

Spatio-temporal evolution and influencing factors of land-sea coordination in China's coastal areas

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Research Article

Keywords: Land-Sea Coordination, Coupling Coordination, Spatio-Temporal Evolution, Integrated Coastal Management, Tobit Model

Posted Date: October 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11095644/v1>

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Additional Declarations: No competing interests reported.

Abstract

Land-sea coordination is fundamental to China's maritime power strategy. This study evaluates the coordinated development of land and sea systems using panel data from 11 China's coastal provinces (2008–2024). Using the entropy weight method, coupling coordination model, and random-effects Tobit model, the study finds that: (1) the coordination degree has improved over time but remains spatially imbalanced, with significant inter-provincial disparities; (2) 87% of regions remain at mild disorder, barely coordinated, or primary coordination levels; (3) Government support and openness positively influence coordination, whereas marine-related industrial agglomeration exerts a negative impact. These findings suggest strengthening strategic planning for coordinated land-sea development, promoting the upgrading of the marine industry, enhancing marine ecological protection, and deepening international exchange and cooperation.

1. Introduction

Human activities and land-sea coordination development interact with each other in complex ways (Stancheva et al., 2021). The integration of land and marine governance has been a persistent challenge for coastal nations. Historically, regulation of inter-tidal activities was fragmented, with poor coordination between land-use planning and marine licensing (Turner & Essex, 2016). The UK's Coastal Concordat (Department for Environment, Food and Rural Affairs, 2019) improved inter-agency communication, but benefits remained largely confined to the public sector, with marine businesses largely unaware of its advantages—underscoring that administrative coordination alone is insufficient without active private-sector participation and adequate resourcing (Alves et al., 2013; Pittman & Armitage, 2016).

At the Europe Union level, Marine Spatial Planning (MSP) has advanced the “blue economy” but remains focused on legal and policy dimensions, often overlooking socio-ecological complexities (Douvere & Ehler, 2009; Ehler, 2021). Integrated Coastal Zone Management (ICZM) has been widely promoted yet hampered by overlapping jurisdictions and weak stakeholder engagement (Cicin-Sain, 1993; Kidd et al., 2020; Portman, 2011; Schernewski et al., 2014). In the USA, the Coastal Zone Management Act provides a decentralized model emphasizing flexibility but criticized for prioritizing ecology over balanced development (Smith et al., 2011; Thompson, 2013). In Southeast Asia, island states face challenges from geographic fragmentation and customary tenure, where customary governance can be effective when supported by legislation, but government-led processes often fail to ensure sustained implementation (Jupiter et al., 2017; Neal et al., 2003). These indicate that the theoretical foundations of land-sea integration have evolved from natural processes to socio-economic drivers and cross-system threats (Alvarez-Romero et al., 2011; Pittman & Armitage, 2016). Effective governance requires spatial planning, institutional coordination (Stancheva et al., 2025), and ecosystem-based principles (Kidd et al., 2020; Pittman & Armitage, 2016; Yue et al., 2023). Yet operationalization remains challenging, particularly in balancing economic development, ecological protection, and social equity (O'Hagan et al., 2020; Tocco et al., 2024).

In China, “land-sea coordination” (LSC) was formally introduced in the 12th Five-Year Plan (2011) and elevated to national strategy in 2017. Unlike ICZM or MSP, LSC emphasizes coordinated development of land and marine economies, resource utilization, ecological protection, and social welfare as an integrated whole (Li et al., 2024; Yue et al., 2023; Zhang, 2005). This has been institutionalized through the Ministry of Natural Resources and the Ecological and Environmental Code (Liu & Xing, 2019; Liu et al., 2019; Wang & Zhang, 2026). For example, for the spatial planning, Long et al. (2023) introduced marine zoning under China's “Three Lines One Permit” policy. Yue et al. (2023) reviewed LSC implementation, evaluation linkage, and management coordination, proposing polycentric governance and participatory planning. Methodologically, evolutionary game theory has been applied to stakeholder interactions. L. Zhang et al. (2025) constructed a quadrilateral game model involving governments and scientific institutions, finding governance costs and incentives are key determinants. Yan et al. (2026) incorporated dynamic ecological compensation and time-delay effects, revealing that delayed higher-government responses can enhance stability.

Despite these contributions, gaps remain. Most studies focus on single aspects of LSC, such as economic, ecological, or spatial, and without integrated assessment (Gao et al., 2022; Ju, 2020; Li et al., 2017; Zhao et al., 2017). Existing studies mostly focus on separate dimensions of land-sea coordination. City-scale mechanism quantification is limited due to data constraints (Gao et al., 2022; Yan et al., 2023). To address these gaps, this study constructs separate comprehensive evaluation frameworks for land-system and sea system development covering economy, resource utilization, technological progress and ecological protection. Due to limited publicly available provincial statistical data on cross-system material-energy fluxes across the land-sea interface, direct indicators for land-sea symbiosis interface are not incorporated. Instead, land-sea coordination is reflected indirectly via coupling-coordination modelling of two subsystems. The 17-year panel allows identification of stable long-term trends. This study provides references for national coastal development planning and regional development initiatives.

2. Methodology

2.1. Data Sources

This study focused on 11 coastal provinces (cities) in China, namely Liaoning, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi and Hainan. In the following analysis, the eleven provinces (cities) along China's coast are further divided into three major marine economic circles, including the northern marine economic circle, the eastern marine economic circle, and the southern marine economic circle (Guo et al., 2022). The study period is from 2008 to 2024. Data sources include the China Statistical Yearbook, China Fixed Investment Statistical Yearbook, China Environmental Statistical Yearbook, China Marine Economic Statistical Yearbook, China Science and Technology Statistical Yearbook, China Marine Statistical Yearbook, China Marine Disasters Bulletin, and National Economic Development Bulletin of each province. Missing data were estimated using linear interpolation and supplementary calculations.

2.2. Index and Variables

Drawing on system coupling theory and synergetic development theory, this study constructed separate comprehensive evaluation systems for the land system and the sea system. Referring to Li et al. (2024), Tian et al. (2025) and Yue et al. (2023), the indicators were carefully selected. On the one hand, it is essential to adopt a coordinated and sustainable development approach for the integrated advancement of land and sea. This strategy aims to balance the economic, social, and environmental factors associated with both domains while minimizing conflicts arising from land-sea development activities (Yuan & Chang, 2021; Yue et al., 2023). On the other hand, scientific and technological innovation has become an integral component of land-sea synergistic development. The state has adopted scientific and technological innovation as a fundamental strategy to enhance marine development and promote economic growth in coastal areas (Fan et al., 2014; Xia et al., 2019). For example, Year-end ownership of marine motorized fishing vessels is selected because fishing vessels constitute the primary capital equipment of marine production (Utama et al., 2025) and reflect the technological equipment level and capital intensity of the marine fishery sector. Therefore, whether it is a land system or a sea system, economic efficiency, resource utilization, technological progress, and ecological protection are important criteria to measure the comprehensive development degree of a system. Therefore, this study takes the above four as the dimensional layer in the evaluation index system, and each sub-indicator is set under each dimensional layer. The specific indicators are shown in Table 1.

Table 1
Evaluation index system for the development degree of the land and sea systems.

Target Layer	Rule Layer	Index Layer	Direction
Development degree of land system	Economic benefit	Share of land-based primary sector	+
		Share of land-based secondary sector	+
		Share of land-based tertiary sector	+
		GDP growth rate	+
		Total investment in fixed assets	+
	Resource utilization	Crop sown area	+
		Urban road space per capita	+
		Water resources per capita	+
	Technological progress	Number of general higher education institutions	+
		Technology market turnover	+
		Financial expenditure on science and technology	+
		Number of applications for three types of patents	+
	Ecological protection	Volume of urban domestic waste removal	-
		Daily urban wastewater treatment capacity	+
		Greening coverage in built-up areas	+
Development degree of sea system	Economic benefit	Share of marine-based primary sector	+
		Share of marine-based secondary sector	+
		Share of marine-based tertiary sector	+
		Gross marine product	+
		Port cargo throughput	+
	Resource utilization	Number of berths at coastal ports	+
		Number of persons employed in marine fisheries	+
		Number of travel agencies in the coastal region	+

Target Layer	Rule Layer	Index Layer	Direction
	Technological progress	Year-end ownership of marine motorized fishing vessels	+
		Number of marine scientific research institutions	+
		Number of marine science and technology practitioners	+
		Number of marine scientific research patents granted	+
	Ecological protection	Number of observatory stations along the coastal area waterfront	+
		Direct economic losses from marine disasters	-
		Coastal wetland area	+

The coordination between land system development and sea system development is affected by a variety of factors, so it is important to accurately identify various factors to improve the coordination between the two. As shown in the Table 2, based on the existing studies and the current situation of China's land-sea system development, this study selects government support (GS), openness degree (OL), talent aggregation degree (DTA), sea-related industry concentration degree (MIC), and people's living standard (PLS) as the main influencing factors (Yan et al., 2023; T. Zhang et al., 2025). Meanwhile, this study takes the general budget expenditure of local finance, the amount of actual utilization of foreign direct investment (FDI), the total amount of regional R&D personnel, the entropy of marine industry location, and the per capita consumption expenditure of all residents as specific indicators.

Table 2
Descriptions of variables.

Variables		Introduction
Explained variables	Degree of coordinated development	The degree of coordinated development of land and sea
Explanatory variables	Strength of government support	General budget expenditure of local finance
	Open degree	Actual utilization of FDI
	Degree of talent aggregation	Total number of regional R&D personnel
	Degree of sea-related industrial agglomeration	Location entropy of the marine industry
	People's living standard	Per capita consumption expenditure of all residents

2.3. Entropy Weight Method

This study employs the entropy weight method to measure the development degree of the land system and the sea system in eleven China's coastal provinces and cities, reducing the subjectivity inherent in expert-based approaches such as AHP or Delphi, thereby more objectively reflecting the relative importance of each indicator. The entropy weight method determines weights from data variance, ensuring objectivity and cross-provincial comparability. The specific measurement steps and principles are described below:

The matrix is constructed according to the original formula, where “i” represents the province and “j” represents the number of evaluation indicators.

$$Y = (X_{ij})_{nm}, i = 1, 2, \dots, n; j = 1, 2, \dots, m \# (1)$$

The data in this indicator have been standardized as shown in equations (2) and (3):

$$X_{ij} = \frac{X_{ij} - \min(X_{1j}, X_{2j}, \dots, X_{nj})}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 0.1, i = 1, 2, \dots, n; j = 1, 2, \dots, m \# (2)$$

$$X_{ij} = \frac{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - X_{ij}}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 0.1, i = 1, 2, \dots, n; j = 1, 2, \dots, m \# (3)$$

Calculate the weight of the ith indicator among the j-th indicator to determine the weight coefficient of each indicator. As shown in formula (4):

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}}, j = 1, 2, \dots, m \# (4)$$

The entropy value of each indicator is calculated according to Eq. (5):

$$e_j = -k \times \sum_{i=1}^n P_{ij} \times \ln P_{ij} \# (5)$$

Calculate the coefficient of variation for the jth indicator X_{ij} according to Eq. (6):

$$g_j = 1 - e_j \# (6)$$

The weighting of the indicators is done according to formula (7):

$$W_j = \frac{g_j}{\sum_{j=1}^m g_j} (j = 1, 2, \dots, m) \# (7)$$

A composite score calculation is performed, as shown in Eq. (8):

$$S_i = \sum_{j=1}^m W_j \times P_{ij} (i = 1, 2, \dots, n) \# (8)$$

2.4. Coupling Coordination Degree Model

The coupling coordination degree model draws from the physical sciences to conceptualize the concept of coupling and is employed in the study of interaction between two or more systems. It is also utilized to assess the degree to which systems are developed in conjunction (Wang & Wang, 2021). In order to comprehensively consider the interactions and relationships between the two systems, land and sea, which reflect the degree of synchronized development and synergy between the system elements, this study adopts the coupled coordination degree model to measure the coordinated development degree of land and sea.

Despite more complex alternatives, this model remains the most policy-friendly framework due to its interpretability (Peng et al., 2022): the D-value maps directly onto an intuitive ordinal scale (severe disorder to senior coordination). The two-component structure—separating interaction intensity (C) from overall performance (T)—provides analytical clarity. The coupling degree (C) is a key metric for assessing inter-system coordination. Typically, the value of the coupling coefficient C ranges between 0 and 1, reflecting the degree to which the elements within the system are interconnected. The specific formula is as follows:

$$C = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \# (9)$$

The degree of coupling is important for assessing the strength of coupling between systems. Nevertheless, the method of calculating the coupling degree may result in erroneous assessment outcomes when conducting multi-regional comparisons in spatial dimensions (C. Gao et al., 2023). It does not identify the overall effect and synergy of the system (Liu et al., 2020). C may produce “false high-coupling” under double-low convergence (L. Gao et al., 2023). Cross-examining all provincial samples, we found no extremely low U_1 and U_2 paired with near-unity (C); low-coordination provinces like Tianjin showed divergent land–sea scores instead. These indicate that false-coupling bias is limited in the study’s dataset. Therefore, the development degree of the whole system is included in the coupled coordination degree model and the model can avoid false assessment results. The specific formula is as follows:

$$D = \sqrt{C \times T}, T = \alpha U_1 + \beta U_2 \# (10)$$

where D is the degree of coupling coordination between the two systems; C is the degree of coupling; T is the comprehensive evaluation index, which is used to evaluate the degree of comprehensive coordinated development of the two systems, and measures the overall coordinated development degree of the land system and the sea system in 11 provinces and municipalities directly under the central government. α and β denote the coefficients to be determined.

In this study, the development of the land system is considered to be as significant as that of the sea system; therefore, it is hypothesized that $\alpha = \beta = 0.5$. In order to provide an unambiguous presentation of the development status of the coupling coordination level between the land and maritime systems, the coupling coordination level is categorized into six levels: serious disorder ($0 \leq D < 0.3$); mild disorder (0.3

$\leq D < 0.4$); barely coordinated ($0.4 \leq D < 0.5$); primary coordination ($0.5 \leq D < 0.6$); intermediate coordination ($0.6 \leq D < 0.8$); senior coordination ($0.8 \leq D \leq 1.0$).

2.5. Random-Effects Tobit Model

The dependent variable CDL (land-sea coupling-coordination degree) is theoretically bounded in $([0,1])$. We adopt random-effects Tobit model for two reasons: (1) OLS may generate out-of-bounds predictions outside $([0,1])$; (2) this estimator is widely used in LSC literature for comparability with prior studies. To test for multicollinearity among the independent variables, the Variance Inflation Factor (VIF) test was conducted, revealing VIF values ranging between 1.80 and 9.10. Notably, this falls below the critical value 10, indicating minimal multicollinearity concerns. The results of the Likelihood Ratio Test indicate that the random-effects Tobit model is better than the pooled Tobit model, so the random-effects Tobit model is selected for this study. The following random-effects Tobit model was developed in this study.

$$CDL = \alpha + \beta_1 GS + \beta_2 OL + \beta_3 DTA + \beta_4 MIC + \beta_5 PLS + \epsilon \# (12)$$

CDL is the dependent variable that indicates the degree of coordinated land-sea development, quantified by the coupled coordination degree calculated in the previous section, which indicates the coordinated relationship between the development of the land system and the development of the sea system, and takes the value $[0,1]$. ϵ is the random error term.

3. Results

3.1. Spatial-Temporal Evolution of the Development of Land-Sea System

As illustrated in Fig. 1a, the comprehensive development level of the land area system for specific provinces and cities from 2008 to 2024 has been determined using the entropy weight method (Ju, 2020; Li et al., 2017). Supplementary Table 1 shows the average value of the development degree of the land area system of eleven coastal provinces and cities in China, including the marine economic circle to which each province and city belongs. In terms of the time trend, Liaoning, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, and Guangdong, have experienced increasingly rapid growth of land area systems since 2017. There are fluctuations in the development degree of land systems in some provinces from 2008 to 2024, especially in three provinces, Fujian, Guangxi and Hainan. However, overall, the comprehensive development degree of China's land area system from 2008 to 2024 is generally better, showing a continuous upward trend.

In terms of spatial development, the development degree of land systems shows a pattern of “high in the south and low in the north”, with the Eastern Marine economic circle slightly higher than the Southern Marine economic circle and the Northern Marine economic circle. Specifically, Guangdong in the Southern Marine economic circle has a much higher average comprehensive development degree of land systems than other provinces and cities, and is in a dominant position. Jiangsu and Zhejiang in the

Eastern Marine economic circle are among the top four in terms of average degree. In the Northern Marine economic circle, Shandong is more prominent, but the average degree of Tianjin still needs to be improved. The synthesis shows that there is a large gap between the coordinated development degrees of land-based systems in coastal regions.

As illustrated in Fig. 1b, the entropy weight method was utilized to assess the comprehensive development degree of sea systems in selected provinces and cities from 2008 to 2024 (Liu et al., 2022; Wang et al., 2022). Supplementary Table 2 shows the average value of the development degree of sea systems of eleven coastal provinces and cities in China, including the marine economic circle to which each province and city belongs. In terms of temporal trends, the comprehensive development degree of China's sea system generally shows an upward trajectory from 2008 to 2024, albeit at a relatively slow growth rate. During 2008–2015, most provinces exhibited year-on-year increases in sea system development. In 2020, the majority of provinces recorded a marked decline, a temporal shift that coincides with the COVID-19 shock, although strict causal attribution cannot be established within the current model. Development rebounded across provinces in 2021. Notably, Shandong experienced a pronounced surge in 2023.

In terms of spatial development, the gap between the average coordinated development degree of the sea system in the provinces of the Eastern Maritime Economic Circle is small, while the gap between the Southern Maritime Economic Circle and the provinces of the Northern Maritime Economic Circle is large. In particular, Guangdong in the Southern Marine economic circle has the highest average development degree, while Guangxi and Hainan are lower. In the Northern Marine economic circle, Shandong has a higher average development degree of sea systems, but Tianjin has a lower average degree, so the internal gap is larger. This shows that even in the same marine economic circle, the comprehensive development capacity of its sea system is different. As time progresses, a divergence in the development of the sea system among different provinces becomes increasingly evident.

3.2. Spatial-Temporal Evolution of the Coordinated Development of Land-Sea System

3.2.1. Results of Spatial-Temporal Evolution

In order to elaborate the spatial development of the degree of coordinated development of the land-sea system, the degrees of coordination in 2008, 2013, 2018 and 2022 were selected for this study to be described and mapped. As shown in Fig. 2, since 2008, there has been no serious disorders in the process of land-sea coordinated development in China's 11 coastal provinces and municipalities (Gao et al., 2022; Han et al., 2017), which indicates that the government attaches great importance to land-sea coordinated development, and a series of policies and plans have been formulated and implemented to effectively guide and support land-sea coordinated development. Specific changes in the degree of land-sea coordinated development are summarized below:

(1) Mild disorder: Tianjin's development degree of LSC is in a mildly dislocated state from 2008 to 2022, and it is at the lowest degree among the selected provinces and cities. In addition, the development degree of LSC in Hebei Province and Shanghai Municipality was also in a slightly disturbed state in 2008. This indicates that LSC in Tianjin, Hebei, and Shanghai was low in 2008.

(2) Barely coordinated: In 2008, the development degree of LSC of Liaoning, Jiangsu, Zhejiang, Fujian, Guangxi and Hainan provinces was barely coordination. In 2013, Hebei Province and Shanghai Municipality got out of the state of mild disorder and rose to the state of imminent dislocation, while Liaoning Province, Jiangsu Province, Zhejiang Province and Fujian Province improved and rose to the state of primary coordination. In 2018, Liaoning Province fell back to the state of imminent dislocation.

(3) Primary coordinated: The integrated land-sea coordinated development of Shandong Province and Guangdong Province remained at a primary coordinated state in 2008. By 2013, Liaoning, Jiangsu, Zhejiang, and Fujian provinces had progressed to this primary coordination level. However, in 2018, only Jiangsu and Fujian provinces maintained this primary coordinated status. The latest data from 2022 reveals that Jiangsu Province has advanced beyond the primary coordination stage, while Liaoning Province has regressed to this initial level. This fluctuation pattern demonstrates that Liaoning Province exhibits instability in its land-sea coordinated development process, characterized by periodic reversals in developmental progress.

(4) Intermediate coordinated: a review of the literature reveals that only Shandong Province and Guangdong Province exhibited a moderate degree of coordination in 2013. Zhejiang Province was added in 2018, and Jiangsu Province was added in 2022.

(5) Senior coordinated: only Guangdong Province reached the senior coordination degree during the study period, but only just, with much room for future development.

In summary, the degree to which China's eleven coastal provinces and municipalities are integrating land and sea is not exceptional, indicating significant potential for advancement. However, it is evident that these regions are progressing in a favorable direction. However, certain provinces, such as Liaoning, demonstrate unstable development factors, oscillating between positive and negative growth trends. Guangxi Province has experienced a state of instability over the past four years, which may be attributed to its role as an essential link in the emerging land and sea corridor in the west. The province is undergoing a transition from a "corridor economy" to a "hub economy", a shift that has been accompanied by a deficiency in robust land and sea industrial linkages. Consequently, the province's land and sea industries have been struggling to establish robust interconnectivity, which has contributed to their persistent state of near-dysfunction. A discrepancy in the coordinated development of land and sea in China's coastal regions is evident between the northern and southern regions (L. Gao et al., 2023). In four selected years, the southern provinces have exhibited a higher level of coordination compared to their northern counterparts. A greater number of southern provinces are classified as intermediate coordinators compared to their northern counterparts. Notably, in 2022, Guangdong Province attained the advanced coordination level, signifying a notable advancement in the southern provinces. The rate of

progress in land-sea integration in the southern provinces has consistently outpaced that of the northern provinces. Consequently, in the course of promoting the development of land-sea integration, the government should prioritize the northern provinces, ensuring that both regions progress in tandem and collectively advance the coordinated development of China's land-sea integration.

3.2.2. Sensitivity Analysis of Parameter Specifications

To eliminate potential subjective bias associated with the equal-weight assumption ($\alpha = \beta = 0.5$) in the composite coordination index, a parameter sensitivity analysis was conducted by simulating weight adjustments. This section varied the land system weight coefficient α from 0.40 to 0.60 with an increment of 0.05, while setting the sea system weight $\beta = 1 - \alpha$. As presented in Fig. 3a, adjusting the weight allocation yielded only minor numerical deviations in the coupling coordination degree (D). During 2008 to 2024, the annual ID value fluctuations under different α settings remained consistently under 0.00966. According to Fig. 3b, the temporal trajectory remained perfectly synchronous across all parameter scenarios. These simulation findings demonstrate that the coupling coordination model is highly insensitive to parameter specification within the interval between 0.40 and 0.60, confirming that the baseline equal-weight assignment ($\alpha = \beta = 0.5$) is empirically stable, robust, and reliable; the baseline results should be supported.

3.3. Factors Affecting the Land-Sea System Coordination

3.3.1. Descriptive Statistics

Table 3 shows the descriptive statistics of the variables. Descriptive statistics show that, the mean value of the dependent variable, the degree of coordinated development of land and sea, is 0.504, which indicates that the overall degree of coordinated development of the land system and the sea system is low. Meanwhile, the minimum value of the degree of openness to the outside world and the degree of talent pooling is 0.033 and 0.173, respectively, and the maximum value is 13.349 and 144.127, respectively, which indicates that the degree of openness to the outside world and the degree of talent pooling vary widely among provinces.

Table 3
Descriptive statistics of the variables.

Variables	Symbol	N	Mean	SD	Minimum	Maximum
Degree of coordinated development	CDL	187	0.504	0.109	0.264	0.834
Strength of government support	GS	187	0.616	0.419	0.036	1.853
Open degree	OL	187	1.208	2.163	0.033	13.349
Degree of talent aggregation	DTA	187	33.274	32.031	0.173	144.127
Degree of sea-related industrial agglomeration	MIC	187	2.134	1.114	0.632	5.109
People's living standard	PLS	187	2.098	0.996	0.557	5.272

3.3.2. Empirical Results Analysis

Table 4 shows that the strength of government support and the degree of opening up to the outside world have a positive effect on the coordinated development of the land and the sea system, whereas sea-related industrial agglomeration exerts a negative impact. The specific performance is as follows:

(1) The impact coefficient of government support is the highest, reaching 0.131, which passes the 1% significance test, i.e. for every 1 percentage point increase, the degree of coordinated development of the land and sea system will increase by 0.131 percentage points. Governments can provide robust policy support for LSC by formulating and implementing measures spanning finance, taxation, infrastructure, ecological protection, and technological innovation. Consequently, the strength of government support exhibits a considerable positive impact on the LSC degree.

(2) The impact coefficient of the degree of external development reaches 0.003 and passes the 1% significance test. This means that for every one percentage point increase in the degree of external development, the degree of coordinated development of the land system and the sea system will increase by 0.003%. China's coastal area is an important window for China's opening up to the outside world, and has a higher degree of opening up to the outside world than other regions, and the increase in the degree of opening up to the outside world means the expansion of the international market. For the land system, it can enter a wider market and obtain more resources and opportunities through international trade and investment. At the same time, the sea system can also expand the international market and improve the international competitiveness of the marine economy through international shipping and fisheries cooperation. Such market expansion will help promote the mutual promotion and coordinated development of land and sea in terms of economic development.

(3) The impact coefficient of the sea-related industrial agglomeration is -0.009 and passes the 5% significance test. It should be stressed that the significant negative coefficient reflects statistical correlation rather than definitive causal evidence. We offer plausible mechanism interpretations below

for further empirical verification: The agglomeration of marine industries, while fostering localized growth and efficiency within coastal regions, can inadvertently hinder the coordinated development of land and marine economies (Li & Kang, 2021; Najafinasab et al., 2015). This may occur partly because industrial clustering tends to concentrate capital, talent, infrastructure, and policy support in coastal hubs, potentially creating a spatial and structural imbalance that could marginalize inland areas. As marine industrial parks and port-centered economic zones expand, they often compete with rather than complement land-based industries for resources such as energy, water, land, and logistics capacity. Furthermore, the institutional fragmentation between maritime and land planning systems, especially each governed by different administrative bodies and regulatory frameworks, exacerbates this divide, making integrated planning and cross-sectoral investment difficult. The result is a dualistic economic structure in which advanced marine clusters thrive while inland regions remain disconnected from maritime value chains, thereby weakening the synergy, resource circulation, and mutually reinforcing growth that define true land–sea coordination.

(4) By contrast, talent aggregation (DTA) and people's living standard (PLS) show insignificant effects in full-sample estimation. For the industrial agglomeration, the possible reason is that, on the one hand, sea-related industrial agglomeration can form scale effect, improve production efficiency, reduce costs, promote the development of related industries, form a complete industrial chain, and then promote the coordinated development of land and sea, which has a positive promoting effect; On the other hand, if the sea-related industrial agglomeration is excessive, it may lead to the over-concentration of resources, resulting in environmental pollution, ecological damage and other problems, which leads to the coastal region's economic coordination and adjustment problems, cannot effectively promote the development of land areas, and ultimately affect the degree of coordinated development of land and sea. For people's living standard, the consumption upgrading brought about by rising living standards may strengthen the demand for high-value-added land-based products and services, but it does not necessarily translate automatically into a pull for marine resource development, marine industry upgrading, or the docking of land-sea industrial chains. Consequently, it remains a notable but non-dominant variable in the overarching process of land-sea coordinated development. Their specific relationship needs to be further discussed.

Table 4
Model regression results.

Variables	Estimating coefficient	Standard error	Z-value	P-value	Confidence interval
GS	0.131***	0.018	7.41	0.000	[0.0962208, 0.1654177]
OL	0.003***	0.001	2.61	0.009	[0.0008447, 0.0059721]
DTA	0.0003	0.000	1.23	0.218	[-0.0001773, 0.0007767]
MIC	-0.009**	0.005	-2.00	0.046	[-0.01864, -0.0001799]
PLS	0.004	0.004	0.90	0.368	[-0.0046778, 0.0126267]
_Cons	0.422***	0.021	20.52	0.000	[0.3813076, 0.461834]
$LRtest(\sigma_u = 0) : \chi^2 = 27.61, p < 0.001$					

Note

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.3.3. Spatial Heterogeneity Analysis

To further elucidate the driving mechanisms underlying spatial heterogeneity in integrated land-sea development, this study categorizes the 11 coastal provinces into three major marine economic circles. Random-effects Tobit models are separately estimated for each sub-region. The empirical results of the spatial heterogeneity analysis are presented in Table 5.

Table 5
Spatial heterogeneity analysis of integrated land-sea development

Variables	Northern	Eastern	Southern
GS	0.001 (0.03)	0.108** (2.00)	0.171*** (8.31)
OL	0.019*** (2.73)	0.009 (0.59)	0.001 (0.77)
DTA	0.002*** (5.37)	0.000 (0.19)	0.001* (1.75)
MIC	0.009 (1.19)	-0.024** (-2.00)	0.006 (0.88)
PLS	0.035*** (5.04)	0.014 (1.34)	-0.029*** (-4.12)
_Cons	0.319*** (6.13)	0.424*** (13.56)	0.438*** (24.56)
N	68	51	68
Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.			

The results of spatial heterogeneity analysis show that MIC has a statistically significant negative effect on LSC ($\beta = -0.009$, $p < 0.05$). Sub-regional regressions reveal that this negative inhibitory effect originates predominantly from the Eastern Marine economic circle ($\beta = -0.024$, $p < 0.05$), whereas it remains statistically insignificant in the Northern and Southern circles. As the core economic engine of eastern China, the Yangtze River Delta features a high density of port-adjacent industries and marine enterprises. However, excessive industrial agglomeration has induced severe resource competition and environmental stress on coastal ecosystems. Furthermore, insufficient supply-chain linkages between marine-related and land-based industries have resulted in a fragmented enclave-style agglomeration, causing the congestion effects of over-agglomeration to outweigh its agglomeration economies, thereby hindering LSC.

Although the impact of talent agglomeration (DTA) is statistically insignificant in the full-sample estimation ($\beta = 0.0003$, $p > 0.1$), the sub-regional analysis uncovers pronounced spatial disparities. DTA significantly promotes integrated land-sea development in the Northern ($\beta = 0.002$, $p < 0.01$) and Southern ($\beta = 0.001$, $p < 0.1$) Marine economic circles, while remaining insignificant in the Eastern region. The northern coastal region, dominated by traditional industrial structures, benefits markedly from the inflow of R&D personnel, which fills crucial technological gaps in marine industries

and yields a notable short-board replenishment and increasing marginal returns. In the southern region, vibrant emerging marine sectors allow high-skilled talent to effectively support land-sea industrial synergies. Conversely, the eastern region possesses a high baseline talent density with diminishing marginal returns, where R&D personnel are predominantly concentrated in finance and traditional land service sectors, leading to a structural mismatch with sea-related physical industries.

While people's living standard (PLS) exhibits no statistically significant effect in the full sample ($\beta = 0.004$, $p > 0.1$), the regional analysis demonstrates contrasting underlying mechanisms between the north and south. Per capita consumption expenditure significantly fosters land-sea integration in the Northern circle ($\beta = 0.035$, $p < 0.01$), whereas it exerts a significant negative effect in the Southern circle ($\beta = -0.029$, $p < 0.01$). In the northern region, upgrading consumption expenditure broadens domestic demand for land-sea integrated industries. The negative PLS coefficient for the Southern Marine economic circle is suggestive. One potential explanation relates to consumption-driven coastal ecological pressure, though this cannot be directly validated without additional pollution-emission intermediate variables. In contrast, the exceptionally high living standards in the southern region stimulate intensive coastal tourism and resource exploitation, while increased land-based consumption waste aggravates the ecological load on nearshore environments. Consequently, the ecological pressure generated by high consumption offsets its positive economic demand pull.

The strength of government support (GS) exhibits a powerful positive driving effect in both the Eastern ($\beta = 0.108$, $p < 0.05$) and Southern ($\beta = 0.171$, $p < 0.01$) circles, reflecting higher marketization and superior leverage efficiency of fiscal expenditure in southern and eastern China. In contrast, fiscal support in the northern region fails to achieve statistical significance, indicating a need to optimize public fund allocation toward LSC. Furthermore, the openness degree (OL) is statistically significant only in the Northern Marine economic circle ($\beta = 0.019$, $p < 0.01$), highlighting the northern coastal region's continued reliance on foreign direct investment to upgrade heavy industries and marine equipment manufacturing.

Beyond the cross-circle comparisons, the empirical results also reveal substantial intra-circle heterogeneity at the provincial level, which further validates the informative value of provincial-scale data. For instance, within the Northern Marine economic circle, Shandong Province consistently exhibits a much higher degree of land-sea coordination than Tianjin and Hebei, with a gap exceeding 0.2 in the average coordination index over the study period. Similarly, within the Southern Circle, Guangdong far outperforms Guangxi and Hainan, while the Eastern Circle shows relatively narrower internal disparities. These intra-circle variations suggest that provincial-level aggregation does not simply average out all spatial information; rather, it captures meaningful differences in provincial governance capacity, resource endowments, and policy implementation effectiveness. Such within-group divergence merits further investigation in future research, as it points to the possibility that institutional and policy factors at the provincial level—rather than merely geographical location—play a decisive role in shaping land-sea coordination outcomes.

4. Discussion

4.1. Empirical Findings and Theoretical Contributions

Marine issues are receiving increasing international attention (Pittman & Armitage, 2016; Portman, 2011). The EU pioneered MSP but focuses primarily on legal and policy dimensions (Douvere & Ehler, 2009). China was among the first to theorize land–sea coordination, with research spanning marine functional zoning (Fu et al., 2021) and coastal sustainable development (Yu et al., 2010). International contributions to coastal sustainability are also substantial (Cicin-Sain, 1993; Karim & Hoque, 2009; Schernewski et al., 2014; Stancheva et al., 2025). Evaluation indicators have diversified, covering coastal ecology (Shi et al., 2020; Tang et al., 2018) and land–sea industrial synergy (Ni et al., 2024; Pan et al., 2022; Peng et al., 2022).

Building on these, our study constructs an indicator system across four dimensions (economy, resources, technology, ecology), applies the coupling coordination model, and uses random-effects Tobit regression to identify influencing factors. This enriches LSC theory and informs policy for other coastal nations. The index system provides detailed data for territorial and marine spatial planning. Regional differences in LSC levels indicate uniqueness across regions, enabling tailored strategies. The empirical results show that LSC is influenced by multiple factors, especially in terms of government and economy.

Provincial-level data simplify coastal land–sea interactions. Within provinces, coastal and inland municipalities differ markedly; ecological conditions and industrial structures vary across adjacent port cities. Findings should be interpreted as macro-level regularities, not local diagnoses. However, this limitation does not undermine core contributions: (1) Tobit coefficients for GS and OL are robust, indicating macro-policy instruments systematically affect coordination outcomes; (2) the consistent north–south gradient and divergent driving mechanisms across circles suggest provincial data capture genuine structural patterns. Future research should downscale to prefectural or county level as granular data become available.

4.2. International Comparison and Global Relevance

Our empirical findings allow a grounded dialogue with international coastal governance, rather than a mere institutional comparison. There are three significant results: (1) government support (GS) has the largest positive effect on land–sea coordination ($\beta = 0.131$, $p < 0.01$); (2) sea-related industrial agglomeration (MIC) significantly inhibits coordination ($\beta = -0.009$, $p < 0.05$), originating predominantly from the Eastern Marine economic circle; and (3) talent agglomeration and living standards are spatially contingent, significant only in specific circles.

Institutional integration and government support. The strong GS coefficient is consistent with China's top-down, legally binding approach through the Ministry of Natural Resources and national spatial planning law (Wang & Zhang, 2026; Yue et al., 2023). This contrasts with the UK's Coastal Concordat, a voluntary inter-agency framework that improved public-sector communication but left marine

businesses largely unaware of its benefits (Smith et al., 2011; Turner & Essex, 2016). The UK case suggests administrative coordination without fiscal and regulatory leverage is insufficient; our finding that GS is the dominant driver supports this. Yet GS is insignificant in the Northern Circle, where marketization and fiscal leverage efficiency are lower (Yin & Hu, 2026). This echoes the UK lesson that institutional integration alone cannot guarantee outcomes. For other coastal nations, government support must be matched by local implementation capacity; a centralized mandate without sub-national fiscal capacity may produce uneven results, as in China's north.

Industrial agglomeration and enclave risk. The negative MIC effect, concentrated in the Eastern Circle, speaks directly to EU MSP experience. EU MSP has advanced the blue economy but has been criticized for overlooking socio-ecological complexities (Douvere & Ehler, 2009; Ehler, 2021; Kidd et al., 2020). Our finding that excessive marine industrial agglomeration creates congestion—resource competition, environmental stress, and weak supply-chain linkages with land-based industries—provides quantitative evidence for this concern. It also mirrors the Southeast Asian island experience, where government-led processes fail when local economic structures are fragmented (Jupiter et al., 2017; Neal et al., 2003). The Eastern Circle's enclave-style agglomeration suggests that blue-economy promotion without deliberate land–sea linkage policies can undermine coordination. This is a cautionary lesson for rapidly industrializing coasts: agglomeration economies have thresholds, beyond which coordination costs outweigh benefits.

Spatial contingency and policy templates. The spatially contingent effects of DTA and PLS—positive in the Northern Circle, negative for PLS in the Southern Circle—reinforce the US Coastal Zone Management Act's decentralized model, which emphasizes flexibility over uniform standards (Thompson, 2013). A single national policy template is unlikely to be optimal. In the Northern Circle, where traditional industrial structures dominate, talent inflow fills technological gaps; in the Southern Circle, high living standards stimulate coastal tourism and resource exploitation but also generate ecological pressure that offsets demand-side benefits. This aligns with O'Hagan et al. (2020) and Tocco et al. (2024), who argue that land–sea integration requires context-specific balancing of economy, ecology, and equity. Policy transfer must therefore account for local development trajectories, consumption patterns, and ecological carrying capacity—not merely institutional design.

4.3. Implications for Global Coastal Governance

Based on provincial-level empirical findings, this study proposes both general and region-differentiated policy recommendations for land-sea coordinated development.

(1) Strengthen government guidance and strategic planning. Improve policy frameworks covering infrastructure, industry, ecology, technology and talent. Set up special fiscal funds targeting land-sea integration. Eastern and southern coastal provinces can further leverage fiscal expenditure to boost land-sea synergy. Northern provinces should optimize the efficiency of fiscal resource allocation since government support shows insignificant baseline effects in this sub-region. Regular supervision and evaluation systems should be implemented.

(2) Promote industrial development and structural optimization. Foster emerging marine industries and upgrade port-related industries. Build tighter industrial linkages between inland hinterland and marine sectors. Special attention should be paid to eastern coastal provinces: excessive sea-related industrial agglomeration produces crowding-out effects that undermine land-sea coordination. Local governments in the Eastern Marine economic circle should avoid blind expansion of marine industrial clusters and prioritize inter-sectoral linkage rather than simple agglomeration scale.

(3) Strengthen coastal ecological protection. Build joint land-sea pollution prevention mechanisms to control land-sourced pollution. Implement restoration projects for coastal wetlands and marine pastures. For southern coastal provinces, the ecological pressure brought by high consumption levels should be controlled to offset adverse impacts on near-shore environments.

(4) Deepen international cooperation and external exchanges. Northern coastal provinces benefit significantly from opening-up; they should keep utilizing foreign investment to upgrade marine-equipment and heavy coastal industries. All regions should participate in global ocean governance and draw international experience from ICZM and marine spatial planning.

4.4. Limitations

It should be noted that the provincial level, as an aggregate spatial unit, may obscure intra-provincial heterogeneity along the coastline, such as differences between major port cities and peripheral coastal counties. Nevertheless, this scale choice is justified by both data availability and research objectives. First, most marine-related statistical indicators in China—particularly gross marine product, marine scientific research personnel, marine disaster losses, and marine industry employment—are officially released only at the provincial level. Disaggregated prefectural-level data are either unavailable or suffer from inconsistent statistical coverage across years, making a reliable city-level panel for 2008–2024 infeasible. Second, the three major marine economic circles (Northern, Eastern, and Southern) are themselves defined by aggregating provincial units, and the significant inter-provincial differences within each circle (as shown in Supplementary Tables 1 and 2) indicate that provincial data do retain substantial spatial variation. Third, the 17-year panel dimension of this study facilitates the identification of stable long-term trends that are less susceptible to local transient shocks. Hence, although the findings are intended for macro-level policy guidance rather than localized planning, the provincial scale remains the most appropriate and reliable unit for a systematic, nationally comparative assessment of land–sea coordination dynamics. In the future, with the continuous improvement of data disclosure, consideration can be given gradually to incorporating intra-provincial indicators into the evaluation system for further research at a smaller unit of analysis.

5. Conclusions

Using panel data from 11 China's coastal provinces (2008–2024), this study applies the entropy weight method, coupling coordination model, and random-effects Tobit model to measure LSC and its influencing factors. This study found that both land and sea system development levels show upward

trends but with uneven spatial distribution and significant inter-provincial disparities. Land systems developed more rapidly and consistently; sea systems showed greater variability. Guangdong, Jiangsu, Zhejiang, and Shandong led land system development. Spatially, LSC follows a “high south, low north” pattern, with the Eastern Circle slightly ahead. In addition, LSC coordination has improved but remains unexceptional. Guangdong consistently leads; Liaoning shows instability. Southern provinces outperform northern provinces, and the south's improvement rate exceeds the north's. Government support and openness have positive effects on LSC, while sea-related industrial agglomeration has a negative effect. These conclusions are valid at the provincial-aggregate level and intended for macro-level policy coordination.

Declarations

Competing interests

The authors declare no competing interests.

Author Contribution

Y.L. proposed the research questions and research objectives. Y.L., W.G., and H.W. designed the research methodology. H.W. collected the data. W.G. and H.W. applied computer technology to analyse the data. Y.L. drafted the initial versions of Sections 1 and 4. W.G. and H.W. drafted the initial versions of Sections 2, 3, and 5. L.H., D.L., R.F., and K.M. critically reviewed and revised the manuscript. W.G. and H.W. created the figures and tables. L.H., D.L., R.F., and K.M. provided supervision and academic guidance for the project. Y.L. managed and coordinated the research activities. Y.L. acquired the research funding.

Data Availability

All data used in this research are publicly available and details are provided in the paper. Further inquiries can be directed to the corresponding authors.

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Figures

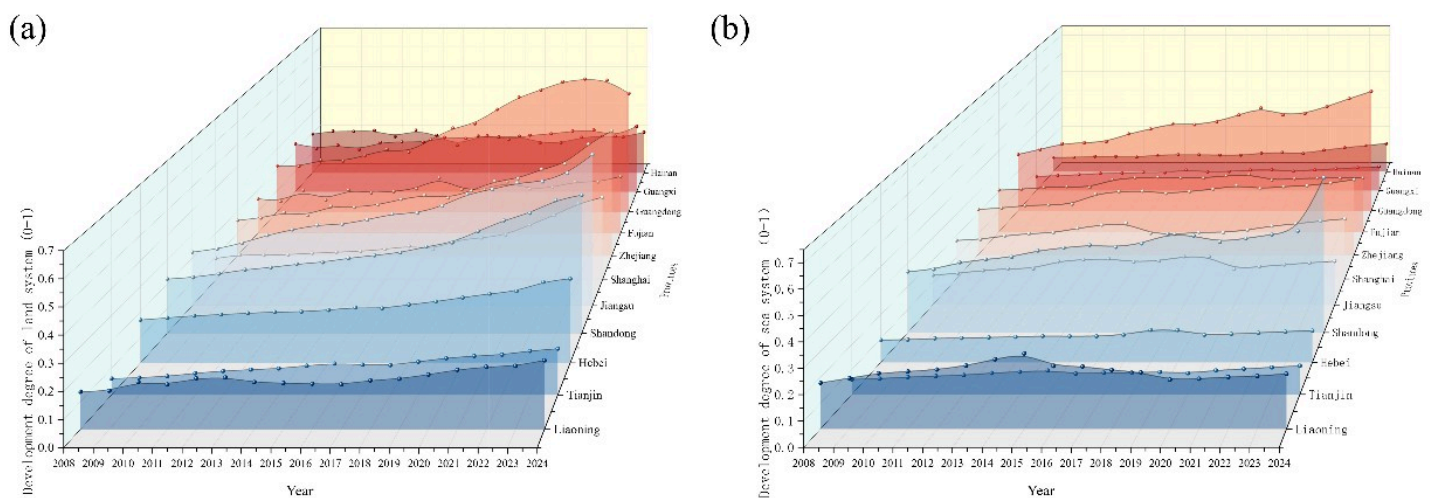


Figure 1

Changes in the level of development of the (a) land system and (b) sea system in 2008-2024.

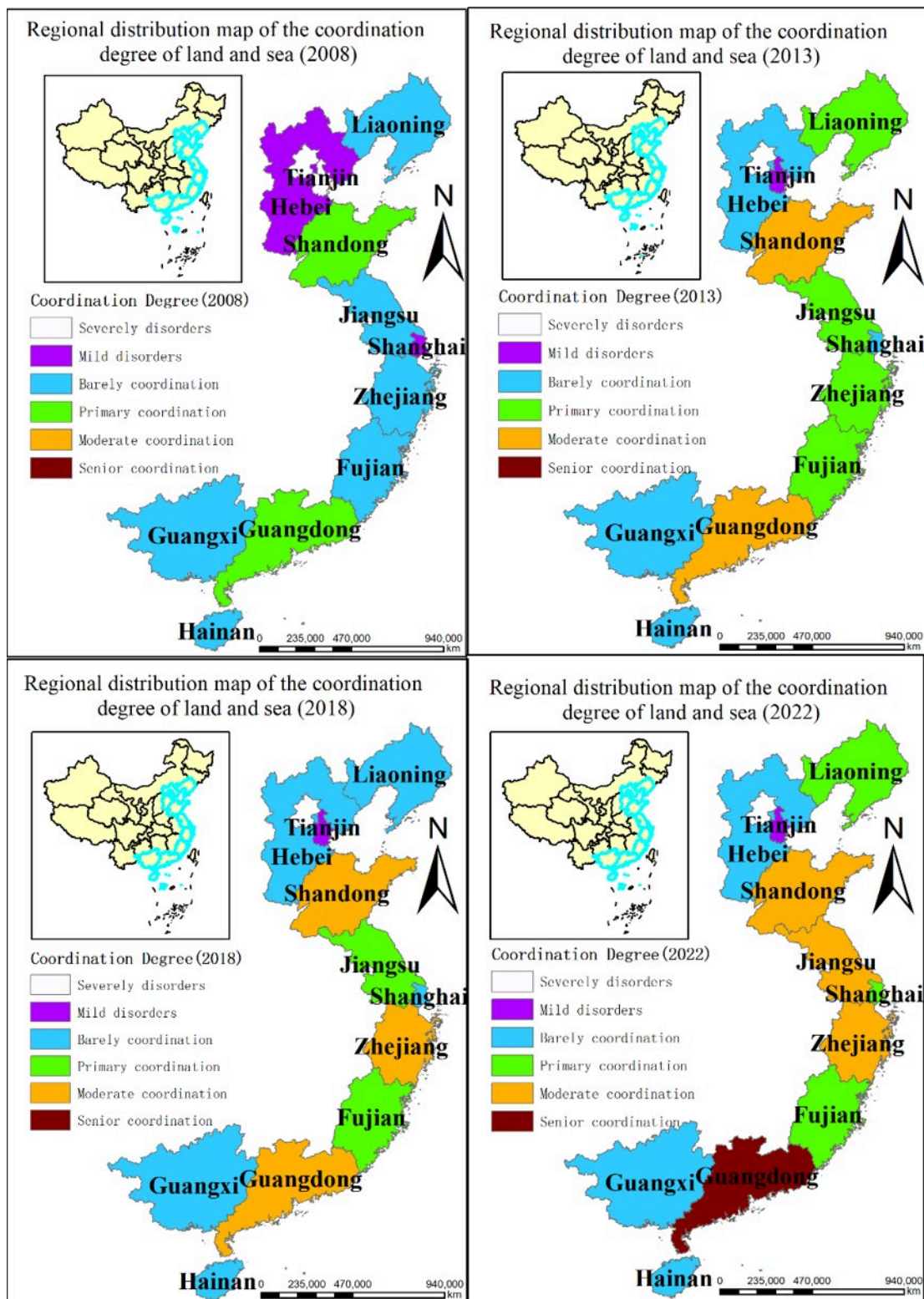


Figure 2

Spatial patterns of the degree of coordinated development between the land and sea systems in typical years.

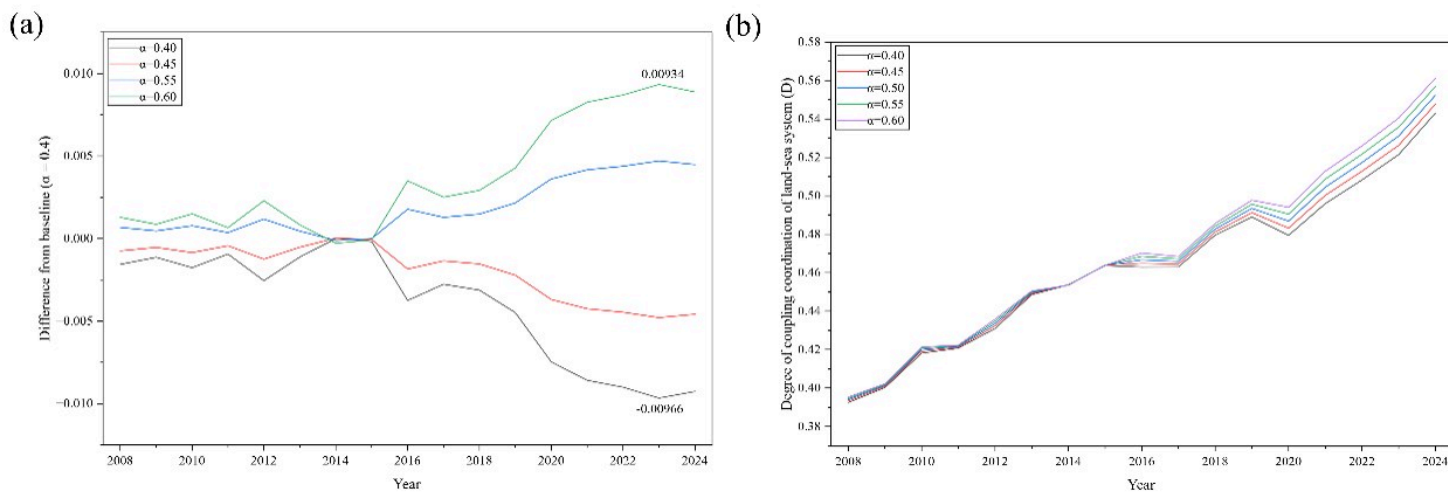


Figure 3

(a) Sensitivity analysis of coupling coordination degree. (b) Deviations of coupling coordination degree under different α settings relative to the baseline.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryMaterial.docx](#)