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Research Article

Analysis of Coupling Co-Ordination between Intensive Sea Use and the Marine Economy in the Liaoning Coastal Economic Belt of China

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At present, there are few relevant studies on the intensive sea use, and few scholars have provided qualitative and quantitative research examples on the interaction and interaction coupling relationship between intensive sea use and the marine economy. This study constructs comprehensive evaluation indicator systems using the Liaoning Coastal Economic Belt as the research object. The set pair analysis method is used to obtain comprehensive results, and the coupling coordination degree model is employed to carry out an in-depth analysis of the spatiotemporal characteristics of the interaction between intensive sea use and the marine economy. The results show the following. (1) The six cities in the Liaoning Coastal Economic Belt exhibited a fluctuating upward trend in the composite index for intensive sea use, but the intensive sea use level differed among the cities. The intensive sea use level of Huludao was the lowest among the six cities. (2) All cities in the Liaoning Coastal Economic Belt witnessed an upward trend in the marine economy development index, and the gaps between the cities gradually narrowed. The marine economy development index was ranked from top to bottom as follows: Jinzhou, Panjin, Dalian, Yingkou, Dandong, and Huludao. (3)The coupling coordination degree between intensive sea use and marine economy development was relatively stable in Dalian, Jinzhou, Yingkou, and Panjin, ranging approximately from 0.76 to 0.96, which indicates that the four cities witnessed good coordination between sea area utilization and marine economy development. The coupling coordination degree of Dandong and Huludao were relatively low, and Huludao consistently witnessed a low value.

1. Introduction

With the launch of the "Maritime Power Strategy" and "Maritime Silk Road Initiative," Chinese coastal provinces have begun to increase the utilization intensity of sea areas, gradually leading the marine economy to provide an important impetus for China's economic growth [1]. However, with the growing imbalance between the development of the marine economy and increased social demand, the current development of most marine resources still lacks overall coordination and macroregulation. In the past 30 years, large-scale sea encirclement and reclamation, together with the construction of salt pans and shrimp pools, have led to a shrinking of the gulf areas and shortening of the natural coastline. Due to high-density and high-intensity development of some sea areas, the sea use rate is low, and these sea areas are overexploited [1]. The resources in these areas are extensively developed and utilized, and the scale of sea reclamation used for industry and town construction has grown rapidly, resulting in inappropriate investment and a serious waste of marine resources [2].

Development activities in some coastal belts have had negative impacts on the marine environment, including habitat loss, degradation of fishery resources, deterioration of water quality, excessive pollutants in edible fish and shellfish, channel siltation, decline in productivity of biological resources, and invasion of alien species [3–7]. As a result, offshore sea areas have witnessed a decline in the potential for development and utilization as well as the capability of sustainable development. The ocean is both a common space and a valuable source of wealth for human society that is essential to its survival and sustainable development. Therefore, it is necessary to explore the optimal allocation and utilization structure of sea areas, protect the marine ecological environment, economize and intensively utilize marine resources, and correctly understand the interaction between marine economic development and the utilization of sea areas. This is a key issue that affects the sustainable development of the marine economy, which requires coordination and balance between marine development and marine protection. This is of great significance for promoting the sustainable development of the region and ensuring the implementation of an integrated strategy for land and sea.

Research on marine economies has long been under development and mainly includes (1) research on marine economies [8–10] and the vulnerability and stability of the marine economic system [11–14] based on sustainable development; (2) research related to the efficiency [15, 16] and transformation [17] of marine economies; and (3) research on the relationship between marine economies and the environment [18], resource development [12], and marine industries [19–23]. In 2011, the concept of intensive sea use was officially proposed [24], and it has been gradually applied to relevant practical research on the development and utilization of sea areas. More recently, some researchers have studied the impacts of intensive sea use on marine ecology, marine resources, and coastal urban economies [25–28].

Several studies delve into the marine economy, but only a few studies exist on intensive sea use. Researchers have conducted qualitative and quantitative studies on intensive sea use, but there is no example of the interaction and coupling between sea area utilization and the marine economy.

Therefore, the innovation of this paper lies in taking the Liaoning Coastal Economic Belt as an example, through the model method, the interaction and coupling between sea area utilization and the marine economy are quantitatively analyzed; this study constructs a comprehensive evaluation indicator system for both intensive sea use and the marine economy. Then, the set pair analysis method is used to comprehensively measure intensive sea use and the marine economy specifically in the Liaoning Coastal Economic Belt. This study explores the correlation mechanism between the intensive utilization of sea areas and the marine economy and probes into the coordinated relationship between the two. This study draws lessons from the principles of the index system for intensive land utilization established in previous research to create an index system for intensive water use, and this study using a relative development degree model to measure the level of intensive sea utilization and marine economic development.

2. Theoretical Framework

Establishing a concept of intensive sea use is an important basis for constructing a relevant evaluation indicator system, and it is necessary for analyzing the interaction and coupling mechanism between intensive sea use and the marine economy. The theory of intensive use was first applied to land use. Based on relevant theoretical research on the intensive use of land [18, 29–32], this study combined the characteristics of sea area development and utilization and referred to related literature [25–28] to define intensive sea use as follows. Intensive sea use seeks coordination and balance between marine development and protection and is, thereby, a more efficient and scientific approach to sea use. It refers to a process of continuously improving the benefits of the marine economy through various means, such as increasing factor inputs in sea use, improving the management of sea areas, and optimizing the utilization structure and layout of sea areas. Intensive sea use reflects the optimization of the sea use structure, improvement in the earnings of the marine economy, and sustainability of sea area use.

Research on the human-sea relationship in coastal areas must recognize that oceans are an important part of the human-sea regional system. The marine system is closely related to the development of human society. Human beings rely on land to form a human-sea system (consisting of human beings, oceans, and land) in the process of marine development and utilization. The human-sea regional system essentially exhibits an interrelated and interactive relationship between human society and the sea and land resource environments. The human-sea regional system always transforms between disorder and order and between balance and imbalance due to the interaction between its complex internal and external connections. The human-sea regional system and the synergy among its components enables the system to shift from disorder to order, thereby leading to system evolution from simple to complex levels [33–35].

From the perspective of self-organization theory, human beings develop and utilize marine resources and marine space by investing in certain production factors such as labor, technology, and capital to promote constant and steady growth in the marine economy and facilitate orderly change in the structure and scale of sea area utilization and improvement in the potential of sea resources [36] (Figure 1). The combination of marine economy development and sea area utilization is an entropy reduction process of the human-sea regional system. On the contrary, excessive pursuit of marine economic benefits, extensive use of sea areas, and inappropriate structure of marine industries lead to various issues, such as environmental pollution in sea areas, waste of marine resources, severe depletion of marine resources, and the frequent occurrence of marine disasters. That is, the mutual restriction between the marine economic system and sea area utilization is an entropy increase process of the human-sea regional system.

3. Study Area and Data Sources

3.1. Overview of the Study Area. Under the human-sea regional system, human beings rely on land to develop and utilize marine resources, forming a human-sea regional

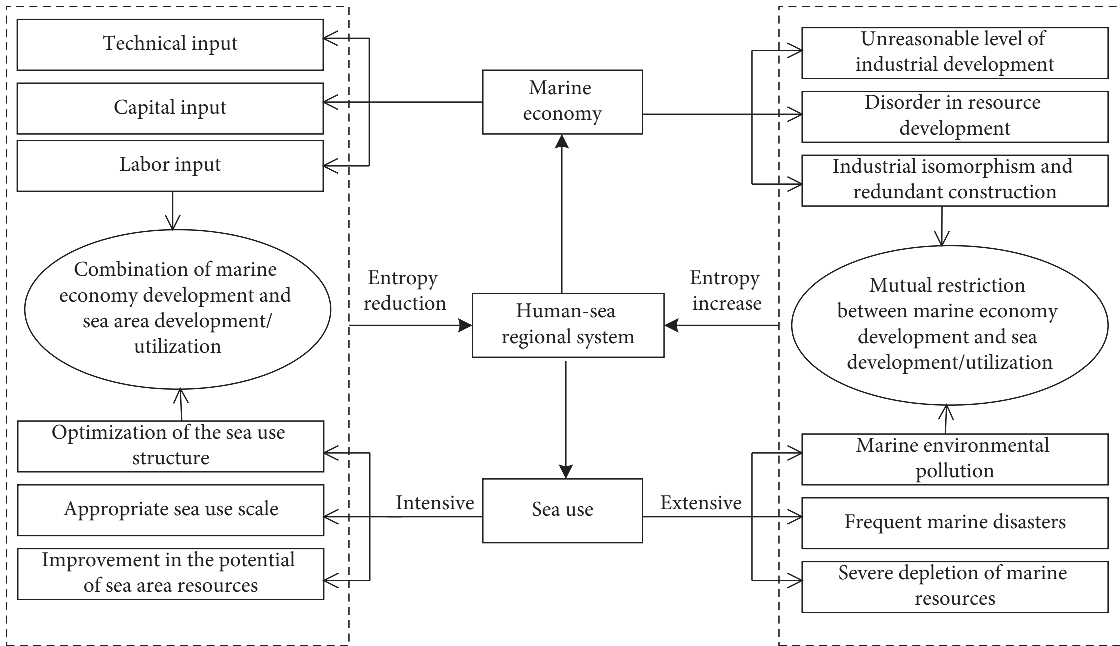

Figure 1: Mechanism of interaction between intensive utilization and the marine economic system in sea areas.

system composed of humans, oceans, and land. This study, in reference to the *Guidelines for the Overall Planning for Comprehensive Protection and Utilization of Coastal Belts* [37], took into account the completeness and integrity of the adjacent ecosystem in coastal economic belts and the dependence of the terrestrial economy on oceans. Consequently, this study focused on the Liaoning Coastal Economic Belt, including the terrestrial administrative jurisdiction for the land and sea areas within the external edges, defined by the marine functional zoning of Liaoning Province on the seaside.

The Liaoning Coastal Economic Belt, located in the northeastern part of China, is adjacent to the Bohai Sea and Yellow Sea and includes six coastal cities: Dalian, Dandong, Jinzhou, Yingkou, Panjin, and Huludao (Figure 2). The sea area is approximately 41,300 km^2, and the coastline is approximately 2,920 km, with the coastlines of the mainland and islands being 2,292.4 km and 627.6 km, respectively [38].

In 2016, the regional GDP of the Liaoning Coastal Economic Belt was CNY 1,141.04 billion. The marine GDP reached CNY 391.7 billion, accounting for 31% of the regional GDP [39].

Liaoning coastal economic belt has obvious geographical advantages. It is the main sea passage and important window of opening up for the combination of Northeast China and Beijing-Tianjin-Hebei metropolitan circle. It has extremely prominent strategic position and regional advantages. The adoption of *The Development Plan of the Liaoning Coastal Economic Belt*, in 2009, marked that the Bohai Rim economic circle had been included in the key development strategy of the national economy and had become a state-level development new area in parallel with the Pearl River Delta and the Yangtze River Delta. In recent years, all kinds of industries in Liaoning province have been further concentrated in coastal areas. The contradiction between Marine economic growth and sea area utilization is prominent in Liaoning coastal economic belt, and the spatial layout of sea area development and utilization is in urgent need of adjustment and optimization. Therefore, the Liaoning Coastal Economic Belt, the focus area of this study, is a good representation.

3.2. Data Sources. The sea use type and area data in this study were obtained from the relevant confirmation data of the Department of Ocean and Fisheries of Liaoning Province from 2005 to 2017 (Table 1). Some data were obtained from remote sensing image information. The sea use types were divided into eight level-1 types. The socioeconomic data were primarily taken from the China Ocean Statistical Yearbook (2005–2017), Liaoning Statistical Yearbook (2005–2017), Bulletin of Liaoning's Marine Environmental Status (2005–2017), and the statistical yearbooks and statistical bulletins of national economic and social development of the relevant cities. Data on the fixed-asset investment per unit of sea area, the total production per unit of sea area, and the marine GDP of the coastal areas were calculated mainly based on the indicator data from the China Ocean Statistical Yearbok. Indicators such as the sea use type diversity index, sea use balance index, sea use rate, coastline development intensity, and coastline economic density were calculated based on the relevant confirmation data from the Department of Ocean and Fisheries of Liaoning Province and the indicator data extracted from remote sensing image information. The contribution rate of the marine economy, port cargo throughput, intensity of science, and technology investment, rate of return on fixed-asset investment of marine industries, and labor elasticity

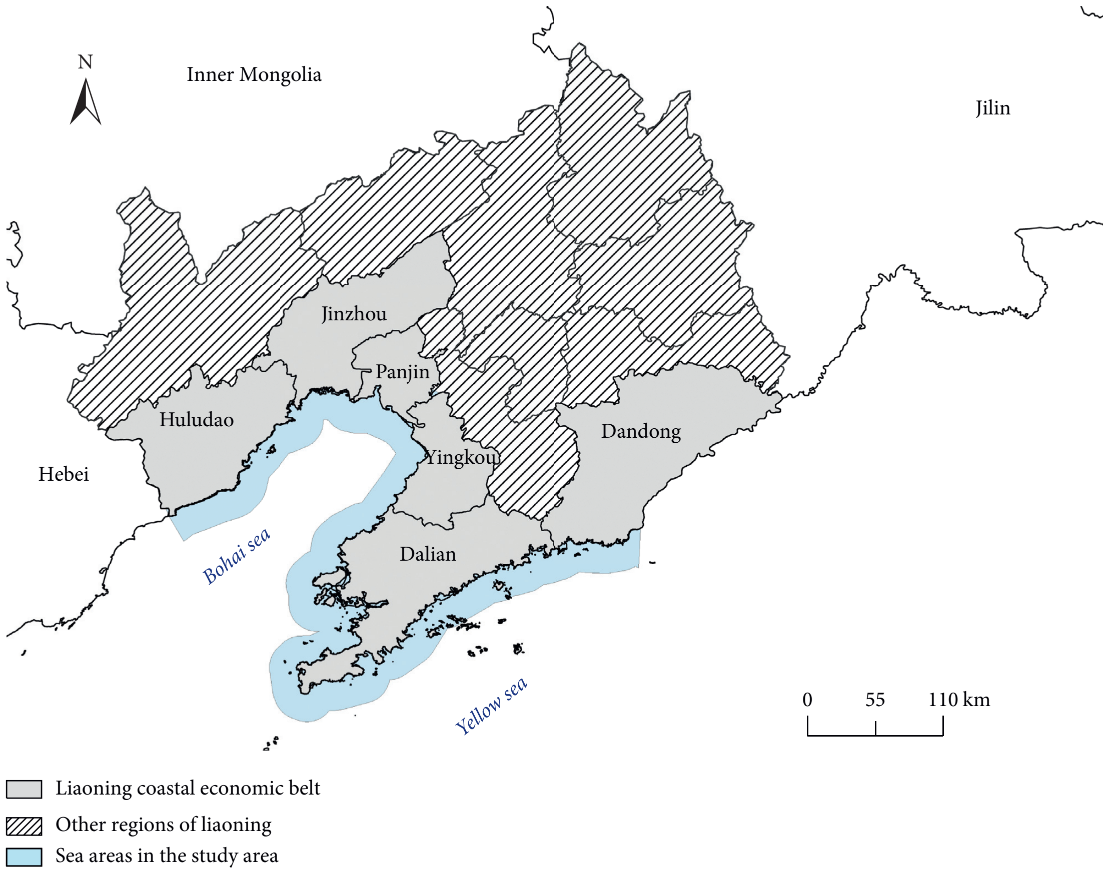

Figure 2: The geographical location of the research area.

Table 1: Introduction of data and data sources.

Data	Data sources
Marine utilization type and ocean area data	Based on confirmation data from Liaoning provincial department of marine and fishery, and some data is obtained from remote sensing
Socioeconomic data	China Ocean Statistical Yearbook, Liaoning Statistical Yearbook, Bulletin of Liaoning's Marine Environmental Status, and statistical yearbooks and statistical bulletins on national economic and social development for the relevant cities
Investment in fixed assets in coastal areas, gross product per unit sea area, and marine GDP	Calculation is based on index data from the China Marine Statistical Yearbook
Diversity index of sea area use types, sea area use equilibrium index, sea area utilization rate, shoreline development intensity, and economic density of coastline	The department of oceanography and fisheries of Liaoning province extracted information from remote sensing images based on relevant confirmation data
Marine economy contribution rate, port cargo throughput, technology investment intensity, return on investment for fixed assets, and coefficient of labor elasticity	Based on the statistical yearbook of Liaoning province and the statistical yearbook and bulletin on national economic and social development of the cities
Marine water quality composite index and marine function zoning compliance	Liaoning bulletin on the state of the marine environment and reports on the quality of the marine environment in the cities concerned

Note. all data used in this study were from 2005 to 2017

coefficient were calculated based on the Liaoning Statistical Yearbook and statistical yearbooks and statistical bulletins of national economic and social development of the relevant cities. Indicator data such as the composite index for sea water quality and conformity of marine functional zoning were calculated based on the Bulletin of Liaoning's Marine Environmental Status and the Marine Environmental Quality Report of the cities involved.

4. Research Process and Method

4.1. Construction of Indicator Systems

4.1.1. Indicator System for Intensive Sea Use. According to the definition of intensive sea use, input status, utilization structure, economic benefits, and sustainability of sea area utilization are the main factors determining the level of intensive sea use. Based on the definition and connotation of intensive sea use, this study drew on the indicator system for intensive land use evaluation [18, 29–32] and took into account the actual situation of sea area utilization in the Liaoning Coastal Economic Belt to measure the intensive sea use level of the Liaoning Coastal Economic Belt in terms of the sea input intensity, sea use structure, marine economic benefits, and sea use sustainability. The specific indicator system is presented in Table 2.

(1) Sea use structure mainly refers to the utilization structures of different sea use types, indicating the structural allocation status of sea resources and the distribution of marine industries and sea use types. It was measured by the sea use type diversity index (h_i) and the sea use structure balance index (w_i).

(2) Sea input intensity reflects the material basis provided by each production factor in the sea use process. It was measured by three indicators: fixed-asset investment per unit of sea area, coastline development intensity, and sea use rate. The fixed-asset investment per unit of sea area indicates the amount of capital investment in sea areas; the coastline development intensity indicates the investment in coastline resources; the sea use rate reflects the sea use level of the study area.

(3) Marine economic benefits were measured by three indicators: total production per unit of sea area, expropriation of sea use royalties, and contribution rate of the marine economy. The total production per unit of sea area represents the economic benefits generated per unit of sea area. The expropriation of sea use royalties indicates the paid use of sea areas, which is expressed by the ratio of the total sea use royalties expropriated to the sea area used. The contribution rate of the marine economy is expressed by the proportion of the total marine GDP in the regional GDP, which reflects the proportion of marine economic growth in regional economic growth.

(4) The sustainability of sea use reflects the sustainability of intensive sea use based on the advantages and disadvantages of the marine environment. It was measured by two indicators, composite index for sea water quality and the conformity of marine functional zoning. The composite index for sea water quality is reflected by the compliance rate of sea water quality. The conformity of marine functional zoning indicates the suitability of sea area development to marine functional zoning.

4.1.2. Indicator System for Marine Economy Development. The marine economy indicates the status of various industrial activities for developing, utilizing, and protecting the oceans and the associated economic activities [39]. By referring to relevant research results [12–17], this study carried out a comprehensive analysis from the perspectives of the degree of development and quality of the marine economy. The specific indicator system is presented in Table 3.

(1) The degree of development of the marine economy was measured by three indicators: total marine GDP, port cargo throughput, and coastline economic density. Total marine GDP represents the overall development of the marine economy. Port cargo throughput represents the role of ports in marine economic growth. Coastline economic density represents the economic intensity of coastline resource utilization and development activities.

(2) The structure of marine industries reflects the composition, interrelationship, and proportion of each marine industry. It was measured by the location quotient of marine industries and the marine industry structure index. The location quotient of marine industries reflects the contribution of leading marine industries to marine economic growth. The marine industry structure index reflects the structural status of secondary and tertiary marine industries.

(3) The potential of marine economy development is used to measure sustainable use in marine economy development. It was measured by three indicators: labor elasticity coefficient, density of marine scientific research institutions, and the rate of return on fixed-asset investment of marine industries. The labor elasticity coefficient reflects the promotion of sea-based employment growth to the marine economy. The density of scientific research institutions reflects the support of marine science and technology investment for the development of the marine economy. The rate of return on fixed-asset investment of marine industries reflects the degree of support of marine capital investment for marine economic benefits.

(1) $h_i = 1 - (\sum_{i=1}^{n} x_i^2 / \sum_{i=1}^{n} x_i^2)$, where x_i is the area coverage of the ith sea use type and n is the number of sea use types.

(2) $w_i = \sum_{i=1}^{n} (G_i \ln G_i)/\ln n$, where $G_i = P_i / \sum_{i=1}^{n} P_i$. P_i is the area coverage of a sea use type, G_i is the ratio of the area coverage of a sea use type to the total sea area, and n is the number of sea use types.

(3) It is used to evaluate the development and utilization of coastline by human activities. It is expressed by the artificial index of coastal zone, that is, the length of artificial shoreline/total length of shoreline.

(4) The conformity of marine function zone planning reflects the connection between marine function zoning and sea area use. According to the degree, it is

Table 2: Comprehensive evaluation indicator system for intensive sea use.

Criterion level	Level-1 indicator	Level-2 indicator	Weight
Measures for intensive sea use level	Sea use structure	Sea use type diversity index $(h_i)^2$	0.47
		Sea use structure balance index $(w_i)^2$	0.53
	Sea input intensity	Fixed-asset investment per unit of sea Area	0.36
		Sea use rate	0.42
		Coastline development intensity[3]	0.22
	Marine economic benefits	Total production per unit of sea area	0.48
		Expropriation of sea use royalties	0.26
		Contribution rate of marine economy	0.25
	Sustainability of sea use	Composite index for sea water quality	0.46
		Conformity of marine functional zoning[4]	0.54

Table 3: Comprehensive evaluation indicator system for the marine economy.

Criterion level	Level-1 indicator	Level-2 indicator	Weight
Comprehensive evaluation of the marine economy	Degree of development of the marine economy	Total marine GDP in coastal areas	0.13
		Port cargo throughput	0.13
		Coastline economic density	0.14
	Structure of the marine industries	Location quotient of marine industries $(F_i)^5$	0.09
		Marine industry structure index[6]	0.14
		Technology investment intensity	0.2
	Development potential of the marine economy	Rate of return on the fixed-asset investment of marine industries	0.14
		Labor elasticity coefficient	0.03

divided into five grades: consistent, well compatible, compatible, conditionally compatible, and nonconforming.

(5) $F_i = (q_{ij}/q_i)/(q_i/q)$, where q_{ij} is the production of marine industries in Liaoning, q_j is the total production of all industries in Liaoning, q_i is the production of marine industries in the Liaoning Coastal Economic Belt, and q is the total production of all industries in the Liaoning Coastal Economic Belt.

(6) It is used to evaluate the intensity of economic activities and resource utilization on the coastline of coastal urban units, that is, gross marine product/coastline length.

4.2. Method and Model for Analyzing the Coupling Co-Ordination between Sea Area Utilization and Marine Economy Development

4.2.1. Weight Calculation. In this study, the data were nondimension processed using the min-max normalization method. The coefficient of variation was used to determine the weight of each indicator. The weighting was based on the degree of variation of the observed values of the indicators on the to-be-evaluated objects [32], which can effectively avoid the subjectivity and deviation of the subjective weighting method and make the weighting results more objective and scientific.

Generally, the larger the difference of index value, the more can reflect the difference of evaluated units and the greater the impact on comprehensive evaluation. The calculation formula is as follows:

$$V_j = \frac{S_j}{X_j},$$
$$W_j = \frac{V_j}{\sum_{j=1}^{n} V_j}, \tag{1}$$

where V_j is the coefficient of variation of the index; S_j is the standard deviation of the index; X_j is the mean value of the index; W_j is the weight of the index; and n is the number of observation values of the index j.

4.2.2. Set Pair Analysis. Set pair analysis refers to an identity-discrepancy-contrary (IDC) quantitative analysis on certain and uncertain problems. It can solve multi-objective decision-making and multiattribute evaluation problems and has been widely used in related research fields [13, 40, 41]. Its core idea is to analyze the certainty and uncertainty between the objective items of the research as a system in the context of specific problems. The certainty includes two aspects, identity and contrary. Uncertainty refers to discrepancy. This method analyzes items and their systems from three aspects (i.e., identity, discrepancy, and contrary) and establishes the IDC association of the system. In this study, the sea use status and marine economic system are affected by many factors, with typical uncertainty. Therefore, they were quantitatively evaluated based on the set pair analysis method, as shown in the following equations:

$$\mathrm{TY} = \sum_{j=1}^{n} w_j \frac{x_{ij}}{\max(x_i) + \min(x_i)},$$

$$\mathrm{DL} = \sum_{j=1}^{n} w_j \frac{\max(x_i) * \min(x_i)}{(\max(x_i) + \min(x_i)) * x_{ij}}, \quad (2)$$

$$U = \frac{\mathrm{TY}}{(\mathrm{TY} + \mathrm{DL})},$$

where TY is the identity, DL is the contrary degree, And U is the degree of association, expressing the degree to which the to-be-evaluated object fits the optimal solution set standard. The larger the U value, the higher the fit. This study used U to reflect the intensive sea use level or the marine economy development in the Liaoning Coastal Economic Belt. When U is large, it indicates that the level of intensive sea use is higher, or the development of the marine economy is better. x_{ij} represents the jth indicator of the ith sample, w_j represents the weight, and $\max(x_i)$ is the optimal indicator of i samples, while $\min(x_i)$ is the worst indicator of i samples.

4.2.3. Calculation of the Coupling Degree between Sea Area Utilization and Marine Economy Development. The capacitive coupling model from physics [42] was introduced into this study to analyze the interaction between intensive sea use and marine economy development, as shown in the following equation:

$$C = 2\left[\left(\frac{U(m) * U(n)}{U(m) + U(n)}\right)^2\right]^{1/2}, \quad (3)$$

where C is the coupling degree between intensive sea use and marine economy development, with a value range of [0, 1], and $U(m)$ and $U(n)$ are the composite indexes for intensive sea use and the marine economy development index, respectively. The greater the coupling degree, the more coordinated and orderly the development between the two systems and the more stable their relationship.

4.2.4. Calculation of the Coupling Co-Ordination Degree between Sea Area Utilization and Marine Economy Development. The coupling degree only refers to the degree of mutual influence between the two systems, whereas the coupling coordination degree can express the degree of coordination between the two systems [42], as given by the following equations:

$$\begin{aligned} D &= \mathrm{sqrt}[C \times (a * U(m) + b * U(n))], \\ T &= a * U(m) + b * U(n), \end{aligned} \quad (4)$$

where D is the coupling coordination degree index, with a value range of [0, 1]. The coupling coordination degree can be used to quantitatively analyze the coupling coordination level between intensive sea use and marine economy development. T is a comprehensive evaluation value of intensive sea use and development of the marine economy. A is the weight of the marine economy development system, and b is the weight of the intensive use system of sea areas. In the process of coupling between intensive sea use and marine economy development, a higher level of intensive sea use provides a bigger boost to the growth of the marine economy and reduces the entropy of the human-sea regional system. On the contrary, the marine economic system and the sea area use are mutually constrained, leading to an increase in the entropy of the human-sea regional system. The two systems are of equal importance in promoting each other. Referring to the relevant literature [43–47], this study set $a = b = 0.5$.

4.2.5. Calculation of the Relative Degree of Development between Sea Area Utilization and the Marine Economy. The coupling coordination degree model can evaluate the degree of coupling coordination between intensive sea use and marine economy development but cannot evaluate their relative degree of development. Therefore, the relative development degree model was used to calculate the relative development coefficient of intensive sea use and the marine economy:

$$E = \frac{U(m)}{U(n)}, \quad (5)$$

where E is the relative degree of development. This study drew on the related literature [41] to classify the coupling coordination between intensive sea use and the marine economy into 4 stages and 12 types. The specific types are listed in Table 4.

5. Results and Analysis

5.1. Analysis of Intensive Sea Use and Marine Economy Development. As shown in Figure 3, from 2004 to 2016, the six cities in the Liaoning Coastal Economic Belt exhibited a fluctuating upward trend in the composite index for intensive sea use, but the intensive sea use level differed among the cities. During the study period, the intensive sea use level of Huludao was the lowest among the six cities. The development of the marine economy in the Liaoning Coastal Economic Belt accelerated. The adjustment of its sea use structure and the increase of sea input led to a rise in the intensive sea use index of the six cities, but the overall rise was small. The composite index for intensive sea use in Huludao was the lowest for a long time due to the low sea use structure index. The coastline of Huludao is 261 km long, starting from Laohekou in Shangkanzi Village, Tashan Township, Lianshan District in the east to the Hongshi Reef in Mengjia Village, Wanjia Town, and Suizhong County in the west. However, the sea use types in Huludao were not very diverse during this period, mainly including sea reclamation for industrial and urban use, port shipping, and aquaculture. The structural adjustment of marine industries was slow, making the sea use structure index and sea use type diversity index relatively low. Sea resources were not appropriately used, which negatively affected the improvement of the intensity of the sea use level in Huludao.

Table 4: Classification criteria and types of degree of coordination.

Degree of coupling coordination	Relative development degree	Characteristics of coordination types	Type	Coordination stage
$0 < D \leq 0.3$	$0 < E \leq 0.8$	The sea use status lags behind the marine economy, restricting the development of the marine economy; sea areas tend to be extensively utilized	I	Separation
	$0.8 < E < 1.2$	The sea use status synchronizes with the marine economy, facilitating the development of the marine economy; sea areas tend to be intensively utilized	II	
	$1.2 \leq E$	The sea use status is ahead of the marine economy, affecting the development of the marine economy; sea areas tend to be excessively utilized	III	
$0.3 < D \leq 0.5$	$0 < E \leq 0.8$	The sea use status lags behind the marine economy, restricting the development of the marine economy; sea areas tend to be extensively utilized	IV	Antagonism
	$0.8 < E < 1.2$	The sea use status synchronizes with the marine economy, facilitating the development of the marine economy; sea areas tend to be intensively utilized	V	
	$1.2 \leq E$	The sea use status is ahead of the marine economy, affecting the development of the marine economy; sea areas tend to be excessively utilized	VI	
$0.5 < D \leq 0.8$	$0 < E \leq 0.8$	The sea use status lags behind the marine economy, restricting the development of the marine economy; sea areas tend to be extensively utilized	VII	Run-in
	$0.8 < E < 1.2$	The sea use status synchronizes with the marine economy, facilitating the development of the marine economy; sea areas tend to be intensively utilized	VIII	
	$1.2 \leq E$	The sea use status is ahead of the marine economy, affecting the development of the marine economy; sea areas tend to be excessively utilized	IX	
$0.8 < D \leq 1$	$0 < E \leq 0.8$	The sea use status lags behind the marine economy, restricting the development of the marine economy; sea areas tend to be extensively utilized	X	Coordination
	$0.8 < E < 1.2$	The sea use status synchronizes with the marine economy, facilitating the development of the marine economy; sea areas tend to be intensively utilized	XI	
	$1.2 < \mathrm{E}$	The sea use status is ahead of the marine economy, affecting the development of the marine economy; sea areas tend to be excessively utilized	XII	

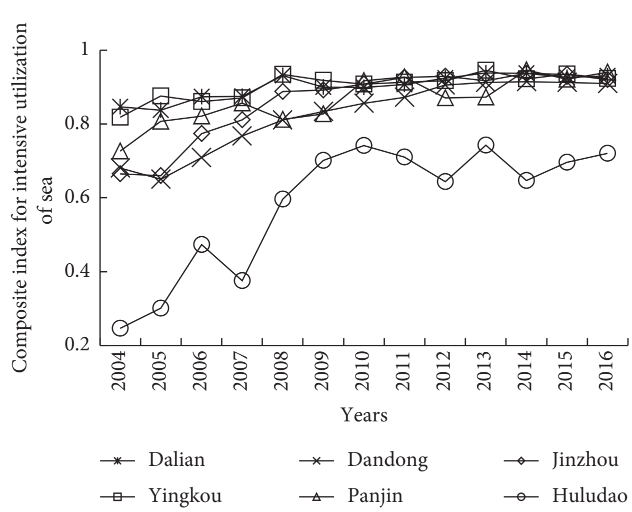

Figure 3: Composite index for intensive sea use.

It can be seen in Figure 4 that, from 2004 to 2016, all cities in the Liaoning Coastal Economic Belt witnessed an upward trend in the marine economy development index, and the gaps between the cities gradually narrowed. The marine economy development index was ranked from top to bottom as follows: Jinzhou, Panjin, Dalian, Yingkou, Dandong, and Huludao. The marine economy development index of Jinzhou was high and stable. The marine economy development index of Panjin showed a V-shaped trend, indicating that the marine economy development of this city was unstable. The marine economy development index of Dalian fluctuated, rising from 0.39 in 2004 to 0.71 in 2016. Among the six cities, Yingkou, Huludao, and Dandong witnessed a relatively low marine economy development index, which still showed a slow upward trend. According to the analysis of the marine economy development in the six cities, Jinzhou's marine industry structure was relatively appropriate, and its marine industry location quotient, marine industry structural index, and marine economy development degree were the highest.

Panjin witnessed a constant decline in the marine economy development index before 2009 and a slow rise after 2009. This is because the sea use type diversity index and sea use structure balance index of Panjin were relatively low, and the endogenous power for the development of the marine economy was insufficient from 2004 to 2009. With the establishment of Panjin Port and the gradual transformation of its marine industry structure after 2010, the comprehensive strength of Panjin's marine economy gradually increased. Dalian, as an important city in the Liaoning Coastal Economic Belt, is economically developed and possesses unique marine resources. However, due to its large sea area and coastline base, Dalian had relatively low fixed-asset investment intensity, coastline development intensity, and sea use rate. Its marine economy development index was ranked in the middle of the six cities. The sea use type for Dandong was of low diversity, with fish culture being the main type for a long time. The long-term low value of the sea use structure index has restricted the development of marine economy in Dandong. Yingkou Port has obvious resource advantages; however, an insufficient investment in science and technology and inappropriate industrial structure have led to relatively limited capability with regards to overall sea development. In Huludao, low diversity of sea use types and inefficient use and idleness of coastal resources were the main reasons for the long-term low marine economic benefit index in the city. Huludao should further diversify its development efforts in terms of sea use in the future.

5.2. Spatiotemporal Evolution of the Coupling Co-Ordination Degree between Sea Area Utilization and Marine Economy Development. From 2004 to 2016, the coupling coordination degree between intensive sea use and marine economy development was relatively stable in Dalian, Jinzhou, Yingkou, and Panjin, ranging approximately from 0.76 to 0.96 (see Figure 5). This phenomenon indicates that the four cities witnessed good coordination between sea area utilization and marine economy development, an organic combination between intensive sea use level and marine economy development, an orderly change in the sea use structure and scale, a constant improvement in the potential of sea area resources, and constant and stable growth in the marine economy, reflecting an entropy reduction process of the human-sea regional system.

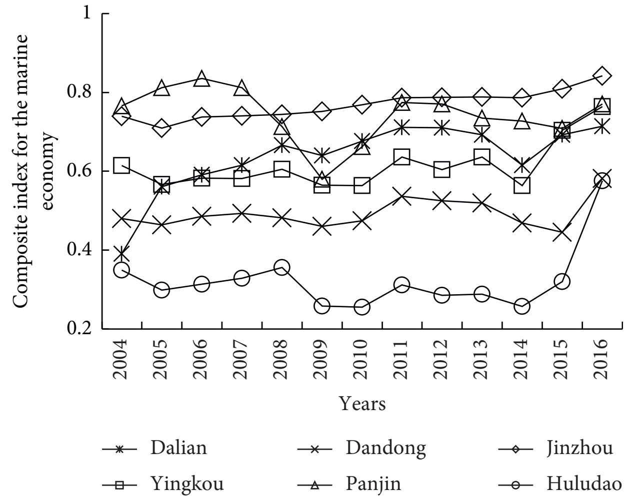

Figure 4: Composite index for the marine economy.

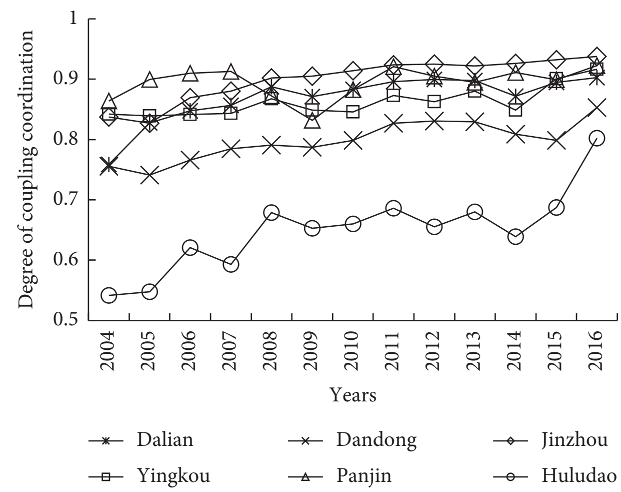

Figure 5: Evaluation of the degree of coordination between intensive sea use and marine economy.

The degrees of coupling coordination between intensive sea use and marine economy development in Dandong and Huludao were relatively low, and Huludao consistently witnessed a low value. This was due to the low diversity in the sea use types of these two cities. Dandong has long used sea areas for fish cultivation. In both 2004 and 2016, the sea area for fishery accounted for 92% and 70% of the total sea area, respectively. In Huludao, engineering construction is the main type of sea use, and the marine industry structure is not reasonable. However, during the study period, the index showing coupling coordination between intensive sea use and marine economy development in Huludao increased from 0.54 in 2004 to 0.80 in 2016, making Huludao the fastest growing region among the six coastal cities in the Liaoning Coastal Economic Belt. This phenomenon indicates that, in Huludao, both the structure and scale of sea area utilization are undergoing orderly changes, and the sea use structure tends to be rationalized. In addition, the rational use of sea resources has promoted the development of the marine economy, indicating that Huludao is in the process of entropy reduction of the human-sea regional system.

5.3. Analysis of the Relative Development between Sea Area Utilization and Marine Economy. The degree of coupling coordination can only indicate the coordination value between intensive sea use and marine economy development, while the relative development degree can be used to analyze the relative development between intensive sea use and marine economy development. Therefore, this study used ArcGIS software to draw a spatial evolution map for the relative development degree of the six cities in the Liaoning Coastal Economic Belt in 2004, 2008, 2012, and 2016. On this basis, the changes in the relative development degree between intensive sea use and marine economy development in the six cities were analyzed, as shown in Figure 6. In order to deeply analyze the relative development between intensive sea use and the marine economy, this study divided the relative development into three states: lagging, synchronous, and advanced. During the study period, the intensive sea use in the six cities of the Liaoning Coastal Economic Belt did not lag behind the development of the marine economy, indicating that since 2004, the sea areas in the six cities have been rationally used, and did not restrict the development of the marine economy.

In 2004, Dandong and Huludao were classified under Type VIII, indicating that their intensive sea use and the marine economy were developing synchronously in the run-in state; Jinzhou and Panjin fell under Type XI. In 2008 and 2012, Jinzhou and Panjin also fell under Type XI. However, in 2016, only Jinzhou fell into Type XI. In 2004, Dalian fell under Type IX, indicating that the intensive sea use and the marine economy were in the run-in state, the intensive sea use was ahead of the development of the marine economy, and excessive sea use led to the degradation of the human-sea regional system; Yingkou fell into Type XII. In 2008, Dalian, Dandong, and Yingkou were classified as Type XII. In addition, Huludao fell into Type IX, indicating that the intensive sea use and the marine economy were in the run-in state. The intensive sea use was ahead of the development of marine economy, and excessive sea use led to the degradation of the human-sea regional system. In 2012, Dalian, Dandong, and Yingkou fell into Type XII, and Huludao fell under Type IX. In 2016, Dalian, Dandong, Yingkou, Panjin, and Huludao all fell into Type XII. In general, intensive sea use was ahead of marine economy development in more and more regions during the study period, that is, excessive sea use caused a waste of sea resources. As a result, the use of sea areas was inconsistent with the development of the marine economy, and the human-sea regional system generally remained in the entropy increase process. Therefore, in the future, these cities should appropriately plan the use of sea areas based on the principle of maximizing the comprehensive benefits to promote the sustainable development of the marine economy.

6. Conclusions and Discussion

Taking the Liaoning Coastal Economic Belt as the research object, this study constructed an evaluation indicator system for intensive sea use and marine economy development from the perspective of the human-sea-land relationship and based on the connotation of intensive sea use. The set pair analysis method was employed to conduct a quantitative analysis on the levels of intensive sea use and marine economy in the study area from 2004 to 2016. The coupling coordination degree model was used to analyze the spatiotemporal evolution characteristics of the coordination between intensive sea use and the marine economy in the Liaoning Coastal Economic Belt. The following conclusions were drawn:

(1) From 2004 to 2016, the composite indexes for both intensive sea use and the marine economy in the Liaoning Coastal Economic Belt rose. In terms of the composite index for intensive sea use, there was a great gap between Huludao and other five cities. In terms of the composite index for the marine economy, the gap between cities gradually narrowed during the study period.

(2) According to the calculation results of the coupling coordination degree model, the level of coupling coordination between intensive sea use and marine economy in the Liaoning Coastal Economic Belt gradually increased from 2004 to 2016, which tended to be good resonant coupling. Huludao was in the separation state prior to 2016 and evolved into the run-in state in 2016. Dandong was in the run-in state before 2016 and evolved into the coordination state in 2016. Dalian, Panjin, Jinzhou, and Yingkou were in the coordination state throughout the study period.

(3) In terms of the relative development index, the relative degree of development between intensive sea use and marine economy in the Liaoning Coastal Economic Belt did not show any of the characteristics of Types I–VII. It did not experience the separation and antagonism stages during the study period. The regions in the run-in stage gradually disappeared, and there were a small number of cities that experienced synchronous development. Intensive sea use was ahead of marine economy development under the coordination and optimization stage in more and more regions. Even in the same coordination stage, the relative degree of development between intensive sea use and marine economy varied with cities. In actual planning, it is necessary to coordinate and distinguish among the differences between cities.

Based on the analysis of the mechanism of intensive sea use and marine economy from the perspective of the human-sea system, this paper builds a comprehensive

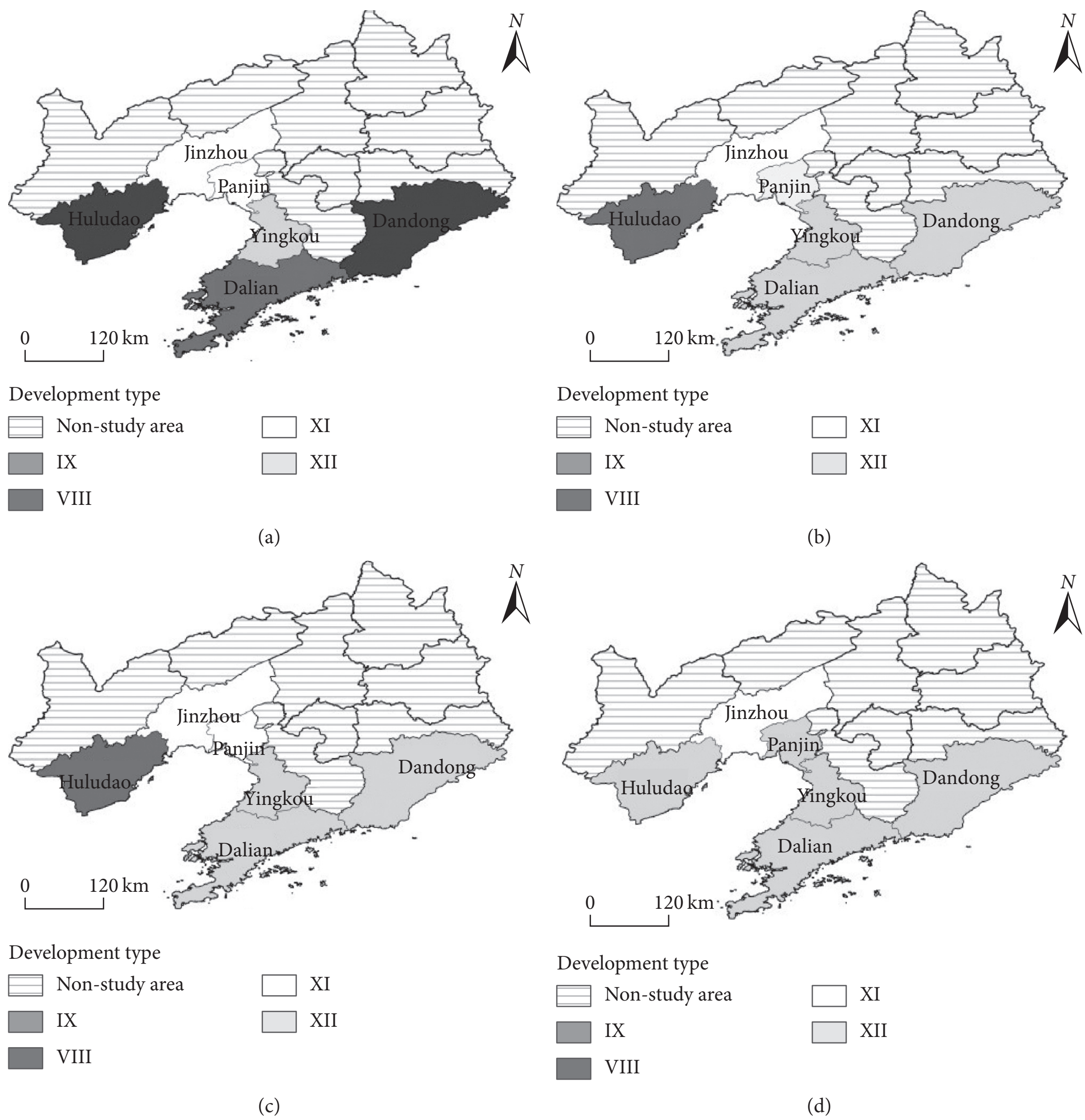

Figure 6: Spatial variation of relative development degree of six coastal cities in Liaoning Province. (a) 2004. (b) 2008. (c) 2012. (d) 2016.

evaluation index system of intensive sea use and marine economy. Based on the set pair analysis method, the comprehensive evaluation of the sea area intensive utilization and marine economy of the Liaoning coastal economic belt is carried out. Through calculation and coupling model, the in-depth analysis of the spatial and temporal evolution characteristics between the intensive use of the sea area and the marine economy in the Liaoning coastal economic zone reveals the interaction mechanism and the law of development and change of the intensive use of the sea area and the development of the marine economy. The research results can provide support for the rational development and utilization of marine resources and the formulation of marine economic development policies and have important scientific and practical significance.

However, the study does have some limitations. The definitions and connotation of the index system of intensive utilization in China needs to be further improved because the research on intensive utilization is still in the exploratory stage. In addition, in terms of the model, the coupling coordination degree model is established to evaluate the coupling coordination between intensive utilization and marine economy by referring to the coupling concept in physics. In order to quantify the relationship between the marine economy and marine intensive utilization more accurately, the model needs to be further explored.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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