Coupling Analysis of Eco-Economic Systems in the Ecological Restoration of the Kubuqi Desert (Postprint)

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Abstract

Taking the Kubuqi Desert, a typical ecologically fragile area, as the study region, this study conducts a dynamic quantitative analysis of the coupling status of the eco-economic system for ecological governance in the Kubuqi Desert from 2008 to 2017 based on the coupling degree model and coupling coordination degree model. The results indicate that: (1) From 2008 to 2017, the coupling development of the eco-economic system for ecological governance in the Kubuqi Desert demonstrated a stable trend at a relatively high level, with the coupling degree mostly maintained between 0.819 8 and 1, exhibiting an alternating pattern of initial decline followed by subsequent increase. (2) From 2008 to 2010, the ecosystem parameter contribution degree of ecological governance in the Kubuqi Desert was lower than that of its socio-economic system, whereas from 2011 to 2017, the reverse was true, and the temporal variation of parameter contribution degrees for both systems showed a year-by-year increasing trend. (3) From 2008 to 2017, the coupling coordination degree of the eco-economic system for ecological governance in the Kubuqi Desert increased annually, with its coupling pattern transitioning from disordered recession type and excessive development type to coordinated development type, and significant differences existed among coupling pattern types across different years. (4) From 2008 to 2012, the system coupling degree remained at a high level, but the coupling coordination degree was not at a high level. From 2013 to 2017, the variation trends of system coupling degree and coupling coordination degree were basically consistent. In the future, desertification areas in Kubuqi should prioritize promoting ecological economization and economic ecologization as key breakthrough points to achieve regional eco-economic sustainable development.

Full Text

Coupling Analysis of the Eco-Economic System for Ecological Management in the Hobq Desert

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Abstract

Taking the Hobq Desert—a typical ecologically fragile region—as the study area, this paper conducts a dynamic quantitative analysis of the coupling status of the eco-economic system for ecological management in the Hobq Desert from 2008 to 2017 based on coupling degree and coupling coordination degree models. The results show that: (1) The coupled development of the eco-economic system for ecological management in the Hobq Desert exhibited a stable trend at a relatively high level from 2008 to 2017, with the coupling degree mostly between 0.8198 and 1, showing an alternating pattern of initial decline followed by subsequent increase. (2) From 2008 to 2010, the contribution of ecosystem parameters was less than that of socioeconomic system parameters for ecological management in the Hobq Desert, while the opposite was true from 2011 to 2017. The temporal variation of parameter contributions from both systems showed an increasing trend year by year. (3) The coupling coordination degree of the eco-economic system increased annually from 2008 to 2017. The coupling pattern underwent changes from dysfunctional decline and over-development to coordinated development, with significant differences in coupling pattern types across different years. (4) From 2008 to 2012, the system coupling degree remained high, but the coupling coordination degree was not high. From 2013 to 2017, the variation trends of system coupling degree and coupling coordination degree were basically consistent. In the future, desertification areas in the Hobq Desert should focus on promoting ecological economization and economic ecologization as key breakthrough points to achieve sustainable development of the regional eco-economy.

Keywords: desertification control; coupling degree; coupling coordination degree; eco-economic system; Hobq Desert

1. Introduction

Desertification is one of the major ecological and environmental problems facing the world today, and its intensification poses a serious threat to human survival and socioeconomic development [1]. In recent years, desertification

control has attracted high attention from academia and political circles [2]. Desertification control is a comprehensive project involving regional ecosystems and socioeconomic systems [3]. Since the beginning of the 21st century, China has implemented a series of desertification control projects centered on returning farmland to forests and grasslands, grassland grazing bans, and natural forest protection, which have greatly promoted regional ecological environment improvement and socioeconomic development [4]. Given that desertification control involves ecology, society, economy, and technology, correctly coordinating the various interest relationships in desertification prevention is crucial.

System coupling refers to the phenomenon where two or more systems interact and become mutually compatible. When external conditions are ripe, systems combine through interaction to form a higher-level functional structure [5]. In recent years, most research on system coupling has focused on coupling coordination measurement. Zhu Haijuan et al. [6] analyzed the coupling state of the eco-economic system for desertification control in Ningxia by constructing a comprehensive evaluation index system for ecology and socioeconomic development, concluding that desertification control projects facilitated the formation of a benign coupling trend in Ningxia' s eco-economic system. Wang Jijun et al. [7] took the agricultural eco-economic system in the Zhifanggou watershed of Shaanxi Province as the research object, established an agricultural eco-economic coupling degree model, and explored the coupling state of the agricultural eco-economic system. Yuan Linna [8] took Maqu County in Gansu Province as the research area, used a coupling coordination degree model to analyze the coupling coordination degree of the ecological, economic, and social systems in the study area, and found that the system coupling state showed an inverted "U" shape trend. Liu Xiuli et al. [9] constructed an evaluation model for the eco-economic system of returning farmland to forests in Ningwu County from the perspective of farmer well-being and conducted a scientific analysis of the coupling coordination degree before and after returning farmland to forests. Wang Jieyong et al. [10] constructed a regional eco-economic system coupling process model to analyze the coupling process and evolution trend of the eco-economic system in the Yellow River Delta region, with results showing an interactive and coordinated development trend between the ecosystem and economic system in the Yellow River Delta.

Through literature review, it is found that current research on eco-economic system coupling mainly analyzes from a certain aspect of the eco-economic system, with relatively insufficient comprehensive research among multiple systems. Moreover, existing literature lacks research on the coupling of eco-economic systems in desertification control. Therefore, based on ecological economics theory, this study constructs an evaluation index system for ecological management in the Hobq Desert and uses coupling degree and coupling coordination degree models to conduct a dynamic quantitative analysis of the coupling coordination state of the eco-economic system for ecological management in the Hobq Desert from 2008 to 2017, aiming to provide scientific support for ecological restoration and sustainable socioeconomic development in desertification areas of the Hobq

Desert.

2. Study Area Overview

The Hobq Desert is the seventh largest desert in China, located between 107°18 - 111°30 E and 39°30 -40°41 N, belonging to one of China' s typical ecologically fragile areas. The Hobq Desert stretches about 400 km in length, with a width of about 50 km in the wider southern part and narrower eastern part, and sand dunes about 15-20 m high. The Hobq Desert has an annual average evaporation of 2,162 mm, large temperature differences, an annual average temperature of 6.3°C, and 25-35 days of strong winds per year, with prevailing westerly and northwesterly winds [11]. Since 1988, governments at all levels, enterprises, and individuals in Inner Mongolia have participated in ecological management of the Hobq Desert [12]. Currently, the ecological environment in desertification areas of the Hobq Desert has been greatly improved, and the social economy has developed rapidly, with people' s living standards gradually improving.

Reviewing the history of ecological management in the Hobq Desert, it can be roughly divided into five stages: (1) Passive afforestation period (1988-1995), characterized by capital shortage, backward technology, passive afforestation, and small control area. (2) Active afforestation period (1996-2000), with enterprises and individuals actively participating in desertification control and strong government promotion. (3) Idealized afforestation period (2001-2005), with some enterprises trying ecological management but with unclear results. (4) Regularized afforestation period (2006-2010), with government attention, sufficient funds, mature sand control technology, and significant control effects. (5) Scientific and large-scale afforestation period (2011-2017), with relatively advanced sand control technology, large afforestation area, formation of the Hobq ecological poverty alleviation and sand control model, and remarkable ecological management effects. Currently, the ecosystem for ecological management in the Hobq Desert tends to be stable, with strong buffering capacity against external environmental impacts, the socioeconomic system tends to be stable, and system coupling gradually moves toward benign development, but the coupling state in the region has not yet reached the optimal state.

3. Research Methods

3.1 Coupling Degree Model and Coupling Coordination Degree Model

The coupling degree model and coupling coordination degree model have been widely applied in system coupling state research. For example, Liu Xinping et al. [13] used coupling mathematical models and coupling system evaluation index systems to calculate the coupling degree of ecology and economy in arid areas of Xinjiang. Therefore, this study analyzes the coupling state of the eco-economic system for ecological management in the Hobq Desert by constructing coupling degree and coupling coordination degree models.

3.1.1 Coupling Degree Model Coupling degree can be used to evaluate the coupling degree between systems or subsystems [14]. Since this study mainly discusses the ecosystem and socioeconomic system, comprehensive evaluation functions f(x) and g(y) are established for the ecosystem and socioeconomic system respectively. f(x) represents the parameter contribution of the ecosystem, and g(y) represents the parameter contribution of the socioeconomic system, which can be expressed by indicators x_1,⋯,x and y_1,⋯,y respectively.

$$f(x) = \sum_{i=1}^{m} a_i x_i$$

$$g(y) = \sum_{j=1}^{n} b_j y_j$$

where: m and n are the numbers of indicators in the ecosystem and socioeconomic system respectively; a and b are the weights of each evaluation indicator in the ecosystem and socioeconomic system respectively; x and y are the standardized values of each evaluation indicator in the ecosystem and socioeconomic system respectively. According to formulas (1) and (2), the parameter contribution degrees of the desertification control ecosystem and socioeconomic system can be obtained, with larger values being better and vice versa.

Based on the principle that smaller deviation coefficients indicate better coordination, the calculation formula for the coupling degree of the desertification control eco-economic system can be derived [15]:

$$C = \sqrt{\frac{f(x) \times g(y)}{\left(\frac{f(x)+g(y)}{2}\right)^2}} \times k$$

where: k is the adjustment coefficient, k [0,1]. Since this study mainly explores the coupling degree of two systems (ecosystem and socioeconomic system), and draws on the research results of Tang Qing and other scholars [16], combined with the actual situation of desertification areas in the Hobq Desert, the k value is taken as 0.5. C represents the coupling degree of the desertification control ecosystem and socioeconomic system, and satisfies C [0,1]. The larger the C value, the higher the coupling degree between the two systems, and the closer C is to 1, the greater the interaction between the two systems, and vice versa.

3.1.2 Coupling Coordination Degree Model The coupling degree model has good guiding significance for analyzing the coupling degree of the eco-economic system for desertification control in the study area. However, the coupling degree model also has certain limitations: first, due to the interactive complexity of the system, its coupling degree indicator cannot effectively

express the overall function of the ecosystem and socioeconomic system in desertification control; second, in the case of multi-regional research, exploring the coupling state of the system solely from the coupling degree model may lead to misleading results. Based on this, the coupling coordination degree model [17] is introduced on the premise of the coupling degree model to more objectively reflect the coupling state between systems.

$$D = \sqrt{C \times T}$$

$$T = \alpha f(x) + \beta g(y)$$

where: D is the coupling coordination degree, and a larger D value indicates higher coordination between the ecosystem and socioeconomic system, and vice versa; T is the comprehensive coordination index of ecology and economy, representing the contribution rate of the ecosystem and socioeconomic system to the overall system; α and β are undetermined weights. Combined with the actual situation of desertification control and referring to relevant research results, and considering that the ecosystem and socioeconomic system are equally important in desertification control, this study takes $\alpha = \beta = 0.5$.

3.1.3 Classification and Evaluation Criteria of Coupling Coordination Degree Types for Desertification Control Eco-Economic System After more than 30 years of efforts from all parties, the ecological environment of the Hobq Desert has been effectively improved, economic development has been rapid, and both ecological and economic benefits of desertification control in the Hobq Desert are relatively obvious. However, the ecosystem of the Hobq Desert is still relatively fragile, farmers' living standards are relatively low, which greatly restricts the level of socioeconomic development and has a greater impact on the regional eco-economic system. In addition, farmers' livelihood levels will also affect the system. For example, overgrazing and high-intensity cultivation for livelihoods not only cause ecological environment deterioration but also become limiting factors for the implementation of desertification ecological control policies. Therefore, when classifying the coupling coordination degree types of the eco-economic system for ecological management in the Hobq Desert, both the ecological environment conditions of desertification areas and farmers' livelihood levels should be considered. Based on this, drawing on the research results of Du Ying and Su Xin and other scholars [18,19], and combining with the current eco-economic situation of the Hobq Desert, the coupling coordination degree is divided into three major categories, and then further divided into 10 subcategories according to the relative relationship between ecosystem parameter contribution and socioeconomic system parameter contribution (Table 1).

3.2 Data Sources

The data for this study come from the *Inner Mongolia Statistical Yearbook*, *Ordos Statistical Yearbook*, *Hangjin Banner Statistical Yearbook*, and relevant statistical reports provided by Elion Resources Group from 2008 to 2017. Among them, ecosystem evaluation indicator data were obtained through comprehensive analysis of Inner Mongolia land and resources bulletins, ecological environment bulletins, and remote sensing image interpretation. Economic system evaluation indicator data mainly came from statistical yearbooks, questionnaires, surveys, and in-depth interviews. Research team members conducted field investigations three times in Ordos Forestry Bureau, Poverty Alleviation Office, Human Resources and Social Security Bureau, and Statistics Bureau, obtaining economic system evaluation indicator data through in-depth interviews with relevant unit leaders. Missing data for some years were supplemented using the mean imputation method. Another part of the data came from questionnaire surveys. Research team members used participatory rural appraisal methods to investigate sand control effectiveness perception and livelihood conditions of farmers in different areas of Hangjin Banner in the hinterland of the Hobq Desert in 2016 and 2017. The survey was conducted on a household basis using stratified random sampling. A total of 400 questionnaires were distributed, with 382 valid questionnaires, for a recovery rate of 95.5%. The questionnaire content included farmers' willingness for desertification control, recognition of sand control work, perception of control effectiveness, basic livelihood conditions of farmers, economic income, etc. The collected data were processed and analyzed.

4. Coupling Analysis of the Eco-Economic System for Ecological Management in the Hobq Desert

4.1 Construction of the Evaluation Index System

Many factors affect the eco-economic system of desertification control. Representative and quantifiable evaluation indicators should be selected according to the actual situation of ecological management in the Hobq Desert. Therefore, the selection of evaluation indicators should follow the principles of comprehensiveness, operability, scientificity, combination of systematicity and independence, integrity, and combination of qualitative and quantitative analysis. Field investigation, expert interviews, and frequency statistics methods were used to determine the evaluation indicators for ecological management in the Hobq Desert.

Regarding the selection and construction of evaluation indicators for ecological management in the Hobq Desert: first, drawing on relevant research results, frequency statistics method was used to analyze the frequency of commonly used indicators for desertification control evaluation, and 20 indicators with the highest usage frequency were selected as the indicator set for desertification control evaluation. Second, field investigation was conducted in desertification areas of the Hobq Desert to collect relevant data, and 10 experts from the Northwest

Institute of Eco-environment and Resources of the Chinese Academy of Sciences, Northwest Normal University, Lanzhou University, China West Normal University, Ordos Natural Resources Bureau, and Forestry and Grassland Bureau who have long been engaged in desertification control and regional sustainable development research were invited to score the importance of each indicator through a designed survey form. The average value was taken as the final basis for evaluation indicator selection. Data accessibility was also considered to construct the evaluation index system (Fig. 1). Third, the analytic hierarchy process (AHP) and expert consultation method were used to determine the weights of evaluation indicators.

[Figure 1: see original paper]

The meanings of indicators in the figure are as follows:
A_1: Carbon sequestration value (10^4 yuan); A_2: Oxygen release value (10^4 yuan); A_3: Water purification value (10^4 yuan); A_4: Forest and grassland fertilizer conservation value (10^4 yuan); A_5: Forest and grassland soil consolidation value (10^4 yuan); A_6: Biodiversity maintenance value (10^4 yuan); A_7: Per capita forestry output value (yuan); A_8: Per capita agricultural output value (yuan); A_9: Per capita animal husbandry output value (yuan); A_{10}: Recreation and ecotourism income (yuan); A_{11}: Per capita net income (yuan); A_{12}: Per capita living area ($m^2 \cdot person^{-1}$); B_1: Rural surplus labor transfer rate (%); B_2: Proportion of low-income population (%); B_3: Children' s enrollment rate (%); B_4: Satisfaction with current life (%); B_5: Recognition rate of sand control work (%).

4.2 Standardized Data Processing

According to the constructed evaluation index system for desertification control, original data for the above evaluation indicators were obtained from the *Inner Mongolia Statistical Yearbook*, *Ordos Statistical Yearbook*, and *Hangjin Banner Statistical Yearbook* from 2008 to 2017, combined with field investigation (Table 2). Since different evaluation indicators have different meanings and dimensional differences exist, which affect the evaluation results, the evaluation indicators should be nondimensionalized to obtain results eliminating dimensional effects. The calculation formula is as follows:

$$U_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}$$

$$U_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}}$$

where: U is the standardized value, x is the original data value of the indicator, and x and x represent the maximum and minimum values of the original indicator data, respectively. When the target value is larger better, formula (6)

is used, and vice versa, formula (7) is used. The calculated standardized values are shown in Table 3.

4.3 Determination of Evaluation Indicator Weights

This study uses the analytic hierarchy process (AHP) and expert consultation method to determine the weights of evaluation indicators. First, according to the principle of AHP, 10 experts and scholars from the Northwest Institute of Eco-environment and Resources of the Chinese Academy of Sciences, Lanzhou University, Northwest Normal University, China West Normal University, Ordos Natural Resources Bureau, and Forestry and Grassland Bureau who have long been engaged in desertification control and regional sustainable development research were invited to compare and score the relative importance of indicators at each level in pairs. The scoring standard adopted the 1-9 scale and its reciprocals for relative importance. To avoid subjective bias in expert analysis, deviation information was eliminated to obtain the group judgment matrix. Second, hierarchical single sorting, total sorting, and consistency tests were conducted, and Yaahp software was used to obtain the weights of each evaluation indicator. The results are shown in Table 4.

4.4 Analysis of System Coupling Results

According to formulas (1), (2), (3), and (4), the ecosystem parameter contribution degree f(x), socioeconomic system parameter contribution degree g(y), coupling degree C, and coupling coordination degree D for ecological management in the Hobq Desert from 2008 to 2017 can be calculated step by step.

4.4.1 Temporal Variation of Socioeconomic and Ecological Environment Coupling As shown in Fig. 2, the eco-economic coupling degree for ecological management in the Hobq Desert was mostly between 0.8198 and 1 from 2008 to 2017, indicating a high coupling degree between its ecosystem and socioeconomic system, with strong interaction between the two systems, and the system gradually tending toward a stable and healthy state. Moreover, economic development in the Hobq Desert area has a strong positive promoting effect on desertification ecological management, which can effectively curb desertification spread. From the temporal variation of system coupling degree, the eco-economic system coupling degree for ecological management in the Hobq Desert showed an alternating trend of first decreasing and then increasing from 2008 to 2017. The coupling degree slightly decreased from 2008 to 2009, reaching the lowest value of 0.8198 in 2009. The coupling degree increased from 2010 to 2011, slightly decreased in 2012, and then gradually increased from 2013 to 2017, indicating that this stage was transitioning to a system running-in period, which is greatly related to scientific desertification prevention and regional ecological environment improvement.

The coupling degree fluctuated and decreased from 2015 to 2016, which is closely related to water resource shortage in the Hobq area. Due to increased ecological

water consumption in the Hobq area in recent years, coupled with drought-induced water shortage during this period, the vulnerability of the ecosystem was aggravated to a certain extent, ultimately leading to a decline in coupling degree between the two systems. The coupling degree reached its peak value of 1 in 2017.

From the perspective of parameter contribution degrees between the ecosystem and socioeconomic system (Fig. 3), the ecosystem parameter contribution degree was less than the socioeconomic system parameter contribution degree from 2008 to 2010, while the opposite trend was observed from 2011 to 2017, showing that the socioeconomic system parameter contribution degree was less than the ecosystem parameter contribution degree. This is because the socioeconomic structure of the study area was reasonable from 2008 to 2010, with significant socioeconomic benefits from desertification control, while ecological benefits have a lag effect and are a long-term, gradual process, so the ecosystem parameter contribution degree was less than the socioeconomic system parameter contribution degree. From 2011 to 2017, the socioeconomic system parameter contribution degree was less than the ecosystem parameter contribution degree, which is related to the low coordination of the internal structure of socioeconomic development during this stage. The unreasonable socioeconomic structure has become a major obstacle to the eco-economic system for ecological management in the Hobq Desert.

From the temporal variation of parameter contribution degrees of the two systems (Fig. 3), except for the fluctuating decline of socioeconomic system parameter contribution degree from 2008 to 2009, the overall trend was increasing year by year, indicating that the internal structure of each system for ecological management in the Hobq Desert is becoming more coordinated. Among them, from 2008 to 2017, the ecosystem parameter contribution degree increased by about 47.6%, and the socioeconomic system parameter contribution degree also showed an increasing trend year by year, increasing by about 38.2%.

[Figure 2: see original paper]

[Figure 3: see original paper]

4.4.2 Analysis of Eco-Economic System Coupling Coordination Degree As shown in Fig. 3, the eco-economic system coupling coordination degree for ecological management in the Hobq Desert remained between 0.198 and 0.796 from 2008 to 2017, and has maintained a yearly increasing trend. The development relationship between the ecological environment and socioeconomic development in the Hobq Desert from 2008 to 2017 generally belonged to the coordinated development category. From the perspective of the coupling coordination degree, the development relationship between the ecological environment and socioeconomic development in the study area from 2008 to 2010 belonged to the dysfunctional decline category, but the coupling coordination degree showed an increasing trend, with the coupling coordination degree reach-

ing 0.198 in 2010, and the eco-economic system belonging to the co-loss coupling pattern. From 2008 to 2010, both the ecosystem parameter contribution degree and socioeconomic system parameter contribution degree of the study area were relatively low, and ecological environment construction seriously constrained regional socioeconomic development. Conversely, socioeconomic development also had a greater impact on the health and stability of the ecosystem, which was one of the main reasons for the low coupling coordination degree and dysfunctional decline state of the ecosystem and socioeconomic system in the study area. In the future, improving the ecological environment and developing the economy should be important directions for sustainable development in desertification areas of the Hobq Desert.

From 2011 to 2013, the development relationship between the ecological environment and socioeconomic development in the study area belonged to mild dysfunctional decline, with the coupling coordination degree reaching 0.396 in 2013, and the ecosystem and socioeconomic system belonging to the ecological loss coupling pattern. From 2014 to 2015, the development relationship belonged to the barely coordinated development category, with the coupling coordination degree increasing to 0.495-0.596, but the coupling patterns of the ecosystem and socioeconomic system were different, being ecological lag type and ecological-economic synchronization type respectively. From 2016 to 2017, the development relationship belonged to the coordinated development category, with the coupling coordination degree increasing from 0.696 to 0.796, and the coupling pattern of the ecosystem and socioeconomic system gradually transitioning from primary coordinated development ecological-economic synchronization type to premium coordinated development ecological-economic synchronization type, indicating that the system coupling coordination state is developing from disorder to order.

Overall, the coupling coordination degree between the ecosystem and socioeconomic system for ecological management in the Hobq Desert showed an increasing trend year by year from 2008 to 2017, with the comprehensive coordination index of the system showing basically the same variation trend. The coupling pattern underwent changes from dysfunctional decline and over-development to coordinated development, with significant differences in coupling pattern types across different years.

Comparing the coupling degree and coupling coordination degree of the eco-economic system for ecological management in the Hobq Desert from 2008 to 2017, it was found that except for 2009, the system coupling degree remained high in all other years, but the coupling coordination degree was not high, especially from 2008 to 2012 when the system coupling coordination degree was relatively low. This indicates that during this stage, there were relatively large material flows and energy flows between the ecosystem and socioeconomic system in the study area, with strong interaction between them. However, given the complexity of the eco-economic system structure itself, the development of a subsystem within a certain system may hinder the overall evolution of

the system, thereby triggering self-regulation of the system. The result of this regulation did not promote the overall system evolution in a benign direction, ultimately leading to low coupling coordination degree between the ecosystem and socioeconomic system.

From 2013 to 2017, the variation trends of coupling degree and coupling coordination degree for ecological management in the Hobq Desert were basically consistent, indicating that ecological environment improvement plays a positive role in socioeconomic development. Through material flow, energy flow, and material cycling between the two systems, the ecosystem and socioeconomic system continue to develop in a coordinated manner.

5. Discussion

From 2008 to 2017, the coupling coordination types of the eco-economic system for ecological management in the Hobq Desert underwent changes from "dysfunctional decline, over-development, to coordinated development." With further intensification of desertification control in the Hobq Desert, ecological water consumption will increase accordingly, which will lead to regional water resource shortage to a certain extent. The vulnerability of the ecosystem in desertification areas of the Hobq Desert 潜伏了系统耦合协调发展的危机 (harbors crises for coordinated system coupling development). This scientific judgment is consistent with the actual situation in this region, further proving that analyzing "system coupling degree and coupling coordination degree" has important guiding significance for exploring the coupling state of eco-economic systems in desertification control. Studying the coupling state of the eco-economic system for ecological management in the Hobq Desert can provide scientific support for determining the ecological-economic-social interaction relationship in desertification control and predicting the coupling development trend of eco-economy in desertification areas.

Analysis shows that from 2008 to 2012, both the ecosystem parameter contribution degree and social system parameter contribution degree for ecological management in the Hobq Desert were relatively low. There exists a mutually constraining and influencing relationship between the ecological environment and regional socioeconomic development, manifested as ecological environment construction affecting regional socioeconomic development, and socioeconomic development in turn affecting the health and stability of the ecosystem. This is one of the main reasons for the low coupling coordination degree of the eco-economic system in the study area. Therefore, it is necessary to adjust the industrial structure in desertification areas of the Hobq Desert, optimize industrial upgrading, eliminate ecological poverty, and effectively regulate and manage desertification issues. At the same time, actively promote the sustainable development model of ecological management in the Hobq Desert. This model, with desertification control and eco-economic development as its core, has broad application prospects in desertification areas of the Hobq Desert and has been promoted and applied in similar desertification areas in China (such as

Wuwei in Gansu, Hotan in Xinjiang, etc.), achieving coordinated and sustainable development of eco-economic systems in desertification areas.

Previous research results show that [20], the system coupling degree can only reflect the development trend of system coupling but is difficult to reflect the effect of system coupling coordination. This is also prominently manifested in this study area, where the coupling coordination effects under different coupling degrees in different years differ significantly. For example, the coupling degree in 2016 was higher than in 2015, but the coupling coordination degree was lower than in 2015, with obviously different coupling coordination effects. Therefore, the coupling degree indicator should be combined with other relevant indicators to characterize the coupling state of eco-economic systems in desertification control. In addition, regarding the classification of coupling coordination degree for the eco-economic system of Hobq Desert management, this study draws on research results of the Grain for Green Project and other related studies. With changes in the eco-economic system of the study area, the classification standards for coupling coordination degree should be scientifically adjusted, which is the direction for future efforts in this study.

6. Conclusions

(1) From 2008 to 2017, the coupled development of the eco-economic system for ecological management in the Hobq Desert showed a stable trend at a relatively high level, with coupling degree values mostly between 0.8198 and 1. The coupling degree showed an alternating trend of first decreasing and then increasing, with strong interaction between the ecosystem and socioeconomic system. Studies on eco-economic system coupling in Ningxia desertification control [6], Loess Plateau Grain for Green Project [9], and Zhifanggou watershed [7] show that coupling degree temporal conditions present an increasing trend year by year. However, this study contradicts the above regional research findings, as the coupling degree of the eco-economic system for ecological management in the Hobq Desert shows a development trend of first decreasing and then increasing.

(2) From 2008 to 2010, the ecosystem parameter contribution degree for ecological management in the Hobq Desert was less than the socioeconomic system parameter contribution degree, while the opposite was true from 2011 to 2017. Comparing the temporal variation of parameter contributions of the two systems, except for the fluctuating decline of socioeconomic system parameter contribution degree from 2008 to 2009, the overall trend was increasing year by year. This indicates that socioeconomic system indicators played a leading role in regulating the ideal state of the eco-economic system for ecological management in the Hobq Desert from 2008 to 2010, while ecosystem indicators played a leading role from 2011 to 2017. When the ecological environment in the study area is greatly improved, the eco-economic system has strong feedback and interaction effects, which is consistent with previous research results.

(3) From 2008 to 2017, the coupling coordination degree of the eco-economic system for ecological management in the Hobq Desert remained between 0.198 and 0.796, showing a yearly increasing trend. The system coupling coordination state is developing from disorder to order. The coupling pattern underwent changes from dysfunctional decline and over-development to coordinated development, with significant differences in coupling pattern types across different years. This indicates that coordinating the relationship between the ecological environment and socioeconomic development in the study area is the key to promoting coordinated system coupling development. Due to different coupling pattern types in different years, the coupling coordination degree between the ecological environment and socioeconomic development in the study area needs to be further improved.

(4) Comparing the coupling degree and coupling coordination degree of the eco-economic system for ecological management in the Hobq Desert from 2008 to 2017, except for 2009 when the system coupling degree was relatively low, the system coupling degree remained high in all other years, but the coupling coordination degree was not high, especially from 2008 to 2012 when the system coupling coordination degree was relatively low. This indicates that during this stage, there were relatively large material flows and energy flows between the ecosystem and socioeconomic system in the study area, with strong interaction between them. However, this interaction did not promote the overall coordinated development of the system. From 2013 to 2017, the variation trends of system coupling degree and coupling coordination degree were basically consistent, which is consistent with the research results of Wang Jieyong et al. [10] on the eco-economic system of the Yellow River Delta region.

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Note: Figure translations are in progress. See original paper for figures.