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Using the resource-environment-economy coordination degree model to guide China's national blue bay remediation action plan in Qingdao*

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Abstract The China National Blue Bay Remediation Action Plan (NBBRAP) is a crucial step towards achieving the overall goal of building a maritime power and a beautiful ocean. This paper presents the resource-environment-economy (REE) composite system from the three-dimensional perspective of REE. Especially, through the coordination degree model of the composite system based on the order degree of subsystems, empirical analysis of the coordination degree of the REE composite system in a typical coastal city Qingdao from 2005 to 2016 was carried out. Results indicate that the degree of coordination and interactive coordination of the REE composite system in Qingdao were in a low-quality state. Qingdao's economy development depended largely on the expense of over-exploitation of resources and environmental degradation in 2013–2015. Government policy implementation was less persistent in 2009–2010 and 2011–2013. The immediate stimulating effect was significant, making the coordination degree of the REE composite system fluctuate in a volatile manner. Analysis of the coordination degree of the REE composite system has practical guiding significance for the successful implementation attainment of the NBBRAP target in Qingdao and is conducive to deepening the learning and promotion of this plan in other coastal cities.

Keyword: China National Blue Bay Remediation Action Plan; resource-environment-economy; coordination

1 INTRODUCTION

The 21st century is the century of the oceans. Facing the shortage of land resources and the deterioration of the environment, countries around the world have begun to formulate a series of comprehensive management policies of the marine economy and resources (Reis and Lowe, 2012; Qiu and Jones, 2013; Rodwell et al., 2014; Maier, 2014; Vince et al., 2015; Su and Yang, 2018; Wang, 2018). Coastal cities have long been an important base for the development of the marine economy, and the ecological problems in these areas are receiving increasing attention worldwide (Sun et al., 2017). China is a country with abundant marine resources. Its economic development in the coastal region has also brought problems, such as excessive consumption of marine resources and serious environmental degradation, which has increased the pressure on the environment and resources (Wang et al., 2018). There is poor coordination between resource consumption, environmental protection, and economic growth. Therefore, answers to the questions of how to coordinate the relationship among them to maintain high-speed economic growth, save and protect resources reasonably, and improve the environment level are essential requirements of China's important strategy to realize sustainable development. In 2015,

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the Fifth Plenary Session of the Eighteenth Central Committee carried out the China National Blue Bay Remediation Action Plan (NBBRAP), which pointed out a correct direction and a new goal for the ecological environmental management of China's coastal cities.

Qingdao is a typical coastal city in China and is located in the southeast of Shandong Peninsula and on the west coast of the Yellow Sea (Fig.1). Its gross marine product accounted for 27.7% of GDP in 2018 (Qingdao Municipal Statistics Bureau, 2018). There are many bays in the harbor area, with great advantages of maritime location advantages and scientific research strength. Among them, Jiaozhou Bay (JZB) with semi-closed sector, is the largest bay in Qingdao, and has abundant fishery and harbor resources (Zeng et al., 2004; Yu et al., 2006; Xu et al., 2013). In recent years, there has been considerable coastal economic development activity in Qingdao, which has damaged the balance of the marine ecological environment (Han et al., 2011; Zhang et al., 2017). The problems, such as the recession of marine resources, the decline of environmental carrying capacity, and the deterioration of water quality, are becoming increasingly severe. Therefore, it is essential to discuss the level of coordinated development of resources, environment, and economy in Qingdao, which not only affects the sustainability and harmony of the local economy and society but also affects the economic development of Qingdao and even the Shandong Peninsula. In 2016, Qingdao was approved to participate in the NBBRAP, and took the lead in launching it in Huangdao District in the same year. Therefore, analysis of Qingdao's coordination degree under the increasing constraints of resources and environment has essential theoretical and practical guiding significance for the smooth completion of the anticipated objectives of the NBBRAP. And it is also an excellent reference for the sustainable development of other coastal cities that also have been approved to join this plan in China.

In order to reveal the internal mechanism of sustainable economic growth, economists such as Romer (1986), Lucas (1988), Grossman and Helpman (1993) internalized technological progress and put forward endogenous growth theory. On this basis, some scholars like Smulders (1995) and Wang (2000) further introduced natural resources and environment as endogenous factors into the production function, and discussed resource consumption and ecological environment deterioration under the framework of endogenous growth model, to achieve sustainable

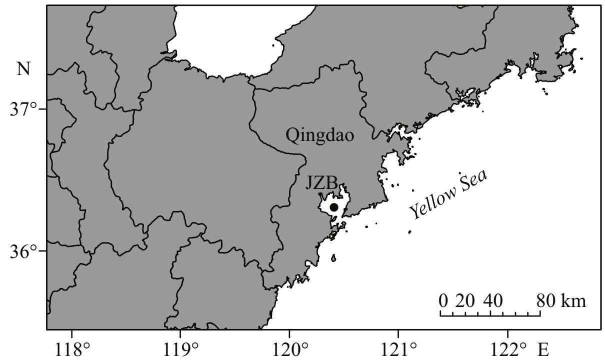

Fig.1 Location of Qingdao

economic development. Resources, environment, and economy are applied theory as a whole by scholars to the gradually study of sustainable. The implementation of the NBBRAP is an extension of the sustainable development concept in the marine field. Many scholars have conducted research on sustainable marine development (Kwak et al., 2005; Kildow and McIlgorm, 2010; Gogoberidze, 2012; Monaco and Prouzet, 2015; Stead, 2018). For the marine sector, it is necessary to understand the coordinated development of resources, environment, and economy of coastal cities for achieving sustainable development.

For the coordinated development of the resource-environment-economy (REE), many scholars concentrated on the coordination of economy and resources or economy and environment (Eichner and Pethig, 2005; Li et al., 2016; Drews et al., 2018). Furthermore, some scholars focused on economic development at the level of urbanization, studying the coordinated development between urban development level and ecological environment (Zhang et al., 2008; Wang et al., 2014). Some scholars refined resources and environment, and study the coordination between economic development and CO_2 emissions, water resources (Wang et al., 2015; He et al., 2018). In addition, there are scholars who have integrated institutional quality and climate into the coordinated development study (Arminen and Menegaki, 2019). With the deepening research, scholars have used and developed the coupling coordination model to analyze the coupling and coordinated development of regional resource, environment, and economic development at the provincial level (Shen et al., 2018; Song et al., 2018; Cheng et al., 2019) or municipal city level (Xiong, 2011; Liu et al., 2018; Xing et al., 2019), respectively.

Studies at present focus on the coordinated development between regional ecological resources and environment (e.g., air pollution, water resources, and carbon emissions) and economic development (e.g., urbanization, and economic growth), from the perspective of the interaction and coupling relationship, which provided a series of reference opinions for the sustainable and high-quality development of the regional economy from various perspectives and makes important research contributions in the field of the REE coordinated development. However, available results often involve only one or two subsystems, and it is rare that multiple subsystems are placed in the same system. Moreover, even considering the resources, the economy, the environment, and other subsystems in the actual operation, the interaction and coupling relationship between the systems are mostly emphasized. In addition, the REE coordination degree based on the order degree of subsystems is seldom studied. Secondly, most of the above studies have been carried out at national, provincial, or regional level, with more macro-analysis. The micro-analysis also focuses on inland cities. There are still some deficiencies in the analysis of the overall REE coordination degree of coastal cities, which is dominated by the development and utilization of marine resources. Considering the situation comprehensively in the three-dimensional perspective of the REE, we built an index system of coastal cities, and then explore the coordination degree of the overall system of resource, environment, and economy in Qingdao. This is innovative in expanding the REE research into the marine field and further broadening the application in coastal cities. Moreover, we use the coordination degree model of the composite system based on the order degree of subsystems for analysis. This can not only simplify the complicated relationship of the systems but also deeply explore the root factors that affect the disorder and inconsistency of the overall system, and put forward more specific and targeted policy recommendations, which have particular practical guiding significance and innovation value.

Section 2 presents system characteristics and builds model. Section 3 provides index system and data sources. Section 4 presents the results. The final section concludes and suggests.

2 COORDINATION DEGREE OF A RESOURCE-ENVIRONMENT-ECONOMY COMPOSITE SYSTEM

2.1 System characteristics

The REE composite system is an open, dynamic system formed by two or more subsystems through the relationship between elements. It has dual characteristics of natural and human-made systems, which influence and restrict each other in the whole system. Within the system, the resources are the basis of supporting human survival and economic-social development. It provides material base for the economy, and the utilization of it can cause the demand of environmental protection. The environment is the guarantee of the REE composite system. It creates conditions and space for economic development and a good environment is conducive to the regeneration of resources. Economy is the core of the whole REE system, which provided a technical support for resource development and environmental protection. The healthy operation of the composite system depends on the interaction and feedback of subsystems. Because of its natural characteristic, it has the function of self-recovery for normal resource consumption and environmental pollution. However, excessive human economic activities will exceed the limit of self-recovery ability, and certain management activities are required to repair the system at this time. The proposal of the NBBRAP aims to solve the problems of marine environmental pollution and over-exploitation of resources caused by intensive coastal development in essence, and promotes the economic sustainability of coastal development (Wang and Wang, 2018). According to the content of the action plan and system characteristics, using the REE composite system to analyze the NBBRAP of Qingdao and other coastal cities is suitable.

2.2 Model building

Most of the studies on the coordination degree of the system are based on the coupling coordination degree model (Xiong, 2011; Liu et al., 2018; Shen et al., 2018; Song et al., 2018; Cheng et al., 2019; Xing et al., 2019), but it is mostly applicable to the analysis between two systems, and it is unable to analyze the order degree of the subsystem. The coordination degree model of the composite system based on the order degree of subsystem can calculate the coordination degree of more than two subsystems scientifically and effectively by simplifying the complex system relationship, and can also analyze the cooperative evolution law of each subsystem and element in the composite system, to clarify the subsystem that plays the leading role. Thus, we summarize and review the previous research results (Wu et al., 1996; Meng and Han, 2000) and uses traditional method to analyze the coordinated development in coastal areas. The smooth implementation of the NBBRAP depends on the overall coordinated development of resources, environment, and economy in the coastal areas. It needs to take into account the contribution of the resource subsystem and the carrying capacity of the environmental subsystem while the economic subsystem is developing. In addition, each subsystem in the composite system must also develop in an orderly direction, and its changes can have an impact on the overall composite system. Therefore, it is appropriate to use the coordination degree model of REE composite system for analyzing the implementation of the NBBRAP of coastal cities.

2.2.1 Standardization of indicator data

For the order parameter $D_1=(D_{11}, D_{12}, \cdots, D_{1j}, \cdots, D_{1n})$ under resource subsystem B_1, we set its value as $d_1=(d_{11}, d_{12}, \cdots, d_{1j}, \cdots, d_{1n})$; for the order parameter $D_2=(D_{21}, D_{22}, \cdots, D_{2j}, \cdots, D_{2n})$ under environment subsystem B_2, we set its value as $d_2=(d_{21}, d_{22}, \cdots, d_{2j}, \cdots, d_{2n})$; for the order parameter $D_3=(D_{31}, D_{32}, \cdots, D_{3j}, \cdots, D_{3n})$ under economy subsystem B_3, we set its value as $d_3=(d_{31}, d_{32}, \cdots, d_{3j}, \cdots, d_{3n})$. Considering that the original data of the selected indicators differ in dimension and orders of magnitude, the indicator data were standardized by the following formulas:

$$U\left(D_{ij}\right)=\frac{\beta_{ij}-d_{ij}}{\beta_{ij}-\alpha_{ij}},\left(\alpha_{ij}\le d_{ij}\le\beta_{ij}\right),$$
$$U\left(D_{ij}\right)=\frac{d_{ij}-\alpha_{ij}}{\beta_{ij}-\alpha_{ij}},\left(\alpha_{ij}\le d_{ij}\le\beta_{ij}\right). \quad (1)$$

It is assumed that α_{ij} and β_{ij} are their lower and upper limits respectively, namely, $(\alpha_{ij}\le d_{ij}\le\beta_{ij})$, $j\in[1, n]$, $(i=1, 2, 3)$. The change of order parameters has two effects on the orderliness of subsystems: one is the positive effect, that is, the increased value of order parameters will increase the orderliness of the system, such as per capita fishery cultivation area. We use the first formula of Eq.1 to standardize. The other is the negative effect and that means the increased value of order parameters will reduce the orderliness of the system, such as total industrial wastewater emission. We use the second formula of Eq.1 to standardize. If the value of the order parameter is higher than is the planning value, it is calculated by 1 in the positive effect and 10^{-6} in the negative effect; if the value of the order parameter is lower than is the planning value, it is calculated by 10^{-6} in the positive effect and 1 in the negative effect.

2.2.2 Order degree calculation of subsystem

The geometric averaging method is used to measure the order degree of the resource, environment and economy subsystems. The specific formula is as follows:

$$U_i\left(D_i\right)=\sqrt[n]{U\left(D_{i1}\right)U\left(D_{i2}\right)\cdots U\left(D_{in}\right)}$$
$$=\sqrt[n]{\prod_{j=1}^{n}U\left(D_{ij}\right)}, \quad (2)$$

2.2.3 Coordination degree calculation of the composite system

The level of coordinated development of the REE composite system is represented by REE. The specific formula is as follows:

$$\mathrm{REE}=\theta\sqrt[3]{\prod_{i=1}^{3}\left(U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\right)}$$
$$\theta=\frac{\min\left\{U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\neq 0\right\}}{\left|\min\left\{U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\neq 0\right\}\right|},i\in\left[1,3\right]. \quad (3)$$

For a given initial moment t_0, the order degrees of the resource, environment, and economy subsystems are U_i^0, $i\in[1, 3]$, and when the composite system evolves for the moment t_1, the order degree of each subsystem is U_i^1, $i\in[1, 3]$. The change range of order degree of systems with order parameters is $U_i^1(D_i)-U_i^0(D_i)$. REE$\in[-1, 1]$, the greater its value, the higher the coordinated development of the composite system, and vice versa. The parameter θ denotes that if and only if $U_i^1(D_i)-U_i^0(D_i)>0$, $\forall_i\in[1, 3]$, the composite system has a positive coordination degree.

2.2.4 Interactive coordination degree calculation of the two subsystems

Analyzing the interactive coordination degree of the two subsystems of the REE can not only reflect the time series difference between the two systems but also provide a certain explanation for the conclusion of the coordinated development of coastal cities' economy and society.

$$\mathrm{IC}=\theta\sqrt{\prod_{i=1}^{2}\left(U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\right)}$$
$$\theta=\frac{\min\left\{U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\neq 0\right\}}{\left|\min\left\{U_i^1\left(D_i\right)-U_i^0\left(D_i\right)\neq 0\right\}\right|},i\in\left[1,2\right]. \quad (4)$$

To fully reflect the coordination degree grade, we refer to relevant scholars (Tian et al., 2016; Xing et al., 2019) to develop the evaluation criteria, as shown in Table 1 below.

Table 1 Evaluation criteria of coordination degree grade

Degree section	[-1, 0)	[0, 0.3)	[0.3, 0.5)	[0.5, 0.8)	[0.8, 1]
Coordination degree grade	Uncoordination	Low coordination	General coordination	High coordination	Perfect coordination

Table 2 Coordination degree index system of the resource-environment-economy composite system

Destination layer (A)	System layer (B)	Criterion layer (C)	Order parameter index layer (D)
Resource-environment-economy coordinated development (A)	Resource subsystem (B_1)	Biological resources (C_1)	Per capita fishery cultivation area (D_{11})
			Per capita output of aquatic products (D_{12})
		Seawater resources (C_2)	Area of seawater of Class I and Class II qualifying the standard (D_{13})
		Oil and gas resources (C_3)	Per capita marine crude oil production (D_{14})
			Per capita natural gas production (D_{15})
		Space resources (C_4)	Per capita coastline length (D_{16})
			Per capita sea area (D_{17})
			Cargo throughput of ports (D_{18})
			Total numbers of tourists (D_{19})
	Environment subsystem (B_2)	Pollution emission (C_5)	Ocean dumping of three types of dredged material (D_{21})
			Total industrial wastewater emission (D_{22})
			Total chemical oxygen demand emission (D_{23})
			Total ammonia nitrogen emission (D_{24})
		Pollution treatment (C_6)	Comprehensive utilization of industrial solid waste (D_{25})
			The treatment capacity of wastewater treatment facility (D_{26})
	Economy subsystem (B_3)	Economic development (C_7)	Per capita GDP (D_{31})
			The proportion of tertiary production to the total GDP (D_{32})
			Total amount of fixed asset investment above the scale (D_{33})
			Urban per capita disposable income (D_{34})
			Social employment (D_{35})
		Economic innovation (C_8)	Science and technique achievements(D_{36})
			Expenses of independent scientific research institutions (D_{37})

3 INDEX SYSTEM AND DATA SOURCES

3.1 Construction of index system

The establishment of the coordination degree index system of REE is the basis for evaluating the coordination degree of the composite system. The selection principle of the REE indicators are: it can reflect the resources, environment, and economy of coastal cities comprehensively, and also response the main characteristics of coordinated development of coastal areas. Moreover, the indicators must be continuous in time, not only to be able to assess the current situation accurately, but also to be able to better describe and measure the past situation and future development trends. Therefore, we constructed the index system shown in Table 2, based on previous case studies (Zhang et al., 2008; Shen et al., 2015, 2018; Cheng et al., 2019; Xing et al., 2019) and combined the overall correspondence, appropriate proportions, outstanding emphasis, and other principles.

(1) The REE coordinated development is taken as the destination layer, with the resource, environment and economy subsystem at the system level.

(2) The resource contribution of coastal cities is fully reflected by biological resources, seawater resources, oil and gas resources, and space resources. Among them, coastal cities are built by the sea, and their biological resources refer to the total amount of economic animals and plants contained in the sea mainly. Therefore, we choose per capita fishery cultivation area and per capita output of aquatic products for analysis. Oil and gas resources and seawater resources have a large development space, which is an important direction of future development of marine resources. In this paper, per capita marine

crude oil production, per capita natural gas production, and area of seawater of Class I and Class II qualifying the standard are selected to reflect. Space resources refer to the marine space used as the resources of transportation, production, tourism, leisure, and other activities, while the marine industry and coastal tourism are the pillar industries of most coastal cities. Therefore, the indicators of per capita coastline length, per capita sea area, cargo throughput of ports and total numbers of tourists are selected to reflect the contribution of space resources to the coastal cities' resources comprehensively.

(3) Marine pollution caused by intensive economic development activities affects the environmental conditions in coastal areas, and pollution control can reduce the impact of pollution. Therefore, we reflect the environmental carrying capacity of coastal areas from two aspects: pollution emission and pollution treatment. For pollution emission, the main choice is the amount of pollutants generated by human activities and discharged into the sea directly, such as ocean dumping of three types of dredged material, total industrial wastewater emission, total chemical oxygen demand emission and so on. For pollution emission, choosing solid waste and wastewater treatment indicators that can reflect fully the capacity and level of treatment for analysis, such as comprehensive utilization of industrial solid waste and the treatment capacity of wastewater treatment facility.

(4) The economic subsystem needs to be changed from the disordered state of over development to the orderly state, which can be reflected by economic development and economic innovation. We choose indicators such as per capita GDP, total amount of fixed asset investment above the scale, urban per capita disposable income, and social employment to reflect the level of economic development comprehensively. The optimization and promotion of the development structure is mainly to improve the industrial structure, so the proportion of tertiary production to the total GDP is chosen. In addition, economic innovation can be expressed through the scientific and technological innovation that can reflect the potential of economic development. Therefore, we select science and technique achievements and expense of independent scientific research institutions as indicators.

3.2 Data sources

Without destroying the completeness and rationality of the above coordination degree index system of the REE, we combine the actual situation of

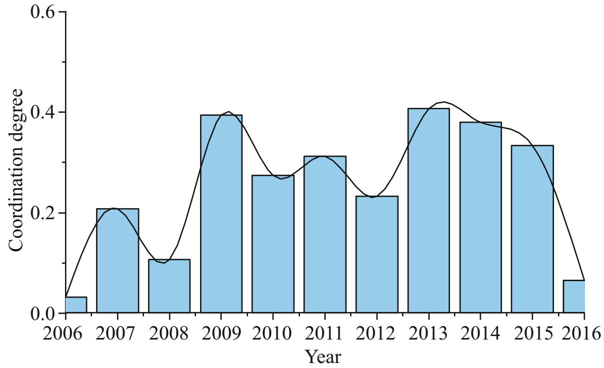

Fig.2 Coordination degree of the composite system

Bars indicate the level of coordination degree of the composite system and the curve indicates the changing trend of coordination degree of the composite system.

Qingdao City and choose 18 indicators to analyze the coordinated development level of city's resources, environment, and economy. The original data choose related time series data of city's resource, environment, and economy system order parameter index from 2005 to 2016, mainly from the Qingdao Statistical Yearbook and the Qingdao Marine Environment Bulletin. Some hard-to-obtain data, such as per capita GDP, per capita area of fishery cultivation area, and the total numbers of tourism, are calculated by the author.

4 RESULT AND DISCUSSION

In this study, we select 1.02 times the maximum and minimum values of the order parameter data of each subsystem from 2006 to 2015 as the upper and lower limits of the index system. The original data are calculated preliminarily according to Eq.1 in this paper, and then the calculated results are brought into Eqs.2, 3, and 4. The order degree of subsystems, the coordination degree of the composite system, and the interactive coordination degree between the two subsystems are shown in Table 3 and Figs.2–4.

First, we analyze the level of coordination of Qingdao City. As shown in Table 2, during 2006–2016, the coordination degree of the composite system did not reach a level of either high coordination or perfect coordination, but appears to be in low quality. The coordination degree of the composite system achieved a general coordination level in 2009, 2011, and 2013–2015, and a low level in the remaining years. The level of the three interactive coordination degrees over the years was also close to the coordination degree of the composite system, still at either a low or general coordination state, and did not reach a high-quality coordination state. The interactive

Table 3 Coordination degree values of composite system

Year	Order degree of resource subsystem	Order degree of environment subsystem	Order degree of economy subsystem	Coordination degree of composite system	Interactive coordination degree of resource-environment	Interactive coordination degree of environment-economy	Interactive coordination degree of resource-economy
2005	0.000 716	0.059 127	0.000 027	–	–	–	–
2006	0.131 215	0.075 035	0.015 253	0.031 619	0.045 563	0.015 564	0.044 576
2007	0.178 221	0.483 600	0.118 024	0.207 162	0.274 492	0.223 800	0.144 724
2008	0.027 816	0.300 580	0.185 117	0.106 593	0.080 891	0.211 401	0.070 823
2009	0.392 536	0.583 623	0.296 694	0.393 580	0.453 330	0.394 462	0.340 940
2010	0.434 551	0.185 906	0.373 973	0.273 985	0.234 523	0.217 734	0.402 779
2011	0.458 939	0.251 398	0.344 600	0.311 954	0.296 822	0.257 394	0.397 355
2012	0.438 657	0.338 489	0.103 345	0.232 945	0.349 777	0.169 892	0.212 714
2013	0.392 692	0.380 316	0.533 823	0.406 567	0.354 822	0.414 065	0.457 422
2014	0.280 219	0.374 758	0.621 883	0.379 972	0.297 018	0.443 032	0.416 906
2015	0.195 286	0.294 502	0.809 206	0.333 396	0.214 002	0.436 417	0.396 790
2016	0.007 108	0.110 046	0.850 195	0.065 163	0.018 040	0.208 062	0.073 716

– means no data.

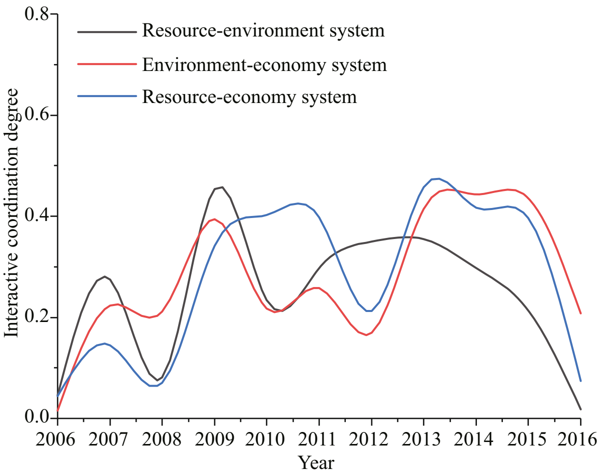

Fig.3 Interactive coordination degree between subsystems

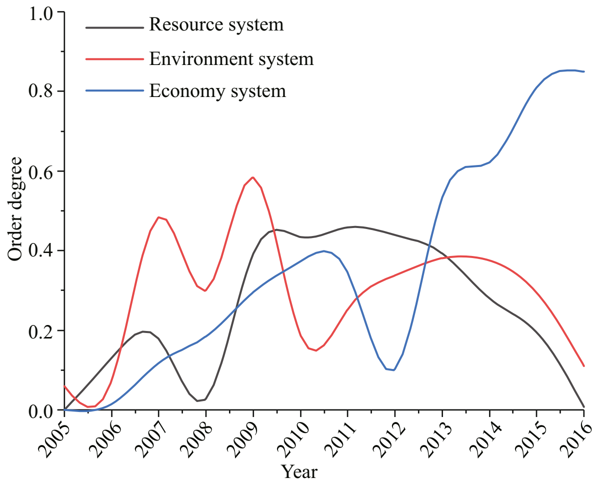

Fig.4 Order degree of subsystems

coordination degree of the resource-environment subsystem reached general coordination in 2009, 2012, and 2013, the resource-economy subsystem reached general coordination in 2009 and 2013–2015, and the environment-economy subsystem reached general coordination status more often than others, reaching that level in 2009–2011 and 2013–2015. Moreover, the three interactive coordination degrees were at a low coordination state in the other years. Second, the changing trend of coordination degree and order degree of Qingdao can be reflected fully in Figs.2–4. As can be seen in Fig.2, the overall change in the coordination degree of the composite system in Qingdao was in an irregular state and did not show a favorable development trend. The time-series difference (Fig.3) of the interactive coordination between the two subsystems in Qingdao was analyzed. These three coordination degrees also showed unstable fluctuation in 2006–2016. The trend of the interaction coordination degree of the environment-economy subsystem was consistent with the coordination degree of the composite system. The resource-economy and resource-environment subsystems were also the same, whereas there were some differences in 2009–2010 and 2011–2013. Furthermore, in Fig.4, we can see that except for a sharp decrease in 2008, the order degree of the resource subsystem generally showed a change trend from slowly increasing to decreasing. The order degree of the environment subsystem fluctuated sharply before 2010, and then increased to decrease slowly after 2010. The order degree of the economy subsystem increased slowly before 2012 and then decreased, which began to increase sharply after 2012.

Further analysis of Figs.2–4 shows that the coordination degree of the composite system first increased and then decreased from 2006 to 2008, while the order degree of the economy subsystem increased slowly and that of both the resource and the environment subsystems increased and then decreased. The three interactive coordination degrees were also consistent with the changing trend of the coordination degree of the composite system. This means that, during this period, both the composite system and the interactive coordination degrees are subject mainly to the changes of the resource and environment subsystems. From 2008 to 2009, the coordination degree of the composite system and the three interactive coordination degrees increased massively, and they all reached a general coordination state in 2009. Combined with the actual situation in Qingdao, it can be seen that, as a co-host city of the 2008 Beijing Olympic Games, Qingdao benefited greatly from the Olympic dividend. In the summer of 2008, for example, Qingdao spent nearly $100 million to clean up algae inshore to meet the Olympic standards (Wang et al., 2009). During this period, the order degree of the resource and environment subsystems changed from decreasing to increasing under the stimulation of the Olympic dividend, while the order degree of the economy subsystem maintained the original increasing trend, increasing the coordination level of the composite system and the interactive coordination. This shows that the Qingdao government department was able to seize the opportunity of the Olympics and improve the coordination level of Qingdao through improvement of the ecological environment.

Subsequently, the coordination degree of the composite system fluctuated between 2009 and 2013 and reached a general coordination state in 2011 and 2013. The coordination degree of the composite system dropped sharply in 2009–2010, and the resource-economy subsystem also showed inconsistency with the composite system. Considering the order degree change of subsystems, it can be seen that this is related to the environment subsystem. When the order degrees of the resource and economy subsystems continue to increase, there are significant increases in the emissions of some types of pollutants, such as chemical oxygen demand, ammonia nitrogen, and industrial wastewater, which increased from 48 479.82 tons, 6 154.38 tons and 10 401.73 tons, respectively, in 2009 to 166 962.71 tons, 14 473.92 tons and 10 800.37 tons, respectively, in 2010 (Qingdao Municipal Statistics Bureau, 2011, 2012). Consequently, the order degree of the environment subsystem has been reduced greatly, exceeding the increases of the resource and economy subsystems. This shows that the Qingdao Municipal Government weakened the implementation of environmental policies after the Olympic Games, and the immediate stimulus characteristics of the policies are significant.

However, the reduction of the coordination degree of the composite system in 2011–2012 and the inconsistency between the resource-environment subsystem and the composite system is related mainly to the reduction of the order degree of the economy subsystem. Although the environment subsystem appeared to increase slightly, the resource subsystem reduced slightly, especially in the order degree of science and technology innovation indicators, which led first to a significant reduction of the economy subsystem and, ultimately, to a reduction in the coordination degree of the composite system. The science and technology achievements and the expenses of independent scientific research institutions fell from 345 items and 2.3 billion Yuan in 2011 to 304 items and 2.1 billion Yuan in 2012, respectively (Qingdao Municipal Statistics Bureau, 2013). Since then, the coordination degree of the composite system has increased owing to the significant increase in the order degree of science and technology innovation indicators in 2012–2013. The number of scientific and technological achievements and the expenses of independent scientific research institutions have increased to 433 items and 2.3 billion Yuan, respectively (Qingdao Municipal Statistics Bureau, 2014). This indicates that the effect of the implementation of the science and technology policy is also unstable, leading to fluctuations in the coordination of the composite system.

Although the coordination degree of the composite system decreased from 2013 to 2015, it was in a general coordination state. At that time, the order degree of the economy subsystem increased, whereas the order degree of both the resource and the environment subsystems decreased slowly. The joint force of the two types eventually led to a slow reduction of the coordination degree of the composite system. However, because the order degree of the economy subsystem increased significantly, the coordination degree of the composite system was still in the general coordination state. During this period, the interactive coordination degree of the resource-environment and the resource-economy subsystems were also decreasing, and the interactive coordination degree of the environment-economy subsystem increased slightly and then decreased. This also illustrates that in the last three years of the 12th Five-Year Plan, Qingdao developed its economy through excessive consumption of resources and environmental pollution. In 2016, the coordination degree of the composite system and the three interaction coordination degrees decreased significantly, caused by the further enhancement of the order degree reduction of the resource and environment subsystems and the slowdown of the increase of the economy subsystem. This means that during this period, the Qingdao Municipal Government formed the negative idea of developing the economy at the cost of eco-environmental destruction, which runs counter to sustainable development and reflects the urgency and necessity of implementing the NBBRAP in Qingdao.

5 CONCLUSION AND RECOMMENDATION

This study provides new thinking on the coordinated development of coastal cities. To this end, we examined the coordination degree of the resource-environment-economy (REE) composite system using related data from Qingdao city. We used the index system of the REE and the coordination degree model based on the order degree of subsystems. We found that the coordination degree of the composite system and interactive coordination degrees in Qingdao are in a low degree and a general coordination state, and have not reached a high-quality coordination level. Therefore, Qingdao has a long way to go in promoting coordinated development. After 2013, the coordination degree of the composite system and the interactive coordination degree decreased, accompanied by an increase of the order degree of the economy subsystem and a decrease of the order degree of both the resource and the environment subsystems, indicating that the economic development of Qingdao is due mainly to the excessive consumption of resources and the environmental pollution. This makes it challenging to improve the coordination level of the composite system.

Moreover, the coordination degree of the composite system and the interactive coordination degree are also precarious, and it is difficult to maintain a good development trend without the influence of external conditions. As an external intervention agency, the Qingdao government department can stimulate the overall economic development of Qingdao in a coordinated and orderly manner. However, the early stage effect is significant and is more likely to fluctuate due to weak implementation later. The increase in the coordination degree of the composite system and interactive coordination degree in 2008–2009 reflects the fact that Qingdao has enjoyed the Olympic dividend thoroughly. However, the decline of the environment subsystem in subsequent years also shows that the government pursues too many superficial achievements, and the persistence of policy implementation is poor. The fluctuation of science and technology innovation indicators from 2011 to 2013 also illustrates that. With the opportunity of being approved to join the NBBRAP, we conclude that Qingdao should accelerate its economic development towards a good trend of going from quantity to quality and consistency, following a series of policy measures, such as the Qingdao 13th Five-Year Plan for the Construction of Blue Economic Zone and Qingdao City's "Ocean+" Development Plan, to work toward healthy development of the blue economy. Based on the previous analysis, we put forward the following suggestions in combination with the actual situation of Qingdao:

Firstly, increase the efficiency of scientific and technological innovation to realize the coordinated development of the REE. During the research period, the indicators of economic innovation are not stable, which affect the order degree of the economic subsystem and the coordination degree of the overall composite system. As a leading city in marine science and technology, Qingdao's steady growth in marine science and technology investment will be conducive to the protection of resources and environment, and thus maintain the sustainable development of the coastal cities' economy. For one thing, Qingdao should further increase its investment in scientific and technological research institutions and the number of achievements based on the construction of "Blue Silicon Valley". Then, the establishment of ocean science and technology achievements promotion center and construction of a marine science and technology achievements' application platform are indispensable. For another thing, it is necessary to strengthen the training and introduction of marine science and technology talents among universities, scientific research institutions, and enterprises, deepen the improvement of the skills of talented people, and combine CEEUSRO to transform scientific research and innovation achievements into productive forces smoothly and rapidly, to ensure the steady advance of the order degree of the economy subsystem and to realize the coordinated development of the whole REE in Qingdao.

Secondly, improve the governance of offshore resources and environment to maintain high-quality development of the REE. Strengthen the rational development of resources and protection for the environment while promoting economic growth. From the empirical results, it can be seen that the fluctuation of environment and resource, especially the environment subsystem, led to the instability of the overall composite system for many times. The protection of resources and environment is also one of the essential needs of the NBBRAP. On the one hand, we should scientifically explore the carrying capacity of offshore resources to avoid over-exploitation. We need to make overall plans for economic development activities in offshore areas such as mariculture and coastal tourism and reduce emissions of industrial wastewater and solid waste directly into the sea while further improving pollutant treatment capacity. On the other hand, we should do an excellent job in real-time monitoring of economic activities in the coastal areas, highlight the ecological supervision of "Three Bays and One Line" (Jiaozhou Bay, Laoshan Bay, Lingshan Bay, and the urban coastal line), and improve the monitoring of the emergency disposal system of "Three Lines of Defense" (sea interception line, sea salvage line, shore cleaning line). In this way, we can improve the orderly level of resources and environment in Qingdao and maintain high-quality development of the overall REE comprehensively.

Finally, strengthen the sustainability of policy implementation to improve the stability of the coordinated development of the REE. The empirical results show that the eco-environment policies implemented by the government have certain effect on the system intervention. The eco-environment policy opinions and the greening and environmental protection projects implemented by Qingdao in the application of the "Green Olympics" are particularly eye-catching. The same is true for Qingdao's new round of environmental quality improvement programs during the preparations for the Shanghai Cooperation Organization Qingdao summit, but it is difficult to maintain long-term. To prolong the timeliness of the Olympic dividend and the summit dividend and avoid the phenomenon of lax policy implementation in a later period, Qingdao should give full play to its supervisory role at the national level, with the form of up-bottom inspection. In addition, we should strengthen the sense of supervision of public opinion at the same time, conducting bottom-up guidance through spontaneous public exposing and abandoning the backward thinking of pursuing "surface achievements" blindly. Qingdao needs to improve the long-term mechanism of beautiful Qingdao action, deepen the policy protection of the eco-environment, and improve the stability of the coordinated development of the REE of Qingdao.

6 DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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