

Article

An Evaluation of the Coordinated Development of Coastal Zone Systems: A Case Study of China's Yellow Sea Coast

Jian Fang ^{1,2} , Min Xu ^{1,*}, Baiqiao Liu ² and Zhou Chen ¹

¹ School of Marine Science and Engineering, Nanjing Normal University, Nanjing 210023, China; aqfj173@163.com (J.F.); jou_cz@163.com (Z.C.)

² School of Geographic and Environmental Sciences, Tianjin Normal University, Tianjin 300387, China; 13803012027@139.com

* Correspondence: xumin0895@njnu.edu.cn

Abstract: The coastal zone is an area of transition between land and sea, containing rich resources, and it is an important spatial unit where humans engage in production and livelihood. However, in the process of benefiting from the coastal zone, people have neglected the coordinated development of the ecological environment, the economy, and society. To investigate the coordinated development mechanisms of coastal zone systems influenced by human activities, the DEMATEL (Decision making trial and evaluation laboratory) model was applied to identify the key factors influencing a complex coastal zone system. The results were used to construct an indicator system to evaluate the developmental stages of three coastal zone subsystems (ecological environment (EE), society (SOC), and economy (ECO)). The developmental levels of these subsystems over the past ten years were evaluated in five cities along the Yellow Sea coast of China, and the degrees of coupling and coordination among the subsystems were calculated using the coupling coordination degree model. The results showed that during the past decade, the developmental levels of the EE, SOC, and ECO subsystems increased in all five coastal regions, except for Yancheng, where there was a small decrease in the EE level; the coupling degrees of all five regions were high, and the interactions between the EE, SOC, and ECO were very close; the coordination degree was relatively poor. The mean values of Qingdao and Nantong were at an 'Intermediate coordination level', and the other three cities were at the 'Primary coordination' or 'Barely coordination level'. Three types of interactions between the subsystems emerged: (1) three subsystems have benign interactions and collaboration with each other; (2) the EE, SOC, and ECO compete with each other and have fluctuating upward development; (3) there is a focus on development in the SOC and ECO, and there is a neglect of environmental protection. Based on the development trends of the subsystems and the coupling and coordination laws, some suggestions were proposed.

Keywords: coastal system; key factor; coupling and coordination; ecological environment; society; economy



Citation: Fang, J.; Xu, M.; Liu, B.; Chen, Z. An Evaluation of the Coordinated Development of Coastal Zone Systems: A Case Study of China's Yellow Sea Coast. *J. Mar. Sci. Eng.* **2022**, *10*, 919. <https://doi.org/10.3390/jmse10070919>

Academic Editors: Yannis N. Krestenitis and Marcello Di Risio

Received: 5 May 2022

Accepted: 30 June 2022

Published: 2 July 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Coastal zones are areas where land and sea interact and are rich in natural resources [1]. In addition to acting as complex and dynamic natural systems, these areas are subjected to high-intensity human activities and are impacted by global climate change [2]. Coastal zones have a flat terrain and a pleasant climate and are thus generally highly populated with a well-developed socio-economic system [3]; for example, more than one-third of the world's population lives within 150 km of a coastal zone [4,5]. The coastal zone of mainland China accounts for approximately 13% of the country's land area, hosts 42% of the population, and produces more than 60% of the country's GDP. Thus, it become a crucial area and a "golden zone" in China's economic development [2,6]. However, shocks can have adverse effects on coastal zones. With respect to land-based pressures,

industrial, agricultural, and domestic wastewater is discharged in such areas, solid waste is disposed of, water conservation projects are constructed, and sea sand is mined, among other factors adversely affecting these zones. Coastal zones are also subjected to various forms of natural disasters [7], such as storm surges, tsunamis, and typhoons (hurricanes), resulting in human casualties, the destruction of towns, coastal erosion, the salinization of estuaries and coastal plains, and other adverse events that affect coastal zone eco-systems and human lives. Furthermore, increases in the sea level due to global temperature changes severely affect coastal zones. There are also effects associated with interactions between the land and sea, such as those associated with sea farming, urban construction, and the construction of seawall protection projects, which can result in water pollution, ecosystem pattern changes, and coastal wetland loss. Intense human use and development activities have greatly affected coastal zones [8,9]. After years of anthropogenic interventions, the coastal zone has formed a nonlinear, complex land–sea interaction system influenced by multiple factors associated with both land and sea, and all aspects and elements within the system are coupled with and have adapted to each other. Therefore, coastal zones form various developmental states (economic, social prosperity and poor ecological environment, and superior ecological environment with lagging economic and social development), that directly affect the overall developmental quality of the coastal zone.

To identify the factors influencing coastal zone development, we conducted a literature review. In studies of coastal zones or regional sustainable development, coupled coordination methods are frequently used to treat the study object as a composite system and to explore the interactions and collaborations between different subsystems or elements of the coastal zone [10–14]. The indicators used to evaluate the developmental quality of different subsystems within the coastal zone are mainly selected in relation to the natural environment, population, economy, government management, and social development [15–18]. Xiao et al. [18] established an evaluation indicator system for a coupled marine industry cluster and city development based on input–output data and marine enterprise data of coastal cities and explored the coupled development relationship. Qv et al. [16] used the technical method of similarity ranking with an ideal solution to improve the coupled coordination model, and analyzed the coupled and coordinated development relationship between the two subsystems in 10 coastal cities. In addition, Shang and Liu. [17] proposed countermeasures for the sustainable development of Chinese coastal zone cities using the coupling coordination degree model. Lin et al. [15] quantitatively analyzed the land–sea coordination degree of the Xiamen coastal zone by shore section and proposed spatial planning guidelines for different shore sections with the goal of land–sea integration.

To alleviate the ecological, environmental and social problems arising from the coastal zone, various countries and international organizations have adopted integrated coastal zone management approaches to achieve sustainable and coordinated coastal zone development [19]. As early as 1972, the United States proposed managing coastal zones through "integrated development, rational protection and optimal decision-making". In 1992, the United Nations Agenda 21 proposed a framework for integrated coastal zone management, which involves the marine and terrestrial sectors and multiple interests [20]. In 1998, the Australian government issued the 'Australian Oceans Policy', the implementation of which covers biological, navigational, environmental, and marine law enforcement [21]. In 2003, the EU developed a system of progress indicators for coastal zone management, covering economic, social and environmental aspects [22]. Many countries and international organizations have recognized that coastal zone management requires coordination among multiple parties and the application of an integrated perspective for its development.

Numerous studies as well as government management have shown that the coastal zone system is divided into three major categories: the ecological environment, the economy, and society. We selected the evaluation indicators based on the attribute characteristics of these three aspects, which were used as a reference for designing the evaluation indicator system for the coastal zone subsystems. However, we found two main limitations associated with previous studies: (1) the spatial evaluation scope of the coastal zone is

relatively broad, and the concept and scope of the actual needs and management responsibilities of coastal area development have not been clearly defined, and (2) the selection of the evaluation indicators for the coastal zone subsystem was highly subjective, and no indicator screening was conducted based on objective analytical methods. Therefore, this study was conducted to (1) define the evaluation scope of the coastal zone in terms of the administrative boundaries between land and sea to enable effective coastal zone management; (2) apply the DEMATEL model to identify key factors affecting coastal zone development; construct an indicator evaluation system based on three subsystems: the ecological environment (EE), society (SOC), and economy (ECO) subsystems, and evaluate the developmental level of each subsystem; and (3) we use the coupled coordination degree model to study the ten-year correlation mechanism among the coastal zone subsystems of China's Yellow Sea coast and explore the detailed mechanisms involved in the mutual influences and collaborations between the subsystems. The goal of this study was to better reflect dynamic changes in the developmental levels of the EE, SOC, and SOC subsystems within the coastal zone in different periods.

2. Materials and Methods

2.1. Study Scope

Since China's reform and opening up, there has been a large influx of capital, labor, and technology in the eastern coastal region, leading to great achievements [23]. To examine the coordinated development of the EE, SOC, and ECO subsystems in the coastal zone, five cities along the Yellow Sea were selected as the study areas: Qingdao, Rizhao, Lianyungang, Yancheng, and Nantong (Figure 1). These cities are in the middle part of the eastern coast, where the water quality is excellent and the climate is pleasant. The area is rich in tourism and marine biological resources. Large wetland tidal flats lie in the center and to the south (Figure 1) and are important for the migration and roosting of birds; these regions have both high scientific research and tourism value. With a large population and economic volume, the five cities are important development engines for China. The sea is mostly open and the coast is only 500 km from the Korean Peninsula. Relying on the natural advantages of Jiaozhou Bay, Haizhou Bay, and Tongzhou Bay, many foreign trade ports have been built, including Qingdao Port, Lianyungang Port, and Nantong Port, which are hubs for foreign sea transportation and national transport inland. This region was selected as the study area because of its important role in the economy of China's coastal area and its large impact on the ecological environment of the eastern coastal region.

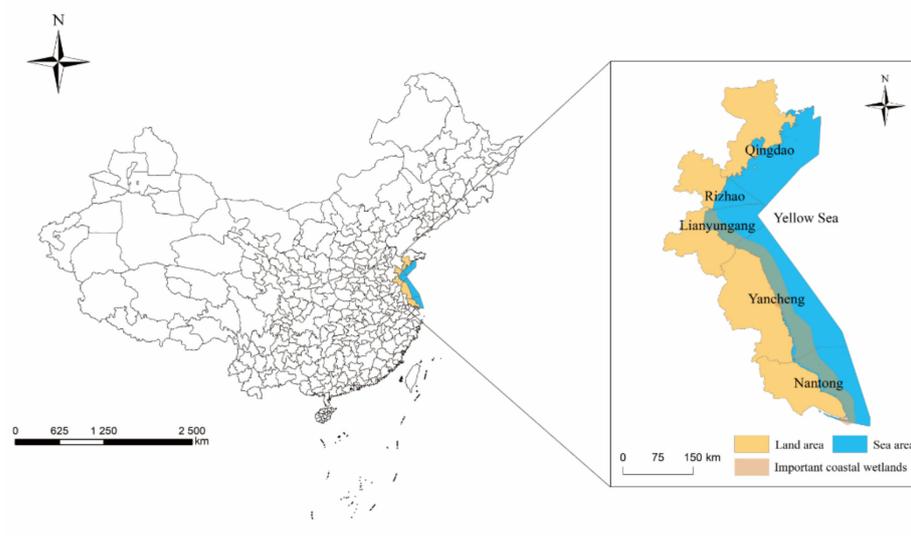


Figure 1. Study area: Five coastal cities on China's Yellow Sea coast.

The definitions used in this study are mainly based on both the natural tidal or wave activity law and human demand for using the coastal zone [24] and those for the coastal zone are based on the coastline extending landward and seaward over a certain range of areas [2,25]. Development of coastal zones must involve consideration of human–land relationships [26], and human activities should be controlled based on clearly defined management strategies. In China, municipal administrative regions are generally used as the main control unit for unified marine development and management. For the convenience of data acquisition and the practical needs of this study, we define the coastal zone as an area extending to the administrative unit of the prefecture-level city on the landward side, and all sea areas under the jurisdiction of the administrative unit on the seaward side (Figure 1).

2.2. Key Factors Influencing the Identification Method

Coastal zones are complex and nonlinear systems in which elements are interconnected and interact. The material circulation, energy flow, and information transferred within the system depend on the interaction and collaboration among the elements and subsystems, and effective processes are key to the sustainable operation of the entire system. Numerous and complex internal elements affect the development of the system. To eliminate weaker factors, we selected the key elements from among the many influential factors with an obvious influence on the system and a greater influence on other elements to build an evaluation index system of the coastal zone subsystem and provide a research basis for the subsequent coupling and coordination association mechanism of each subsystem.

The DEMATEL (Decision making trial and evaluation laboratory) model was used to analyze and identify the key factors affecting coastal zone development. This model was proposed by Professors Gabus and Fontela of Battelle Laboratories in the United States at a conference in Geneva in 1971 and was developed to solve complex and difficult problems in the real world. This systematic analysis method uses graphical and matrix tools [27,28] to determine the strength of an influential relationship between elements in a complex system, establish a judgment matrix, and perform corresponding matrix operations to derive the row sum (R_i) and column sum (C_i) of each element and each element of the complex system. The sum and difference relationship of each element R_i and C_i are the prominence (P_i) and relation (N_i) of each element with respect to the complex system. Key factors were identified through a comprehensive analysis of the P_i and N_i indicators of the system factors.

The specific calculation steps of the DEMATEL model are described below:

- Step 1. System information was collected. All factors influencing the study system were collected, including those influencing the internal and external environments. Based on the collected system information, the n elements contained in the system were denoted as $\{N_1, N_2, N_3, \dots, N_n\}$
- Step 2. A direct influence matrix was generated. Experts in related fields were invited to judge the influence of the strength relationship between factors within a complex system on a scale of 0, 1, 2, 3, and 4, where 0 means no influence, 1 means very little influence, 2 means some or little influence, 3 means great influence, and 4 means great influence. The direct-influence matrix, Z , was then obtained,

$$Z = \begin{bmatrix} 0 & \dots & a_{1j} & \dots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \dots & 0 & \dots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \dots & a_{nj} & \dots & 0 \end{bmatrix}.$$

where a_{ij} indicates the degree of direct influence of factor i on factor j . If $i = j$, then $a_{ij} = 0$.

- Step 3. The normalized direct-influence matrix was established. Each row and column factor of the direct-influence matrix, Z , was summed, and the maximum value was selected (Equation (1)). Each value of the matrix, Z , was then divided by the maximum value (Equation (2)) to obtain the normalized direct-influence matrix, $X = [x_{ij}]_{n \times n}$

$$s = \max \left(\max_{1 \leq i \leq n} \sum_{j=1}^n Z_{ij}, \max_{1 \leq j \leq n} \sum_{i=1}^n Z_{ij} \right), \tag{1}$$

$$x_{ij} = \frac{Z_{ij}}{s}. \tag{2}$$

- Step 4. The total-influence matrix T , was constructed using the following formula,

$$T = (t_{ij})_{n \times n} = X(I - X)^{-1} \tag{3}$$

where I is a unit matrix.

- Step 5. R_i , C_i , P_i , and N_i were calculated for each factor using the following formula, R_i is the sum of the values of the influence of factor a_i on other factors:

$$R_i = \sum_{j=1}^n T_{ij}, \tag{4}$$

C_i is the sum of the values of factor a_i influenced by the other factors:

$$C_i = \sum_{i=1}^n T_{ij}, \tag{5}$$

P_i is the sum of R_i and C_i for factor a_i (and the larger the P_i , the more significant the influence of the factor on the system):

$$P_i = R_i + C_i, \tag{6}$$

N_i is the difference between R_i and C_i for factor a_i (where a larger N_i indicates that the other factors are susceptible to the influence of that factor):

$$N_i = R_i - C_i. \tag{7}$$

- Step 6. The system's key factors were identified. With P_i as the horizontal axis, N_i as the vertical axis, and (P_i, N_i) as the coordinates, an influence correlation diagram was drawn to comprehensively analyze the cause-effect relationship of the factors within the complex system and to then identify the key factors.

2.3. Weight Determination Method

To avoid unpredictable effects from differences between dimensions, the initial matrix was first formed using all data, $X = (x_{ij})_{mn}$, $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$, where m is the number of indicators, n is the number of studies, and x_{ij} is the j -th indicator value of the i -th city. The indicators were divided into benefit and cost indicators, based on the needs of the study. The formulas for standardizing both types of indicators are as follows:

For the benefit indicator:

$$y_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}}, \tag{8}$$

For the cost indicator:

$$y_{ij} = \frac{x_{jmax} - x_{ij}}{x_{jmax} - x_{jmin}} \tag{9}$$

To overcome the influence of subjective evaluation and reduce error, the indicator information entropy e_i was used to determine the indicator weights [29], and the formula for indicator information entropy is as follows:

$$e_i = -\frac{1}{\ln m} \sum_{j=1}^m (v_i \ln v_i), \quad v_i = y_{ij} / \sum_{j=1}^m y_{ij}, \quad (10)$$

$$w_i = \frac{1 - e_i}{n - \sum_{i=1}^n e_i} \quad (11)$$

where, n is the number of indicators, and w_i is the indicator weights.

The coastal zone subsystem evaluation index was used to represent the level of subsystem development in accordance with the following formula,

$$f(S_t) = \sum_j^m w_{jt} y_{jt} \quad (12)$$

where $f(S_t)$ is the sum of the product of all indicator weights (w_{jt}) and standardized values (y_{jt}) within the subsystem.

2.4. Coupling Coordination Degree Model

Coupling and coordination degree models are used to reflect the interdependence and constraints between systems and have been widely used in research within the socioeconomic, biological, agricultural, and ecological domains [17]. Coupling was derived from a physical concept [30] to describe the interaction between systems or elements, their influence on each other, and the degree of interaction [10]. The degree of coordination reflects whether there is orderly development between two or more systems, or elements within the system and whether the interaction between them is benign [31,32]. Coupling and coordination between the EE, SOC, and ECO subsystems in the coastal zone were analyzed to illustrate the degree of interconnection and interaction among the subsystems in the development process and to reflect trends in the system interactions from disorder to order. In this respect, a greater degree of coordination indicates that the coastal zone system has a higher level of development, good adaptation, benign interaction between subsystems, and a good degree of coordination.

The capacity coupling coefficient model in physics was used to calculate the coupling degree of the coastal zone to construct the coordination evaluation model of the land–sea interaction process as follows,

$$C_t = \sqrt[3]{\frac{f(S_{EE}) \times f(S_{SOC}) \times f(S_{ECO})}{(f(S_{EE}) + f(S_{SOC}) + f(S_{ECO})/3)^3}} \quad (13)$$

where C_t denotes the coupling degree. The larger the value, the better the coupling degree, and a large value indicates that the systems influence each other and are closely related.

$$T_t = \alpha f(S_{EE}) + \beta f(S_{SOC}) + \gamma f(S_{ECO}). \quad (14)$$

T_t is the coastal zone comprehensive evaluation index and $\alpha, \beta, \gamma \in [0, 1]$, and $\alpha + \beta + \gamma = 1$. Considering that each subsystem is equally important, $\alpha = \beta = \gamma = 1/3$.

The coordination model is calculated as:

$$R_t = \sqrt{C_t \times T_t} \quad (15)$$

where R_t is the coordination degree. The larger the value of R_t , the better it reflects a benign interaction relationship and a collaborative orderliness between systems.

To describe the coordination levels of the three subsystems EE, SOC, and ECO of the coastal zone system [16,17], we divided the calculation results into ten levels (Table 1).

Table 1. Classification of coordination degree.

Coordination Level	R_t Value
Extreme disorder	$0.0000 \leq R_t < 0.1000$
Serious disorder	$0.1001 \leq R_t < 0.2000$
Moderate disorder	$0.2001 \leq R_t < 0.3000$
Light disorder	$0.3001 \leq R_t < 0.4000$
Near disorder	$0.4001 \leq R_t < 0.5000$
Barely coordination	$0.5001 \leq R_t < 0.6000$
Primary coordination	$0.6001 \leq R_t < 0.7000$
Intermediate coordination	$0.7001 \leq R_t < 0.8000$
Advanced coordination	$0.8001 \leq R_t < 0.9000$
Extreme coordination	$0.9001 \leq R_t < 1.0000$

3. Results

To determine the quantitative relationship between the EE, SOC, and ECO subsystems for the five coastal cities along the Yellow Sea, data from 2011 to 2020 were collected. The initial indicator values were collected from the China Marine Statistical Yearbook (2011–2017), China Marine Disaster Bulletin (2011–2020), Jiangsu Statistical Yearbook (2011–2020), Shandong Statistical Yearbook (2011–2020), Jiangsu Marine Environmental Quality Bulletin (2011–2020), Jiangsu Marine Disaster Bulletin (2011–2020), Qingdao Marine Environment Bulletin (2012–2017), Qingdao Statistical Yearbook (2011–2020), Rizhao Statistical Yearbook (2011–2020), Lianyungang Statistical Yearbook (2011–2020), Yancheng Statistical Yearbook (2011–2020), and Nantong Statistical Yearbook (2011–2020).

3.1. Key Influencing Factors Identification Results

We combined the analysis of the literature on the coupling and coordination of coastal zones and urban sustainable development with relevant expert opinions and practical experience. We summarized 24 influencing factors from three major aspects— ecological environment, society, and the economy, and formed a collection of influencing factors for coastal zone development (Table 2).

Table 2. Collection of factors influencing coastal zone development.

Elements	References
Coastline erosion(N ₁)	[33,34]
Benthic biodiversity (N ₂)	[35,36]
Wetland area (N ₃)	[16,35]
Percentage of natural coastline (N ₄)	[16,35,37]
Fishery production (N ₅)	[16]
Forest coverage (N ₆)	[16,38]
Seawater quality compliance rate (N ₇)	[16,35,36,39]
Disaster losses (N ₈)	[40]
Sea level change (N ₉)	[33,34,41–43]
Number of nature reserves(N ₁₀)	[35]
Population density (S ₁)	[15,35,39,44–46]
Sea-related employment (S ₂)	[44]
Coastal seawater quality up to standard (S ₃)	[16,17,35]
Number of pollution incidents (S ₄)	[16,17]
Traffic network density (S ₅)	[16,44]
Port throughput (S ₆)	[37,38,47]
Marine education and research (S ₇)	[16,17,37,44]
Marine development and utilization mode (S ₈)	[16,35]
Marine development utilization rate (S ₉)	[16]
Industrial assets (E ₁)	[45]
GDP per capita (E ₂)	[37,38,47]
GDP per unit of coastline (E ₃)	[35,39,45,46]
Coastal tourism revenue (E ₄)	[23,46,47]
Sea-related technology expenditure (E ₅)	[17]

The DEMATEL model was used to calculate the P_i and R_i of each factor for the coastal zone system and to establish a causal coordinate system (with P_i and R_i as the horizontal

axis and the vertical axis, respectively) (Figure 2) to identify the key influential factors affecting coastal zone development. These key influential factors were organized and combined with the data used to establish the coastal zone subsystem evaluation indicator system (Table 3).

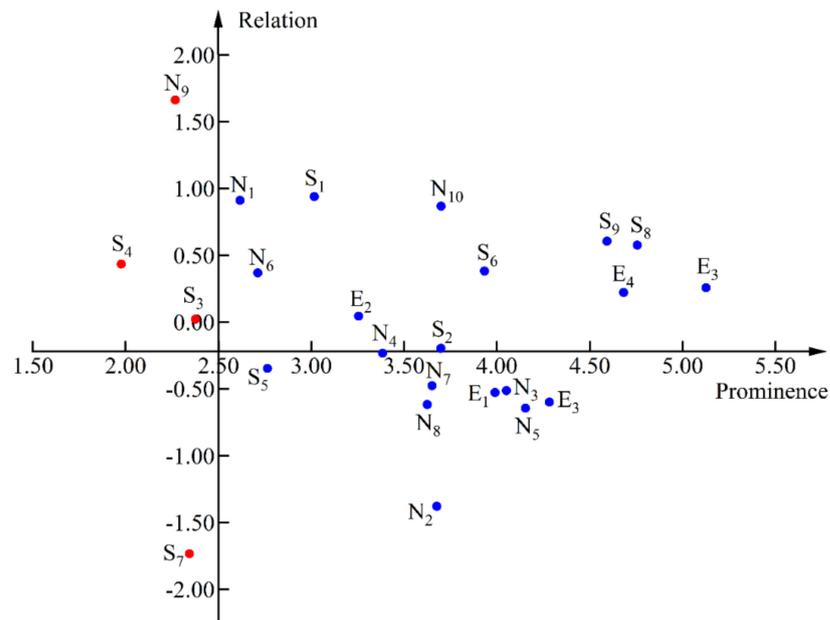


Figure 2. Causal relationships among factors of the coastal zone system: The first quadrant is the region with the highest P_i and R_i , indicating that not only each factor in this region has a great influence on the system, but also each factor has a large influence on the other factors. Therefore, all factors in this quadrant can be used as the key influence factors of the system (blue dots); R_i in the fourth quadrant is low but P_i is high, indicating that each factor in this quadrant has limited ability to influence the other factors, but has a greater impact on the system. Therefore, all factors in the fourth quadrant also serve as key influencing factors of the system (blue dots); The P_i and R_i of the second and fourth quadrants are low and have limited influence on the system and other factors, so they are not considered as the key influence factors (red dots).

Table 3. Coastal zone subsystem evaluation indicator system.

Subsystems	Indicators	Description (Unit)	Attributes	Weight
EE	Coastline erosion	The length of the coastline eroded by waves and tides per year (m/a).	–	0.0693
	Benthic biodiversity	Diversity of benthic organisms within the jurisdictional sea area.	+	0.0674
	Wetland area	Total area of natural and artificial coastal wetlands (km ²).	+	0.1941
	Percentage of natural coastline	The ratio of natural shoreline to total shoreline length (%).	+	0.1872
	Forest coverage	Ratio of the vertical projection of all forests to the total area of the region (%).	+	0.2040
	Seawater quality compliance rate	The ratio of the area of seawater quality above class II to the total sea area (%).	+	0.1404
	Number of marine-protected areas	Number of marine protected areas in the region (Number).	+	0.1376

Table 3. Cont.

Subsystems	Indicators	Description (Unit)	Attributes	Weight
SOC	Population density	Number of people per unit area (People/km ²).	+	0.2390
	Sea-related employment	Total number of employed persons engaged in marine-related industries (People).	+	0.0677
	Traffic network density	Length of all traffic lines constructed within a unit area (km/km ²).	+	0.1783
	Port throughput	Intra-regional seaport cargo throughput (10,000 ton).	+	0.0924
	Marine development and utilization type	The form or mode of marine exploitation. The calculation formula is: $(\sum_{i=1}^n S_i \times L_i) / M$, S_i is the coefficient of the i th marine utilization mode and n is the number of regional marine utilization modes.	+	0.2144
	Marine development utilization rate	Utilization rates of different modes of marine development. The calculation formula is: $(\sum_{i=1}^n T_i) / n$, T_i is the sea-used area of the i th type of marine utilization type, l is the coefficient of the i th type of marine utilization, M is the total sea-used area for marine utilization in the region	+	0.2083
ECO	Marine fishery production value	The production value of fishery resources within the administrative sea area (10,000 yuan).	+	0.0906
	Marine disaster losses	Annual economic losses caused by marine disasters to coastal areas (10,000 yuan).	-	0.1297
	Industrial fixed asset investment	In the form of currency, the construction and acquisition of fixed assets and related expenses by enterprises within a certain period of time (100 million yuan).	+	0.1549
	GDP per capita	GDP per capita in the region (Yuan/km ²).	+	0.1490
	GDP per unit of coastline	GDP per kilometer of coastline (Yuan/km).	+	0.1616
	Coastal tourism revenue	Total revenue of all tourist attractions in the coastal zone (100 million yuan).	+	0.1931
	Sea-related technology expenditure	Total expenditure on marine-related scientific research, enterprise, and other affairs (100 million yuan).	+	0.1210

We identified 20 key factors affecting the development of the coastal zone. The final evaluation indicator system included seven EE, six SOC, and seven ECO indicators (Table 3).

3.2. Results of the Subsystem Development Level

Equations (8) and (9) were used to calculate the standardized values of the indicators, Equations (10) and (11) were used to calculate the indicator weights (as shown in the final column in Table 3), and Equation (12) was used to obtain the evaluation index of each subsystem (Figure 3).

In general, the Qingdao and Nantong coastal zones showed high mean indices for the EE, SOC, and ECO subsystems, whereas Yancheng and Rizhao also showed high levels for EE the subsystem. In terms of the annual growth rate, Rizhao’s SOC subsystem achieved high growth (15.47%), whereas Yancheng’s EE subsystem underwent negative growth (Figure 3; Table 4). The three subsystems in Qingdao had a high level of development and good synergy (mean value of the subsystems was 0.5–0.6), mainly because of the region’s expertise in marine disaster management, biological habitat protection, sea water quality improvement, marine utilization transformation and utilization rates, real economy investment, coastal tourism, and technological progress. The exponential growth in the SOC subsystem in Rizhao was highly related to the contribution from the EE subsystem, which in turn led to improvements in the ECO subsystem. Implementation of an ecological

priority strategy has increased infrastructure within the region, transformed the marine utilization mode, and improved the utilization rate of resources. In addition, Rizhao has attracted foreign investment and technical talent and its overall coastal zone development level has improved. The EE subsystem of Yancheng showed negative growth, whereas the SOC and ECO subsystems achieved high growth rates. It is possible that the area developed with a preference for economic and social benefits, resulting in ecological and environmental protection being neglected. The local government should conduct appropriate ecological restoration work to address specific environmental problems. The developmental levels of the three subsystems in Lianyungang were the lowest, indicating certain constraining relationships and conflicts with coastal zone development. Although the annual growth rates of the three subsystems have been positive for the last decade, EE and SOC showed fluctuations(Figure 3). These results are related to the increased artificiality of natural coastlines due to regional economic development needs and the wastage of marine resources due to extensive marine utilization practices. Although certain ECO and SOC benefits have been achieved, deficiencies in the developmental approach have not been fundamentally resolved, ultimately resulting in collective low-level subsystems.

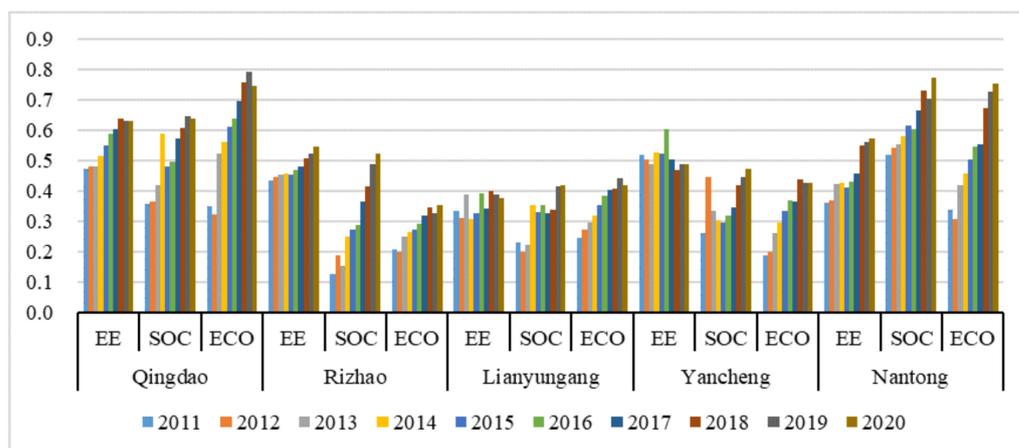


Figure 3. Trends in development levels in each subsystem.

Table 4. Mean index of coastal zone subsystem development.

Area	Subsystem	Mean	Annual Growth Rate
Qingdao	EE	0.5580	2.93%
	SOC	0.5162	6.00%
	ECO	0.5992	7.94%
Rizhao	EE	0.4762	2.35%
	SOC	0.3061	15.47%
	ECO	0.2828	5.46%
Lianyungang	EE	0.3559	1.19%
	SOC	0.3190	6.10%
	ECO	0.3536	5.38%
Yancheng	EE	0.5114	−0.62%
	SOC	0.3643	6.09%
	ECO	0.3298	8.48%
Nantong	EE	0.4552	4.75%
	SOC	0.6287	4.09%
	ECO	0.5275	8.31%

The time series (Figure 3) showed an increasing trend for the evaluation level of the five regional coastal zone subsystems in most years, indicating improvements in the SOC, ECO, and EE subsystems within the Yellow Sea coastal area over the last decade. In terms of

spatial characteristics (Figure 4), we found that in the early period, Yancheng in the center had the highest EE level, but this was overtaken by Qingdao in the north and Nantong in the south after 2018. This trend of high levels in the north and south and low levels in the central area was maintained until 2020. Overall, the SOC and ECO subsystems showed a trend of being high in the north and south and low in the central region. Therefore, the spatial characteristics of the three subsystems were as follows: the EE subsystems were superior in the northern and central parts throughout the early-stage development period, whereas the SOC and ECO subsystems were better developed in the north and south. In the later period, the development of the north and south was rapid, and the three subsystems show the north and south poles, whereas the development gap with the central region has gradually widened. The main reasons for this spatial disparity are that Qingdao in the north and Nantong in the south have their own economic foundations, investment in environmental protection and society in the later processes have gradually increased, and the quality of the EE subsystem level has significantly improved. In contrast, the ECO levels of Rizhao, Yancheng, and Lianyungang in the central region have become relatively poor because capital, technology, and talent are lacking and some cities have had to rely on, or sacrifice, some of the EE to ensure their continued development.

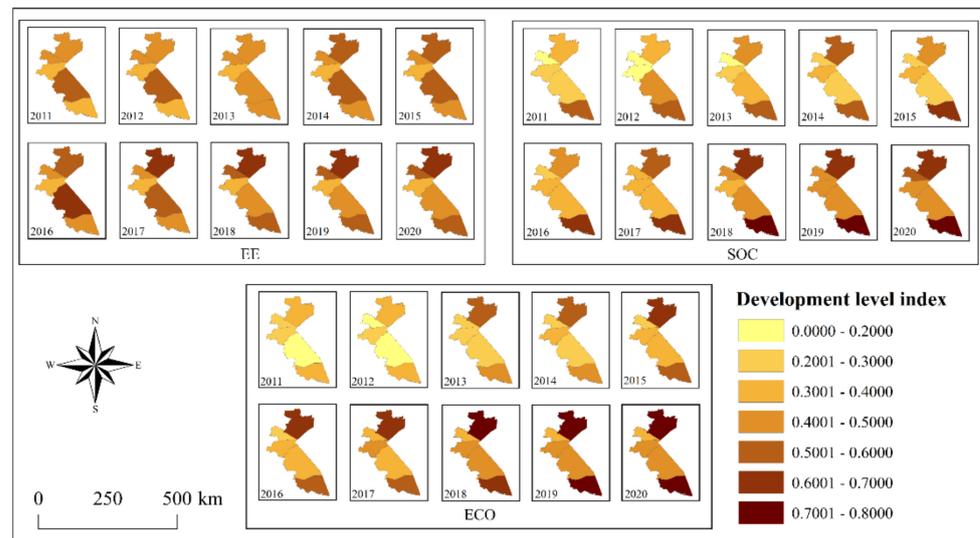


Figure 4. Coastal zone subsystem development level index changes from 2011 to 2020.

3.3. Results of Coupling Coordination between Subsystems

The degrees of coupling and coordination (C_t and R_t) between the EE, SCO, and ECO subsystems were calculated using Equations (5)–(7). The C_t represents the extent to which the subsystems interact and influence each other and how closely they interact, regardless of their associated benefits or disadvantages. The R_t reflects whether development among the subsystems is orderly and how well the subsystems collaborate. The results showed that the C_t was high between the subsystems of the coastal zone in each region (mean value > 0.9) (Table 5), demonstrating that the subsystems in the study area interact well and are closely connected. The R_t between the subsystems in each regional coastal zone was relatively low (Table 6), but the R_t trend increased over time, indicating that the coordination between the subsystems is developing and mutual adaptation and positive interaction among the systems are gradually improving.

Table 5. The coupling degrees of the cities in the years 2011–2020.

Area	Coupling Degree (C_t)										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
Qingdao	0.9901	0.9863	0.9960	0.9985	0.9950	0.9945	0.9965	0.9955	0.9947	0.9969	0.9944
Rizhao	0.8432	0.8778	0.8852	0.9361	0.9461	0.9538	0.9670	0.9757	0.9637	0.9624	0.9311
Lianyungang	0.9703	0.9800	0.9686	0.9937	0.9995	0.9983	0.9989	0.9978	0.9996	0.9986	0.9905
Yancheng	0.9120	0.9258	0.9667	0.9629	0.9690	0.9610	0.9865	0.9989	0.9984	0.9983	0.9679
Nantong	0.9821	0.9712	0.9914	0.9910	0.9864	0.9901	0.9885	0.9928	0.9935	0.9911	0.9878

Table 6. The coordination degrees of the cities in the year 2011–2020.

Regions	Coordination Degree (R_t)										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
Qingdao	0.6229	0.6195	0.6872	0.7434	0.7374	0.7550	0.7874	0.8149	0.8278	0.8181	0.7414
Rizhao	0.4423	0.4744	0.4818	0.5294	0.5420	0.5589	0.5941	0.6289	0.6432	0.6605	0.5556
Lianyungang	0.4919	0.4861	0.5230	0.5532	0.5673	0.6012	0.5878	0.6045	0.6354	0.6233	0.5674
Yancheng	0.5434	0.5949	0.5910	0.6008	0.6098	0.6426	0.6319	0.6644	0.6727	0.6796	0.6231
Nantong	0.6306	0.6277	0.6795	0.6946	0.7092	0.7220	0.7434	0.8039	0.8117	0.8321	0.7255

With respect to the C_t and R_t relationships, the following observations were made: (1) When the C_t of each subsystem was low, the R_t was also low. In this respect, coupling between Rizhao and Yancheng was weak in the early years and the R_t was relatively low, suggesting that each subsystem was at a low developmental level in these two regions during the early years. In addition, the coupling ability between the systems was poorer than that of the other cities, and there was a lack of positive interaction between the subsystems, resulting in poor coordination. Thus, the R_t can be based on the C_t and the R_t is limited by the C_t . (2) When the C_t of each subsystem was high (mean value > 0.9878), there were differences between the R_t . High C_t levels have been maintained in Qingdao, Lianyungang, and Nantong over the past decade. The levels of Qingdao and Nantong were greater than 0.7 in most years, whereas that of Lianyungang was relatively low with a maximum R_t of less than 0.65 (Table 6). These results indicate that the subsystems in Qingdao and Nantong are closely interconnected with positive interactions and adaptability between the systems, and each subsystem contributed to coastal zone coherence. Lianyungang showed a high C_t , but it was less coordinated, and there were fewer positive interactions between the subsystems. These results are related to the conflict between the ecological environment and the development approach arising from the development of the subsystems in the region.

During the last 10 years, the R_t between the coastal zone subsystems of the five cities has increased, and coordination between the systems has improved. The year-by-year coordination levels of the five cities show that Qingdao and Nantong had the highest original levels in 2011 and reached the primary coordination level. Yancheng had the next highest level and reached a barely coordinated level (Figure 5). Lianyungang and Rizhao were ranked lowest (Near disorder) and were in a disordered state. All five cities entered a coordinated state after 2014. From a regional perspective, Qingdao and Nantong maintained a high R_t level and an advanced coordination level after 2018. A higher level of coupling coordination was achieved among the EE, SOC, and ECO subsystems. After 2018, both R_t levels advanced (Figure 5), which was related to a two-level leap between the two cities in a decade. Although Rizhao and Lianyungang did not show a high original coordination level, they achieved a two-level leap from near disorder to primary coordination after many years of development. However, Yancheng has remained at a primary coordination level since 2014, and coordination among the EE, SOC, and ECO subsystems has developed more slowly.

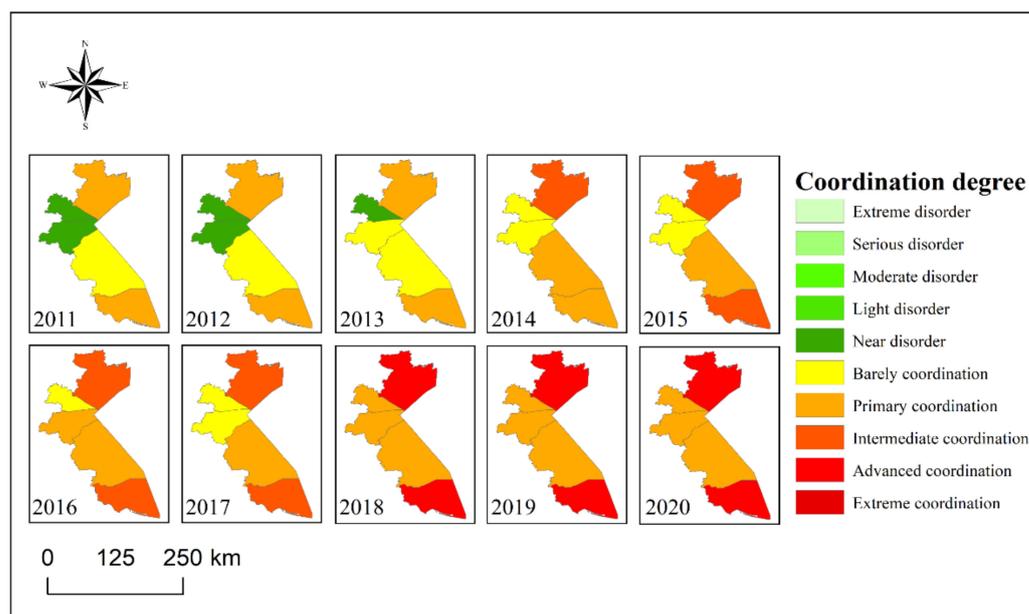


Figure 5. The characteristic of coordination degree of EE, SOC, and ECO from 2011–2020.

4. Discussion

We investigated the level of development and the mechanism of coordinated interactions among subsystems of the coastal zone. Previous coordination studies also focused on coastal areas, but mostly focused on land areas [10,16]. The selection of the evaluation indicators is often set based on experience and relevant previous literature [11] and no appropriate model has been adopted to screen the indicators. We considered the coastal zone as a whole and examined the land and sea areas in one evaluation system to explore the coordinated development between the subsystems, which is in line with the concept of land–sea coordination currently advocated by China in marine management. In addition, the DEMATAL model was used to select evaluation indices, eliminate factors with little impact on the system, and construct a coastal zone evaluation index system based on the key factors. Compared with previous studies, the determination of the spatial scope of the study area is closer to the needs of coastal zone management, the design of the evaluation indicators is more reasonable and objective, and the evaluation results reflect the actual situation of the interactions and collaborations among the coastal zone subsystems in the study area.

According to Equation (15), the R_t is a function of the C_t and the coastal zone comprehensive evaluation index and is positively correlated with both. The comprehensive evaluation index of the coastal zone was influenced by the level of the evaluation index of each subsystem, which showed a positive correlation. Thus, the development of the subsystems in the coastal zone may directly affect the R_t . Therefore, effective paths to the future coordinated development of coastal zones can be explored by examining the developmental law and coupled coordination mechanism of each regional coastal zone subsystem. In this respect, (1) the development of each subsystem in Qingdao and Nantong underwent rapid growth over the last decade, with minimal changes in the C_t but a significant increase in the R_t , indicating that improvement in the development level of each subsystem was the fundamental factor affecting the R_t in the two regions. Qingdao’s “Qingdao City Sea Coastal Zone Protection and Utilization Plan”, which was initiated in 2015, and Nantong’s “Nantong Three-Year Action Plan for Coastline Remediation and Restoration (2018–2020)”, which was initiated in 2018, have directly enhanced the EE subsystem, and a large amount of capital investment and the introduction of technology have led to the development of the SOC subsystem and the consequent enhancement of the ECO subsystem. This has increased the positive interaction between the subsystems, resulting in effective coastal zone development. These results also confirm that improvements in the quality of the

EE subsystem have a large positive effect on the SOC and ECO subsystems. However, Qingdao has experienced a slight decline in the EE subsystem in recent years, and thus it is necessary to focus on protecting the ecological environment and particularly marine life protection in the future. In addition, in Qingdao in 2020, the development of the SOC and ECO subsystems decreased because of the impact of COVID-19, mainly via decreases in marine development activities, coastal tourism revenue, and technological investment. Thus, the local government should increase the input of funds to ensure that work and production resume in accordance with epidemic prevention policies. Furthermore, the developmental level of the EE subsystem in Nantong is lower than that of the SOC and ECO subsystems, and measures are needed to improve the development level of this subsystem and raise the R_t . (2) Rizhao showed a good EE foundation, and the annual evaluation level index of the EE subsystem was higher than that of the SOC and ECO subsystems in the current year. The EE annual growth rate, although not as large as that of ECO, developed rapidly after 2018. The SOC has also grown exponentially, and its development levels have quadrupled over the last decade. Superficially, the Rizhao coastal zone subsystem appears to have been unevenly developed, and the C_t is not as good as that of other regions. However, the region is actively developing the natural ecological environment, tourism, and eco-industry, driving population mobility and employment and making economic and social progress, thus improving the R_t among the subsystems. If Rizhao further deepens its ecological priority strategy, its SOC and ECO subsystems will benefit and the coordination level will be greatly improved. (3) The low C_t of Yancheng in the early years was related to the large gap in the EE, SOC, and ECO development levels. Because of the need for regional development, Yancheng developed the SOC and ECO subsystems by maximizing its unique ecological environment potential and exploiting mudflats. The development levels among the subsystems gradually synergized and the C_t and R_t improved. Although certain achievements have been made in Yancheng, the natural ecological environment has been negatively impacted. This area should focus on protecting the ecological environment. (4) The R_t of Lianyungang fluctuates and is closely related to the fluctuating development of each subsystem. Among the subsystems, there has been a greater fluctuation in the EE evaluation index, whereas that of SOC has undergone cyclical fluctuations of 3–4 years; however, both subsystems have maintained a generally upward trend and the ECO subsystem has maintained an increasing trend. The fluctuating processes of the EE and SOC subsystems caused the C_t to fluctuate significantly, which also resulted in the R_t showing a fluctuating upward trend. This fluctuation may have resulted from the conflict between the EE, SOC, and ECO subsystems, which competing by each subsystem, wax and wane, or increase and decrease in the development process. The upward trend may also be related to continuous regulations enforced by the local government to maintain subsystem stability.

Based on the analysis of the evaluation results, we found three types of coordinated interactions among the subsystems: (1) The subsystems progress simultaneously and interact positively, creating a coordinated development trend. (2) The subsystems compete with each other and fluctuate during development; and (3) The focus is on developing ECO and SOC and neglecting environmental protection. The three approaches reflect the different development paths of the coastal zone in the study area, which reminds us that the government should coordinate the development interests of all parties, and that the quality of the coastal zone development can be improved if all subsystems interact in a benign manner and make concerted progress in the future.

5. Conclusions and Suggestions

We assessed the coordinated developmental levels of the EE, SOC, and ECO subsystems in five regions of the Yellow Sea coast of China. The DEMATEL model was employed to identify 20 key factors influencing coastal zone development, and an indicator system for evaluating coastal zone subsystems was constructed. The indicator weights of the different subsystems were determined using the entropy method, which reduced the influence of subjective opinions to some extent. The C_t and R_t of the EE, SOC and ECO subsystems

were calculated using the coupling coordination degree model to characterize the level of coordinated coastal zone development. The main results are as follows: (1) The levels of development of the three subsystems in the coastal zones within the study area have all improved over the past decade, and the C_t between them has generally remained at a high level, with the R_t between them progressing enormously. (2) Qingdao and Nantong are at a “high coordination” level, with not only a high level of subsystem development but also a high level of coupling and coordination. (3) Rizhao, Yancheng and Lianyungang are at a “primary coordination” level and show uneven development of subsystems; each region should adjust its specific development policies according to its reality and coordinate the development of each subsystem.

The contributions of this study are as follow: (1) it defines the scope of the coastal zone based on coastal zone management and combines the coastal land and sea areas into one evaluation system to explore the development trends and coordinated interaction mechanisms of the subsystems; and (2) it identifies three different interaction mechanisms for coordinated development among the subsystems from the evaluation results. The implementation of different development strategies under different mechanisms will be beneficial for the sustainable development of the coastal zone.

The following recommendations are made based on the mechanisms of coordinated interaction of the different subsystems in the study area: (1) The overall development level of the Qingdao and Nantong coastal zones is better than that of the other study areas; the C_t has been maintained within a high-level range and the R_t has greatly improved with the development of the subsystems. In the future, these two regions should continue to implement relevant coastal zone development and protection plans to emphasize and improve the quality of marine and nearshore ecological environments, enhance the development of the marine economy and marine scientific research, and strive to build a marine center city; (2) Rizhao and Yancheng have relied on their own specific ecological advantages to achieve development; Rizhao has developed by further improving the EE, whereas Yancheng’s development has been achieved by sacrificing part of its EE. Rizhao improved its R_t by two levels and Yancheng improved this degree by only one level. These results demonstrate that implementing strategies that prioritize ecological development is superior to those that encourage development at the expense of the ecological environment. In the future, Rizhao should continue implementing an ecological priority strategy to promote the development of the SOC and ECO subsystems along with the EE subsystem. Yancheng should learn from Rizhao’s coastal zone development experience and increase forest coverage within the coastal zone, improve the near-shore seawater quality and the ability to withstand marine disasters, reduce economic losses, and implement ecological restoration projects in areas that have experienced considerable ecological damage. In addition, the government should actively introduce foreign investment, technology, and highly qualified personnel and adopt a more scientific and rational approach to developing marine resources. (3) the Lianyungang coastal zone is highly coupled; however, the quality of its subsystem development is low, which is related to irrational marine development activities in the area. In the future, Lianyungang should protect marine life and the near-shore ecological environment, as well as improve forest coverage and marine development and utilization. The government should conduct macro-controls to regulate contradictions and conflicts in the development process among the subsystems to improve the stability and quality of subsystem development.

Author Contributions: Methodology, J.F. and M.X.; Data curation, J.F. and Z.C.; Investigation, J.F.; Formal Analysis, J.F.; Writing—Review and Editing, J.F. and B.L.; Funding Acquisition, M.X.; Supervision, M.X. Validation. Z.C. and B.L.; Software, Z.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the special fund for natural resources development of Jiangsu Province, China (Grant No. JSZRHYKJ202002).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Schlüter, A.; Van Assche, K.; Hornidge, A.-K.; Văidianu, N. Land-sea interactions and coastal development: An evolutionary governance perspective. *Mar. Policy* **2020**, *112*, 103801. [CrossRef]
- Luo, Y.M. Sustainability Associated Coastal Eco-environmental Problems and Coastal Science Development in China. *Bull. Chin. Acad. Sci.* **2016**, *31*, 1133–1142. [CrossRef]
- Brommer, M.B.; Bochev-van der Burgh, L.M. Sustainable Coastal Zone Management: A Concept for Forecasting Long-Term and Large-Scale Coastal Evolution. *J. Coast. Res.* **2009**, *251*, 181–188. [CrossRef]
- Brown, C.; Unep, N.E.; Corcoran, E.; Herkenrath, P.; Thonell, J. *Marine and Coastal Ecosystems and Human Well-Being: Synthesis*; United Nations Environment Programme: Nairobi, Kenya, 2006.
- Cohen, J.E.; Small, C.; Mellinger, A.; Gallup, J.; Sachs, J.; Vitousek, P.M.; Mooney, H.A. Estimates of coastal populations. *Science* **1997**, *278*, 1209–1213. [CrossRef]
- Xu, S. Preliminary Study on the Development Stages and Basic Thinking of Strategic Marine Emerging Industries in China. *Mar. Economy* **2011**, *1*, 6–11. [CrossRef]
- Ewing, L.C. Resilience from coastal protection. *Philos. Trans.* **2015**, *373*, 0383. [CrossRef]
- Halpern, B.S.; Walbridge, S.; Selkoe, K.A.; Kappel, C.V.; Micheli, F.; D'Agrosa, C.; Bruno, J.F.; Casey, K.S.; Ebert, C.; Fox, H.E.; et al. A global map of human impact on marine ecosystems. *Science* **2008**, *319*, 948–952. [CrossRef]
- Vitousek, P.M.; Mooney, H.A.; Lubchenco, J.; Melillo, J.M. Human domination of Earth's ecosystems. *Science* **1997**, *277*, 494–499. [CrossRef]
- Cen, X.T.; Wu, C.F.; Xing, X.S.; Fang, M.; Garang, Z.; Wu, Y. Coupling Intensive Land Use and Landscape Ecological Security for Urban Sustainability: An Integrated Socioeconomic Data and Spatial Metrics Analysis in Hangzhou City. *Sustainability* **2015**, *7*, 1459–1482. [CrossRef]
- Fan, Y.P.; Fang, C.L.; Zhang, Q. Coupling coordinated development between social economy and ecological environment in Chinese provincial capital cities—assessment and policy implications. *J. Clean. Prod.* **2019**, *229*, 289–298. [CrossRef]
- Fang, C.L.; Liu, H.M.; Li, G.D. International progress and evaluation on interactive coupling effects between urbanization and the eco-environment. *J. Geogr. Sci.* **2016**, *26*, 1081–1116. [CrossRef]
- Joore, J.P. New to Improved—The Mutual Influence between New Products and Societal Change Processes. VSSD. 2010. Available online: <https://repository.tudelft.nl/islandora/object/uuid%3A447d8e32-25f5-4d16-b1dd-f11cc245829c> (accessed on 10 June 2022). [CrossRef]
- Shi, X.Q.; Yang, J.X. A material flow-based approach for diagnosing urban ecosystem health. *J. Clean. Prod.* **2014**, *64*, 437–446. [CrossRef]
- Lin, X.R.; Lv, Y.P.; Hong, S.J.; Wang, A.L. Research on land and sea coupling coordination degree measurement in coastal zone and its optimization strategy: Taking the coastal zone of Xiamen as an example. *City Plan. Rev.* **2022**, *46*, 54–62. Available online: <https://kns.cnki.net/kcms/detail/11.2378.TU.20211209.0850.002.html> (accessed on 10 June 2022).
- Qv, M.Y.; Chai, H.Q.; Li, Z.G. Coupling research on the two-way development of marine ecological civilization and urbanization in coastal cities. *Arab. J. Geosci.* **2021**, *14*, 1–11. [CrossRef]
- Shang, Y.S.; Liu, S.G. Spatial-Temporal Coupling Coordination Relationship between Urbanization and Green Development in the Coastal Cities of China. *Sustainability* **2021**, *13*, 5339. [CrossRef]
- Xiao, W.W.; Zhao, B.X.; Wang, L.L. Marine Industrial Cluster Structure and Its Coupling Relationship with Urban Development: A Case of Shandong Province. *Pol. Marit. Res.* **2016**, *23*, 115–122. [CrossRef]
- Rosendo, S.; Celliers, L.; Mechisso, M. Doing more with the same: A reality-check on the ability of local government to implement Integrated Coastal Management for climate change adaptation. *Mar. Policy* **2018**, *87*, 29–39. [CrossRef]
- Gibson, J. Integrated Coastal Zone Management Law in the European Union. *Coast. Manag.* **2003**, *31*, 127–136. [CrossRef]
- Tsamenyi, M.; Kenchington, R. Australian Oceans Policymaking. *Coast. Manag.* **2012**, *40*, 119–132. [CrossRef]
- DEDUCE Consortium. Indicators Guidelines to Adopt an Indicators-Based Approach to Evaluate Coastal Sustainable Development [DB/OL]. Available online: https://im.umg.edu.pl/images/ksiazki/2007_indicators_guidelines.pdf (accessed on 10 June 2022).
- Duan, P.L.; Liu, S.G.; Peng, Y.; Zhang, H.F. Spatial-Temporal Coupling Coordination Relationship Between Development Strength and Resource Environmental Bearing Capacity of Coastal Cities in China. *Econ. Geogr.* **2018**, *38*, 60–67. [CrossRef]
- Lou, X.C. Coast, Coastline, Coastal. *Hydrogr. Surv. Charting* **1996**, *2*, 49–54.
- De Andrés, M.; Barragán, J.M.; Scherer, M. Urban centres and coastal zone definition: Which area should we manage? *Land Use Policy* **2018**, *71*, 121–128. [CrossRef]
- Walsh, S.J.; Mena, C.F. Interactions of social, terrestrial, and marine sub-systems in the Galapagos Islands, Ecuador. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 14536–14543. [CrossRef]

27. Gabus, A.; Fontela, E. *World Problems, An Invitation to Further Thought within The Framework of DEMATEL*; Battelle Geneva Research Centre: Geneva, Switzerland, 1972.
28. Si, S.L.; You, X.Y.; Liu, H.C.; Zhang, P. DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications. *Math. Probl. Eng.* **2018**, *2018*, 1–33. [[CrossRef](#)]
29. Wang, Y.B.; Yang, T.B.; Wang, S.D. Evaluation on Urban Public Security Sense Based on Combined Weighting and Grey Correlation. *Stat. Decis.* **2019**, *35*, 45–50. [[CrossRef](#)]
30. Ruehli, A.E. Equivalent circuit models for three-dimensional multiconductor systems. *IEEE Trans. Microw. Theory Tech.* **1974**, *22*, 216–221. [[CrossRef](#)]
31. Vefie, L. *The Penguin Dictionary of Physics*; Foreign Language Press: Beijing, China, 1996; pp. 92–93.
32. Xiong, J.X.; Chen, D.L.; Peng, B.F.; Deng, S.T.; Xie, X.M. Spatio-temporal Difference of Coupling Coordinative Degree of Ecological Carrying Capacity in the Dongting Lake Region. *Sci. Geogr. Sin.* **2014**, *34*, 1108–1116. [[CrossRef](#)]
33. Ashraful Islam, M.; Mitra, D.; Dewan, A.; Akhter, S.H. Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh—A geospatial approach. *Ocean Coast. Manag.* **2016**, *127*, 1–15. [[CrossRef](#)]
34. Djouder, F.; Boutiba, M. Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters: Case of the Gulf Coast of Bejaia, Algeria. *Arab. J. Geosci.* **2017**, *10*, 299. [[CrossRef](#)]
35. Zhao, W.J.; Zhao, G.R.; Yang, J.; Xu, M.; Kou, J.F. Assessment of the Ecological Security of the Coastal Zone of the Guangdong/Hong Kong/Macao Greater Bay Area. *J. Coast. Res.* **2020**, *102*, 287–295. [[CrossRef](#)]
36. Riemann, B.; Carstensen, J.; Dahl, K.; Fossing, H.; Hansen, J.W.; Jakobsen, H.; Josefson, A.B.; Krause-Jensen, D.; Markager, S.; Stæhr, P.A.; et al. Recovery of Danish Coastal Ecosystems after Reductions in Nutrient Loading: A Holistic Ecosystem Approach. *Estuaries Coasts* **2016**, *39*, 82–97. [[CrossRef](#)]
37. Huang, L.H.; Jiang, Y.; Lin, Q.; Li, T.; Chen, F.; Wang, W. Research on the coupling coordination relationship between Xiamen Port development and coastal eco-environment evolution. *Environ. Pollut. Control.* **2020**, *42*, 890–893. [[CrossRef](#)]
38. Chang, L. Study on Coordinated Development with Coastal Zone City Multi-dimensional Coupling System—Taking on Dalian Coastal Zone As An Example. *Environ. Sci. Manag.* **2016**, *41*, 34–38.
39. Sun, T.T.; Lin, W.P.; Chen, G.S.; Guo, P.; Zeng, Y. Wetland ecosystem health assessment through integrating remote sensing and inventory data with an assessment model for the Hangzhou Bay, China. *Sci. Total Environ.* **2016**, *566–567*, 627–640. [[CrossRef](#)]
40. AlQahtany, A.M.; Abubakar, I.R. Public perception and attitudes to disaster risks in a coastal metropolis of Saudi Arabia. *Int. J. Disaster Risk Reduct.* **2020**, *44*, 101422. [[CrossRef](#)]
41. Arkema, K.K.; Guannel, G.; Verutes, G.; Wood, S.A.; Guerry, A.; Ruckelshaus, M.; Kareiva, P.; Lacayo, M.; Silver, J.M. Coastal habitats shield people and property from sea-level rise and storms. *Nat. Clim. Chang.* **2013**, *3*, 913–918. [[CrossRef](#)]
42. Doney, S.C.; Ruckelshaus, M.; Duffy, J.E.; Barry, J.P.; Chan, F.; English, C.A.; Galindo, H.M.; Grebmeier, J.M.; Hollowed, A.B.; Knowlton, N.; et al. Climate Change Impacts on Marine Ecosystems. *Annu. Rev. Mar. Sci.* **2012**, *4*, 11–37. [[CrossRef](#)]
43. Sajjad, M.; Li, Y.F.; Tang, Z.; Cao, L.; Liu, X. Assessing Hazard Vulnerability, Habitat Conservation and Restoration for the Enhancement of China’s Coastal Resilience. *Earths Futur.* **2018**, *6*, 326–338. [[CrossRef](#)]
44. Kirby, R.H.; Reams, M.A.; Lam, N.S.N.; Zou, L.; Dekker, G.G.J.; Fundter, D.Q.P. Assessing Social Vulnerability to Flood Hazards in the Dutch Province of Zeeland. *Int. J. Disaster Risk Sci.* **2019**, *10*, 233–243. [[CrossRef](#)]
45. Ku, H.; Kim, T.; Song, Y.-I. Coastal vulnerability assessment of sea-level rise associated with typhoon-induced surges in South Korea. *Ocean Coast. Manag.* **2021**, *213*, 105884. [[CrossRef](#)]
46. Liu, C.; Liu, G.Y.; Yang, Q.; Luo, T.; He, P.; Franzese, P.P.; Lombardi, G.V. Emergy-based evaluation of world coastal ecosystem services. *Water Res.* **2021**, *204*, 117656. [[CrossRef](#)] [[PubMed](#)]
47. Qiu, Q.Q.; Zhang, Y.; Ying, H.X.; Cui, S.T.; Zhai, L. Development and ecological coupling analysis of Panjin coastal zone. *Sci. Surv. Mapp.* **2017**, *42*, 44–49. [[CrossRef](#)]