

Assessment Method for Marine Ecological Loss Compensation in Sea-use Construction Projects and Its Application: Post-print

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Abstract

Marine ecological compensation is an environmental policy designed to prevent marine ecological damage and enhance and promote the sound development of marine ecosystems. It constitutes a monetary compensation mechanism through which sea users fulfill their responsibility for the paid use of marine resources, compensating for losses in marine ecological value caused by the development and utilization of marine resources. Based on the principles of rapid, quantitative, and differentiated compensation assessment, we have compiled ecological value baseline tables, ecological damage coefficient tables, and compensation coefficient tables for the coastal waters of Shandong Province, establishing a novel assessment methodology system for marine ecological loss compensation in sea-use construction projects. This system encompasses compensation assessments for marine ecological value losses in two dimensions: marine biological resources and marine ecosystem services, covering both occupied sea areas and adjacent affected sea areas. For five typical sea-use projects in Shandong Province in 2016, we calculated the required marine ecological compensation funds and compared the results with those obtained using the old standard “Assessment Methods for Marine Ecological Damage Compensation and Loss Compensation in Shandong Province” (DB37/T 1448-2009). The results indicate that under this assessment method, sea-use enterprises would be required to pay increased ecological compensation funds to varying degrees, which would enhance their awareness of paid resource use, guide enterprises toward rational sea use, and under market economy conditions, facilitate the optimal allocation of marine resources and improve sea-use efficiency. Furthermore, implementing differentiated compensation for marine ecological losses caused by sea-use construction projects based on varying industrial policies and the ecological vulnerability of affected sea areas renders the assessment results of marine ecological compensation standards more scientific and rational. Currently, this method has been applied in the

assessment of marine ecological loss compensation across nine sea areas in seven coastal cities of Shandong Province and has been adopted by the newly issued Shandong Provincial local standard “Technical Guidelines for Assessment of Marine Ecological Loss Compensation in Sea-Use Construction Projects” (DB37/T 1448-2015). This assessment methodology can provide a scientific foundation for marine management departments in ecological capital accounting, ecological compensation accounting, environmental impact assessment approval, and permit issuance, and plays a positive role in promoting marine ecological environment protection, green development of the marine economy, and the implementation of the ecological compensation system in China.

Full Text

Preamble

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Assessment Method and Application of Compensation for Marine Ecological Loss Caused by Marine Construction Projects

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Abstract

Marine ecological compensation is an environmental policy that prevents marine ecological damage and enhances the benign development of marine ecosystems. It represents monetary compensation for the loss of marine ecological value caused by the development and utilization of marine resources by sea users. Based on the evaluation principles of rapidness, quantification, and differentiated compensation, we compiled baseline value tables for marine ecological capital, ecological damage coefficient tables, and compensation coefficient tables for the coastal waters of Shandong Province, establishing a novel assessment system for marine ecological loss compensation caused by marine construction projects. The compensation for marine ecological value loss encompasses two aspects: compensation for the loss of marine living resources and compensation for the loss of marine ecosystem services, both applying to the constructed sea area and nearby affected sea area. We calculated the required marine ecological compensation funds for five typical sea-use projects in 2016 and compared the

results with those obtained using the old local standard “Shandong Province Marine Ecological Damage Compensation and Loss Compensation” (DB37/T 1448–2009). The results indicate that the compensation funds required under the new evaluation method increase to varying degrees, which strengthens awareness of paid resource use, guides enterprises to use the sea rationally, and optimally allocates marine resources while improving sea-use efficiency under market economy conditions. Moreover, according to different industrial development policies and the ecological vulnerability of affected areas, differentiated compensation for marine ecological loss is implemented, yielding more scientific and reasonable evaluation results. Currently, this method has been applied to assess compensation for marine ecological loss caused by marine construction projects across seven coastal cities and nine sea areas in Shandong’s jurisdictional waters, and has been approved by academia and marine administrative departments. This evaluation method has been adopted by the newly issued Shandong provincial standard “Technical Directives of Assessment of Compensation for Marine Ecological Loss Caused by Marine Construction Projects” (DB37/T 1448–2015). The method can provide key technical means for marine ecological capital accounting, ecological compensation accounting, and environmental assessment approval and licensing for sea-use enterprises, offering a scientific basis for the rapid, quantitative, and comprehensive assessment of marine ecological compensation business. It plays a positive role in promoting marine ecological environmental protection and the green development of China’s marine economy.

Keywords: marine construction projects; marine ecological loss; ecological compensation; assessment

Introduction

Ecological compensation is an effective incentive mechanism to coordinate economic and social development with ecological and environmental health. It is a public institution aimed at protecting the natural ecological environment and achieving harmonious development between humans and nature, internalizing environmental external costs, and using government and market instruments to regulate interest relationships among stakeholders in ecological protection. International research on ecological compensation has primarily focused on forests, mineral resources, and protected areas, with relatively limited research on marine ecological compensation. Elliott and Cutts [?] theoretically studied marine ecological compensation, proposing that it can be divided into economic compensation, resource compensation, and habitat compensation. Depondt and Green [?] investigated countries along the coasts of Southeast Asia, the Indian Ocean, and the Atlantic Ocean, analyzing the funding support system for marine protected area ecological compensation. Mow et al. [?] used the collaborative planning and management of coastal and marine resources in the San Andrés Archipelago, Colombia as a case study to analyze opportunities and obstacles in implementing ecological compensation. Beaumont et al. [?] explored UK ma-

rine biodiversity conservation, arguing that economic evaluation methods should be employed to promote marine biodiversity conservation management by optimally allocating limited management resources and enhancing managers' awareness of ecological compensation importance. Thur [?] used Bonaire National Marine Park as an example to explore user fees as a funding mechanism for the sustainable development of marine protected areas, determining the range of willingness to pay.

China has also conducted exploratory research on marine ecological compensation. Han Qiuying et al. [?] analyzed stakeholders, compensation intensity, and compensation approaches in marine ecological compensation, proposing that future research directions should focus on marine ecological resource value assessment. Li Jingmei and Liu Tieying [?] suggested that compensation subjects and objects should be defined according to changes in marine ecosystem service functions and their impacts on stakeholders, that compensation standards should follow the principle of combining theoretical calculations with existing practice, and that fiscal transfer payments and environmental resource taxes should be the main compensation approaches. Li Ruiqian and Meng Fanping [?] used energy analysis to calculate the loss of bay ecosystem service value caused by land reclamation, arguing that existing ecological compensation assessment methods cannot comprehensively reflect the impacts of reclamation on bay ecosystems and underestimate the total value of losses. Qu Yanmin et al. [?] elaborated on the connotation of marine ecological compensation and the current status of its development in China, pointing out that marine ecological compensation policy and legal systems should be established and improved and the management system perfected. Rao Huanhuan et al. [?] established a marine engineering ecological damage assessment framework and ecological damage compensation standard estimation model, applying it to a case study of Xinglin Cross-sea Bridge in Xiamen.

International and domestic research on marine ecological compensation has focused on macro-level implementation issues, discussing compensation subjects and objects, compensation approaches, and funding channels. However, key issues such as compensation fund accounting, compensation standard determination, and compensation scope and duration remain insufficiently studied. Marine ecological compensation is an environmental policy that prevents marine ecological damage and enhances the benign development of marine ecosystems, representing monetary compensation for marine ecological value loss caused by marine resource development. It fulfills the responsibility of sea users to pay for marine resource use.

In 2009, Shandong Province pioneered the marine ecological damage compensation system nationwide by issuing the local standard "Shandong Province Marine Ecological Damage Compensation and Loss Compensation" (DB37/T 1448–2009). During its implementation, nearly 1,000 sea-use construction projects were approved, with 800 projects paying ecological compensation funds, averaging 45,000 yuan per hectare. This standard provided an important legal basis

for protecting Shandong's marine ecological environment and penalizing destructive behaviors. However, because the standard only considered marine living resource value loss in occupied sea areas and failed to incorporate important marine ecosystem service value loss and ecological value loss in nearby affected areas, the ecological compensation funds collected by the government were generally low. The assessment scope, methods, and parameters stipulated in this standard have lagged behind technological development and marine management needs. The "Technical Guidelines for Marine Engineering Environmental Impact Assessment" (GB/T 19485–2014) revised in 2014 urgently requires revision to meet new requirements of the Party Central Committee regarding marine ecological civilization construction, accountability for ecological and environmental damage by Party and government officials, and natural resource 离任审计 (departure audit) for leading officials.

Based on marine ecological capital theory and ecological loss compensation theory, this paper establishes a new assessment method for marine ecological loss compensation caused by sea-use construction projects. We selected five typical sea-use projects in Shandong waters in 2016, calculated their required marine ecological compensation funds using this method, and compared the results with those from the old standard. This assessment method can provide scientific support for ecological compensation accounting, environmental assessment approval, and licensing for national and local marine authorities, playing a positive role in protecting China's marine ecological environment and promoting green development of the marine economy.

1. Assessment System and Structural Elements for Marine Ecological Loss Compensation of Sea-Use Construction Projects

Based on the principles of rapid, quantitative, and differentiated compensation assessment, this paper establishes an assessment system for marine ecological loss compensation of sea-use construction projects and compiles baseline value tables for marine ecological capital, ecological damage coefficient tables, and compensation coefficient tables for Shandong's coastal waters. This assessment system mainly includes the following key indicators and structural elements for quantitatively evaluating marine ecological loss compensation of sea-use projects.

1.1 Determination of Baseline Ecological Values for Damaged Sea Areas

Baseline marine ecological values include baseline values for marine living resources and marine ecosystem services. Shandong's sea areas are divided into nine assessment units according to seven coastal cities: Yantai sea area is divided into two assessment sea areas—Yantai Area I includes the jurisdictional waters of Laizhou, Zhaoyuan, and Longkou; Yantai Area II includes the jurisdictional

waters of Yantai Development Zone, Penglai, and Changdao. Because Laishan District and Muping District are located on the boundary between the Yellow Sea and Bohai Sea, and their ecological characteristics are closer to the Yellow Sea, they are grouped with Yantai Development Zone, Penglai, and Changdao as Yantai Area II. Laixi and Haiyang, located on the southern coast of the Shandong Peninsula between Weihai and Qingdao sea areas, are grouped as the Laixi-Haiyang sea area. Based on the national standard “Technical Guidelines for Ecological Capital Assessment” (GB/T 28058–2011), spatial interpolation and overlay were performed to map the spatial distribution and calculate the average distribution density of biological resource value and ecosystem service value in Shandong’s coastal waters in 2014.

[Figure 1: see original paper] Assessment system of compensation for marine ecological loss caused by marine construction projects

[Figure 2: see original paper] Assessment scope of coastal ecological values in Shandong Province

The average distribution density of biological resource value in the nine sea areas is used as the baseline value for marine living resources. The average distribution density of ecosystem service value in the nine sea areas shows significant regional differences. To facilitate practical implementation of ecological compensation standards, scientific adjustments are needed to reduce regional disparities. The minimum value (1.6000) is kept unchanged, while the maximum value is reduced to one-third of its original value (7.6100), resulting in 2.5300. The gap between minimum and maximum values is thereby reduced from the original 6.0100 to 0.9300.

The baseline value for ecosystem services in a given sea area is calculated as:
(Baseline value) = (Average distribution density of ecosystem service value in the sea area - 1.6000) / (7.6100 - 1.6000) × 0.9300 + 1.6000

Ecological values and their average distribution density of nine sea areas in Shandong Province

Base value of coastal ecological values in Shandong Province

1.2 Determination of Ecological Damage Coefficients for Sea-Use Construction Projects

Ecological damage coefficients quantitatively characterize the degree of damage to the marine ecosystem and its components caused by sea-use projects, including biological resource damage coefficients and ecosystem service damage coefficients. The marine ecosystem comprises three structural elements: water body, water surface, and surface seabed. The ecological damage coefficient is obtained through weighted summation of the weights and damage degrees of these three elements. A questionnaire was designed using the Delphi method, with experts from marine ecology, marine economics, and sea area use demonstration conducting three rounds of face-to-face discussions. Based on expert

consensus, the overall degree of marine ecological damage was assessed. Experts independently scored the damage degree and weight of structural elements such as phytoplankton, zooplankton, benthic organisms, swimming organisms, and fish eggs and larvae according to the sea-use construction project' s construction and operation periods (commonly called the use period, operation period, or recovery period). The ecological damage coefficients were then obtained by synthesizing the weight and damage degree scores for each ecosystem structural element and conducting consistency tests.

1.2.1 Determination of Ecological Damage Coefficients for Occupied Sea Area During Construction and Operation Periods Based on indicators such as damage mode, damage objects, and damage degree of sea-use construction projects, a classification system for sea area occupation modes was proposed to assess marine ecological loss. Different ecological damage coefficients for occupied sea area during construction and operation periods were determined for various occupation modes.

Ecological damage coefficient of constructed sea area during construction period and operation period

1.2.2 Determination of Ecological Damage Coefficients for Nearby Affected Sea Area During Construction Period The main environmental impact of reclamation projects during the construction period is suspended sediment discharge. The characteristic impact factor for nearby affected sea areas during construction is suspended sediment. In the assessment system, different ecological damage coefficients correspond to different variation ranges of suspended sediment increase.

Ecological damage coefficient of nearby sea area during construction period

1.2.3 Determination of Ecological Damage Coefficients for Nearby Affected Sea Area During Operation Period The characteristic impact factors for nearby sea areas during the operation period are mainly tidal current changes and local scouring or siltation. Both tidal current changes and local scouring or siltation cause ecological damage to varying degrees. Referring to the hydrodynamic evaluation indicators in the national standard “Technical Guidelines for Environmental Impact Assessment of Bay Reclamation Planning” (GB/T 29726–2013), the ecological damage degree for nearby affected sea areas during the operation period is determined based on the variation range of maximum tidal velocity change or change rate at characteristic points of ecologically sensitive areas, as well as annual scouring reduction or siltation increase. Several variation ranges were designed, corresponding to different ecological damage coefficients.

Ecological damage coefficient of nearby sea area during operation period

1.2.4 Determination of Ecological Damage Coefficients for Thermal Discharge Occupation Mode During Operation Period

Power plant construction projects use large amounts of seawater as cooling water, transferring tremendous heat energy to nearby sea areas and causing temperature increases that create thermal pollution. Temperature increase mainly leads to marine organism death, water body damage, and benthic ecological destruction. For sea-use projects with thermal discharge occupation mode, the construction period is short and the occupied sea area is small, so construction period ecological damage can be neglected, focusing mainly on operation period ecological damage. According to research by Xu Xiaoqun et al. [?], the average semi-lethal temperature is a temperature increase of 13°C. Temperature increases within 1°C have minor impact, 1-2°C have moderate impact, 2-4°C have significant impact, and above 4°C have severe impact. Class I and II temperature increase standards are 1°C, Class III and IV standards are 2°C, and Class V standard is 4°C. Several temperature increase variation ranges correspond to different ecological damage coefficients during the operation period.

Ecological damage coefficient during operation period for power plant intake seawater projects

1.3 Determination of Ecological Compensation Coefficients for Sea-Use Construction Projects

Ecological compensation coefficients include baseline compensation coefficients, policy adjustment compensation coefficients, and additional compensation coefficients. The sum of these three constitutes the comprehensive compensation coefficient. Differentiated ecological compensation policies for different industries are implemented to promote the transformation and upgrading of marine industrial structure and establish a green development model.

1.3.1 Determination of Baseline Ecological Compensation Coefficients

Based on economic and social indicators such as industry concentration, profit level, and job provision of the sea-use construction project's industry, and considering corporate economic indicators (debt-paying ability, capital turnover ability, profitability) and social responsibility indicators (social contribution), the Analytic Hierarchy Process (AHP) and expert scoring method were used to determine indicator weights. The Vague value similarity method was ultimately used to determine baseline compensation coefficients. According to the "Marine and Related Industries Classification" (GB/T 20794-2006), commercial and service sea use refers to urban and commercial facility construction after reclamation; public welfare sea use refers to non-operational projects mainly providing public services; other operational sea use refers to other non-marine industrial operational uses such as navigation support and military purposes. Sample enterprises were selected from listed companies and leading enterprises in each industry.

Base compensation coefficient of different industry types

1.3.2 Determination of Policy Adjustment and Additional Compensation Coefficients Policy adjustment and additional compensation coefficients are determined based on whether the sea-use construction project complies with Shandong's industrial policy and whether it affects marine ecologically sensitive areas. If the project content belongs to the encouraged category in the currently effective "Shandong Province Marine Industry Development Guidance Directory," the policy adjustment coefficient is -0.1; if it belongs to the restricted category, the coefficient is +0.1; if it belongs to the eliminated category, the coefficient is +0.2; if not listed, it is treated as encouraged with a coefficient of -0.1. For public welfare sea-use projects and non-operational projects mainly providing public services, the policy adjustment coefficient is -0.2.

Ecologically sensitive areas mainly refer to national and provincial marine nature reserves, aquatic germplasm resources reserves, marine special protected areas, other sea areas in the Shandong Province Marine Ecological Red Line, national Class I and II protected species distribution areas, other species distribution areas in the China Species Red List, and distribution areas of other protected species approved by provincial-level and above government departments. If any of these ecologically sensitive areas exist within the occupied or nearby affected sea area of a sea-use construction project, the additional compensation coefficient for calculating compensation funds for the damaged ecologically sensitive area follows Table 8; if none exist, the additional compensation coefficient is 0.

Additional compensation coefficient

1.4 Determination of Damaged Sea Area Scope

Damaged sea area refers to the sea area where ecological damage occurs, including both the occupied sea area of the sea-use construction project and nearby affected sea areas. The scope of nearby affected sea area during the construction period can be determined based on the maximum envelope range of suspended sediment increase, with distribution maps of different variation ranges drawn. The scope of nearby affected sea area during the operation period is mainly determined based on the spatial scope and impact degree of predicted hydrodynamic environment and erosion-siltation environment changes in the environmental assessment report. It can be determined separately based on the maximum envelope range of characteristic point maximum tidal velocity change or change rate, and scouring reduction or siltation increase, to determine the impact scope of different variation ranges. For sea-use projects with thermal discharge occupation mode, the scope of nearby affected sea area can be determined based on the maximum envelope range of temperature increase, with distribution maps of different temperature increase ranges drawn.

1.5 Determination of Damage Duration

In the assessment system, marine living resource loss is defined as one-time loss, while marine ecosystem service value loss is defined as persistent loss, requiring

multiplication by damage duration when calculating losses. Damage duration includes construction period and operation period. The damage duration for occupied and nearby affected sea areas during the construction period is calculated according to the actual construction years. The damage duration for occupied sea area during the operation period equals the proposed or approved sea-use years minus the construction period years. For sea-use modes such as sea sand mining, channel construction and dredging, and submarine pipeline excavation, the damage duration for nearby affected sea area during the operation period is set at 2 years. For thermal discharge occupation mode, the damage duration for nearby affected sea area is calculated according to the designed drainage period.

2. Application of the Marine Ecological Loss Compensation Assessment Method for Sea-Use Construction Projects

This paper selected five typical sea-use construction projects in Shandong waters in 2016 and calculated their marine ecological loss compensation funds using this assessment method. Due to space limitations, detailed calculation processes are not elaborated. The results were compared with those from the old standard.

Accounting of compensation fund of marine ecological loss for 5 typical marine projects in 2016

The five cases are: Laizhou Port channel construction project, Qingdao Port Dongjiakou Port Area Datang Wharf, Laizhou Power Plant sea-use project, Rizhao Fishing Port sea-use project, and Dongying Guangli Seawall sea-use project. The results show that the ecological compensation funds calculated using this method increase to varying degrees compared with the old standard, roughly 1.5-4.5 times the original amount. This leads to a higher proportion of ecological compensation funds in total project investment, meaning increased sea-use costs for enterprises. Under market economy conditions, this is conducive to optimal allocation of marine resources and improved sea-use efficiency, enhancing enterprises' awareness of paid resource use and guiding rational sea use.

3. Conclusions

Marine ecological civilization construction has become an important component of national ecological civilization construction, with a series of marine ecological civilization systems taking root nationwide. Establishing a marine ecological compensation mechanism is an effective and long-term approach to adjusting the relationship between marine development and protection, promoting intensive marine resource utilization and marine ecological environmental protection. The marine ecological loss compensation assessment method established in this paper updates and improves Shandong's old compensation standard, representing a positive response and practice to the Party's strategy of incorporating ecological civilization construction into the "Five-in-One" overall layout. Based on the principles of rapidness, quantification, and differentiated compensation, this

method adjusts baseline ecological values for damaged sea areas and introduces innovative research results by proposing the concept of compensation coefficients to adjust compensation funds that enterprises must pay. The method compiles baseline value tables for marine ecological capital and ecological damage coefficient tables for Shandong's coastal waters to quantitatively assess marine ecological loss of sea-use construction projects. In terms of ecological compensation fund accounting, after determining the location of the sea area applied for, the baseline marine ecological value can be quickly identified, and then adjusted using ecological damage coefficients and compensation coefficients based on occupation mode, industry type, and other factors to calculate the final compensation funds enterprises must pay. This approach features unified standards and clear procedures. Regarding feasibility, compensation fund accounting fully considers enterprises' payment capacity, using compensation coefficients to adjust funds within enterprises' payment ability, ensuring enforceability. This method significantly improves efficiency in both accounting convenience and implementation feasibility.

Through the case studies, we can see that ecological compensation funds calculated using this method increase to varying degrees compared with the old standard. The increase in compensation funds will create certain pressure on corporate profits, which helps enhance enterprises' awareness of paid resource use, guide rational sea use, and optimize marine resource allocation. Notably, this method does not simply increase compensation amounts but more comprehensively considers the ecological vulnerability of affected areas, enterprises' investment willingness, government policy orientation for marine industry development, and other factors to implement differentiated compensation for marine ecological loss caused by sea-use construction projects, making assessment results more scientific and reasonable. This assessment method has been adopted by the newly issued Shandong provincial standard "Technical Directives of Assessment of Compensation for Marine Ecological Loss Caused by Marine Construction Projects" (DB37/T 1448–2015) and has become a supporting technical document for the newly introduced "Shandong Province Marine Ecological Compensation Management Measures," closely meeting national and provincial marine ecological civilization construction needs. It can provide a scientific basis for marine management departments in ecological capital accounting, ecological compensation accounting, environmental assessment approval, and licensing, playing a positive role in promoting China's marine ecological environmental protection, green development of the marine economy, and implementation of the ecological compensation system.

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

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