curve. This evolution means that

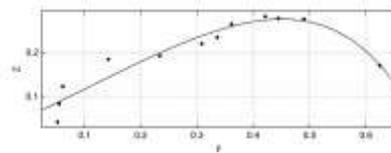
the development of the tourism economy has an obvious compulsory effect on the eco-environment, and the eco-environment also has a strong restrictive effect on the tourism economy.

Tab.3 Double-exponential coupling functions between tourism economy and eco-environment in Pearl River Delta from 2007 to 2018

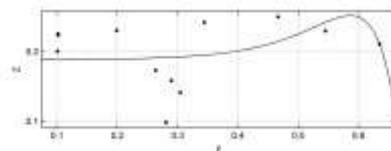
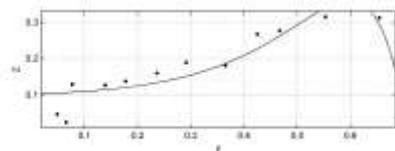
City	Double-exponential coupling functions	a	b	m	n	p
Guangzhou	$Z = 0.364 - 0.594 * (10^{\frac{y-0.552}{0.576}} - 0.822)^2$	0.576	0.552	0.364	0.594	0.822
Shenzhen	$Z = 0.276 - 0.664 * (10^{\frac{y-0.451}{1.200}} - 1.000)^2$	1.200	0.451	0.276	0.664	1.000
Huizhou	$Z = 0.350 - 0.730 * (10^{\frac{y-0.994}{0.325}} - 0.060)^2$	0.325	0.994	0.350	0.730	0.060
Jiangmen	$Z = 0.251 - 0.410 * (10^{\frac{y-0.663}{0.190}} - 0.392)^2$	0.190	0.663	0.251	0.410	0.392
Zhuhai	$Z = 0.256 - 1.010 * (10^{\frac{y-0.377}{1.755}} - 1.167)^2$	1.755	0.377	0.256	1.010	1.167
Dongguan	$Z = 0.304 - 0.721 * (10^{\frac{y-0.526}{0.080}} - 0.501)^2$	0.080	0.526	0.304	0.721	0.501
Foshan	$Z = 0.225 - 0.402 * (10^{\frac{y-0.667}{0.960}} - 0.705)^2$	0.960	0.667	0.225	0.402	0.705
Zhaoqing	$Z = 0.207 - 0.359 * (10^{\frac{y-0.520}{0.937}} - 0.805)^2$	0.937	0.520	0.207	0.359	0.805
Zhongshan	$Z = 0.354 - 0.673 * (10^{\frac{y-0.456}{0.351}} - 0.699)^2$	0.351	0.456	0.354	0.673	0.699



(a) Guangzhou



(b) Shenzhen



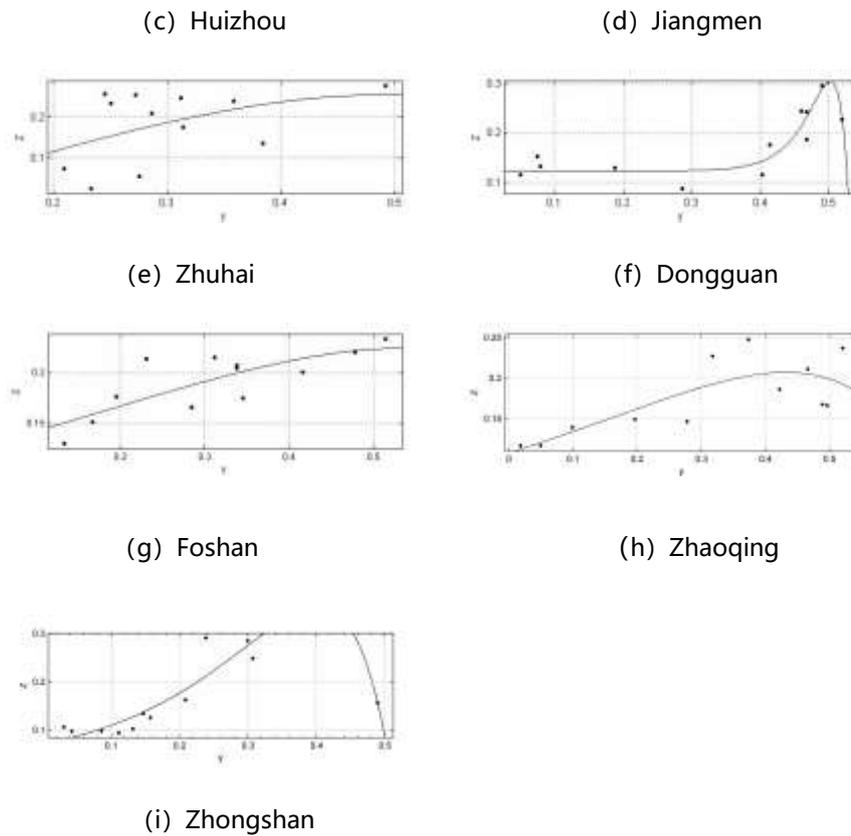


Fig.4 Double exponential curve of tourism economy and eco-environment in Pearl River Delta from 2007 to 2018

4 Conclusions and discussion

Pearl River Delta, as the main area of Chinese participation in economic globalization and a bridge of china and the world, is an important engine for economic development. For a long time, Pearl River Delta has been a core tourist area, and its tourism industry has developed rapidly, which also lead this region's economy. The basis for the sustainable development of tourism is how to effectively guarantee the ecological resources and environment. In recent years, Chinese government has highly promoted environmental protection and sustainable social and economic development of Pearl River Delta. Chinese government and scholars need pay attention to the way to coordinate the development of Pearl River Delta's tourism economy and rational use of eco-environment. Based on this, this paper collects the tourism economy and eco-environment data of 9 cities in Pearl River Delta from 2007 to 2018 and uses the coupling coordination degree model to measure the coupling coordination degree and analyze their spatio-temporal evolution trajectories. Moreover, the interactive stress model's double-exponential functions verifies the interactive stress relationship between the two systems.

(1) From the perspective of time, in 18 years from 2007 to 2018, the coordination degree between the tourism economy and the eco-environment in the Pearl River Delta has shown a steady upward trend. The degree has gradually changed from an unbalanced state to a state of preliminary coupling and coordination, which continuously deepens the coordination. Before 2010, the comprehensive index of the tourism economy in the Pearl River Delta is lower than the

comprehensive index of the eco-environment. After 2010, the comprehensive index of the tourism economy exceeds the comprehensive index of the eco-environment, and the gap between the two begin to fluctuate. From the perspective of spatial pattern, Pearl River Delta is divided into coastal areas and non-coastal areas according to whether it is coastal or not. The coupling coordination level of tourism economic system and the eco-environment system presents a pattern of "high coastal areas and low non-coastal areas". The coupling coordination degree of the tourism and ecological systems of the two regions develops in the same direction as their economic development.

(2) The interactive stress model the interactive stress relationship between the tourism economy and the eco-environment in Pearl River Delta. From the curve fitting, it can be seen that the trajectory between two systems conforms to evolution of double-exponential function. The logarithmic curve equation and the inverted "U" shape fit well. From the time of inflection point, the deterioration of the eco-environment in the non-coastal areas of Pearl River Delta is earlier than that of the coastal areas. The coastal areas have more developed economies and tourism economy, while the eco-environment of non-coastal areas is more likely to deteriorate. From the perspective of the change of the eco-environment with the development trend of the tourism economy, before the turning point, the eco-environment is affected by the growth of the tourism economy. But after the turning point, the impact of eco-environmental systems by the growth of tourism economy is weakened. The tourism economy has a strong coercive effect on the eco-environment, and the tourism economy is restricted by the eco-environment.

Based on the above research results, the following recommendations are provided: (1) The extensive growth of Pearl River Delta's tourism economy at the expense of the environment has caused environmental resource problems to a certain extent. Pearl River Delta needs to focus on green and sustainable development, which could accelerate the improvement of Pearl River Delta's eco-environment. First, it is necessary to reduce energy consumption and industrial waste discharge in the eco-environment system, promote rational use of ecological resources, and find a balance of nature and development in Pearl River Delta. Second, formulating an ecological compensation mechanism, expanding the scope of environmental governance, and formulating a scientific and systematic urban plan is the key to take the tourism economy and eco-environment protection's development in Pearl River Delta in the same direction. (2) As an export-oriented region, the Pearl River Delta needs to give full play to its geographical advantages adjacent to Hong Kong and Macau. At the same time, it must make rational use of tourism resources and cooperate with relevant government policies to attract foreign investment and talents from all over the world, and lay a solid foundation for creating distinctive tourism products and services. Also, it is possible to appropriately reduce tourism activities, focus more on updating tourism products and services, and the promotion of key tourism resources, enhance the taste of tourism development in Pearl River Delta and create favorable conditions to get a coordinated and common development for Pearl River Delta's tourism economic system and eco-environment system.

In terms of evaluation index system construction and model construction, due to the limitations of data acquisition and methods, there are still many shortcomings in the case of being

as scientific and reasonable as possible. Because data on tourism economy and eco-environment of 9 cities in Pearl River Delta are difficult to obtain, the number of second-class indexes used in this paper is relatively small, with only 2 to 3 indicators per first-class level indexes; the degree calculated by the coupling coordination degree model can reflect the relative difference between the eco-environment and the tourism economy, but it cannot show the specific numerical difference between the two systems. Given the above problems, group still needs to continuously deepen and improve.

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