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Study on the coupling coordination effect and dynamic relationship between tourism development and the ecological environment: a case study of Hainan Island

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As a Free Trade Port in China, the protection of ecological environment and high-quality tourism development on Hainan Island have become a national strategy. Exploring the coupling relationship of the two subsystems holds great practical significance for promoting the island's international demonstration area and high-quality development. Based on the characteristics of international islands, a comprehensive index system is established to explore the coupling coordination evolutionary process and interactive stress relationship of tourism development and the ecological environment in Hainan Island from 2005 to 2020. The results show: (1) From 2005 to 2019, the comprehensive evaluation index of the two subsystems of Hainan Island generally showed a continuous growth trend. (2) From 2005 to 2019, the coupling degree of the two subsystems of Hainan Island strengthened continuously, the coupling coordination degree increased steadily from a moderate imbalance to good coordination, and tourism development and the ecological environment entered a stage of parallel and benign interactive development. (3) In 2020, affected by COVID-19, the tourism development indicators declined rapidly, while the ecological environment still maintained a rising trend. (4) Based on the inverted U-shaped curve model, when the tourism development index reaches 0.7269, the ecological environment quality reaches the maximum value of 0.7956, which is the best state between the two subsystems. The ecological environment and tourism development of Hainan Island are generally in a benign interaction, but there are signs of interactive stress starting in 2017. In the future, the pressure on the ecological environment of Hainan Island will increase.

KEYWORDS

ecological environment, tourism development, coupling coordination model, interactive stress, Hainan Island

1 Introduction

In China, coastal tourism contributes 49% of the total marine economy (Ministry of Natural Resources of China, 2020). Coastal zones have become the most preferred tourist destinations, and in them, the economy is highly promoted by tourism development and accompanied by substantial ecological impacts (Martinez et al., 2007). Charming coastal zone tourism is inseparable from natural environmental resources such as sunshine, sandy beaches, seawater and tropical vegetation (Pickering and Hill, 2007). Therefore, environmental support and resource consumption are the basic attributes of such tourism, which also determines that there is a dialectical relationship between tourism development and the ecological environment (Wang and Li, 2022). The ecological environment here not only considers the natural environment related to humans, but also considers the organisms and its ecological relationships. How to achieve the coordinated development of the two subsystems has always been a hot and difficult issue for scholars. Since the construction of Hainan Free Trade Port of China in 2020, Hainan Island has further become a demonstration and leading area of China's coastal zone tourism. The protection of its ecological environment and its high-quality tourism development have been incorporated into the national strategy. Exploring the dynamic change process of the coupling and coordination relationship between the island's ecological environment and tourism industry development holds important practical significance for high-quality development decision-making. The results of this research can also provide a reference for other island tourism and coastal zone tourism in China. The interactive stress between tourism development and the ecological environment on Hainan Island is becoming a hot research point.

Research on the relationship between tourism and the ecological environment can be traced back to the 1920s (Gössling, 2002). With the rapid development of the tourism industry worldwide, the relationship between tourism and the ecological environment has become increasingly prominent. In the early stage of research, scholars focused on the concept of the environmental impact of tourism activities, the environmental changes brought by tourism activities, tourism and environmental ethics, and sustainable tourism evaluation systems (Wall and Wright, 1977; Romeril, 1985; Hockings and Twyford, 1997; Miller, 2001; Gössling, 2002; Chen et al., 2009; Guan et al., 2011; Liu et al., 2011a). Wall and Wright (1977) discussed the concept and research methods of the impact of tourism on the environment, as well as the relationship and impact mechanism between tourism activities and environmental factors. Romeril (1985) systematically analyzed the interaction between tourism and the environment. Miller (2001) proposed an evaluation system for sustainable tourism development based on the relationship between tourism and the environment. With the deepening of research, scholars have begun to pay attention to the impacts of the ecological environment on tourism, such as the significant impacts of climate change on coastal tourism, mountaineering tourism, ice and snow tourism, etc (Shani and Arad, 2014; Joye, 2018; Vyddiyaratnam et al., 2021). Recently, some scholars have found that recreational beaches are polluted by new pollutant microplastics, which pose potential threats to the health of coastal organisms and coastal tourists (Defeo et al., 2021; Wu et al., 2021). Meanwhile, research on the relationship between tourism and the ecological environment has begun to expand to a higher level of interaction, symbiosis and coupling coordination. Common research methods include the tourism pressure index method, ecological footprint analysis method, and panel regression method (Patterson et al., 2008; Brahmasrene and Lee, 2017; Yu et al., 2021).

Research on the relationship between tourism and the ecological environment in China started relatively late, but the results are considerable (Liang et al., 2022; Wu et al., 2022). Zhang et al. (2013) studied the coupling relationship between tourism cities and the environment in coastal areas based on sustainable development theory and a coupling model, and they found that the coupling degree of the level of tourism orientation and ecological environment in the coastal area of China stayed in the antagonistic period between 2000 and 2010. Tang (2015) analyzed the spatiotemporal characteristics of the coupling coordination degree between the tourism economy and ecological environment in Heilongjiang Province from 2005 to 2015 by using the entropy approach and coupling coordination model. Geng et al. (2021) explored the coupling coordination relationship between the air environment and inbound tourism and discovered their mutual interaction mechanism. Some empirical studies have been conducted to investigate the coupling relationship between tourism and the environment in Dalian city, Lianyungang city, Shanghai city and Hangzhou (Wang et al., 2006; Cui, 2008; Pang et al., 2011; Luo and Tan, 2012; Liu and Hu, 2020). Recently, some scholars have begun to pay attention to the coupling coordination of three subsystems: the economy, tourism and the ecological environment (Liu and Yang, 2011b; Li and Wang, 2017; Lai et al., 2020; Su et al., 2021; Li et al., 2022).

In general, the coupling coordination relationship between tourism development and the ecological environment has been widely recognized. Scholars have studied it through a variety of methods, and the coupling coordination degree model (CCDM) is widely used. The perspective of existing studies has changed from a static to a dynamic evolutionary process. The contents of research are becoming increasingly richer, from a one-way relationship to a higher level of interactive symbiosis and coupling coordination. As the largest international tourism island in China, the dynamic evolutionary process and interactive stress relationship of the coupling and coordination relationship between tourism and the ecological environment in Hainan Island are still unclear. Therefore, it is necessary to explore the coupling coordination mechanism and to use effective systems and approaches to evaluate the interactions between them so that a coordinated improvement in the ecological environment and tourism can be achieved. Using 2005-2020 data of tourism development and the ecological environment on Hainan Island, this study aims to build a unique comprehensive evaluation index system for the ecological environment and tourism development, and it uses the comprehensive evaluation model, CCDM and RDM to explore the interactive stress relationship between the two subsystems. First, we theoretically discover the coordination mechanism to discuss the coupling coordination relationship of the ecological environment and tourism development in the two subsystems.

Second, we are trying to find the evolutionary rule of the coupling relationship between tourism development and the ecological environment on Hainan Island. Third, we verify and analyze the interactive stress effect between tourism development and the ecological environment on Hainan Island.

2 Materials

2.1 Study area

Hainan Island (109°45'E to 110°08'E and 18°22'N to 18°47'N) is located in the South China Sea (Figure 1). It is the largest tropical island of China, with a 1,823 km coastline, 68 bays, 487 km² of tideland, and various high-quality beaches. It has excellent marine ecosystems, with coral reefs, mangroves, and seagrass beds. Furthermore, it includes 12 coastal cities and 6 inland cities (or counties), which cover an area of 35,400 km². The island's resident population is approximately 9.25 million, 87% of whom live in coastal cities (Hainan Provincial Bureau of Statistics of China, 2023). Northern Hainan has a subtropical climate, and the remainder of the island has a tropical monsoon climate. The annual mean temperature is 22.8-25.8°C, with January and February being the coldest months and July and August being the hottest months. It is a typical tropical tourist destination. In 2020, Hainan Island became the Hainan Free Trade Port in China, and its long coastline and high-quality coastal tourism environment will further promote the development of tourism in Hainan.

2.2 Data sources

The raw data of tourism development were collected from the Hainan Statistical Yearbook (2006-2021) (Hainan Provincial Bureau of Statistics of China, 2023). The raw data of the ecological environment were collected from the Hainan Statistical Yearbook (2006-2021) (Hainan Provincial Bureau of Statistics of China, 2023), China Urban Construction Statistical Yearbook (2005-2020)[1] and Bulletin on the Environmental Situation of Hainan (2005-2020).[2]

3 Methodology

All the Statistic data collection was completed using EXCEL (2016), data analysis was completed using Stata 16.0 software, and maps were made using ArcGIS 10.2 software. Otherwise, some other methodologies are used as below.

3.1 Coupling coordination degree model

Coupling originates from physics. It is a phenomenon in which two or more systems influence each other through various interactions (Illingworth, 1996). This paper constructs the coupling degree Equation (1) between tourism development and ecological environment to analyze and measure the relationship between tourism and the ecological environment of Hainan Island. The degree of coupling can explain only the strength of the interaction between the two subsystems and cannot reflect the overall development level. It is possible that the actual development level of the two systems is low and that the coupling degree is high. To reflect the overall efficiency and synergy of the two subsystems, the coupling coordination index D is introduced, as shown in Equation (3). The coupling coordination degree model (CCDM) is given in the following formulas:
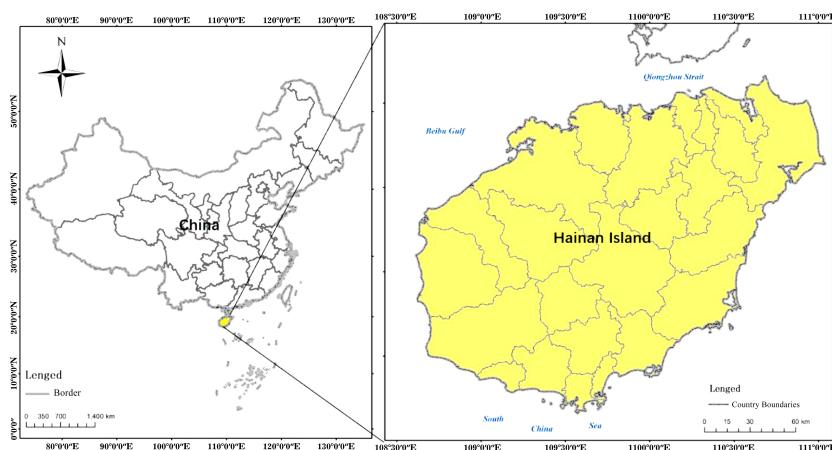
$$C_i = \sqrt{T_i E_i \Big/ (T_i + E_i)^2} \qquad (1)$$

FIGURE 1
The location of Hainan Island.

$$Q_i = w_t T_i + w_e E_i \qquad (2)$$

$$D_i = \sqrt{C_i Q_i} \qquad (3)$$

where T_i and E_i are the integration value of the tourism subsystem and the environment subsystem, respectively; C_i represents the degree of coupling between tourism and the environment; and Q_i reflects the overall level of tourism and the ecological environment. w_t and w_e are the weights of T and E, representing the contributions of tourism and the environment, respectively. For Hainan, tourism development is as equally important as environmental quality; thus, the values of w_t and w_e are equivalent, i.e., $w_t = w_e = 0.5$. D_i represents the degree of coupling coordination, and the development of the coupling of tourism and ecological environment is calculated.

According to existing research (Tang, 2015; He et al., 2017), the coupling degree indicates the interaction degree of two subsystems, and $C \in [0,1]$. When C=1, it means that there exists the greatest coupling degree, and the system will tend toward a new ordered structure; when C=0, it means that there is almost no relationship between the tourism subsystem and ecological environment subsystem, and the system will develop in a disorderly manner (Zhang et al., 2013). When the value of C decreases, it means that the interaction between the tourism economy and ecological environment decreases, and the coupling interaction degenerates and develops in the direction of disorder. When the value of C increases, it indicates that the degree of correlation between the systems is enhanced, and the coupling interaction shows benign development, developing in the direction of orderly self-organization. When $C \in (0, 0.2)$, the coupling interaction between the two subsystems is poor; when $C \in [0.2, 0.4)$, the coupling interaction is ordinary; when $C \in [0.4, 0.6)$, the coupling interaction is fair; when $C \in [0.6, 0.8)$, the coupling interaction is good; and when $C \in [0.8, 1)$, the coupling interaction is excellent.

Accordingly, the coupling coordination degree (D) can be divided into 10 classes, ranging from extremely uncoordinated to highly coordinated (Table 1).

TABLE 1 Classification grades of coupling coordination.

Range	Value	Classification
Uncoordinated	[0, 0.1)	Extremely uncoordinated
	[0.1, 0.2)	Seriously uncoordinated
	[0.2, 0.3)	Moderately uncoordinated
	[0.3, 0.4)	Slightly uncoordinated
Transitional coordinated	[0.4, 0.5)	Approaching uncoordinated
	[0.5, 0.6)	Approaching coordinated
Coordinated	[0.6, 0.7)	Slightly coordinated
	[0.7, 0.8)	Moderately coordinated
	[0.8, 0.9)	Highly coordinated
	[0.9, 1.0]	Extremely coordinated

3.2 Evaluation of the tourism and ecological environment subsystems

As shown in Table 2, T and E represent the level of tourism industry development and the ecological environmental quality of Hainan Island. The integration values of the tourism and ecological environment subsystems are calculated using Equations (4) and (5), respectively.

$$T = \sum_{j=1}^{9} w_j x_j \qquad (4)$$

$$E = \sum_{k=1}^{11} w_k x_k \qquad (5)$$

where w_j is the weight of indicator j of the tourism subsystem and w_k is the weight of indicator k of the ecological environment subsystem.

3.3 Data preprocessing

We normalized the data using Equations (6) and (7), eliminated the influence of different dimensions (Zhang et al., 2013), and obtained the magnitude of positive and negative orientations.

If it is a positive indicator, Equation (4) is used:

$$x'_{ij} = \frac{x_{ij} - \min\{x_j\}}{\max\{x_j\} - \min\{x_j\}} \qquad (6)$$

However, if it is a negative indicator, Equation (5) is used:

$$x'_{ij} = \frac{\max\{x_j\} - x_{ij}}{\max\{x_j\} - \min\{x_j\}} \qquad (7)$$

where x_{ij} represents the value of indicator j in year i and x'_{ij} is the standardized value of x_{ij}.

3.4 Information entropy method

Here, the weights are calculated based on the information entropy method. The concept of information entropy was first proposed by Shannon in 1948. It is an effective tool for measuring the uncertainty of the system status, and it has been popularly used in previous studies (Li et al., 2012; Tang, 2015). If the value of information entropy is higher, the structure of the system is more balanced, and the variation is less. When the value of information entropy is lower, the structure of the system is more unbalanced, and the variation is greater. Therefore, the weight of the indicators, i.e., the degree of variation of the indicators, can be calculated by the value of information entropy, and the bias brought by the influence of subjectivity can be avoided to a certain extent (Shannon, 1948; Li et al., 2012; Tang, 2015). The steps are as follows:

The proportion of indicator j in year i:

$$Y_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}} \qquad (8)$$

TABLE 2 Comprehensive evaluation index system for the relationship between tourism and the ecological environment.

Subsystem	Factor	Indicators	Orientation	Weight
The integration value of tourism subsystem T	Tourism scale (T1)	T_1 Total number of overseas visitor arrivals (10,000person-times)	positive	0.1310
		T_2 Total number of domestic tourists (10,000 person-times)	positive	0.0539
		T_3 Total number of overnight tourists (10,000 person-times)	positive	0.1119
		T_4 Total number of tourist hotels (number)	positive	0.1065
		T_5 Total number of travel agencies (number)	positive	0.0936
	Tourism benefits (T2)	T_6 Earnings from domestic tourism (100 million yuan)	positive	0.1383
		T_7 Earnings from international tourism (10,000 USD)	positive	0.1086
		T_8 Proportion of total earnings from tourism in the tertiary industry (%)	positive	0.1075
		T_9 Proportion of total earnings from tourism in GDP (%)	positive	0.1486
The integration value of the ecological environment E	Ecological environmental pressure (E1)	E_1 Discharge of industrial and domestic waste water into the ocean	negative	0.0735
		E_2 Population density(persons/km^2)	negative	0.0435
		E_3 Percentage of seawater with high quality level (%)	positive	0.1002
	Ecological environmental state (E2)	E_4 Area of urban parks(ha)	positive	0.1310
		E_5 Per Capital area of parks and green land(m^2)	positive	0.0539
		E_6 Green coverage rate of the built-up area (%)	positive	0.1119
		E_7 Forest coverage rate (%)	positive	0.1065
		E_8 Harmless garbage treatment rate (%)	positive	0.0936
		E_9 Town's life sewage treatment rate (%)	positive	0.1383
		E_{10} Ratio of industrial waste water meeting discharge standards (%)	positive	0.1086
		E_{11} Total funds of pollution treatment (10 thousand yuan)	positive	0.1075

Information entropy of indicator j:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} Y_{ij} \times ln Y_{ij} \quad (0 \le e_j \le 1) \quad (9)$$

Entropy redundancy:

$$d_j = 1 - e_j \quad (10)$$

Weight of the indicator:

$$w_j = \left. d_j \middle/ \sum_{j=1}^{n} d_j \right. \quad (11)$$

where n is the number of indicators and m is the number of years. The raw data (2005-2020) describing the indicators of Hainan Island are processed using the above steps (Table 2). The related values are subsequently calculated.

3.5 Relative development model

To further clarify the relative level of tourism and the ecological environment in the development process, this study introduces the relative development model (Wang and Li, 2022). The formula is as follows, where δ is the relative development degree; 0<δ≤0.9 indicates that the ecological environment leads the development of tourism; 0.9<δ≤1.2 indicates the coordinated development of tourism and the ecological environment, which are driven by each other; and δ>1.2 shows that the ecological environment lags behind the development of tourism, and environmental protection should be strengthened.

$$\delta = \left. T_i \middle/ E_i \right. \quad (12)$$

3.6 Verification of the interactive stress effect

To verify the interaction effect between the ecological environment and tourism development on Hainan Island, a new interaction term $E_i{}^*T_i$ is generated on the basis of the main effect of eco-tourism and tourism development. ANOVA and regression analysis are carried out. The variance, determination coefficient R^2 and p value of the

interaction term coefficient are used to determine whether tourism development and the ecological environment have a significant interactive stress effect and whether the interactive stress effect has a significant impact on the coupling and coordination between tourism development and the ecological environment on Hainan Island.

We normalized the data using Equations (6) and (7) and eliminated the influence of different dimensions. The weight of each indicator was calculated using the information entropy method (IEM) [Equations (8)–(11)]. Then, based on the comprehensive evaluation model, coupling degree model, coupling coordination degree model and relative development model, using Equations (4)–(12), we calculate the evaluation values T and E, coupling degree C, coupling coordination degree D and relative development degree δ of the two subsystems (tourism development and the ecological environment).

4 Results

4.1 Coupling mechanism between island tourism development and the ecological environment

Human-land system theory is the foundation of the coupling study of island tourism and the ecological environment (Wang and Li, 2022). The coordinated development of tourism and the ecological environment is an important embodiment of the sustainable development of the human-land relationship. Island

tourism development and the ecological environment constitute an open and complex system, and they interact and restrict each other while maintaining material and energy exchange with the outside world. Both positive and negative effects exist at the same time (Figure 2).

The positive interactions are shown as follows: (1) the ecological environment bears and supports tourism development. On the one hand, the sunshine, beach, climate, vegetation, seawater and other aspects of the ecological environment of the island are favored attractions among tourists and are the basic resources for tourism development. On the other hand, the ecological environment provides a supporting environment for tourism activities and projects and offsets various pollution and damage caused by tourism development within a certain threshold. (2) Tourism development promotes the protection and optimization of the ecological environment. Tourism development needs a beautiful ecological environment. Therefore, the development of tourism will help beautify the ecological environment of the destination and realize the optimization of the spatial pattern of the ecological environment. The sustainable growth of the tourism economy will help to provide more financial support for ecological environment protection. At the same time, technological innovation and improvement in the process of tourism development can effectively reduce the level of consumption of resources and the environment. Tourism development also brings cultural integration, which helps to enhance environmentally friendly awareness and behavior, thus helping to make sustainable use of the ecological environment.

FIGURE 2
Coupling mechanism of island tourism development and the ecological environment system.
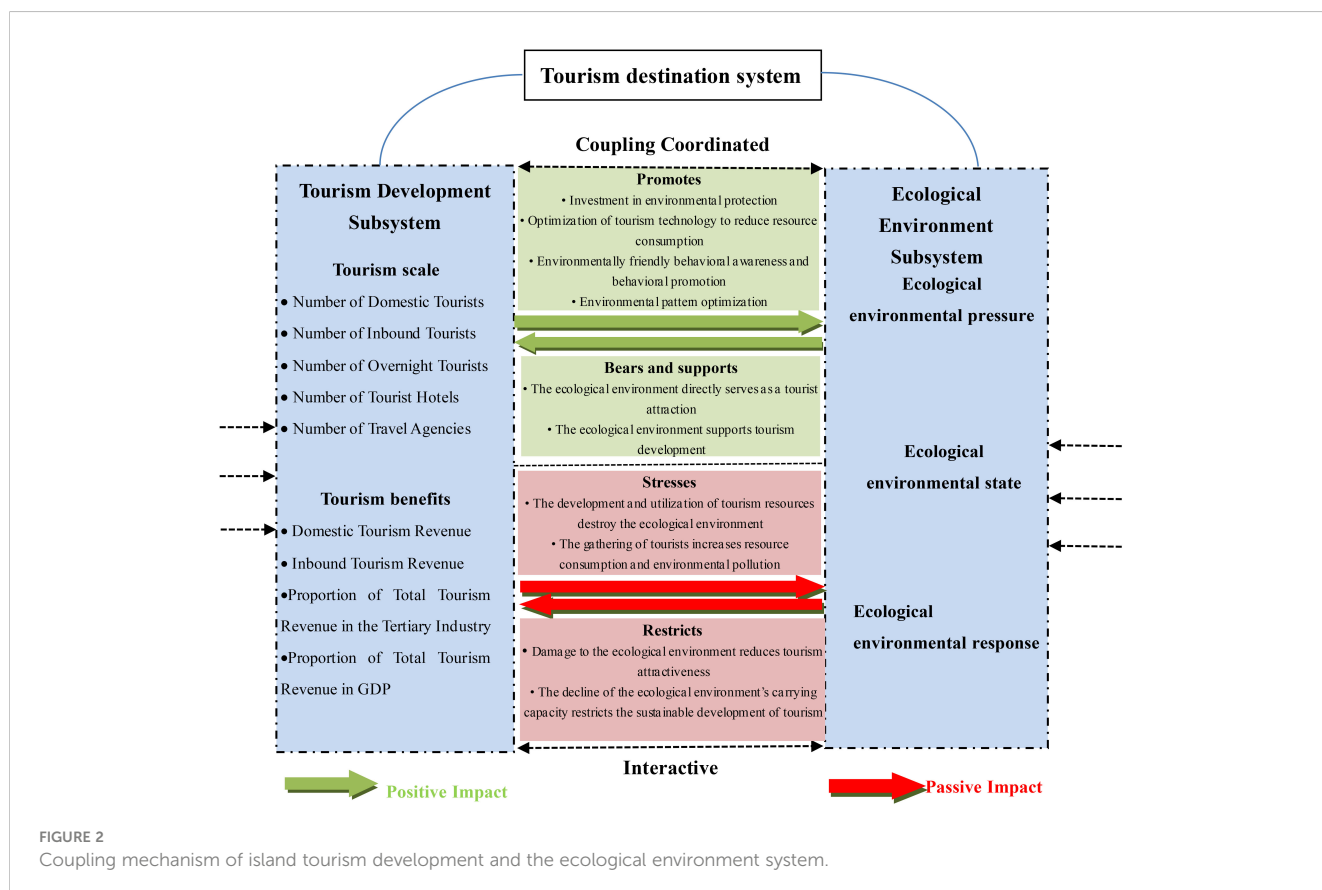
The negative interactions are shown as follows: (1) The development of island tourism leads to pressures on and threats to the ecological environment. The development and utilization of tourism resources will inevitably damage the ecological environment. Examples include the construction of vacation projects, entertainment and reception facilities, and scenic spot roads. Furthermore, the development of tourism brings aggregations of crowds and excessive environmental pollution, such as waste water, solid waste, and domestic waste from hotels and tourist attractions, exhaust gas emissions from intensive tourism traffic, excessive trampling by crowds of people, the destruction of vegetation on coasts, and a reduction of biodiversity. (2) The deteriorating ecological environment also reacts to tourism development, reducing the attractiveness of tourism and the carrying capacity of the ecological environment, which will inhibit or even reverse tourism development. The positive interaction between tourism development and the ecological environment is the premise for achieving sustainable development. By analyzing their coupling, coordination, symbiosis and dynamic changes, we can effectively grasp their sustainable development status.

4.2 Determination of indicators and construction of the index system

Tourism development and the ecological environment form a complex system of mutual connection and restriction. At present, the selection of evaluation indicators for the study of tourism development and ecological environment coupling development has not formed a unified standard. This study follows the indicator selection principles of representativeness, systematization,

independence and availability, refers to the selection of indicators in previous studies, and combines the actual situation of tourism development and the ecological environment on Hainan Island. ecological environment assessment indicators are constructed based on the pressure-state-response (PSR) model, and can effectively evaluate the health of the ecological environment system. Therefore, the ecological environment subsystem includes three levels, i.e., ecological environment pressure, ecological environment status and ecological environment response, with a total of 11 indicators. The tourism development subsystem reflects the overall scale and benefit level, and it includes 9 indicators (Table 2).

4.3 Temporal dynamic changes in tourism and the ecological environment

As shown in Figure 3A, the Q_i curve of the "tourism ecological environment" comprehensive system rose year by year from 2005 to 2019, from 0.156 in 2005 to 0.8618 in 2019, indicating that the complex system composed of tourism and the ecological environment on Hainan Island was in a benign development stage of continuous growth over this 15-year period. In 2020, the overall development index of the system dropped sharply, lower than the overall level two years prior (2017). This result is directly related to the global outbreak of COVID-19 in 2020.

Based on the T_i curve, in the 15 years (2005-2019) before the global outbreak of COVID-19, the tourism development of Hainan Island showed a fluctuating and rapidly increasing dynamic change trend. In 2019, the tourism development index reached the maximum value of 0.9387, which was 6.3 times that of 2005. During this period, Hainan Island experienced several fluctuations. Specifically, from 2005 to 2007, the tourism
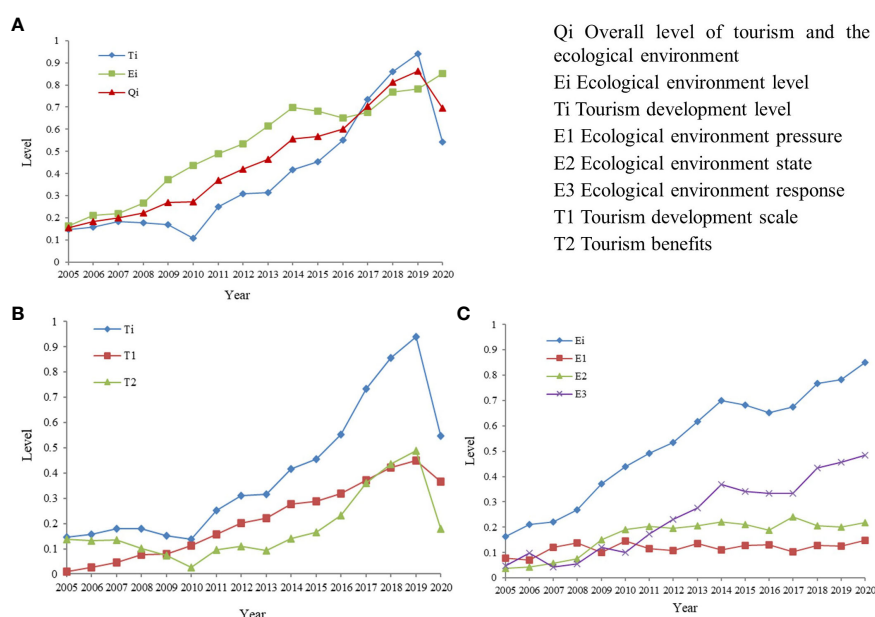

FIGURE 3
(A) Trends of the overall levels of tourism development and the ecological environment Subsystems; **(B)** Trends of the overall levels of tourism Ti; **(C)** Trends of the overall levels of the ecological environment Ei.

development of Hainan Island grew slowly. From 2008 to 2010, there was a shock of a decline of more than 30%. In 2010, it fell to the lowest level of 0.1070 (0.1483 in 2005) and then climbed rapidly. In the nine years after 2011, Hainan Island tourism entered a relatively long period of stable and rapid development. At present, the tourism industry is the leading industry of Hainan Island.

As shown in Figure 3B, the comprehensive level of tourism development was obviously low from 2008 to 2010, but the scale of tourism development T_1 continued to expand during this period. The main reason for its relative underdevelopment was the impact of tourism benefits T_2. Further analysis of the factor indicators of the composition of tourism benefits shows that, despite the positive growth in tourism reception income and the number of people from 2008 to 2010, its contribution to the overall economy and the tertiary industry of Hainan Island was relatively weak. That is, compared with other industries on Hainan Island, the contribution of the tourism economy was poor, showing a relatively underdeveloped trend. However, we also found that although the economic contribution was poor during this period, the investment and supporting facility construction of the state and Hainan Province in tourism development were unprecedented. According to statistical data, the number of hotels on Hainan Island increased from 440 in 2008 to 540 in 2011, an increase of 22.7%. The number of travel agencies increased from 196 to 335, an increase of 70.9%. This is directly related to the national strategy of developing Hainan Island into an international tourism island. The national and local governments have continuously increased tourism investment, which has pushed the island's tourism development into the fast lane. In 2020, the tourism development level of Hainan Island dropped sharply. As we all know, this was due to the global outbreak of COVID-19. The global economy regressed, and the number of tourists decreased by 70-75% compared with 2019 (WTO, 2021). As shown in Figure 2, the tourism development level of Hainan Island dropped to the 2016-2017 level.

As shown in Figure 3C, the ecological environment of Hainan Island was continuously optimized by approximately 5% every year from 2005 to 2019. There was a slight retrogression in the 2015-2017 period, and the ecological environment level rose again after 2017, maintaining the momentum of continuous optimization. The high-quality and unique coastal ecological environment is the basis for the tourism development of Hainan Island. Hainan Island has always attached importance to the protection of the ecological environment. Especially after the development goal of the international tourism island was made clear in 2009, a high-quality ecological environment has become the top priority. The government has invested much in the protection and restoration of the ecological environment. According to statistics, in 2006, Hainan Island invested 540.12 billion yuan in the ecological environment, an increase of 93.8% over the previous year. Such a large investment reached a new high of 5384.42 billion yuan in 2014. In 2018, investment in environmental governance reached a new high, and in the following two years, it maintained a record high. The curve in the figure shows that COVID-19 has had no inhibitory impact on the ecological environment.

4.4 Temporal dynamic changes in the coupling coordination degree of the tourism and ecological environment subsystems

Taking the calculation results of the tourism development T_i and ecological environment E_i of Hainan Island from 2005 to 2020 into Equations (1)–(3), the results of coupling degree C and coupling coordination degree D of the tourism development and ecological environment of Hainan Island are calculated (Figure 4).

As shown in Figure 4, from 2005 to 2020, the coupling degree of the two subsystems had a relatively stable increasing trend, from 0.4 to 0.9, reflecting the increasing trend of the relationship between tourism and the ecological environment and the evolution from low coupling to high coupling. Based on the D values, the coupling and coordination relationship between tourism and the ecological environment on Hainan Island continuously strengthened from 2005 to 2019. It experienced seven stages from moderate imbalance to high coordination. The average time span of each stage was two to three years, and the leap from quantity to quality occurred rapidly. The details are as follows: the coupling and coordination relationship between tourism and ecological environment on Hainan Island experienced moderate incoordination from 2005 to 2007, slight incoordination from 2008 to 2010, and a transition from 2011 to 2012. Then, it entered a relatively long-term coordinated development stage from 2013 to 2019. The stage of coordination of tourism and the ecological environment on Hainan Island specifically includes the qualitative leap from approaching coordinated to slightly coordinated to moderately coordinated and then to highly coordinated from 2013 to 2019.

As shown by the relative development value δ in Table 3, from 2005 to 2020, the ecological environment provided strong support and guarantees for tourism on Hainan Island. From 2005 to 2016, the ecological environment of Hainan Island was always ahead of tourism development, providing favorable ecological environment base dividends for tourism development. From 2017 to 2018, tourism and the ecological environment entered the stage of coupling coordinated development at a medium and high level, driving each other and entering the ideal stage of mutually promoting development. However, it is noteworthy that the ecological environment began to lag behind the development of tourism after 2019. In 2020, due to the impact of the global outbreak of COVID-19, the coupling degree and the coupling coordination degree of tourism and the ecological environment on Hainan Island showed a backward trend, mainly due to the constraints of tourism development.

4.5 Interaction effect between tourism development and the ecological environment on Hainan Island

To verify the interaction between the ecological environment and tourism development on Hainan Island, this study generated a
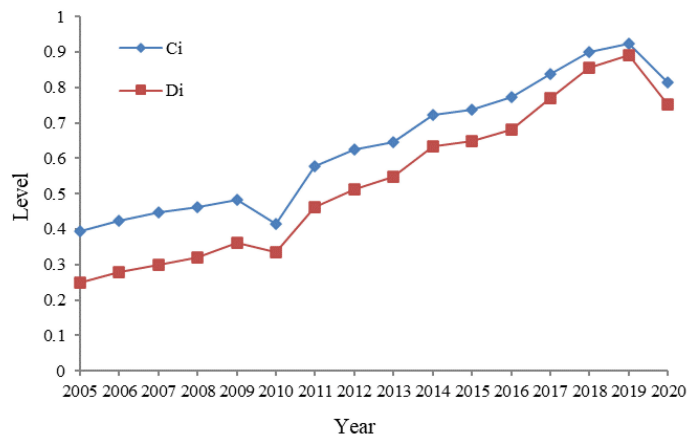
FIGURE 4
Trend of the coupling degree and coupling coordination degree of the integrated system (C_i is the degree of coupling between tourism and the environment, and D_i is the degree of coupling coordination between tourism and the environment).

new interaction term E_i*T_i, which was verified by ANOVA and regression analysis using Stata 16.0 software (Table 4). The validation results show that the coefficient of determination R^2 was 0.9996, the coefficient of the interaction term E_i*T_i was -0.3232, and the p value was $0.0000<0.01$, indicating that tourism development and the ecological environment had significant interactive stress, which had extremely significant impacts on the coupling coordination of tourism development and the ecological environment on Hainan Island.

The results above confirm that the ecological environment subsystem and tourism development subsystem of Hainan Island

had significant interactive stress during the last 16 years. To further analyze the internal interactive stress process, the following assumption is made: there was an inverted U-shaped curve change relationship between Hainan Island's ecological environment and tourism development. That is, the quality of Hainan Island's ecological environment was optimized with the continuous increase in the tourism development level, but the optimization rate gradually decreased until tourism development reached a certain level, and the quality of the ecological environment was no longer optimized, but with the continuous promotion of tourism development, it showed a declining trend.

TABLE 3 Degree of coordinated coupling of tourism development and the ecological environment on Hainan Island.

Year	C	Classification	D	Classification	δ	Relative development level
2005	0.3939	Ordinary	0.2481	Moderately disordered	0.9000	E>T, Ecological environment leading
2006	0.4239	Fair	0.2797	Moderately disordered	0.7483	E>T, Ecological environment leading
2007	0.4455	Fair	0.2996	Moderately disordered	0.8269	E>T, Ecological environment leading
2008	0.4624	Fair	0.3213	Mildly disordered	0.6693	E>T, Ecological environment leading
2009	0.4636	Fair	0.3615	Mildly disordered	0.4576	E>T, Ecological environment leading
2010	0.4594	Fair	0.3364	Mildly disordered	0.2448	E>T, Ecological environment leading
2011	0.5773	Fair	0.4624	Verge of disorder	0.5123	E>T, Ecological environment leading
2012	0.6256	Good	0.5126	Barely coordinated	0.5780	E>T, Ecological environment leading
2013	0.6462	Good	0.5481	Barely coordinated	0.5107	E>T, Ecological environment leading
2014	0.7227	Good	0.6347	Primary coordinated	0.5948	E>T, Ecological environment leading
2015	0.7388	Good	0.6478	Primary coordinated	0.6666	E>T, Ecological environment leading
2016	0.7726	Good	0.6817	Primary coordinated	0.8474	E>T, Ecological environment leading
2017	0.8384	Excellent	0.7691	Intermediate coordinated	1.0875	Coordination and mutual promotion
2018	0.8999	Excellent	0.8558	Senior coordinated	1.1181	Coordination and mutual promotion
2019	0.9237	Excellent	0.8926	Senior coordinated	1.2038	E<T, Tourism leading
2020	0.8158	Excellent	0.7535	Intermediate coordinated	0.6390	E>T, Ecological environment leading

▇ Warning; ▇ Benign.

TABLE 4 Interactive stress and significance of tourism development and the ecological environment on Hainan Island.

Source	SS	df	MS		Number of obs	16
					F (3,12)	8885.31
Model	**.695834612**	3	.231944871		Prob>F	0.0000
Residual	.000313252	12	.000026104f		R-squared	**0.9996**
Total	.696147864	15	.046409858		Root MSE	0.00511
D	Coefficient	Std. err	t	P> |t|	[95% conf.	Interval]
E	.5365522	.0136034	39.44	0.000	.506913	.5661914
T	.6887247	.045767	15.05	0.000	.5890071	.7884424
E*T	**-.323268**	.0586636	-5.51	**0.000**	-.451085	-.195451
_cons	.0658548	.0083515	7.89	0.000	.0476584	.0840512

Significance of bold values is indicated in the text.

The reasons for making the assumption above are as follows: Grossman and Krueger (1995) proposed the hypothesis of the inverted U-shaped environmental Kuznets curve (EKC) for the first time in their environmental economics study, pointing out that there was an inverted U-shaped curve change relationship between the state of the ecological environment and the level of economic development. On this basis, scholars have also proposed that there is an inverted U-shaped curve between the tourism economy and ecological environment (Wang et al., 2006; Wang and Li, 2022). The tourism industry is the leading industry on Hainan Island, plays an important role in its economic development and has a very close relationship with the ecological environment. Therefore, the assumption above is proposed.

Based on the theory of system dynamics, the function change curve between the two subsystems of Hainan Island's ecological environment and tourism development from 2005 to 2020 was fitted and generated by using Stata 16.0 software (Figure 5). The specific parameters are shown in Table 5, and the binomial regression function model is constructed [Equation (13)].

As shown in Table 5, the SSM value is 0.6293, and R^2 is 0.8345, indicating that the curve model fits well. Meanwhile, the p values of the coefficients of tourism development index T and T^2 are 0.000 and 0.003, respectively, which are less than 0.01, indicating that at

the 99% confidence level, the tourism development index T and its square value T^2 have significant impacts on the ecological environment of Hainan Island.

Based on the analysis results above, it can be effectively confirmed that there is a significant inverted U-shaped curve function relationship between the quality of the ecological environment and the level of tourism development of Hainan Island, which is expressed by the binomial regression function as follows:

$$E(t) = -0.0175 + 2.2370t - 1.5383t^2$$

After further adjustment, the following function is obtained:

$$E(t) = 0.7956 - 1.5383(t - 0.7269)^2 \tag{13}$$

Based on Equation (13), when the tourism development index of Hainan Island reaches 0.7269 in a period of time, the optimal value of the ecological environmental quality index is 0.7956, which also represents the best state between tourism development and the ecological environment. In detail, the ecological environment quality of Hainan Island is also optimized with the continuous improvement in the tourism development level, but the optimization rate gradually decreases. Once tourism development reaches 0.7269, the ecological environment quality begins to
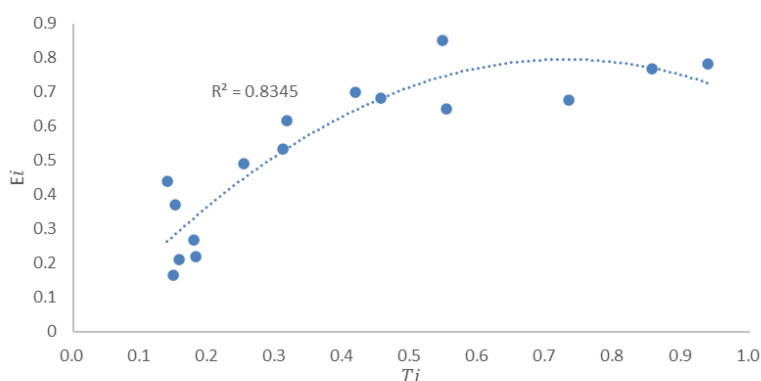

FIGURE 5
Functional change curve between the two subsystems of the ecological environment and tourism development on Hainan Island.

TABLE 5 Correlation coefficient of and variance in the regression model between the ecological environment and tourism development on Hainan Island.

Source	SS	df	MS		Number of obs	16
					F (2,13)	32.76
Model	**0.629321514**	2	0.314660757		Prob>F	0.0000
Residual	0.124851639	13	0.009603972		R-squared	**0.8345**
Total	0.754173154	15	0.05027821		Root MSE	0.098
E	Coefficient	Std. err	t	P> |t|	[95% conf.	Interval]
T	2.23703	0.4414263	5.07	0.000	1.28317	3.190889
Tsq	-1.538519	0.4304648	-3.57	0.000	-2.468482	-0.6085565
_cons	0.0175061	0.0875763	-0.20	0.845	-0.2067032	0.176911

deteriorate with the continuous promotion of tourism development, and the degradation rate gradually accelerates with the improvement in the tourism development level.

5 Discussion

Based on the function law above, corresponding to the history of the relationship between tourism development and ecological environment development on Hainan Island, it is found that the tourism development index of Hainan Island in 2017 was 0.7326, the closest to the critical value of 0.7269. The overall law shows that the ecological environment of Hainan Island was continuously optimized with tourism development from 2005 to 2017, and the two promoted each other and complemented each other. After 2017, Hainan Island's ecological environment and tourism development entered a stage of stress development. With the improvement in the tourism development level, the ecological environment had a trend of degradation. The relative development index of the ecological environment and tourism development δ also showed that the ecological environment lagged behind the development of tourism, proving the credibility of this trend to some extent. This trend constitutes a warning that is worthy of the attention of the tourism development and ecological environment protection departments of Hainan Island. On the one hand, these departments should improve the protection of the ecological environment base of Hainan Island, increase investment in environmental improvement, and build an ecological civilization demonstration area. On the other hand, they should balance the tourism development level index and adhere to the high-quality development path of promoting the integration of culture and tourism.

In addition, the confirmation of the inverted U-shaped curve relationship between the ecological environment and tourism provides evidence for the hypotheses proposed by some scholars. In research on the relationship between the ecological environment and tourism stress, scholars such as Wang et al. (2019) and Wang and Li (2022) directly cited the inverted U-shaped model constructor based on the verification of the inverted U-shaped relationship between the environment and the economy or urbanization and the economy from the studies of Zhou (1982) and Huang and Fang (2003). The results of this study can directly provide evidence that the relationship between ecological environment and tourism exhibits an inverted U-shaped curve.

Multiple models and parameters were applied in the study to analyze the coupling and coordination relationship between ecological environment and tourism development, which inevitably leads to some uncertainties. For example, in the coupling coordination degree model (CCDM), w_t and w_e are the weights of T and E, representing the contributions of tourism and the environment, respectively. For Hainan, tourism development and the ecological environment complement each other, so tourism development and the ecological environmental quality are equally important; thus, the values of w_t and w_e are equivalent, i.e., $w_t = w_e = 0.5$. Although uncertainty still exists, it does not affect the general trend of coupling coordination degree.

Based on the dynamic change process of the coupling and coordination relationship between tourism development and the ecological environment of Hainan Island, we have found that the degradation rate of ecological environment will gradually accelerate with the improvement of tourism development level. It is urgent for Hainan Island to transform its tourism industry, the internationally popular ESG (Environmental, Social and Governance) concept can be introduced. As an evaluation standard to measure the contribution of tourism enterprises in ecological environment protection, social responsibility fulfillment and corporate governance, ESG is highly consistent with the green transformation of tourism industry and the essential requirements of high-quality development, and it is of great significance for promoting the sustainable development of tourism and ecological environment of Hainan Island.

6 Conclusion

Hainan Island is the largest international tourism island in China. Its coastal tourism development and ecological civilization construction have been incorporated into the national development strategy. Revealing the coupling coordination relationship between regional leading industry, i.e., tourism and the ecological

environment holds great value. The following conclusions are drawn from this study:

(1) During the 15 years before the global outbreak of COVID-19, from 2005 to 2019, the complex system composed of tourism and the ecological environment on Hainan Island was in the stage of continuous upward benign development. Tourism development showed a dynamic trend of fluctuating and rapid enhancement, with an increase of 6.3 times in 2019, especially after 2011. Hainan Island tourism entered a relatively long period of stable and rapid development. Overall, the ecological environment was continuously optimized by approximately 5% every year. After being affected by the COVID-19 outbreak in 2020, the tourism development level of Hainan Island experienced a steep decline, falling back to the 2016-2017 level. However, COVID-19 had no inhibitory impacts on the ecological environment, and the ecological environment of Hainan Island continued to remain optimized compared with the 2019 ecological environment level.

(2) From 2005 to 2020, the coupling degree of the two subsystems (tourism development and the ecological environment) showed a relatively stable increasing trend, from low coupling to high coupling. The coupling coordination relationship of the two subsystems continuously strengthened from 2005 to 2019. It experienced seven stages from moderately uncoordinated to highly coordinated. The average time span of each stage was two to three years, and the leap from quantity to quality occurred rapidly. In 2020, due to the impacts of the global outbreak of COVID-19, the coupling degree and the coupling coordination degree of the two subsystems showed backward trends, which were mainly related to tourism development.

(3) From 2005 to 2017, Hainan Island was in the ecological environment leading stage. From 2017 to 2019, it entered the stage in which the ecological environment lagged behind tourism development, while from 2017 to 2018, the relative development degree δ belonged to (0.9,1.2), showing that tourism and the ecological environment were in the mutual promotion and coordinated development stage. In 2019, the ecological environment lagged behind the tourism development index, which is an important warning signal. If tourism development did not slow down due to the impacts of COVID-19, this trend would be likely to continue to strengthen, and the steady optimization trend of the ecological environment of Hainan Island would be blocked.

(4) Tourism development and the ecological environment on Hainan Island have significant interactive stress, which has significant impacts on the coupling coordination of the two subsystems. The relationship of the two subsystems on Hainan Island is an inverted U-shaped function curve. Based on the model, when tourism development reaches 0.7269, the ecological environment quality also reaches the best state.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

CZ: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft. XW: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Writing – review & editing. PJ: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. KZ: Data curation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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