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Coupling Coordination Degree Measurement Between Tourism Urbanization and Ecological Resilience of Zhuhai China

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The development of Zhuhai City relies heavily on tourism, which in turn depends on ecological considerations. This article first analyzes and evaluates the state of tourism development in the process of urbanization. Using the entropy-weighted TOPSIS model, Zhuhai's tourism urbanization can be divided into four stages: the slow development stage before 2007, the first prosperous stage from 2007 to 2013, the second prosperous stage from 2014 to 2020, and the post-pandemic stage after 2020. Secondly, the ecological resilience is evaluated using an indicator evaluation method, and since 2014, the ecological resilience of Zhuhai has tended to stabilize. Finally, the coupling coordination degree of the two are evaluated. Since 2005, this process has gone through stages of imbalance, benign coordination, and high-quality coordination.

Keywords: coupling coordination degree, tourism urbanization, ecological resilience, Zhuhai.

Introduction

The rapid urbanization in China has accelerated high development of the national economy, but it has also caused a series of ecological and environmental problems, such as land loss and habitat fragmentation (Wang et al., 2017). Scholars have been prompted to study the interaction between urbanization and the ecological environment due to the unsustainability of rapid urbanization (Fang et al., 2019). Many studies on urban agglomerations involve examining the relationship between urbanization and the ecological environment, including the curve of urbanization, the impact of urbanization on ecosystem services, and the development of complex systems composed of urbanization, resources, and the ecological environment (Cui et al., 2019; Fang et al., 2019). This relationship is often displayed as an inverted U-shaped or S-shaped curve using historical data from different regions (He et al., 2017). Therefore, in this process, scholars are constantly searching for sustainable urban development paths, and tourism urbanization has become one of the main means of new green urbanization (Heberlig et al., 2017) and has been increasingly pursued by areas that are rich in tourism resources (Kapera, 2018). However, does tourism necessarily equate to being green? According to reports, the global tourism industry accounts for 8% of all greenhouse gas emissions, and countries around the world need to vigorously regulate the tourism industry to reduce carbon emissions (XNA, 2018). This indicates that tourism development may also lead to ecological degradation. Therefore, it is necessary to promote the good coordination between tourism urbanization and ecological environment, which will be beneficial for future urban development.

Resilience was introduced in ecology in the 20th century to describe a system's ability to return to its initial state after external disturbances (Holling, 2003). Urbanization affects ecological resilience through population growth, economic changes, and development processes, which increase human demand on the ecosystem and damage urban ecological resilience (Huang and Fang, 2003). This article argues that tourism urbanization also increases human demand on the ecosystem and impacts the natural ecological system. This includes reducing green space and increasing building density (Tyrvainen et al., 2014). In this case, rising theregional ecological resilience and adaptability is important for the future development of cities.

Many empirical studies have utilized the coupling coordination degree (CCD) model to analyze the specific relationship between urbanization and the environment. This model allows for a more detailed and systematic examination of the coupling and coordination between urbanization and the ecological environment (Liu et al., 2018). According to scholars and existing research in this field, the CCD model is expected to have a positive impact on the development planning of rapidly urbanizing areas in the future. By promoting a shift from static qualitative analysis to dynamic analysis, the model can help to achieve more effective urban development and management (Wang et al., 2014). But there are still some limitations in existing studies. Firstly, many studies have focused on examining a single ecological factor, such as water, soil, or air, which has led to a relatively limited evaluation of the comprehensive ecological factors. Secondly, previous research has often overlooked regional differences. For example, Liu (2018) studied the coordination between urbanization and the environment in 30 provinces in China, but they only used one set of indicators without considering the regional characteristics of each province. Finally, most current research has focused on land and population urbanization, with less attention given to the coordination between tourism urbanization and ecological resilience. However, it is crucial to address the environmental issues arising from the unsustainable use of natural resources in the process of tourism urbanization, and this requires greater attention from the global community (Pan et al., 2018).

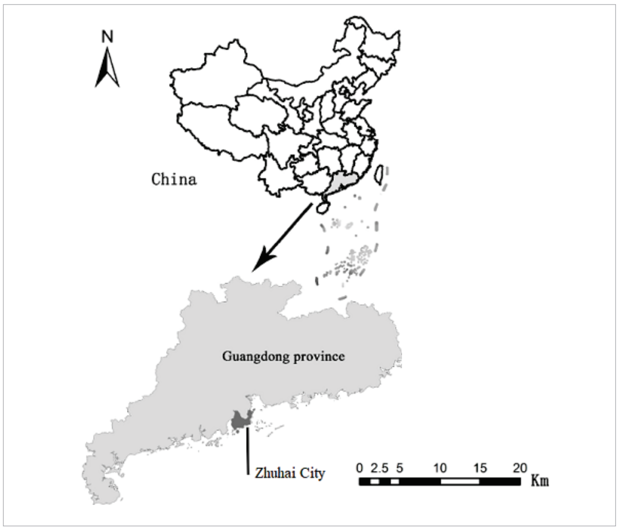
Zhuhai (*Fig. 1*) is considered one of the 40 best tourist destinations in China and has developed various types of tourism, including rural, health, and leisure tourism. However, scholars have pointed out that the tourism development process in Zhuhai is driven by economic interests, leading to problems such as encroachment of forests, and large-scale expansion of construction in ecologically unsuitable areas (Zhao, 2012). To counteract these issues, Zhuhai's ecosystem needs to improve its resilience. Therefore, it is important to study the relationship between tourism urbanization and ecological resilience. In this situation, this study seeks to answer three questions:

1 How many the tourism urbanization stage that Zhuhai divided into??

2 How to evaluate the ecological resilience of Zhuhai?

3 what's the coordination shows between the socio-economic development and ecological resilience in different stages of Zhuhai's tourism urbanization?

Fig. 1. *Map of Zhuhai, China*



Methods

Entropy Weight-TOPSIS model

Entropy Weight-TOPSIS is a comprehensive evaluation method that combines the entropy value method with the technique for order preference by similarity to ideal solution (TOPSIS) method. The entropy value method is an objective weighting method that reduces the bias caused by subjective weighting. The TOPSIS method is a commonly used multi-objective decision analysis method suitable for comparative research of multiple schemes and objects to find the best solution or the most competitive object. Entropy Weight-TOPSIS calculates the objective weights of the indicators using the entropy value method and evaluates each evaluation object using the TOPSIS method.

A. Data standardization:

The data are standardized using the method of standardization of extreme deviation to eliminate the influence of the scale. At the same time, in order to avoid the entropy value meaningless, and the standardized data are all within the interval [0, 1].

$$\text{Positive indicators (+): } X'_{ij} = \left[X_{ij} - min(X_{ij})/max(X_{ij}) - min(X_{ij})\right] \quad (1)$$

$$\text{Negative indicators (-): } X'_{ij} = \left[max(X_{ij}) - X_{ij}/max(X_{ij}) - min(X_{ij})\right] \quad (2)$$

B. Entropy weighting:

$$E_j = -\frac{1}{lnn}\sum_{i=1}^{n}\left(\left(X'_{ij}/\sum_{i=1}^{n}X'_{dij}\right) \times ln\left(X'_{ij}/\sum_{i=1}^{n}X'_{ij}\right)\right) \quad (3)$$

$$W_j = \left(1 - E_j\right)/\sum_{j=1}^{m}\left(1 - E_j\right) \quad (4)$$

$$R_i = \sum_{i=1}^{n}\left(X'_{ij} \times W_j\right) \quad (5)$$

Where: X'_{ij} explains the standardized data for indicator j on year i; X_{ij} explains the original data for indicator j on year i; E_{ij} explains the information entropy of indicator j; W_i explains the weight of the indicator j; R_i explains the comprehensive level in year i.

Coupling coordination degree (CCD) model

The coupling coordination degree (CCD) model originates from the field of physics and is used to analyze the level of coordinated development of things. Coupling refers to the mutual interaction and influence between two or more systems, which can reflect the degree of interdependence and mutual constraint between systems. Coordination degree refers to the degree of benign coupling in the coupling interaction relationship, which can reflect the quality of coordination. The CCD model involves the calculation of three indicators, namely the coupling degree C value, the coordination index T value, and the coupling coordination degree D value. Finally, the coupling coordination degree of each item is obtained by combining the coupling coordination degree D value and the coordination level classification standard.

$$C_i = 2\sqrt{R_{1i}R_{2i}/(R_{1i} + R_{2i})^2} \quad (6)$$

$$T_i = 0.5R_{1i} + 0.5R_{2i} \quad (7)$$

$$D_i = \sqrt{C_iT_i} \quad (8)$$

Where: R_{1i} explains the degree of tourism urbanization on year i; R_{2i} explains the degree of ecological resilience on year i; T_i explains the comprehensive impact of urbanization and the environment; D_i explains the coordination degree between two system.

The coupling coordination degree (D) is between [0, 1]. The larger the value, the better the coupling coordination status.

Results and Discussion

Evaluation of the tourism urbanization

In this paper, the annual economic and environmental data were all derived from the Zhuhai Statistical Yearbook (2001–2021). Data on population, gross domestic product, inbound and outbound tourism, and the scale of the tourism industry are shown in *Table 1* and *Fig. 2.*

The graph clearly indicates that the population density and urbanization rate in Zhuhai have experienced an exponential increase from 2001 to 2010 and again after 2015. Between 2010 and 2015, the relative development was stable. The city has also experienced consistent and rapid economic growth, with an exponential increase in GDP.

Table 1. *Overview of tourism and economic development in Zhuhai since 2001*

Years	Industrial added value (100 million yuan)	GDP (100 million yuan)	GDP per capita (yuan)	Proportion of urban population (%)	Airport passenger throughput (million people)	Overnight visitors (10 000 person-times)	Total tourism revenue (100 million yuan)	Total Passenger Transport (10 000 people)
2001	157	368.34	29222			428.98	78.56	3303
2002	172.87	409.04	31457			493.95	91.27	3387
2003	189.7	476.71	35781			438.19	83.71	3300
2004	223.92	546.28	64900			861.18	103.72	4397.3
2005	261.65	640.53	45682	87.9		640.19	115.95	5065
2006	316	753.63	52690	85.06		729.58	139.02	5391
2007	388	902.45	61826	85.1		758.13	144.88	
2008	465.2	1006.62	67432	85.14		808.21	155.08	6281.4
2009	509.38	1049.04	69235	87.16		1208.74	168.83	16943.87
2010	506.76	1225.88	79002	87.66	181.9	1380.53	219.35	19172.6
2011	619.4	1430.95	90922	87.8	179.7	1535.68	222.93	22652
2012	714.29	1536.74	97565	87.82	209.5	1596.37	235.83	26762
2013	720.25	1709.63	107765	87.85	289.4	1572.13	241.8	29744
2014	775.57	1901.42	118672	87.88	407.6	1808.56	261.79	5084.44
2015	843.18	2066.35	127227	88.13	470.9	1923.77	277.32	5460.9
2016	894.07	2267.02	137005	88.25	612	2226.41	317.08	5240
2017	995.5	2675.18	155502	88.34	921	2288.62	367.7	5379
2018	1133.21	3216.8	159428	88.79	1122.1	2452.62	466.16	5725.73
2019	1258.02	3444.23	175960	89.21	1228	2603.9	541.53	5867.55
2020	1309.07	3482	145645	90.47	733.6	1498.14	187.59	2717.52

Table 2. *Indicators of tourism urbanization degree*

Target layer	Standard layer	Index layer	Weight	type
Degree of tourism urbanization	Tourism development	Total tourism revenue (100 million yuan)	0.2173	+
		Total passenger transport (10 000 people)	0.3332	+
	Urbanization	Population density (person/square kilometer)	0.1299	+
		Proportion of urban population (%)	0.1430	+
		Per capita (yuan, comparable prices)	0.1767	+

Table 1 presents a comprehensive evaluation of independent indicators from 2005 to 2020, given the completeness of the data series after 2005. The total passenger transport volume and the total tourism revenue account for 0.3332 and 0.2173 in weight, respectively (*Table 2*). The results show that tourism plays a significant role in the process of tourism urbanization in Zhuhai. *Fig. 3* illustrates the development progress of tourism urbanization in Zhuhai during different years. While the tourism industry has gone through various stages of development, the city's economy has been in a stage of rapid development for many years. As a result, the tourism urbanization stage in Zhuhai can be roughly divided into four stages: a slow development stage before 2007, a first developed stage from 2007 to 2013, a second developed stage from 2014 to 2020, and the stage after the outbreak of the COVID-19 pandemic in 2020.

During the period from 2005 to 2007, Zhuhai experienced a slow development stage, which was mainly due to the impact of the SARS epidemic. The epidemic had a negative effect on the recovery of the tourism industry, which is a key driver of Zhuhai's economy. Additionally, the global economic downturn during this period also had an impact on the city's economic development, resulting in a relatively slow growth. As a result, the comprehensive development of Zhuhai during this period was relatively slow.

From 2008 to 2013, Zhuhai entered its first stage of development, which marked the beginning of the city's tourism industry. Since 2007, both inbound and domestic tourism have experienced high-speed growth in Zhuhai. In 2010, the number of overnight tourists in Zhuhai had reached 13 million, while nearly 200 million people were transported by air, rail, and road. The significant growth in tourism has stimulated the development of greater tourism planning in Zhuhai. In line with the *Zhuhai City Tourism Development Master Plan (2007-2020)*, Zhuhai aimed to become an important tourism economic powerhouse in China and a sustainable and competitive urban tourist destination. The plan aimed to receive a total of 27.4 million visitors by 2010.

Fig. 2. *List of long series of related indicators*

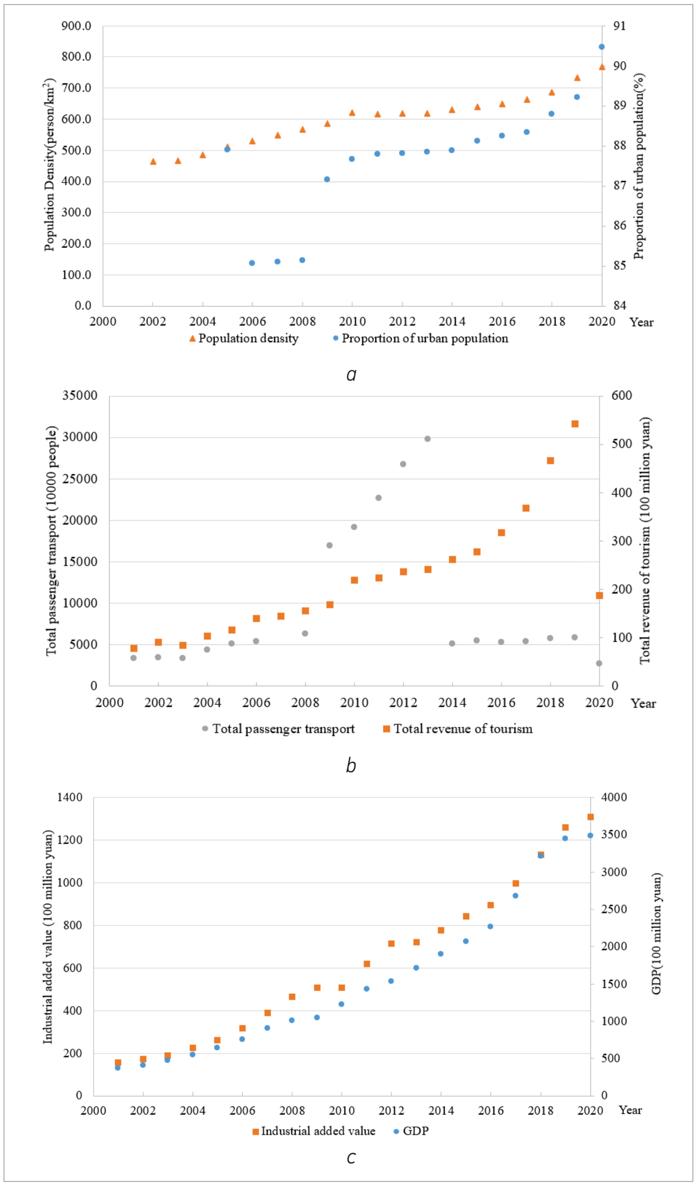
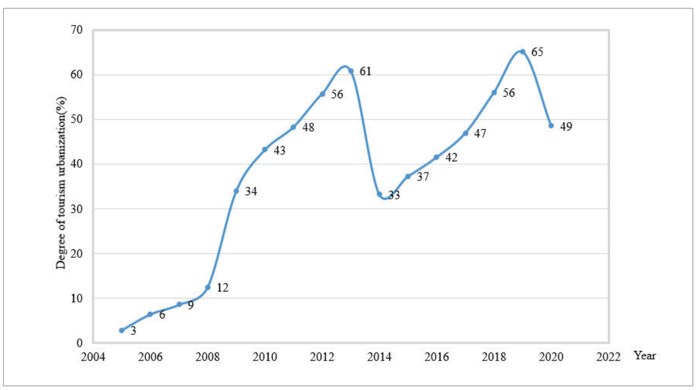


Fig. 3. *Evaluation of tourism urbanization degree*



From 2014 to 2019, Zhuhai entered its second stage of development, which was marked by a period of rapid growth. The opening of the Chimelong International Ocean Tourist Resort in Hengqin, Zhuhai, in 2014 brought a strong tourism attraction to the city. Additionally, the opening of the Hong Kong-Zhuhai-Macau Bridge created a major artery for the transportation of passengers, allowing Zhuhai to attract a large number of transit tourists from Hong Kong and accelerating the development of the regional tourism market in the Guangdong-Hong Kong-Macao Greater Bay Area. However, during the calculation process, it was found that there was a sudden change in the tourism urbanization data in 2014. Upon searching for the original data, it was discovered that there had been a significant change in the total passenger transport volume. As this indicator carries a significant weight in the CCD model, it is possible that the statistical methodology may have caused this issue.

After 2020, Zhuhai entered the post-pandemic era, which had a significant impact on the tourism industry. The pandemic led to a sharp decline in the number of inbound tourists, particularly from overseas. However, scholars have found that the pandemic has also stimulated the tourism motivation of low-income groups to some extent. Multiple organizations predict that tourism recovery will gradually unfold, with the highest expenditure being on accommodation, dining and transportation, respectively. The consumption demands of the middle-income group are expected to undergo significant changes in cultural cognition, consumption preferences, and consumption thresholds, leading to diversified consumption demands. Therefore, future tourism products and services should be diversified and specialized to meet the corresponding needs of different consumer groups.

Evaluation of ecological resilience

Ecological resilience refers to the ability of an ecosystem to withstand shocks, maintain stability, quickly recover to its original state, or evolve in an orderly direction when facing disasters. To reflect ecological resilience more comprehensively and accurately, this study constructed an evaluation index system for ecological resilience from previous research. The index system includes dimensions of recovery, adaptability, and resistance, as shown in *Table 3.* The study also standardized the data and used the entropy method to assign weights to each ecological resilience indicator, ultimately obtaining a comprehensive evaluation score for ecological resilience.

Table 3. *Ecological resilience index*

Target layer	Standard layer	Index layer	Weights	Type
Ecological Resilience	Resilience/ morphological toughness	Per capita park green area (square meter)	0.1712	+
		Green coverage rate of built-up area (%)	0.2090	+
	Resilience/ density resilience	Comprehensive utilization of general industrial solid waste (ton)	0.0939	+
		Sewage treatment rate (%)	0.0921	+
		Decontamination rate of domestic refuse (%)	0.1885	+
	Resistance/ scale resilience	Industrial sulfur dioxide emissions (%)	0.2453	-

1 Resistance/spatial resilience. This indicator measures how well an ecosystem can withstand shocks. Natural features like mountains, forests, and water systems can limit urban expansion and help maintain ecological balance. If a city grows beyond what the ecosystem can support, the ecosystem's ability to resist shocks weakens, making it more vulnerable to disasters. It is important to consider the natural limits of an area when planning urban development to ensure ecological sustainability.

2 Adaptability/density resilience. This indicator reflects the self-adaptive ability of an ecosystem. The density of human activity directly affects the sustainability of the ecosystem. The higher the density of human activity and the more intensive their activities, the greater the pressure on the natural environment.

3 Recovery/morphological resilience. This indicator reflects the ability of an ecosystem to recover after a shock. When water bodies and vegetation are in a balanced layout and well blended with the built environment, they can absorb and reduce the effects of urban waterlogging and heat island effects, thereby improving the ecological resilience of the city.

As shown in *Fig. 4*, decontamination rate of domestic refuse and the urban sewage treatment rate have both experienced a pattern of rapid growth followed by slow growth. This is mainly because in 2010, China advocated

Fig. 4. *Overview of indicators related to ecological resilience*

for environmental governance and introduced environmental regulations such as the *Ten Water Control Measures* and *Ten Soil Control Measures.* Zhuhai City also invested a large amount of money in environmental improvement. The per capita park and green space area has experienced a slow growth followed by a slow decline, mainly due to the gradual increase in the population of Zhuhai City. The comprehensive utilization of industrial solid waste has remained around 250, with little change. The industrial sulfur dioxide emissions have gradually decreased, which is in line with its negative indicator.

Based on the entropy-TOPSIS weighting method, the ecological resilience of Zhuhai City was evaluated. The weights for industrial sulfur dioxide emissions and green coverage rate in the built-up area were 0.2453 and 0.2029 respectively. This indicates that in the process of ecological resilience construction in Zhuhai City, controlling pollution and increasing greenery are equally important. The results for different years are shown in *Fig. 5.* Before 2010, the ecological resilience of Zhuhai City was in a fluctuating state, gradually strengthening after 2010, and becoming stable after 2014.

Fig. 5. *Ecological resilience results*

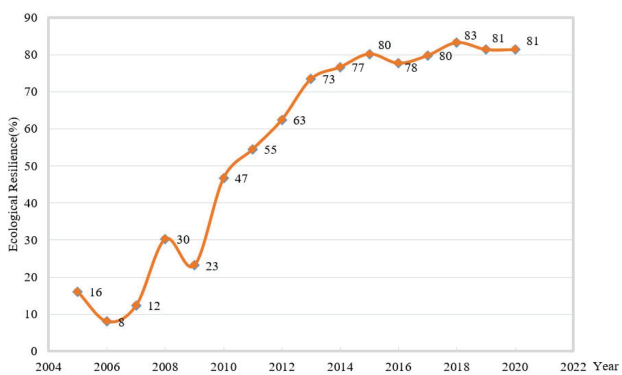


Table 4. *Classification standard of coupling coordination degree*

Coupling coordination degree D value range	Coordination level	Degree of coupling coordination
(0.0~0.1)	1	Extremely disordered
[0.1~0.2)	2	Severe disorder
[0.2~0.3)	3	Moderate disorder
[0.3~0.4)	4	Mild disorder
[0.4~0.5)	5	On the verge of disorder
[0.5~0.6)	6	Barely coordinated
[0.6~0.7)	7	Junior coordinator
[0.7~0.8)	8	Intermediate coordinator
[0.8~0.9)	9	Well coordinated
[0.9~1.0)	10	High quality coordination

Coupling coordination evaluation

A coupling coordination model was established to evaluate the relationship between tourism urbanization and ecological resilience at different stages (as shown in *Table 4* and *5*). The results showed that, before 2009, the development of tourism urbanization and ecological resilience were in a state of imbalance, indicating a low level of coupling coordination. However, with the increasing attention of government departments to the ecological environment, the coupling coordination gradually improved. Between 2010 and 2018, the coordination level turned good, indicating a well-coordinated relationship. After 2018, the coordination level reached a high-quality coordination stage.

In the research conducted by many scholars, it has been observed that the process of urbanization in many cities is intricately linked with the ecological

Table 5. *Coupling coordination degree calculation results*

Years	Coupling degree C value	Harmonization index T value	Coupling coordination degree D value	Coordination level	Degree of coupling coordination
2005	0.998	0.107	0.327	4	Mild disorder
2006	0.840	0.022	0.135	2	Severe disorder
2007	0.677	0.038	0.160	2	Severe disorder
2008	0.923	0.217	0.447	5	On the verge of disorder
2009	0.908	0.355	0.568	6	Barely coordinated
2010	0.992	0.586	0.763	8	Intermediate coordinator
2011	0.995	0.682	0.824	9	Well coordinated
2012	0.995	0.798	0.891	9	Well coordinated
2013	0.998	0.914	0.955	10	High quality coordination
2014	0.949	0.687	0.807	9	Well coordinated
2015	0.960	0.743	0.845	9	Well coordinated
2016	0.979	0.762	0.863	9	Well coordinated
2017	0.988	0.819	0.900	9	Well coordinated
2018	0.997	0.916	0.956	10	High quality coordination
2019	1.000	0.978	0.989	10	High quality coordination
2020	0.989	0.840	0.912	10	High quality coordination

environment, leading to a mutually constraining relationship. Moreover, many cities are in the phase of middle imbalance - impeded development - initial balance (Lei et al., 2021). Also, many cities have gone through a vicious cycle of rapid economic growth-environmental pollution-environmental governance-economic limitations. This raises the question of whether a simple and sustainable approach to break this cycle exists. Zhuhai has provided us with a template to consider. In 1980, Zhuhai identified "building a tourist area that attracts visitors from Hong Kong and Macau" as one of its three major development goals (Sohu,2020), and has shown a relatively balanced state since 2009, indicating that its current state of tourism development can be considered environmentally sustainable.

Presently, China is facing hard challenges in its industrial economy following the COVID-19 pandemic, while the demand for tourism continues growing. Additionally, countries worldwide are imposing increasingly stringent regulations on carbon emissions. Consequently, tourism as a new economic growth driver should be highly valued by sustainable cities.

Conclusions

Based on the research presented above, this article reveals that the tourism urbanization development in Zhuhai City since 2005 has undergone a progression from rapid development to stable development and then to a gradual slowing down, typical of the evolutionary trajectory of any city. Moreover, the change in ecological resilience has gradually stabilized in parallel with the societal development. By evaluating the coupling coordination between the two, we discovered that the coordination transformed from a low level to a high level, indicating that with the evolution of society and the increasing awareness of environmental protection, we are no longer recklessly exploiting the environment but rather are considering the future welfare of our offspring. In this research process, the level of tourism urbanization has been fluctuating, while the ecological resilience has been steadily increasing, and the two are becoming more and more coordinated. The model is very effective in quantifying the relationship between urban development and the ecological environment, and has important reference value for the future development of Zhuhai and others tourist cities.

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