Comprehensive Evaluation Research on Marine Science and Technology Innovation Capabilities

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Abstract: This study seeks to evaluate the marine science and technology innovation capabilities in Shandong Province. By selecting indicators from four key areas—innovation entities, projects, outcomes, and support systems—the research establishes a comprehensive evaluation index system. Shandong Province, known for its extensive marine territory and rich resources, has long been a leader in marine economic development, playing a vital role in the nation's overall marine strategy. Strengthening innovation in marine science and technology is crucial for furthering the province's marine economy. Drawing on statistical data from marine research institutions, the study integrates theories and methodologies from economics, management, statistics, and modern information science to conduct an in-depth assessment of Shandong's marine innovation capabilities. The findings reveal that Shandong has achieved a relatively high level of capability in this area, with marine-focused universities and research institutions playing a particularly significant role. Nevertheless, there remains potential for enhancing investment in marine R&D. This research underscores the importance of a thorough evaluation of marine science and technology innovation in coastal regions, providing valuable theoretical and practical insights for advancing the national marine development strategy.

Keywords: Marine Science and Technology; Innovation Capability; Comprehensive Evaluation; Index System

1. Research Status at Home and Abroad

1.1 Foreign Research Status

There is limited research on the evaluation system of marine science and technology innovation capabilities internationally, though significant work has been done on establishing and refining the broader science and technology innovation evaluation systems. Generally, the United States, Italy, and Japan are pioneers in this field, with their studies being quite representative [1].

First, as a global economic powerhouse, the United States has advanced science, technology, and equipment, and began its research on technology evaluation systems early. The U.S. was the first country to establish and publicly use a science and technology innovation capability evaluation system. Judith Kildow, Charles Colgan, and Jason Scorse (2009) pointed out that the U.S. system covers a wide range of indicators, including funding input, labor input, public enthusiasm, and the educational level of technical professionals, with further subdivisions under each of these indicators, forming a comprehensive system. Notably, public enthusiasm for technological development is a novel indicator, reflecting public awareness and participation in technological progress [2,3]. Additionally, in 2001, the U.S. used this system to evaluate the innovation capabilities of large and medium-sized cities within regions.

Second, Italy adopts a rigorous approach to constructing its science and technology innovation capability system, which is detailed in monographs. Their system focuses on three main aspects: patents, technology, and exports, with a particular emphasis on patent indicators.

Lastly, Japan's Ministry of Science and Technology has developed an authoritative evaluation system, which identifies the added value of manufactured goods, patents, and technology as crucial indicators of science and technology innovation capability [4].

1.2 Domestic Research Status

In China, research on evaluating marine science and technology innovation capabilities remains limited, with most scholars concentrating on two main areas:

First, the structure of the marine science and technology innovation system. Chang Yumiao (2012) proposed a framework for China's marine science and technology innovation system, categorizing it into three subsystems: the development of marine science and technology, the transformation of marine achievements, and innovation within the marine industry. Li Yong (2011) emphasized the importance of integrating marine science and technology innovation with marine economic development, advocating for a collaborative approach that involves government, enterprises, and marine research institutions in building a regional marine science and technology innovation system [5-7].

Second, the development of indicators and evaluation methods for assessing the marine science and technology innovation system. Liu Dahai (2015) identified innovation entities, activities, and environments as key components of an evaluation indicator system for marine science and technology innovation. Building on this, Ma Renfeng (2014), Yin Kedong (2009), Xie Ziyuan (2012), and Liu Chao (2015) applied various analytical methods-such as principal component analysis, fuzzy clustering, the DEA method, and gray correlation analysis—to assess these indicators, thereby identifying the primary factors that influence the innovation capabilities and efficiency within China's marine science and technology sector. [8-10]

1.3 Research Review and Analysis

By analyzing the domestic and foreign research, it can be concluded that scholars have achieved considerable progress in studying marine science and technology innovation, providing valuable references for this project. However, there are still some shortcomings in the relevant research:

There is a lack of research on the evaluation system for marine science and technology innovation capabilities at the municipal level. While studies on marine technology strategy are relatively mature, most countries focus on the current state of their national science and technology and economic needs to formulate medium- and long-term marine science and technology strategic plans. Research on the construction and refinement of evaluation systems for marine science and technology innovation capabilities within specific regions remains scarce.

The evaluation indicators for marine science and technology innovation capabilities are relatively narrow. Most studies focus on specific aspects of the marine science and technology innovation mechanism, such as competition mechanisms, talent cultivation mechanisms, and technology transformation mechanisms, lacking a systematic study of the overall mechanism. Furthermore, analyses of evaluation systems for regional marine science and technology innovation capabilities are rare. There is limited quantitative evaluation of marine science and technology innovation capabilities. Although there is abundant literature on marine science and technology innovation development, empirical studies focusing on the innovation capabilities of specific regions are rare. Currently, most evaluations concentrate on the provincial level.

2. Comprehensive Evaluation Method of Marine Science and Technology Innovation Capability

The marine science and technology innovation capabilities of cities in Shandong Province are measured using the comprehensive evaluation method and the entropy weight method. After normalizing the data, the weights of each indicator are calculated, and then a weighted calculation is performed to ultimately obtain the comprehensive score for the marine science and technology innovation capabilities in Shandong Province. The specific steps are as follows:

Step 1: Dimensionless Processing of Raw Data. The raw indicators are processed using dimensionless normalization to eliminate differences in measurement units, magnitude of values, and relative forms, making the data comparable and facilitating the construction of a comprehensive indicator system. Since all selected raw indicators are positive, positive normalization is applied to the indicator data.

$$S_{ij} = \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}} \quad (1)$$

Sij represents the value of the normalized indicator, xij represents the raw indicator, i denotes the index of the coastal region, and j represents the indicators of marine science and technology innovation capability.

Step 2: Determining Weights.

This study uses the entropy weight method to determine the weights of each indicator. This method calculates the comprehensive indicator by considering various factors, which helps to minimize the influence of subjective factors in the evaluation process.

$$R_{ij} = \frac{S_{ij}}{\sum_{j=1}^{n} S_{ij}} \quad (2)$$

$$e_j = -(\ln m)^{-1} \sum_{j=1}^{n} R_{ij} \ln R_{ij} \quad (3)$$

$$W_j = \frac{1-e_j}{n - \sum_{j=1}^{n} e_j} \quad (4)$$

Among them: Rij is the proportion of Sij indicators; ej is the entropy value of each indicator; wj is the weight of each indicator.

Step 3: Calculation Model for Primary Sub-Indicators of Marine Science and Technology Innovation Capability in Coastal Regions.

$$B_1 = \sum_{i=1}^{4} W_j S_j \quad (5)$$

$$B_2 = \sum_{i=5}^{6} W_j S_j \quad (6)$$

$$B_3 = \sum_{i=7}^{9} W_j S_j \quad (7)$$

$$B_4 = \sum_{i=10}^{11} W_j S_j \quad (8)$$

Among them, B1 represents the sub-index of marine technology innovation entities, B2 represents the sub-index of marine technology innovation projects, B3 represents the sub-index of marine technology innovation achievements, and B4 represents the sub-index of marine technology innovation support; these are the weights of each indicator.

Step 4: Measurement of the comprehensive index of marine technology innovation capability in coastal areas.

$$A = \sum_{K=1}^{4} W_k B_k \quad (9)$$

Among them, A represents the score of the comprehensive index of marine technology innovation capability in coastal areas; represents the scores of each sub-index; represents the weights of each sub-index.

3. Construction of the Comprehensive Evaluation Index System for Marine Science and Technology Innovation Capability

After organizing and summarizing existing research findings, and considering the specific circumstances of Shandong Province, as well as the availability, scientific validity, and feasibility of data, 11 indicators were selected from four aspects: marine science and technology innovation entities, innovation projects, innovation outcomes, and innovation support. These indicators form the evaluation system for marine science and technology innovation capability (Table 1).

Table 1. Evaluation System for Marine Science and Technology Innovation Capability

Comprehensive Indicator A:	Primary Sub-Indicators B:	Secondary Sub-Indicators S
A: Marine Science and Technology Innovation Capability Evaluation System	B1: Marine Science and Technology Innovation Entities	S1: Number of Marine Research Institutions S2: Number of Schools Offering Marine Programs S3: Number of Marine Science and Technology Professionals S4: Proportion of Applied Research Personnel among Science and Technology Personnel
	B2: Marine Science and Technology Innovation Projects	S5: Number of R&D Projects S6: R&D Project Funding
	B3: Marine Science and Technology Innovation Outcomes	S7: Number of Published Marine Science and Technology Papers S8: Number of Invention Patents Owned S9: Number of Published Marine Science and Technology Books
	B4: Marine Science and Technology Innovation Support	S10: Per Capita Gross Domestic Product in Coastal Regions S11: Proportion of R&D Investment to Gross Domestic Product

4. Comprehensive Evaluation Study of Marine Science and Technology Innovation Capability

4.1 Data Sources

This study obtains data related to marine science and technology innovation capabilities from the "2022 China Marine Statistical Yearbook" for 12 provinces and municipalities.

The data is used for comprehensive evaluation and analysis. The analysis results are compared to identify factors that constrain the development of marine science and technology innovation capabilities in Shandong Province. This aims to propose corresponding measures and strategies to further enhance the marine science and technology innovation capabilities of Shandong Province.

4.2 Standardization Process

To eliminate dimensional discrepancies, SPSS software is used to standardize the data of all indicators for the 12 provinces and municipalities. The standardized data are as Table 2.

4.3 Determining Weights

Using the standardized data as indicator values, the entropy weight method is applied to determine the weights of each indicator. The results for the weights of the relevant indicators are shown in the Table 3 below.

Table 2. Standardized Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Shandong	1.5753	2.1935	1.0630	0.1835	1.0874	0.6961	0.8291	0.9411	0.5687	-0.5178	-0.1685
Beijing	-0.2039	-0.9821	1.5001	1.0224	2.2208	1.3780	2.2931	1.4761	2.7122	1.7725	1.3730
Tianjin	-0.7598	-0.7704	-0.5804	-1.3345	-0.7519	-0.7845	-0.6802	-0.7128	-0.3922	0.2017	-0.4391
Hebei	-0.7598	0.2882	-0.7364	-1.0988	-0.8550	-0.8929	-0.6318	-0.9574	0.1499	-1.1278	-0.8770
Liaoning	-1.2046	0.4293	-0.3331	1.2540	-0.7525	0.8945	-0.7064	-0.2039	-0.6632	-0.8865	1.7575
Shanghai	0.0185	-0.4881	0.6929	1.4197	0.3530	1.2731	0.1338	0.3474	0.1745	1.5803	1.1167
Jiangsu	-0.5374	1.1350	-0.3951	-1.1893	0.3024	-0.7537	-0.0164	-0.3800	0.0760	0.7223	-0.8948
Zhejiang	0.3521	-0.4881	-0.2970	-0.2299	-0.5618	-0.6940	-0.6861	-0.2430	-0.9342	0.2039	-0.8165
Fujian	-0.0927	-0.5587	-0.8933	-0.2692	-0.5676	-0.7960	-0.6861	-0.7454	-0.8356	0.3156	-0.8165
Guangdong	2.2424	0.7821	1.8377	-0.4153	1.0167	1.3154	1.3922	2.0763	0.3716	-0.1357	-0.2397
Guangxi	-0.6486	-0.2764	-0.8905	-0.5127	-0.8531	-0.9430	-0.5076	-0.8172	-0.2936	-1.2194	-0.8912
Hainan	0.0185	-1.2643	-0.9679	1.1702	-0.6383	-0.6931	-0.7335	-0.7813	-0.9342	-0.9089	0.8960

Table 3. Summary of Weights Calculated Using the Entropy Method

Summary of weight calculation results using entropy method			
Item	Information entropy value e	Information utility value d	Weight coefficient w
S1: Number of marine research institutions	0.8805	0.1195	5.75%
S2: Number of marine professional schools	0.8831	0.1169	5.62%
S3: Number of marine science and technology professionals	0.8045	0.1955	9.41%
S4: Percentage of applied researchers among scientific and technological personnel	0.8798	0.1202	5.78%
S5: Number of R&D projects	0.7577	0.2423	11.65%
S6: Funding for R&D projects	0.7785	0.2215	10.66%
S7: Number of marine science and technology papers published	0.6957	0.3043	14.64%
S8: Number of invention patents	0.8104	0.1896	9.12%
S9: Number of marine science and technology books published	0.8109	0.1891	9.10%
S10: Per capita GDP of coastal areas	0.8634	0.1366	6.57%
S11: R&D investment as a percentage of GDP	0.7567	0.2433	11.71%

4.4 Comprehensive Scores for Marine Science and Technology Innovation Capability in Coastal Regions

Using the primary sub-indicator evaluation model established above, we derive the sub-indices for marine science and technology innovation entities, marine science and technology innovation projects, marine science and technology innovation outcomes, and marine science and technology innovation support. The details are shown in Table 4.

From Table 4, it can be seen that Shandong Province has a high level of support from marine research institutions, marine-related universities, and marine-related enterprises, ranking first in marine science and technology innovation entities. The province ranks third in marine science and technology projects and outcomes such as marine science and technology papers and patents, following Beijing and Guangdong. However, Shandong's gross domestic product and investment in marine-related areas are at a mid-level and require improvement.

Table 4. Scores for Primary Indicators of Marine Science and Technology Innovation Capability

	Innovation Subject		Innovation Projects		Innovations		Innovation guarantee	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
Shandong	2.3934	1	1.8075	3	1.6493	3	0.7274	7
Beijing	1.6736	3	2.7253	1	3.0436	1	2.5381	1
Tianjin	0.3481	12	0.1396	10	0.2518	9	0.8128	6
Hebei	0.5682	10	0.0339	11	0.3555	6	0.0543	11
Liaoning	1.1569	5	0.9412	5	0.3064	8	1.8285	3
Shanghai	1.6269	4	1.6995	4	1.0656	4	2.3049	2
Jiangsu	0.8968	7	0.7050	6	0.7695	5	0.7080	8
Zhejiang	0.9894	6	0.2821	7	0.2295	10	0.5719	10
Fujian	0.6584	9	0.2303	9	0.1173	11	0.6120	9
Guangdong	2.3831	2	2.0664	2	2.1608	2	0.8192	5
Guangxi	0.5458	11	0.0110	12	0.3270	7	0.0123	12
Hainan	0.8201	8	0.2425	8	0.0589	12	1.2686	4

Based on the comprehensive evaluation method, the overall scores for marine science and technology innovation capability in coastal regions are shown in Table 5.

Table 5. Comprehensive Scores for Marine Science and Technology Innovation Capability

	Score	Ranking
Shandong	1.7138	3
Beijing	2.5164	1
Tianjin	0.3548	10
Hebei	0.2852	11
Liaoning	0.9520	5
Shanghai	1.5826	4
Jiangsu	0.7777	6
Zhejiang	0.5056	8
Fujian	0.3766	9
Guangdong	1.9536	2
Guangxi	0.2571	12
Hainan	0.5231	7

From Table 5, it can be observed that Beijing, despite not being a coastal city, ranks first in marine science and technology innovation capability. This is due to its proximity to the coastal cities of Tianjin and Hebei, its status as the political center, and its access to abundant research resources and policy support.

In recent years, Guangdong Province has continually optimized its marine development and utilization, enhancing its marine strategic capabilities and core competitiveness. It has effectively harnessed the potential of the marine "treasure trove" and has systematically developed new marine productive forces. Guangdong's innovation research institutions, marine-related universities, investment in marine projects, and related papers and patents are all consistently ranked second. Consequently, Guangdong's comprehensive score for marine science and technology innovation capability is second among the 12 major regions.

Shandong Province, known as the "National Science and Technology City," benefits from high-level marine research institutions, marine-related universities, and marine enterprises, which contribute to its third-place ranking in marine science and technology innovation capability. Although Shandong's marine science and technology projects, as well as its research papers, patents, and publications, rank third behind Beijing and Guangdong, its regional GDP and marine science investment are at the 7th position among coastal provinces and cities, indicating a mid-level performance that requires improvement.

Other regions, such as Shanghai, Liaoning, Jiangsu, Hainan, and Zhejiang, have overall marine science and technology innovation capabilities at a mid-level. In contrast, Guangxi, Hebei, Tianjin, and Fujian have lower comprehensive scores, reflecting a relatively lower level of marine science and technology innovation capability.

5. Summary and Recommendations

Based on the comprehensive evaluation and analysis of marine science and technology innovation capabilities across 12 regions in China, the following conclusions are drawn:

The output of marine-related papers, patents, and publications significantly contributes to the development of the marine economy. Additionally, R&D funding has a notable impact on marine science and technology innovation capabilities.

Shandong Province benefits from high-level marine research institutions, marine-related universities, and marine enterprises, which contribute to a strong role of marine science and technology innovation entities. The province is also at an advanced level in marine science and technology projects and outcome inputs. However, there is room for improvement in Shandong's investment in marine science and technology. Based on this analysis, the following recommendations are proposed to promote marine science and technology innovation in Shandong Province:

Resource Sharing and Interaction Among Marine Science and Technology Innovation Entities: Marine science and technology innovation entities include government, higher education institutions, research institutions, and enterprises. The government, as the primary driver of the innovation process, should formulate relevant policies, allocate resources effectively, create a supportive innovation environment, and encourage collaboration among academic institutions, higher education institutions, and enterprises. Universities and research institutions are the main sources of marine science and technology innovation, conducting research activities under government guidance. Enterprises, as demand-side entities, are the ultimate destination for the application of technological achievements. Effective communication, cooperation, and resource sharing among these entities are crucial for a healthy innovation system and positive interactive effects.

Leveraging Shandong's Rich Scientific Education Resources: Utilize Shandong Province's abundant scientific education resources, deepen research system reforms, integrate academic research forces, and build a "blue think tank" to improve mechanisms that promote both human and intellectual development. Take advantage of the agglomeration effect of marine research institutions by establishing new institutions in existing research parks to facilitate cooperation and communication, increase the output of marine science and technology innovation research, and enhance innovation capabilities.

Strengthening Marine Science and Technology Innovation Support Systems: The support system should cover the entire process of marine science and technology innovation, including financial support, talent support, and institutional support. Strengthen the capabilities of marine-related universities, advance marine discipline development, and cultivate high-level professionals in marine science and technology and related humanities and social sciences. Improving marine science and technology innovation capabilities requires substantial capital investment. Effective integration of marine science with modern finance provides dual motivation for sustainable and healthy development of the marine economy.

Research on marine science and technology innovation capability evaluation systems in China is relatively recent. Both theoretical frameworks and evaluation methods are still in the exploratory phase. The evaluation system for marine science and technology innovation capabilities developed based on Shandong Province's specific conditions has general application value. It can be used not only for evaluating marine science and technology innovation capabilities in Shandong but also for other coastal provinces and cities. This method is simple to operate, data is relatively easy to collect, and it provides an objective assessment of the actual level of marine science and technology innovation in coastal regions. It is a scientifically feasible evaluation method with significant practical implications for the development of marine science and technology in Shandong Province.

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