Exploration of the Theory and Measurement Methods for Marine Resources and Environmental Carrying Capacity: Postprint

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Abstract

The strategic position of the ocean in overall economic and social development is becoming increasingly prominent; however, it is also confronted with a severe situation characterized by tightening resource constraints, serious environmental pollution, and ecosystem degradation. Consequently, establishing a monitoring and early warning mechanism for marine resource and environmental carrying capacity is imperative. This article introduces the phased progress of exploratory research on the theory and measurement methods of marine resource and environmental carrying capacity, preliminarily constructs a carrying capacity model based on the "Driving force-Pressure-State-Impact-Response" (DPSIR) theory, establishes an indicator system and assessment and early warning methodology for marine resource and environmental carrying capacity in coastal county-level administrative regions by evaluating the threshold or threshold range when the marine resource and environmental system enters an unsustainable process, and conducts a pilot assessment in the Beijing-Tianjin-Hebei sea area. The results indicate that marine ecological degradation, excessive shoreline development, damage from marine environmental pollution, and the decline of natural fishery resources are the four primary factors affecting the resource and environmental carrying capacity of the coastal waters of Hebei and Tianjin. Future efforts should further deepen research on measurement methods for marine resource and environmental carrying capacity and establish monitoring and early warning mechanisms, scientifically and objectively assess and measure sustainable development levels, and explore effective approaches to alleviating carrying pressure and enhancing carrying capacity in coastal regions.

Full Text

Preamble

Topic: Coastal Science and Sustainable Development

Exploration of Theory and Measurement Methods for Marine Resources and Environmental Carrying Capacity

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Abstract

Marine resources and environments are increasingly vital to China' s socioeconomic development, yet they face severe challenges including resource constraints, serious pollution, and ecosystem degradation. Establishing a monitoring and early-warning mechanism for marine resources and environmental carrying capacity is therefore urgently needed. This paper presents preliminary research progress on the theory and measurement methods for marine resources and environmental carrying capacity. We have initially constructed a carrying capacity model based on the "Driving Forces-Pressure-State-Impact-Response" (DPSIR) theoretical framework. By evaluating the thresholds or threshold ranges at which marine resource-environment systems enter unsustainable states, we have established an indicator system and assessment method for monitoring and early warning of marine resources and environmental carrying capacity at the county level in coastal regions. A pilot assessment was conducted in the Beijing-Tianjin-Hebei sea area, revealing that marine ecological degradation, excessive coastline development, marine environmental pollution damage, and decline of natural fishery resources are the four primary factors affecting the carrying capacity of marine resources and environments in the coastal waters of Hebei Province and Tianjin Municipality. Future work should further deepen research on measurement methods and establish monitoring and early-warning mechanisms to scientifically and objectively evaluate sustainable development levels and identify effective pathways to alleviate coastal carrying pressures and enhance carrying capacity.

Keywords: marine resources and environment, carrying capacity, measurement method, monitoring and early warning

Introduction

China is a major maritime nation, and its oceans constitute a critical domain for socioeconomic development and ecological civilization construction, providing abundant resources and vast space for national economic and social progress. Marine resources serve as an important guarantee for resolving resource bottlenecks, expanding ecological space, and creating beautiful environments. Cur-

rently, China is in a crucial period of building a moderately prosperous society in all respects and advancing ecological civilization. The 13th Five-Year Plan has made strategic arrangements to "expand blue economic space," proposing to "uphold integrated land-sea planning, develop the marine economy, scientifically exploit marine resources, protect the marine ecological environment, safeguard maritime rights and interests, and build China into a maritime power." Consequently, the strategic importance of marine resources and ecological environments in overall socioeconomic development is becoming increasingly prominent. However, China' s marine resource-environment systems are facing severe challenges of tightening resource constraints, serious environmental pollution, and ecosystem degradation, with insufficient overall carrying capacity for socioeconomic development and severe local overloading that fails to meet the requirements of building a maritime power and achieving sustainable development.

The Third Plenary Session of the 18th CPC Central Committee proposed establishing a monitoring and early-warning mechanism for resource and environmental carrying capacity as a major reform task. This mechanism serves as an important management tool for measuring the level of sustainable socioeconomic development and, on this basis, issuing warnings and implementing scientific regulation of inappropriate human development activities. China' s jurisdictional seas, as semi-enclosed continental shelf marginal seas, bear pressures from watershed, coastal zone, and offshore development activities. The lag effects of marine ecological problems and cumulative nature of environmental pollution exceed those of terrestrial ecosystems. The natural connectivity of oceans makes marine resource and environmental issues global, compound, and intergenerational. Research exploring the theory and measurement methods for marine resources and environmental carrying capacity will provide important support for establishing a nationwide, land-sea integrated monitoring and early-warning mechanism for resource and environmental carrying capacity.

1. Theoretical Framework Exploration

1.1 Development of Carrying Capacity Theory

Carrying capacity is a scientific concept measuring the relationship between human socioeconomic activities and the natural environment, and serves as an important basis for sustainable development measurement and management. The theory can be traced back to Malthus' s Essay on Population in 1798 and has evolved from population carrying capacity to resource carrying capacity, environmental carrying capacity, and ecological carrying capacity. This conceptual evolution represents human responses to emerging problems in socioeconomic development. China' s carrying capacity research began in the 1980s, initially focusing on land carrying capacity, then extending to calculations and evaluations of various elements including population, ecology, water resources, and tourism, as well as comprehensive regional elements. By the early 21st century, domestic research perspectives had gradually shifted to comprehensive studies of regional resource and environmental carrying capacity. In recent years, research

on single-element and comprehensive carrying capacity of marine resources and environments has continuously deepened, with numerous researchers analyzing key factors affecting sea area carrying capacity and proposing series of policy recommendations for regional socioeconomic regulation and land-sea integrated planning.

Generally, regional resource and environmental carrying capacity is based on the coupled "resources-ecological environment-socioeconomy" system, consisting of three main elements: (1) the carrying body, referring to resource and environmental systems that provide natural resources and environmental conditions; (2) the carrying object, referring to human development activities and related socioeconomic factors; and (3) the carrying rate, the ratio between the carrying status and carrying capacity of the carrying body. Fan et al. propose that resource and environmental carrying capacity reflects the supporting capacity of resource and environmental conditions for human production and living activities. Focusing on human activities, carrying capacity can be expressed as the maximum economic or population scale that can be sustained while maintaining sustainable processes in the resource-environment system. Focusing on resource and environmental conditions, it can be expressed as the threshold or threshold range at which the resource-environment system enters an unsustainable process when bearing continuously changing human activities.

1.2 Theoretical Framework for Marine Resources and Environmental Carrying Capacity

After years of development, China' s classified management system for marine resource elements and ecological environments has gradually improved, with separate management departments and monitoring institutions established for sea space utilization, resource development, and ecological environmental protection. However, this has also fragmented the organic integrity of marine resources and ecological environments and their associated responses to human development activities. Under the new normal, from the perspective of the coupled "marine resources-ecological environment-socioeconomic" system, China' s marine resources and environmental management should take expanding blue economic space and supporting sustainable development as starting points, comprehensively considering the response relationships between various human development activities and resource depletion, physicochemical property changes, and ecological environmental changes in marine resource-environment systems, thereby achieving transformation from classified element management to integrated human-ocean relationship management, and from status management to process management and risk control.

Based on this, we define "marine resources and environmental carrying capacity" as: under certain temporal and spatial scales, while maintaining regional marine resource structures that meet sustainable development needs and marine ecological environmental functions that retain their stable-state capacity, the ability of regional marine resource-environment systems to sustain various human so-

cioeconomic activities. The carrying body is the marine resource-environment system, the carrying object comprises various marine-related socioeconomic activities, and the external environment consists of management and regulation behaviors, forming a complete chain of interconnections and mutual influences through the "Driving Forces-Pressure-State-Impact-Response"(DPSIR) relationship [Figure 1: see original paper].

In addition to general characteristics of resource and environmental carrying capacity (such as coexistence of objectivity and subjectivity, certainty and variability, hierarchy and comprehensiveness, rigidity and flexibility), marine resources and environmental carrying capacity has distinct marine features, mainly manifested in two aspects: (1) It is based on a dynamic composite system of human-ocean interactions. In this system, marine ecological environmental value is an important carrier of its economic value, and the natural existence and social exploitation of marine resources and environments are unified. Moreover, because private goods attributes are superimposed on the public goods attributes of marine spaces, multiple uses and multi-purpose utilization of the same sea area occur, creating spatial misalignment and long-term temporal accumulation of various pressure-effect relationships. (2) Marine resource-environment systems have significant open connectivity. Due to water flow, biological migration, energy transfer, and land-sea linkages, research boundaries for regional marine resources and environments are difficult to define, research content has significant comprehensiveness and relevance, and research elements are in constant dynamic development.

2. Measurement Methods

2.1 Technical Route

The inherent characteristics and complex influencing factors of marine resources and environmental carrying capacity make it difficult to assess the maximum economic or population scale that can be carried. However, we can characterize the carrying degree or overloading level of marine resource-environment systems in response to human development pressures by evaluating the thresholds or threshold ranges at which these systems enter unsustainable processes—that is, the carrying rate. To this end, this paper proposes an overall technical approach for assessing marine resources and environmental carrying capacity based on China' s actual marine spatial resources, marine fishery resources, marine ecological environment, and island resources and environmental management. Grounded in marine functional zoning, relevant policies, systems, and standard specifications, and using coastal county-level administrative districts as evaluation units, we employ a combined technical method of basic evaluation, specialized evaluation, and process evaluation to achieve progressive measurement of marine resources and environmental carrying status, scientific understanding of carrying mechanisms, and early warning of human development activities. The technical roadmap is shown in [Figure 2: see original paper].

2.2 Individual Evaluations

2.2.1 Basic Evaluation The basic evaluation of marine resources and environmental carrying capacity provides comprehensive coverage of all coastal county-level administrative districts, including four fundamental elements: marine spatial resources, marine fishery resources, marine ecological environment, and island resources and environment. This is determined through seven indicators: coastline development intensity, sea area development intensity, swimming animal index, fish egg and larvae index, marine functional zone water quality compliance rate, marine ecological carrying index, and uninhabited island development intensity and ecological status . The basic evaluation primarily assesses differences in the degree of impact of various development activities on marine resources and ecological environments, with threshold determination fully considering the differentiated requirements of various marine functional zones. The indicator system for basic evaluation is shown in Table 1, with data primarily obtained from historical marine ecological environment monitoring and protection management, sea area use management, marine fishery management, and island protection and management, as well as satellite remote sensing interpretation data.

2.2.3 Process Evaluation The process evaluation of marine resources and environmental carrying capacity primarily characterizes status trends by evaluating marine resource consumption, environmental damage, and ecological changes. The main indicators include sea area/island development intensity change (sea area development resource effect index or uninhabited island development intensity), environmental pollution degree change (proportion of excellent water quality), and ecological disaster risk change (frequency of red tide disasters) . When two or more of these three indicators show "deteriorating" trends, the depletion of regional marine resources and environments is intensifying; otherwise, it is easing.

2.3 Integrated Evaluation

Based on the calculation results of individual indicators from basic and specialized evaluations, we comprehensively classify marine resources and environmental carrying capacity in county-level administrative districts into three types—"overloaded," "critically overloaded," and "not overloaded"—through short-board effect integration. On this basis, according to the process evaluation of resource and environmental loss, we classify warning levels for overloaded and critically overloaded areas. Overloaded areas are divided into two levels: extremely severe warning (red alert) and severe warning (orange alert). Critically overloaded areas are divided into moderate warning (yellow alert) and light warning (blue alert). Not overloaded areas are designated as no warning [Figure 3: see original paper]. The integrated evaluation principle connects with the land integrated evaluation methodology system.

3. Pilot Assessment in the Beijing-Tianjin-Hebei Sea Area

The Beijing-Tianjin-Hebei region lies on the western coast of the Bohai Sea and represents the most important urban agglomeration and economic growth pole in the Bohai Rim area. Since reform and opening up, the GDP of the Beijing-Tianjin-Hebei region has maintained high-speed growth, paid for with enormous resource and environmental costs. According to the Beijing-Tianjin-Hebei Development Report: Carrying Capacity Measurement and Countermeasures (Blue Book), the region' s terrestrial resources and environments face prominent problems, including accelerated population growth, intensifying water crises, regional ecological environmental overdraft, and unbalanced development of land resource carrying capacity within the region. The current permanent population far exceeds the population size that its ecological carrying capacity can accommodate. The insufficient terrestrial resources and environments in Beijing-Tianjin-Hebei cannot support the region' s high-speed socioeconomic development, creating increasing demand for marine space and resources and imposing tremendous carrying pressure on regional marine resources and environments. Additionally, the Bohai Bay has limited water environmental capacity and high ecological vulnerability. Conducting assessment and early warning of marine resources and environmental carrying capacity in the Beijing-Tianjin-Hebei adjacent sea area is of great significance for land-sea integrated coordinated development.

Based on the regional marine resources and environmental carrying capacity measurement method established in this study, the pilot assessment results for warning levels in the sea areas under the jurisdiction of county-level administrative districts in Hebei Province and Tianjin Municipality are shown in [Figure 4: see original paper]. The urban district of Qinhuangdao (including three districts within the city) and Funing County are classified as moderate warning (yellow alert), Huanghua City as extremely severe warning (red alert), and all other evaluation units as severe warning (orange alert). Among these, the marine resources and environmental loss in Qinhuangdao' s urban district and Funing County, classified as moderate warning areas, also shows an intensifying trend. Therefore, the overall carrying capacity of marine resources and environments in the Beijing-Tianjin-Hebei sea area is not optimistic.

The pilot assessment indicates that marine ecological degradation, excessive coastline development, marine environmental pollution damage, and decline of natural fishery resources are the four main factors affecting the carrying capacity of marine resources and environments in the sea areas of Hebei Province and Tianjin Municipality. Among these, marine ecological degradation and excessive coastline development are primarily caused by high-intensity development activities in coastal zones, while marine environmental pollution damage is mainly affected by comprehensive impacts of watershed agricultural pollution and domestic sewage discharge.

According to the regional development positioning determined in the Beijing-

Tianjin-Hebei Coordinated Development Plan Outline and the spatial layout of "one core, two cities, three axes, four zones, and multiple nodes," the eastern coastal area of Beijing-Tianjin-Hebei will become an "eastern coastal development zone" undertaking industrial transfer and functional dispersion from inland areas. Heavy industries such as steel and petrochemicals will continue to concentrate in the eastern coastal area, maintaining high demand for marine spatial resources. The already overloaded and continuously growing large population in Beijing-Tianjin-Hebei has led to more severe regional water resource shortages and arduous tasks for watershed nitrogen and phosphorus pollutant reduction. Since the entire Bohai Sea where Bohai Bay is located has insufficient overall marine resources and environmental carrying capacity, its buffering effect on Beijing-Tianjin-Hebei' s development pressure is limited. If not properly addressed, the trend of intensified regional marine resources and environmental loss will become more severe and may affect the sustainable development of Beijing-Tianjin-Hebei and even the entire Bohai Rim region.

4. Conclusions and Outlook

1. **Measuring marine resources and environmental carrying capacity is of great significance.** Marine resources and environmental carrying capacity is an important indicator for evaluating and measuring regional socioeconomic sustainable development levels. It also provides an important basis for regulating and optimizing the spatial layout of "ecological, production, and living" spaces and promoting transformation of development modes and industrial structure upgrading.

2. **Promoting sustainable development in the Bohai Rim region through carrying capacity measurement in Beijing-Tianjin-Hebei.** The Beijing-Tianjin-Hebei region should promptly establish a dynamic monitoring, assessment, and early-warning mechanism for land-sea integrated resources and environmental carrying capacity to explore effective ways to alleviate coastal carrying pressures and enhance carrying capacity, thereby driving the overall coordinated and sustainable development of the Bohai Rim region.

3. **Advancing more comprehensive and objective carrying capacity measurement methods.** The county-level administrative district-based measurement method for marine resources and environmental carrying capacity represents a relative carrying capacity assessment approach with certain limitations. Future research should be ecosystem-based, properly handle relationships among ecological zoning, functional zoning, and administrative divisions, further deepen studies on potential carrying capacity and comprehensive carrying capacity at different spatial and temporal scales, and closely integrate with related research such as natural resource balance sheets and compensated sea use to comprehensively analyze and objectively judge regional marine resources and environmental carrying status and potential.

4. **Advancing marine resource supply from coastal waters to deep blue waters.** Marine resources and environmental carrying capacity has significant characteristics of systematicness, openness, complexity, and land-sea connectivity. Future efforts should closely integrate with the strategic deployment of "expanding blue economic space," promote land-sea integration and cross-regional cooperation, and through developing the deep blue economy and implementing the "going out" strategy, effectively meet regional socioeconomic development demands for marine resources while reducing development pressure on coastal waters, restoring and improving coastal marine ecological environmental quality, and promoting the transformation of marine resource supply from production factors to consumption factors.

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