Study on the Evaluation Method of Marine Comprehensive Carrying Capacity: Taking Yancheng Sea Area of China as an Example

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Abstract: With the rapid growth of China's economy since the start of the 21st century, the development and utilization of coastal areas have also experienced rapid expansion. With the continuous and high-intensity agglomeration of social and economic factors such as city, industry and population in coastal areas, the fragile and sensitive coastal ecosystem is under great pressure of resources and environment. In this study, we propose a theoretical and methodological framework for the comprehensive evaluation of the sea area carrying capacity to systematically evaluate the coupling and coordination of resources, environment and development in coastal areas. This framework includes 12 representative indicators of three factors: spatial resource endowment, ecological environment pressure and development and utilization intensity. Taking Yancheng sea area of China as an example, we analyzed the development and change of sea area carrying capacity from 2000 to 2015. The results show that the carrying capacity score of Yancheng sea area decreased from 3.12 in 2000 to 1.58 in 2015, indicating that the comprehensive carrying capacity of the sea area in this period is facing an unsustainable severe situation. At the same time, with the development intensity index score increasing from 0.62 to 0.92, the resource endowment index and ecological environment index scores decreased from 0.98 to 0.75 and 0.95 to 0.70, respectively, indicating that the continuous high-intensity development activities in Yancheng sea area during this period put great pressure on resources and environment. This framework can provide technical support for the balance of economic development and the protection of resources and environment in coastal areas.

1. Introduction
Because of its unique land and sea location and resource advantages, coastal areas have become the most active and concentrated area of human social economy. China's three most important economic zones (Bohai Rim, Yangtze River Delta and Pearl River Delta) are all located in the eastern coastal areas [1,2]. According to China Statistical Yearbook, in 2017, China's coastal areas carried 43% of the country's population and 57% of the country's GDP with about 13.5% of the land area. The coastal areas provide trade channels, aquatic products, tourist destinations and living and production space for social and economic development. The global bulk cargo trade is carried out through marine transportation and coastal ports. In 2015, the world's main foreign trade cargo shipping volume reached 10766 million tons. According to FAO statistics, in 2015, aquaculture in major coastal countries (regions) amounted to 76.6
million tons, with 92.6 million tons of aquatic products fishing. Marine aquatic products will become an important way for human to obtain protein. Most of human tourism and leisure destinations are concentrated in coastal areas. In 2015, the number of inbound (overnight) tourists in major coastal countries (regions) exceeded 1.2 billion, the number of outbound tourists exceeded 1.36 billion, and the international tourism revenue reached 1437 billion US dollars.

However, with the continuous concentration of population and economic activities in the coastal areas, the coastal ecological environment is facing great pressure, such as the disappearance of natural coastline, the shrinkage of coastal wetlands, the deterioration of water quality and environment, the reduction of biodiversity, species extinction, eutrophication and so on. Some studies have shown that with the rapid development of coastal areas, the artificial coastline in the coastline has increased dramatically and the natural coastline has decreased sharply. The total length of the artificial coastline in China's coastal areas has increased from 32.3% of the total coastline in 1980 to 68.5% in 2015 [3]. Under the influence of climate change and human activities, the coastal tidal flat wetland continued to shrink and reduce. During 1984-2016, the coastal areas of East Asia, the Middle East and North America decreased by 16.02% [4]. Although the continuous deterioration trend of water quality in China's coastal waters has been effectively curbed, it has not been substantially improved. Marine ecological disasters such as red tide and green tide break out every year, making it difficult to effectively recover the traditional economic fish resources in the coastal areas. Major pollution events have promoted the revolution of the Chinese government's concept of environmental protection. The Chinese government has put forward the development concept with ecological civilization as the core, and has been vigorously implemented through a series of engineering measures and governance measures. China continues to push forward reform in terms of institutional reform, development planning, policy guidance, ecological governance, etc. and local government management decisions must face how to maintain the balance between economic growth and ecological environment protection.

With the rapid growth of China's economy since the 21st century, the development and utilization of sea areas in China's coastal areas have also experienced rapid expansion. With the continuous and high-intensity agglomeration of social and economic factors such as city, industry and population in coastal areas, the fragile and sensitive coastal ecosystem is under great pressure of resources and environment. In recent years, as a basic evaluation method, resource and environment carrying capacity evaluation has been widely used in Chinese government policy-making [5]. As a policy management tool, carrying capacity needs to realize the operability of continuous time series repeated evaluation within a certain range of administrative units, the comprehensive embodiment of the overall situation of the region, so as to realize the effective technical support of management decision. Previous studies on carrying capacity mainly focused on the population or economic scale that the resources and environment can carry, mostly based on single factor evaluation, such as land resource carrying capacity [6,7], water resource carrying capacity [8,9], environmental carrying capacity [10,11], and ecological carrying capacity [12,13]. Under the unified theoretical framework, the relationship and difference of resources, environment and development in a regional sustainable development could not be effectively clarified.

In this study, we propose a theoretical and methodological framework for the comprehensive evaluation of sea area carrying capacity, which is used to systematically evaluate the coupling and coordination among resources, environment and development of coastal waters. The framework of this method includes three indicators: the intensity of economic activity expansion, the spatial resource endowment supporting coastal development and utilization, and the ecological environment pressure restricting the sustainable and healthy use of sea areas. Among them, the factors of spatial resource endowment include sea space and coastline conditions, the supporting factors of ecological environment include sea water quality and ecological protection, and the intensity factors of development and utilization include reclamation and open sea use. Taking Yancheng of China as an example, the development and change of sea area carrying capacity in 2000, 2005, 2010 and 2015 are evaluated by using this method framework. This study proposes that the evaluation method framework of sea area comprehensive carrying capacity can provide technical method support for the research and policy-
making of balanced economic development and resource and environmental protection system in coastal areas.

Table 1. Evaluation index framework of sea area comprehensive carrying capacity.

| Target layer | element layer | factor layer | index layer |
|--------------|---------------|--------------|-------------|
| Coastal Area Carrying Capacity Index (CACCI) | spatial resource endowment (SRC) | sea space | shallow water area (SS) |
| | | shoreline condition | intertidal shoals (IS) |
| | | coastal stability (CS) |
| | development and utilization intensity (DUI) | sea reclamation | the intensity of sea reclamation (RE) |
| | | open sea use | open sea use scale (OS) |
| | | | open sea use ratio (OSO) |
| | ecological environment pressure (EEC) | sea water quality | the scale of clean sea area (WQ) |
| | | coastal wetland habitat (WS) |
| | | diversity index of benthos (BD) |

2. Materials and Methods

2.1 General Situation of Study Area
Yancheng City is located in the east coast of China, the central part of Jiangsu Province, the north wing of the Yangtze River Delta, and the east side is close to the South Yellow Sea. Yancheng City governs 9 counties and districts, 5 of which are distributed along the coast. This study focuses on the coastal areas of Yancheng. The county units distributed from north to south are Xiangshui, Binhai, Sheyang, Dafeng and Dongtai. The total area of the study area is 33483km², including 16931km² of land space, 582km of coastline, 16552km² of sea area (2012 version of marine functional zoning), and a population of 8,261,500.

The type of this coast is silty muddy coast. The main coastal geomorphic system includes the Northern Abandoned Yellow River Estuary and the Southern Radial Sandbank. Controlled by the regional coastal dynamic geomorphology, the coast is generally characterized by the transition state of erosion-deposition from north to south. As an important coastal wetland, two national nature reserves of Yancheng Red Crowned Crane rare bird nature reserve and Dafeng elk nature reserve are established. Relying on sea space resources, the main marine industries include port transportation, port industry, mariculture, salt industry and offshore power. In 2007, Jiangsu issued the development plan of coastal areas, setting off a climax of coastal area development.

CACCI score is calculated by the ratio of resource endowment index, ecological environment pressure index and development intensity index. The increase of CACCI indicates the improvement and enhancement of the sea area carrying capacity, while the decrease indicates that the sea area carrying capacity tends to deteriorate, and the stable value indicates that the sea area carrying capacity is in an overall stable situation. Four representative indexes are selected to calculate resource endowment factor value, ecological environment factor value and development intensity factor value.

\[
CACCI = \frac{I_{SRC}}{I_{DUI}} + \frac{I_{EEC}}{I_{DUI}} \quad (1)
\]

\[
I_{SRC} = \omega_1 I_{SS} + \omega_2 I_{IS} + \omega_3 I_{CN} + \omega_4 I_{CS} \quad (2)
\]

\[
I_{DUI} = \omega_5 I_{RE} + \omega_6 I_{REO} + \omega_7 I_{OS} + \omega_8 I_{OSO} \quad (3)
\]

\[
I_{EEC} = \omega_9 I_{WQ} + \omega_{10} I_{WQT} + \omega_{11} I_{WS} + \omega_{12} I_{BD} \quad (4)
\]

\[
\sum \omega = \omega_1 + \omega_2 + \omega_3 + \cdots + \omega_{12} = 1 \quad (5)
\]
In the formula, $I_{SRC}$ is the spatial resource endowment index, $I_{DUI}$ is the development and utilization intensity index, and $I_{EEC}$ is the ecological environment pressure index. The index value is calculated by the ratio of the current status of the index to the benchmark reference status \[^{[4]}\], and the value range is [0-1].

$$I_i = \frac{X_i}{X_{i,ref}} \quad (6)$$

In this study, three indicators, i.e. spatial resource endowment, development and utilization intensity, and ecological environment pressure, are used to comprehensively characterize the carrying capacity of marine resources and environment to marine development activities. The larger the value of resource endowment index is, the better the state of spatial resources is and the higher the supporting capacity for development activities is; the larger the value of development intensity index is, the greater the intensity of development and utilization activities is and the greater the pressure on resources and environment is; the larger the value of ecological environment pressure index is, the better the state of marine ecological environment is and the less the ecological binding force on development activities is.

Through the expert scoring method to determine the evaluation index weight, we distribute the index system and index weight questionnaire to 12 experts in the four fields of marine resources, sea area management, marine environment and marine engineering. According to the evaluation and weighting of the index weight by experts, the cumulative weights of the three factors, namely, spatial resource endowment, development and utilization intensity, and ecological environment pressure are determined, which, are 0.34, 0.32, and 0.34 respectively.

### 2.2 Data source

Comprehensively considering the implemented five-year plan system of China's national economic and social development, the evaluation period of the research area is 2000-2015, and the evaluation time node span is 5 years. Remote sensing provides an important way for macro scale and long-term monitoring of resources and environment. The scale of shallow water, intertidal tidal flat, natural shoreline distribution, coastal erosion and deposition state, reclamation distribution and salt marsh wetland distribution in the study area are obtained by the combination of remote sensing survey and field survey, and the scale of intertidal zone is also revised in combination with the field tide level data. The data of open sea use come from *China fishery Statistical Yearbook (2001-2016)* and the data of sea area use right. The data of sea water quality and biodiversity are from *China marine environment quality bulletin (2001-2016)* and *Jiangsu marine environment quality bulletin (2001-2016)*.

### 3. Results and Analysis

#### 3.1 Characteristics of Index Change

The spatial resource endowment includes two categories of four indicators: sea space and shoreline condition. The four indexes all show the characteristics of continuous decrease, but the decrease of each index is obvious. The scale of shallow water area represents the scope of the whole study area, and its spatial scale remains relatively stable and slightly decreases, and its index value decreases from 0.98 in 2000 to 0.95 in 2015. The scale of shallow water shoals has changed greatly under the influence of coastal reclamation activities, and its index value has declined sharply from 0.87 in 2000 to 0.53 in 2015, with a slight recovery in 2010 compared with 2005. The ecological quality of coastline shows a continuous decline trend. With the rapid increase of coastal high-intensity development activities, the index value of natural coastline decreased from 1.0 in 2000 to 0.64 in 2015. The overall coastal stability of the study area was relatively stable during 2000-2005, but it continued to deteriorate after that, and the index value dropped sharply from 1.0 in 2000 to 0.83 in 2015.

The intensity of development and utilization includes two categories of four indicators: sea reclamation and open sea use. Since 2000, the four indicators have been increasing in general, among which three indicators, namely, reclamation coastline occupation, open sea use scale and open sea use ratio, showed a slight decline in 2015. Sea reclamation is the most important human development activity in this area. Affected by the continuous increase of sea reclamation scale, the intensity of sea
reclamation scale has been enhanced all the way, and the index value has rapidly increased from 0.34 in 2000 to 1.0 in 2015. The index value of reclamation coastline occupation increased from 0.70 in 2000 to 0.93 in 2015. The continuous sea reclamation of the same coastal section is a significant feature of this area. The continuous sea reclamation activities make the coastal ecological environment continuously disturbed, which limits the natural recovery of coastal ecosystem. The open sea use in the study area is dominated by mariculture. The two indicators of open sea use scale and open sea use ratio increased from 0.82 and 0.80 in 2000 to 0.94 and 0.95 in 2015, both of which reached the highest point in 2010, reflecting that in recent years, with the progress of aquaculture technology and the enhancement of external constraints of ecological environment, the intensive production level of large-scale mariculture has improved.

The state of ecological environment includes two categories of four indicators: sea water quality and ecological protection. The four indicators show a general downward trend, but the four indicators show different characteristics of change. The scale of clean sea area decreased sharply from 2000 to 2010, and the index value decreased from 1.0 in 2000 to 0.68 in 2010, and then stabilized and improved slightly. Compared with the other three indicators, the water quality target of the functional area decreased the most, especially in the first five-year index value in the study period, which dropped sharply from 1.0 in 2000 to 0.57 in 2005, and then it was in a relatively stable state of fluctuation. The coastal wetland habitat is relatively stable as a whole, which experienced a process of decline first and then recovery. The minimum value of the index value appeared in 2010 (0.56). The diversity index of benthos experienced a process of continuous decline and then tended to be stable. The minimum value of the index appeared in 2010 (0.83).

3.2 Condition of Sea Area Carrying Capacity

The comprehensive evaluation results (Table 3) shows that the comprehensive carrying capacity of Yancheng sea area has been declining since 2000, and the CACCI score has decreased from 3.12 in 2000 to 1.58 in 2015. According to the five-year interval, the research period can be divided into three stages: 2000-2005, 2005-2010 and 2010-2015. The comprehensive carrying capacity of the sea area in the three stages shows a downward trend, but the downward range shows different characteristics. The evaluation results take 2000 as the reference point. During the first five years, the score of CACCI dropped sharply, with a drop rate of 32%; in the second five years, the score of CACCI slowed down to a certain extent, but the drop rate was still large, with a drop rate of 13%; in the third five years, the score of CACCI tended to be relatively stable, although it still decreased to a certain extent, but the drop rate was only 4%. During the period of 2000-2015, with the rapid development of coastal development and utilization activities, the comprehensive carrying capacity of the sea area continued to decline, with a cumulative decline of 49%, reflecting the real situation of the rapid increase of resource pressure and ecological environment pressure in the coastal development of Yancheng. The decline of CACCI scores shows three significant characteristics: sharp decline, decline and relative stability. It reflects the coordinated efforts of local governments in maintaining sustainable economic development and protecting resources and environment. The deterioration trend of the comprehensive carrying capacity of the sea area has been slowed down, and the overall trend is stable.

According to the evaluation framework of sea area comprehensive carrying capacity, the evaluation results can be divided into two indexes: resource carrying index (I_{SRC}/I_{DUI}) and ecological carrying index (I_{EEC}/I_{DUI}). It can be seen from the calculation results that although the carrying indexes of both sides show a declining trend, and both of them show the characteristics of sharp decline first and then slow down gradually, there are obvious differences in the development trend between them. The scores of resource carrying index in 2000, 2005, 2010 and 2015 are 1.59, 1.15, 0.92 and 0.82 respectively, and the scores of ecological carrying index in the four periods are 1.53, 0.97, 0.78 and 0.76 respectively. In the period of 2000-2005, the decline of ecological carrying index is more significant than that of resource carrying index, and then it is more stable in 2010-2015 after further relatively small decline. Although the resource carrying index also shows a trend of gradual slowing down, it does not show a stable trend in 2010-2015. It can be seen from the development trend that in the development process of coastal
areas, the ecological carrying index is easy to be interfered by strong human development activities compared with the resource carrying index, but it tends to be stable in the background of ecological environment governance. While the resource carrying index is not as deteriorated as the ecological carrying index, but serves as the spatial support for human development and utilization, it is difficult to achieve stable carrying capacity and overall recovery and improvement in the short term in the process of socio-economic expansion development.

The evaluation framework of sea area comprehensive carrying capacity includes three elements: resources, environment and development, corresponding to three elements: spatial resource endowment, ecological environment status and development and utilization intensity. Each element index includes four evaluation indexes. Resource endowment index, ecological constraint index and development intensity index are evaluated respectively. The calculation results show that the resource endowment index shows a continuous downward trend during the evaluation period; the ecological environment index drops sharply during 2000-2005, and then tends to be stable after a small decline, in which the index score in 2015 is slightly higher than that in 2010; the development intensity index rises rapidly during 2000-2010, and then the upward trend slows down. The intersection point of index curve of resource endowment and development intensity is near the left side of time section in 2005, and the intersection point of index curve of ecological constraint and development intensity is on the left side of time section in 2010. It can be concluded that in 2004, the ecological environment and coastal development activities were in balance, and in 2008, the resources support and development activities were in balance. In the process of rapid development of Yancheng coastal area, the resource environment and development intensity are in a relatively coordinated stage during the period of 2000-2005. Then, with the continuous and high-intensity promotion of development activities, the carrying condition of resource environment in the period of 2005-2010 gradually worsens. During the period of 2010-2015, the coastal development activities gradually change from the initial extensive expansion type to the high-quality development adjustment, but during this period, the pressure on resources and environment is still at a high level, and there is no obvious feature of recovery and improvement.

4. Conclusions
In recent years, major pollution events have promoted the revolution of the Chinese government's concept of environmental protection, and the Chinese government has put forward the goal of high-quality development with ecological civilization as the core. Then in the process of specific policy-making and implementation, how to achieve the balance between resource and environmental protection and sustainable economic development has become a major test for local government management decision-making. As a basic evaluation method, resource and environment carrying capacity evaluation has been widely used in Chinese government policy-making. As a policy management tool, carrying capacity needs to realize the operability of continuous time series repeated evaluation within a certain range of administrative units, the comprehensive embodiment of the overall situation of the region, so as to realize the effective technical support of management decision.

We propose a theoretical and methodological framework for the comprehensive evaluation of sea area carrying capacity, which is used to systematically evaluate the coupling and coordination of resources, environment and development in coastal areas. The framework of this method includes three aspects, namely, the development and utilization intensity elements representing the expansion of economic activities, the resource endowment elements supporting the development and utilization of coastal space, and the ecological environment elements restricting the sustainable and healthy utilization of sea areas. Taking Yancheng of China as an example, the comprehensive carrying capacity of the sea area during 2000-2015 is analyzed and evaluated. The evaluation results show that the comprehensive carrying capacity of Yancheng sea area has been declining continuously since 2000, and the CACCI score has been reduced from 3.12 in 2000 to 1.58 in 2015, which shows three significant characteristics of sharp decline, decline and relative stability. As the supporting conditions and restricting factors of human development and utilization activities, resource endowment and ecological environment have their own development and change rules and characteristics. In the future, the quality of social and
economic development should be further improved, and a series of policy measures such as ecological modification and environmental governance should be adopted to promote the recovery and improvement of the carrying capacity of resources and environment, so as to achieve sustainable and healthy economic and social development.

References
[1] National Bureau of Statistics of China, (2017) China Statistical Yearbook. China Statistics Press, Beijing.
[2] State Oceanic Administration of China. (2017) China Marine Statistical Yearbook. China Ocean Press, Beijing.
[3] Xu N. (2016) Research on Spatial and Temporal Variation of China mainland Coastline and Coastal Engineering. Beijing: University of Chinese Academy of Sciences.
[4] Murray N. J., Phinn S. R., Dewitt M. F., et al. (2019) The global distribution and trajectory of tidal flats[J]. Nature, 565(7738): 222-225.
[5] Fan J., Zhou K., Wang Y. F. (2017) Basic points and progress in technical methods of early-warning of the national resource and environmental carrying capacity (V 2016). Progress in Geography, 36(3): 266-276.
[6] Cohen J. E. (1995) How many people can the earth support. The Science, 35(6): 18-23.
[7] Peters C. J., Bills N. L., Lembo A. J., et al. (2009) Mapping potential food sheds in New York State: A spatial model for evaluating the capacity to localize food production. Renewable Agriculture and Food Systems, 24(1): 72-84.
[8] Falkenmark M., Lundqvist I. (1998) Towards water security: Political determination and human adaptation crucial. Natural Resources Forum, 22(1): 37-51.
[9] Ofoezie I. E. (2002) Human health and sustainable water resources development in Nigeria: Schistosomiasis in artificial lakes. Natural Resources Forum, 26(2): 150-160.
[10] Van Den Bergh J. C. J. M. 1993. A framework for modelling economy-environment-development relationships based on dynamic carrying capacity and sustainable development feedback[J]. Environmental and Resource Economics, 3(4): 395-412.
[11] Esty D. C., Levy M., Srebotnjak T., et al. (2005) 2005 Environmental sustainability index: Benchmarking national environmental stewardship. New Haven, CT: Yale Center for Environmental Law & Policy: 47-60.
[12] Rees W. E. (1992) Ecological footprints and appropriated carrying capacity: What urban economics leaves out. Environment and Urbanization, 4(2): 121-130.
[13] Singh R. K., Murty H. R., Gupta S. K., et al. (2012) An overview of sustainability assessment methodologies. Ecological Indicators, 15(1): 281-299.
[14] Halpern, B.S., Longo, C., Hardy, D., et al., (2012) An index to assess the health and benefits of the global ocean. Nature 488 (7413), 615–620.