Measurement of Ecological Fisheries Efficiency in Selected Coastal Cities Based on the NDDF Model

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Abstract: With global population growth and economic development, the demand for marine resources is constantly increasing, and fishing activities are facing greater pressure. Overfishing and unreasonable fisheries management have led to some fishery resources facing depletion and ecosystem degradation. The health of marine ecosystems is crucial for the ecological balance of the Earth. Overfishing and ecosystem destruction may lead to ecosystem collapse, causing long-term impacts on many species and ecological functions that rely on marine organisms. With the development of technology and innovation, new fishery technologies and management methods continue to emerge, which have the potential to improve the ecological efficiency of fisheries and optimize resource utilization. Based on the panel data of some coastal selected provinces from 2005 to 2019, the NDDF model is used to calculate the marine fishery efficiency and target the path of marine fishery eco-efficiency improvement. The results of the study show that, in terms of spatial pattern, the eco-efficiency value of marine fisheries in southern coastal provinces and municipalities in China is higher than that in northern coastal provinces and municipalities as a whole. Shandong province has the highest eco-efficiency value in the Bohai Rim region, and Shanghai city has the highest eco-efficiency value in the Yangtze River Delta region. In terms of time series, the eco-efficiency values of marine fisheries in the eastern coastal provinces and municipalities of China showed a fluctuating increase, and two peaks occurred in 2011 and 2019. Provinces and cities with high eco-efficiency values have the common characteristics of enjoying national policy support and reasonable resource allocation, while provinces and cities with lower eco-efficiency values have the common characteristics of irrational industrial structure, weak environmental protection awareness, and less scientific and technological investment. Based on this, suggestions are put forward on improving the eco-efficiency value of marine fisheries: vigorously developing fishery-related science and technology, optimising the industrial structure of coastal cities, and increasing policy support.

Keywords: Marine Fishery; Eco-efficiency; NDDF Model; Coastal City

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1 Introduction

In recent years, with the development of ‘carbon neutrality, carbon peak’, green development has become an important issue in the current society, according to the ‘2022 National Fisheries Economy Statistical Bulletin’, China's marine fishery output value accounted for 46.7% of the fishery output value in 2022, compared with 43.6% in 2020 to achieve a steady growth [1]. Due to the increasing scale of development, marine fishery has gradu-

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ally shown a greater role in China's food security and ecological environment, and the '14th Five-Year Plan' National Fisheries Development Plan has also pointed out that marine fishery is an important part of China's economy, and put forward further requirements for its high-quality development [2].

However, the rapid development of marine fisheries has also brought many problems and enormous pressure on the environment, the rough form of development makes the ocean subjected to high-intensity pollution, the carrying capacity of marine fisheries is gradually declining, marine fisheries show a trend of degradation aggravated, in such a context, it is easy to cause unbalanced benefits and insufficient development [3]. Therefore, considering how to improve the efficiency of marine fisheries is a key point for the sustainable development of marine fisheries in the future, and the study of the eco-efficiency of marine fisheries has important theoretical significance and practical significance.

2 Data and Model Analysis

2.1 Indicator Construction

Under the perspective of green development, the green efficiency measurement of marine fisheries is becoming more and more important, in order to determine the eco-fishery efficiency of multiple coastal cities, with reference to Zhang Qihang [4] et al.'s study on the spatial and temporal evolution characteristics of China's forestry carbon sink efficiency, and Du Jun et al.'s analysis of the spatial evolution of China's marine economic efficiency and influencing factors based on Bootstrap-DEA model [5], this paper adopts the non-radial direction under the DEA framework direction distance function model to construct the growth index of green efficiency as in [6]. Several typical coastal cities are selected for analysis, including Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang and Shandong, to measure the eco-efficiency of their marine fisheries.

Table 1 Evaluation index system of marine fishery eco-efficiency in coastal areas

Type of indicator	**Tier 1 indicators**	**Secondary indicators**
Input indicators	Resource inputs	Mariculture area/ha
	Labour inputs	Employees in marine fisheries/person
	Capital inputs	Capital stock of marine fishery/billion yuan
Output indicators	Desired output	Total output value of marine fisheries / million yuan
	Undesired outputs	Total volume of mariculture effluent/tonnes

2.2 Modelling

Taking capital (K), labour (L) and resources (E) as input factors, the value added of the industry (Y) is the desired output, and the total amount of mariculture discharge (S) is the non-desired output [7]. Based on this, the production technology set of 'multiple inputs - multiple outputs' is defined as:

$$P = \{(K, L, E, Y, S): K, L, E\ can\ produce\ Y, while\ generating\ the\ undesired\ S\} \tag{1}$$

The production technology set at this point is satisfied:

$$\begin{cases} (K, L, E, Y)\epsilon P\ and\ Y' \le Y \\ (Y, S)\epsilon pand 0 \ll \theta \ll 1 \\ (Y, S)\epsilon pandS = 0 \end{cases} \tag{2}$$

The province i corresponding to the selected economies is the basic decision-making unit. $(i = 1, 2, \ldots, N)$, choosing the premise of constant returns to scale and constructing the production frontier, the technology set is:

$$\{(K, L, E, Y, S): \sum_{t=1}^{T}\sum_{i=1}^{N} Z_{it}K_{it}\, x \le K, \sum_{t=1}^{T}\sum_{i=1}^{N} Z_{it}L_{it} \le L,\ \sum_{t=1}^{T}\sum_{i=1}^{N} Z_{it}E_{it} \le E, \sum_{t=1}^{T}\sum_{i=1}^{N} Z_{it}Y_{it} \ge Y, \sum_{t=1}^{T}\sum_{i=1}^{N} Z_{it}S_{it} = S, Z_{it} \ge 0\} \tag{3}$$

$Z_{it}\ is\ auxiliary\ parameters, Z_{it} \ge 0$

In calculating the efficiency of ecological marine fisheries, the following NDDF model is defined:

$$\vec{D}(K, L, E, Y, S; g) = sup\{w^T\beta: ((K, L, E, Y, S) + g \cdot diag(\beta)) \in P\} \tag{4}$$

$w^T = (w_K, w_L, w_E, w_Y, w_S)$ is a weight vector; $g = (g_K, g_L, g_E, g_Y, g_S)$ is a direction vector indicating the direction of change of each corresponding variable.

In constructing the eco-fisheries eco-efficiency index, the weight vector is specified: $w^T = \left(\frac{1}{9}, \frac{1}{9}, \frac{1}{9}, \frac{1}{3}, \frac{1}{3}\right)$. The direction vector is $g = (-K, -L, -E, Y, -S)$. Therefore the corresponding distance function, it can be solved by linear programming as follows:

$$\vec{D}(K, L, E, Y, S) = max\left\{\frac{1}{9}\beta_K + \frac{1}{9}\beta_L + \frac{1}{9}\beta_E + \frac{1}{3}\beta_Y + \frac{1}{3}\beta_S\right\} \tag{5}$$

$$\text{s.t. } \sum_{t=1}^{T}\sum_{i=1}^{N} z_{it}K_{it} \le K - \beta_K\beta_K$$

$$\sum_{t=1}^{T}\sum_{i=1}^{N} z_{it}L_{it} \le L - \beta_L\beta_L$$

$$\sum_{t=1}^{T}\sum_{i=1}^{N} z_{it}E_{it} \le K - \beta_E\beta_E \tag{6}$$

$$\sum_{t=1}^{T}\sum_{i=1}^{N} z_{it}Y_{it} \le K - \beta_Y\beta_Y$$

$$\sum_{t=1}^{T}\sum_{i=1}^{N} z_{it}S_{it} \le K - \beta_S\beta_S$$

$$\beta_K, \beta_L, \beta_E, \beta_Y, \beta_S \ge 0 \tag{7}$$

Solving the linear programming problem of the above equation yields the optimal relaxation vector $\beta_{it}^* = \left(\beta_{it,K}^*, \beta_{it,L}^*, \beta_{it,E}^*, \beta_{it,Y}^*, \beta_{it,S}^*\right)^T$, The target value for setting the optimal factor inputs is $\rho_{it} - \beta_{\rho,it}^*\rho_{it}$, The target value of the optimal desired output is $Y_{it} + \beta_{Y,it}^* Y_{it}$ and the target value of the optimal undesired outpu $\eta_{it} - \beta_{\eta,it}^*\eta_{it}$Construction of Green Total Factor Efficiency Index (GDPI) for the corresponding year for each province of the three major economies [8]:

$$GDPI_{it} = \frac{1}{2}\left(\frac{1}{3}\sum_{\rho=K,L,E}\frac{Y_{it}/\rho_{it}}{(Y_{it}+\beta_{Y,it}^* Y_{it})/\left(\rho_{it}-\beta_{\rho,it}^*\rho_{it}\right)}\right) + \frac{1}{2}\left(\sum_{\eta=S}\frac{Y_{it}/\eta_{it}}{(Y_{it}+\beta_{\rho}^*\rho_{it})/(\eta_{it}-\eta_{\eta}^*\beta_{it})}\right) \tag{8}$$

3 Analysis of Results

Through the model, the ecological fishery efficiency in the provinces of Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang and Shandong was measured and further analysed on this basis. The results of which are measured are:

Table 2 Eco-efficiency values of marine fisheries in some provinces and cities along the eastern coast from 2005 to 2019

Province	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Tianjin	1	1	0.9241	1.0821	0.9160	1.0916	1	0.8329	0.7881	0.8366	0.9713	1.2614	1.0050	1.0438	1.0096
Hebei	0.9944	0.9741	1.0152	1.0749	0.8355	1.0949	1.1210	0.9226	0.9213	0.8231	0.9230	1.3894	1.0113	1.0347	0.8592
Shanghai	1	1	1	1	0.7305	1.3690	1	0.8285	0.8086	0.9324	0.7636	1.2027	1.3199	1.1633	1.1353
Jiangsu	1.0238	0.9546	0.9597	1.0120	0.8761	0.9865	0.9869	0.9241	0.9502	0.9117	0.9206	1.2836	0.9573	1.1633	1.1004
Zhejiang	1.0266	0.8052	1.1122	1.0540	0.8441	1.1270	1.2319	0.8220	0.9029	0.9484	0.8832	1.1917	0.9840	1.0838	1.0179
Shan-dong	1	1	1	1	1	1	1	1	0.9325	1.0724	1	1	0.9932	0.9863	1.0209

Overall, the eco-efficiency level of marine fisheries in China's coastal areas is relatively high, with the average efficiency value of each province lying in the range of 0.99-1.01.

In terms of trend, the value of marine eco-efficiency in coastal areas shows fluctuating growth with the passage of years, with two troughs in 2009 and 2015, followed by two peaks in 2011 and 2016. In 2011, the Ministry of Agriculture released the Twelfth Five-Year Plan for the Development of National Fisheries [9], which put forward the modern fishery production-led area, the eco-construction area, and the functional expansion area. In 2011, the Ministry of Agriculture released the Twelfth Five-Year Plan for National Fisheries Development [9], which put forward

the regional layout plan of modern fishery production-led areas, ecological construction areas and functional expansion areas, which led to a rapid increase in the value of marine eco-efficiency in that year.

From a spatial perspective, the eco-efficiency value of the Yangtze River Delta region is slightly higher than that of the Bohai Rim region, but the stability of eco-efficiency in the Bohai Rim region is higher than that of the Yangtze River Delta region.

Among the three provinces of Tianjin, Hebei and Shandong in the Bohai Rim, the fisheries in Hebei Province do not get significant development mainly limited by the ocean area [10]; in Shandong Province, the eco-efficiency value of marine fisheries has been in the range of 0.93-1.1 in the period of 2005-2019, and the eco-efficiency value of marine fisheries has been kept at 1 in the eight consecutive years of the period of 2005-2012, so that it can be seen that Shandong Province's marine fisheries eco-efficiency value has been at a high level and fluctuates smoothly. Shandong Province is a large fishery province with vast sea area and abundant water resources, which makes the fishery development unique. In addition, due to Shandong Province in recent years to grasp the opportunity of digitalisation and information development, focusing on the transformation and upgrading of the fishery industry, and accelerating a series of related support such as the deep integration of new generation information technology and modern fishery [11], it is also a contribution to the current situation of fishery industry in Shandong Province.

In the Yangtze River Delta region, Shanghai has the most significant fluctuations in the eco-efficiency value of marine fisheries. The Yangtze River Delta region has strong economic strength, and the provinces of Shanghai, Jiangsu and Zhejiang have continuously optimised and upgraded the traditional industries of marine fisheries, with a high degree of industrial agglomeration, giving full play to the advantages of their traditional fisheries. Shanghai city has a high degree of openness to the outside world, naturally to withstand greater fishing pressure, at the same time because of the development of industry, agriculture and other industries brought about by openness, aggravated by various kinds of environmental pollution on its marine ecological environment has brought about a certain amount of damage to its marine fisheries eco-efficiency value fluctuations more [12]. The Bohai Sea region is more developed industry, especially heavy industry, pollutant emissions to the marine environment has brought adverse effects, economic growth at the same time the problem of marine environmental degradation is also increasingly prominent. Shandong Province is one of the pilot areas of the national marine economy, which is supported by the national policy focusing on the development of marine fisheries investment, so that its marine fisheries eco-efficiency value is stable at a high level.

Throughout the above, the issue of how to improve the eco-productivity of fisheries while achieving stable growth in the fisheries economy is of paramount importance.

4 Conclusions and Recommendations

Through the above analyses, the overall fishery eco-efficiency of the south is higher than that of the north as a whole, and is one of the most dynamic regions for the development of the fishery industry in China [13]. The fishery industry in the south occupies nearly half of the national aquatic products, providing many jobs for the people, increasing financial income, promoting the development of tourism, and making indelible contributions in the push for poverty alleviation. Moreover, ecological fishery is a major economic source in the south, and the reasons for the low ecological efficiency value of marine fishery are mainly the irrational industrial structure, less investment in science and technology, etc., while the advantages of high ecological efficiency value include national policy support and reasonable allocation of resources. The stability of fishery economic development in the north is stronger than that in the south, and it has made significant contributions to the development of China's fishery economy, but it lacks the opportunity to open up and seek higher quality development. Therefore, it is concluded that the strengths of the north and the south should be combined to seek a new development of the efficiency of the marine fisheries ecological success in China's coastal areas.

With such a conclusion, this paper puts forward the following recommendations for the improvement of the ecological efficiency of marine fisheries in China's coastal areas:

1. Vigorously develop fishery-related science and technology.

Resource wastage and environmental pollution can be effectively reduced by improving mariculture methods. Promote water-saving and emission-reducing seawater

aquaculture techniques and gradually phase out net-pen aquaculture methods with high levels of sewage discharge. Optimise the structure of marine fishing vessels and gradually phase out resource-destroying marine fishing vessels.

2. Optimise the industrial structure of coastal cities.

Promote the transformation and upgrading of traditional industries in coastal areas, and improve product quality and technology content. Relying on the scientific and technological advantages and talent advantages of coastal cities, vigorously develop high-tech industries. Optimise the industrial layout, increase the degree of industrial aggregation and intensify the management of sewage discharge.

3. Pioneer the integrated development of multiple industries and promote the transformation and upgrading of the marine fishery industry.

Actively promote the transformation and upgrading of the fishery industry and build a new type of fishery system that is highly specialised, organised and socialised [14]. Not only to industry transformation, the development of secondary industries, at the same time, Zhucheng City should give full play to its own fishery development advantages, ecological protection as the premise, accelerate the transformation of the fishery development mode; accelerate the development of aquatic products processing industry, leisure fishery, fishery and agriculture fishery, fishery and tourism fishery, and continue to extend the industrial chain, enhance the value chain, improve the quality and efficiency, and achieve the ‘fishing + ’ multi-industry integrated development, high-quality development [15].

4. Increase policy support.

On the one hand, improve the marine fisheries system, establish fishing ban protection zones, protect the marine fisheries ecological efficiency steadily improved; on the other hand, increase the financial allocation, broaden the financing channels, for the environmental management of the sea area as well as fisheries science and technology to improve the level of financial support.

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