STUDY ON EFFICIENCY MEASUREMENT AND SPATIAL SPILLOVER EFFECT OF MARINE FISHERIES CARBON SINK

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Abstract. Improving the efficiency of carbon sequestration in Marine fisheries is an important way for China to achieve the goal of carbon neutrality. This paper uses the Super-SBM model to calculate the carbon sink efficiency of Marine fisheries in nine coastal provinces of China, and analyzes its global and local spatial autocorrelation. Meanwhile, the spatial Dubin model is used to analyze the influencing factors and spatial spillover effects of carbon sink efficiency in Marine fisheries. The study found that: (1) the overall efficiency level of Marine fisheries in nine coastal provinces of China is relatively high, Regional differences are significant; (2) From the overall perspective, There is a spatial positive correlation between the efficiency of carbon sink in regional Marine fisheries, Agglomeration effect is significant; (3) From the direct effect, The number of fishery employees and the per capita disposable income of residents can promote the efficiency of carbon sink in Marine fisheries, The total economic output value of mariculture, the power of aquaculture fishing boats and the area of affected aquaculture have an inhibitory effect on the carbon sink efficiency of Marine fishery; (4) In terms of the spatial effect, The number of fishery employees, the power of aquaculture fishing boats, and the per capita disposable income of residents have a positive spatial spillover effect, The total output value of mariculture and the area of aquaculture have negative spatial spillover effect.
Keywords: *marine fishery carbon sink, carbon sink efficiency, Super-SBM model, space spillover effect*

Introduction

In recent years, with the continuous increase of carbon dioxide and other greenhouse gas emissions, global warming and other non-traditional security issues have become more prominent, and achieving emission reductions and increasing sinks and developing a low-carbon economy have turned out to be an important way to deal with climate change (Yu et al., 2023). The oceans store 93% of the Earth's carbon dioxide and are the largest carbon reservoir on the planet (Rodríguez-Martínez et al., 2020), with a capacity 20 times that of the terrestrial carbon reservoir and 50 times that of the atmospheric carbon reservoir (Cheng and Chen, 2021). Compared with direct emission reduction in industry, ocean carbon sink has obvious advantages (Yun et al., 2022). It is highly operable, low cost and offers long time carbon storage (Xu et al., 2018). Therefore, it has become the choice of many countries to achieve the goal of emission reduction and sink (Fay and McKinley, 2021).

"Fisheries carbon sink" is an important component of ocean carbon sink (Tang et al., 2022), which refers to the process and mechanism of promoting the uptake or use of greenhouse gases such as CO_2 by aquatic organisms through fisheries production activities, and moving the carbon, which has been converted into biological products, out of the water body through harvesting, or depositing it to the water bottom through biodeposition. As a major component of marine carbon sink fisheries, the ability of shellfish aquaculture to sequester carbon is outstanding, and this has been recognized by the academic community (He and Zhang, 2023). Along with the rapid economic and

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social development of China's coastal areas, the function of coastal blue carbon ecosystem is declining, and its carbon sequestration capacity is gradually weakening. This means that the issue of how to improve the carbon sink efficiency of marine fisheries is becoming more and more important (Zhou et al., 2016). At the same time, the carbon sink efficiency of marine fisheries shows a strong cross-regional network, which can influence the carbon sink efficiency of surrounding regions through the transmission mechanisms of factor flow, technology spillover and policy diffusion, i.e., there is a spatial spillover effect. Therefore, a comprehensive measurement of the carbon sink efficiency of Chinese marine fisheries and an in-depth analysis of the spatial effects and influencing factors of carbon sink efficiency will open up a new research direction for the study of global climate change.

At present, domestic and foreign scholars have conducted abundant research on carbon sinks in marine fisheries, mainly focusing on the following three aspects: First, the investigation of carbon sequestration capacity and potential of shellfish. Ji and Wang (2016) used the material quality assessment method to measure the carbon sink of marine aquaculture shellfish, and the results showed that the carbon sink capacity of marine aquaculture shellfish in China is huge. Foreign scholars Cerrato et al. (2004) found that by feeding on particulate organic carbon in seawater, considerate shellfish effectively reduce the partial pressure of carbon dioxide in seawater and promote the growth of benthic plants, thus increasing the amount of carbon sequestration. Yang et al. (2022) included the carbon sink formed by shellfish through the release of POC and DOC in the estimation model to assess the carbon sink potential of Chinese marine fisheries, and found that the carbon sink capacity of Chinese fisheries reaches 3,026,300 tons/year in 2020, and the carbon sink capacity of marine fisheries is 3,355,100 tons/year to 3,999,200 tons/year in 2030, with limited growth potential. Based on the LMDI model, Shao et al. (2019) analyzed the difference of carbon sink capacity of different regions in China and the influencing factors from two aspects of mariculture structure effect and scale effect, and the results showed that the carbon sink capacity of the Yellow Sea is the strongest, and the scale effect always has a positive correlation with the carbon sink capacity. Secondly, the study of green efficiency and spatial effect of fisheries. Foreign scholars Huguenin and Rothwell (1979) characterized the efficiency of marine net-pen aquaculture by the yield per unit area, and assessed the efficiency of mariculture for the first time. Xu et al. (2020) constructed the green evaluation index system of carbon sink fisheries from three aspects of resources, environment and economy to measure the green efficiency and spillover effect of fisheries and found that the green efficiency of fisheries showed regional differences and had a significant spatial spillover effect. Cao and Fang (2022) measured the green efficiency of marine fisheries based on the principle of material balance and found that the overall green efficiency of marine fisheries in China is low and decreasing year by year, especially in Hebei and Jiangsu, and the overall innovation power of marine fisheries is not high. Thirdly, the research on the development path and related policies. Tang et al. (2022) proposed to establish carbon sink fisheries demonstration areas, demonstrate sink enhancement and explore carbon sink expansion pathways, and emphasize and encourage carbon trading types, mechanisms and market practices in carbon sink fisheries. Since macroalgae contribute more to aquatic benthic invertebrates than fish, Zhao et al. (2022) proposes that the carbon sink capacity can be increased by mixed culture of shellfish or fish that feed on shellfish and algae.

Existing studies mainly focus on the estimation and evaluation of the carbon sink capacity of fisheries, and no relevant studies have been conducted on the carbon sink

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efficiency of mariculture shellfish. In this paper, based on the previous studies, the Super-SBM model is used to measure the carbon sink efficiency of marine fisheries in nine coastal provinces of China, and the spatial Durbin model is applied to analyze the influencing factors and spatial spillover effects on the carbon sink efficiency of marine fisheries in nine coastal provinces of China.

Materials and methods

Calculation method and index construction of fishery carbon sink efficiency

Super-SBM model

System analysis methods to evaluate the relative effectiveness of decision units include data envelopment analysis (DEA), which traditionally requires inputs and outputs to vary in the same proportion and is difficult to compare when multiple decision units are 1. Tone (2002) proposes a super-efficient SBM model based on this approach to effectively solve the problem. In this paper, an output-oriented version of this model is used to measure the carbon sink efficiency of marine fisheries. The model is constructed as shown below:

$$
\begin{aligned}
&\min \rho = \frac{1}{1-\frac{1}{q}\sum_{r=1}^{q}\frac{Sr^{+}}{y_{rk}}} \\
&s.t. \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^{-} \le x_{ik} \\
&\sum_{j=1, j\neq k} y_{ij}\lambda_j + s_i^{+} \ge y_{rk} \\
&\lambda, s^{-}, s^{+} \ge 0 \\
&i = 1,2.....,m; r = 1,2,...,q \\
&j = 1,2,...,n(j \neq k)
\end{aligned}
\quad \text{(Eq.1)}
$$

ρ is the carbon sink efficiency of marine fisheries; x and y represent the inputs and outputs; m and q are the number of input and output variables; n is the number of decision units; λ is the weight vector; s- and s + represent the slack variables of inputs and outputs, respectively. The decision unit is valid when $\rho \geq 1$, and there is room for improvement when $\rho < 1$.

Indicator system construction

The mariculture area, mariculture production, and aquatic technology extension funds were selected as input indicators, and the amount of carbon sequestered by shellfish and algae mariculture was taken as output indicators, as shown in *Table 1*.

The amount of carbon sequestered by marine fisheries is expressed as the amount of carbon sequestered by shellfish and algae in mariculture, which can be calculated by the dry matter mass method, using the material mass assessment method (Shao et al., 2019) to account for the total amount of carbon sequestered by mariculture, which is composed of the amount of carbon sequestered by shellfish and algae.

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Table 1. *Index system of carbon sink efficiency of marine fisheries*

Indicators	Variables	Variable description
Input indicators	Mariculture area	The area of marine aquaculture shellfish in each region was used to express
	Mariculture production	Using mariculture shellfish production in each region expressed
	Aquatic technology promotion funds	The use of the regions of science and technology promotion operations funding expressed
Output indicators	Marine fisheries carbon sink	The amount of carbon sequestered by marine aquaculture shellfish was used to express

The total carbon sequestered by mariculture is calculated by the formula:

$$
\begin{aligned}
C_s &= C_{sh} + C_{al} \\
C_{sh} &= \sum Q_i(\alpha_{ij} u_{ij} w_{ij} + \alpha_{ih} u_{ih} w_{ih}) \\
C_{al} &= \sum Q_n \alpha_n w_n
\end{aligned}
\quad \text{(Eq.2)}
$$

Cs, Csh and Cal represent total carbon sequestration by mariculture, carbon sequestration by shellfish and carbon sequestration by algae, respectively; Qi is the yield; α is the wet and dry coefficient; u is the mass weight of shell and soft tissue in shellfish; w is the carbon sink coefficient; i and n are shellfish and algae species; j and h are shell and soft tissue.

Data sources

This study was based on mariculture data from nine coastal areas in China during 2012-2021, which were taken from the China Fisheries Statistical Yearbook. Meanwhile, the dry and wet coefficients of algae were determined by drawing on the findings of Gao and McKinley (1994) and other scholars, and the carbon sink coefficients of shellfish and algae, the dry and wet ratios of shells and soft tissues, and the mass weight of shellfish were determined by drawing on the findings of Zhang et al. (2005) and other scholars.

The geographical locations of the nine coastal provinces in China are shown in Graph 1. Guangdong province, one of the largest economies in China’s coastal areas, has taken a series of steps to reduce carbon emissions, including promoting clean energy and improving energy efficiency. Meanwhile, Guangdong is also developing carbon sink projects, such as forest protection and afforestation; Zhejiang Province, an important economic center in China’s coastal areas, is encouraging carbon reduction and energy saving projects; Fujian Province is one of the coastal provinces of China with rich ecological resources.; Liaoning Province, located in northeast China, has rich resources and industrial base. The province strives to reduce carbon emissions in industrial transformation, while also promoting renewable energy and carbon capture projects; Hebei Province faces the Bohai Sea, rich in ecological resources; Shandong Province is an important economic region in eastern China with diversified industrial structure. The province has taken a number of measures in energy structure and energy efficiency to reduce carbon emissions; Guangxi Zhuang Autonomous Region is located in southern China, rich natural resources. The region also has efforts in carbon sequestration, such as absorbing carbon dioxide through forest conservation and afforestation; Hainan Province is a tropical island province of China with superior ecological environment. The province focuses on protecting Marine ecology and

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developing renewable energy to reduce carbon emissions and increase carbon sink; Jiangsu province is an industrial important coastal area in China, with developed manufacturing and modern service industries. The province has taken several measures to improve energy efficiency and develop clean energy.

Graph 1. *Chinese map*

Analysis of the results of carbon sink efficiency in fisheries

According to the results of the super-efficient SBM model, the carbon sink efficiency of marine fisheries in nine coastal provinces of China from 2012 to 2021 is high and is improving. the carbon sink efficiency of marine fisheries in 2021 is 1.96% higher than that in 2012, and the carbon sink efficiency values of nine coastal provinces are

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concentrated around 0.80 during the decade, which still has a lot of room for improvement. From the regional point of view, Fujian Province has the highest carbon sink efficiency of marine fisheries, with an average value of 1. The average value of carbon sink efficiency of marine fisheries in Hainan Province is 0.174, which is 5.7 times lower than that of Fujian Province, and the regional differences between the two places are obvious. The increase in the number of fishery professionals in Fujian Province from 2012, advanced production techniques and management concepts help to improve production efficiency and increase carbon sinks, which may be the reason for this phenomenon. In contrast, the lowest carbon sink efficiency of Hainan's fisheries may be due to the fact that Hainan is a tourist city, the mariculture industry is not well developed, shellfish and algae account for a relatively small proportion, and the development mode of mariculture industry is more crude and the carbon sink is lower, which eventually leads to the lowest carbon sink efficiency of Hainan's marine fisheries (*Table 2*).

Table 2. *Carbon sink efficiency of marine fisheries in nine coastal provinces of China*

Year	Liaoning	Hebei	Shandong	Jiangsu	Zhejiang	Fujian	Guangdong	Guangxi	Hainan	National
2012	1.000	0.964	1.000	0.784	1.000	1.000	0.670	0.838	0.107	0.818
2013	0.957	0.937	1.000	0.772	1.000	1.000	0.682	0.842	0.109	0.811
2014	1.000	0.964	1.000	0.756	1.000	1.000	0.717	0.863	0.091	0.821
2015	1.000	1.000	1.000	0.710	1.000	1.000	0.735	0.877	0.133	0.828
2016	1.000	1.000	1.000	0.690	1.000	1.000	0.742	0.864	0.191	0.832
2017	0.998	1.000	1.000	0.701	1.000	1.000	0.803	0.867	0.355	0.858
2018	1.000	1.000	1.000	0.698	1.000	1.000	0.814	0.861	0.204	0.842
2019	1.000	1.000	0.990	0.715	1.000	1.000	0.816	0.842	0.199	0.840
2020	1.000	1.000	0.985	0.714	1.000	1.000	0.823	0.829	0.176	0.836
2021	1.000	1.000	0.971	0.754	0.935	1.000	0.827	0.841	0.177	0.834
Average value	0.995	0.987	0.995	0.729	0.993	1.000	0.763	0.852	0.174	0.832

Spatial autocorrelation analysis of carbon sink efficiency of marine fisheries

Spatial weight matrix

In this study, the adjacency space weight matrix is constructed based on whether the regions are adjacent or not. When region i and region j are adjacent, the weight is set to 1, otherwise it is set to 0. The adjacency space weight matrix is shown as

$$Wij = \begin{cases} 1 & i \text{ is next to } j \\ 0 & i = j \text{ or } i \text{ is not next to } j \end{cases} \quad \text{(Eq.3)}$$

Spatial autocorrelation method

The spatial autocorrelation test can be used to analyze the spatial correlation characteristics of the carbon sink efficiency of regional marine fisheries. Among them, the global spatial autocorrelation test and the local spatial autocorrelation test are conducted using the global Moran`I index and the local Moran`I index, respectively.

Global Moran`I index

The global Moran`I index is used to test the overall spatial correlation of the carbon sink efficiency of marine fisheries in each region and is calculated as follows:

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$$I = \frac{\sum_{i=1,}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \quad \text{(Eq.4)}$$

x_i, x_j are the carbon sink efficiency values of marine fisheries in the i-th and j-th regions, respectively; w_{ij} is the spatial weight matrix; n is the number of sample regions; $\bar{x}$ and S^2 are the sample means and variances.

Between [-1,1], the value of Moran`I index can indicate the overall spatial correlation degree of marine carbon sink efficiency in each region. When the Moran`I index is greater than 0, there is positive correlation of marine carbon sink efficiency in each region, i.e., high value and high value clustering and low value and low value clustering; when the Moran`I index is less than 0, there is negative spatial autocorrelation of marine carbon sink efficiency in each region, i.e., high value and low value clustering; when the Moran`I index is equal to 0, there is no spatial autocorrelation of marine fisheries carbon sink efficiency in each region.

Local Moran`I index

The local Moran'I index can be used to examine the degree of spatial variation in the carbon sink efficiency of marine fisheries in different regions. It can reflect the type of spatial aggregation of carbon sink efficiency of marine fisheries in a certain region, and the scatter plot of local Moran'I index can be used to show the aggregation characteristics of carbon sink efficiency in each region more visually. The index is calculated by the formula:

$$I = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x}) \quad \text{(Eq.5)}$$

Analysis of spatial autocorrelation results

Analysis of global Moran`I index results

Figure 1 shows the results of the global Moran`I index of the carbon sink efficiency of marine fisheries measured by using the neighboring spatial weight matrix. The results show that the carbon sink efficiency of marine fisheries shows a significant positive spatial correlation from 2012 to 2021, with the clustering of efficient and inefficient areas respectively, and the "Matthew effect". In addition, the global Moran`I index increased during the study period, indicating that the spatial clustering of areas with similar carbon sink efficiency in marine fisheries gradually increased.

Local Moran`I index scatter plot

Figure 2 shows the local Moran's I scatter plot of the carbon sink efficiency of marine fisheries in China in 2021, with the four quadrants representing "HH", "LH", "LL The four quadrants represent the four spatial correlation patterns of "HH", "LH", "LL" and "HL". As can be seen from *Figure 2,* in the first quadrant are Hebei, Liaoning, Zhejiang, Shandong and Fujian, which have more developed marine fisheries and more advanced farming patterns and technologies, forming a jointly promoted

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spatial agglomeration, and belong to high-high agglomeration (HH); in the second quadrant is only Jiangsu province, which belongs to low-high agglomeration (LH); in the third quadrant are Hainan and Guangdong province, which have limited potential for fishery carbon sinks compared to the other two provinces. In the third quadrant, Hainan and Guangdong provinces have limited potential for fishery carbon sinks and belong to low-low agglomeration (LL); in the fourth quadrant, only Guangxi province belongs to high-low agglomeration (HL). The coastal provinces are mainly concentrated in the first and third quadrants, and the areas with high and low carbon sink efficiency of marine fisheries form “highland areas” and “lowland areas” respectively, showing a group distribution and significant clustering effect.

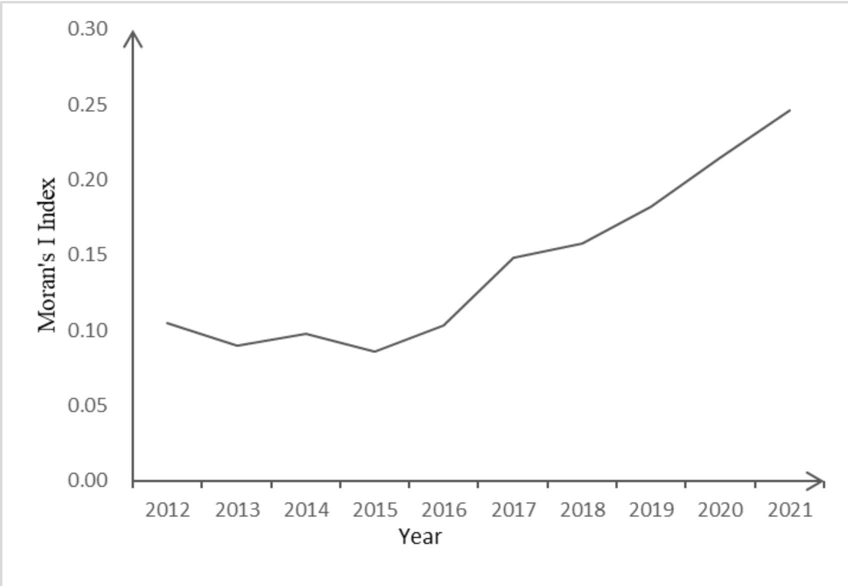

Figure 1. *Moran’s I index of carbon sink efficiency of China’s marine fisheries, 2012-2021*

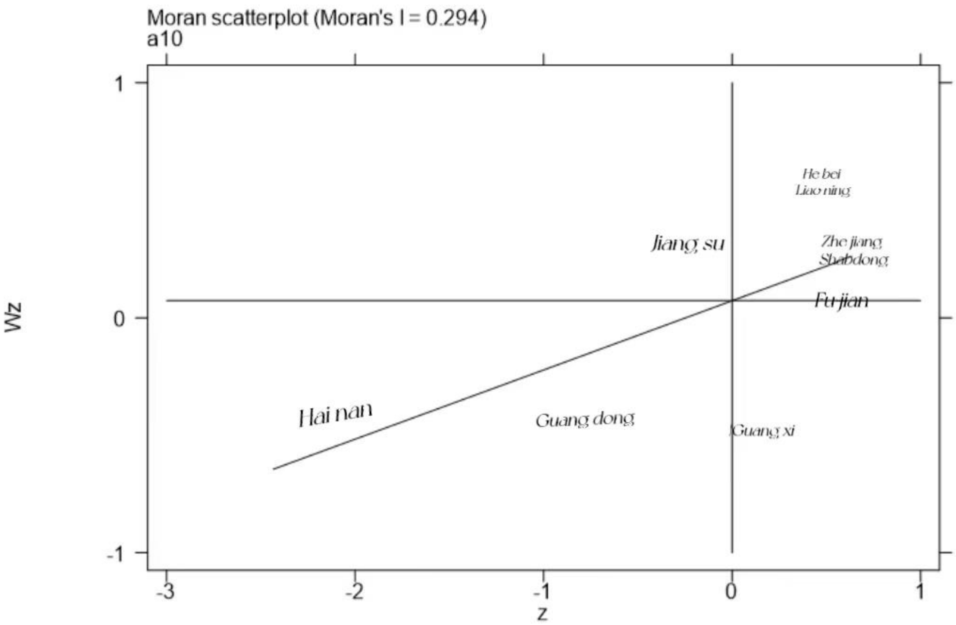

Figure 2. *Local Moran scatter plot of carbon sink efficiency of China’s marine fisheries in 2021*

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Analysis of the spillover effect of carbon sink efficiency of marine fisheries

Model construction

Common spatial econometric models include spatial lag model (SLM), spatial error model (SEM), and spatial Durbin model (SDM). Among them, the spatial lag model and spatial error model consider the spatial spillover effects of the explanatory and explanatory variables, respectively. The spatial Durbin model, on the other hand, considers both effects and can analyze the spatial effects more comprehensively. In addition, to consider the time inertia of variable changes, this study introduces the time lag term of the carbon sink efficiency of marine fisheries into the model and constructs a dynamic spatial Durbin model.

$$CE_{it} = \lambda CE_{i,t-1} + \rho WCE_{it} + \beta_1 X_{it} + \beta_2 WX_{it} + u_i + v_t + \delta_{it} \quad \text{(Eq.6)}$$

where: i represents region; t represents time; CE_{it} is the carbon sink efficiency of marine fisheries; $CE_{t,t-1}$ is the time lagged term of carbon sink efficiency of marine fisheries; W is the spatial weight matrix; X_{it} is the explanatory variable; u_i is the region fixed effect; v_t is the time fixed effect; δ_{it} is the random error term.

Variable selection and data description

Explained variables

Marine fisheries carbon sink efficiency (CE): expressed by the carbon sink efficiency value of marine fisheries measured by the super-efficiency model in the previous section.

Explanatory variables

The following variables were selected with reference to the research of Zhang et al. (2020):

(1) Marine fisheries labor input (LI): the number of professional marine fisheries employees in each region is used to express. An increase in the number of fishery employees can improve production efficiency, provide more advanced concepts and technologies for mariculture, which is beneficial for increasing the production of carbon sink organisms such as shellfish and algae, and help promote the efficiency of carbon sink in marine fisheries.

(2) Marine fishery machinery power input (PI): the total fuel power of farmed fishing vessels in each region is used to express. The higher the total fuel power, the higher the intermediate consumption of fishery, the higher the pollution level, and the impact on the carbon sink efficiency of marine fisheries.

(3) Economic scale (ES): the total economic output value of mariculture reflects the scale of different regions. However, the larger the economic scale, inputs such as bait and fishing medicine lead to environmental pollution of waters and have a negative impact on the growth of shellfish and algae, thus reducing the carbon sink efficiency of marine fisheries.

(4) Economic growth (EG): the per capita income of residents in each region is used to express. The income level is mainly reflected in the living and consumption level of residents. The increase of income level can promote the technological innovation of mariculture industry, which is conducive to the improvement of resource utilization efficiency, and then will have an impact on the efficiency of marine fisheries carbon sink.

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(5) Fishery disaster (FD): marine fishery disaster farming area is used to express. Disasters affect the area of marine fishery culture, thus reducing the production of shellfish and algae, which can negatively affect the carbon sink efficiency of marine fisheries.

Descriptive statistics of data sources and variables

Based on the data from the China Fisheries Statistical Yearbook, we obtained data on the number of people employed in marine fisheries and the total fuel power of farmed fishing vessels. *Table 3* shows the results of descriptive statistics for these variables.

Table 3. *Descriptive statistics of the variables*

Variables	Symbols	Average value	Standard deviation	Minimum value	Maximum value
Carbon sink efficiency in fisheries	CE	0.832	0.258	0.091	1.000
Fishermen	LI	13.363	0.679	11.344	14.214
Farming fishing boat power	PI	12.752	1.992	5.451	15.167
Total economic value of mariculture	ES	14.799	0.789	13.403	16.188
Disposable income per inhabitant	EG	10.185	0.332	9.445	10.960
Affected farming area	FD	9.631	1.599	5.371	11.676

Analysis and discussion of the empirical results

Spatial econometric model testing

After performing LM, Wald, Hausman and LR tests, the results in *Table 4* show that: the LM-lag and Robust LM-lag of the spatial lag model are significant, while the Robust LM-error of the spatial error model is not significant, so the spatial lag model is superior; the Wald test shows that the spatial Durbin model does not degenerate into a spatial lag model or Spatial error model; Hausman test results reject the original hypothesis of random effects, so fixed effects should be selected; LR test shows that both spatial fixed effects and time fixed effects are significant. Therefore, the dual fixed spatial Durbin model is finally selected in this thesis.

Table 4. *Formal and effect tests of the spatial econometric model*

Inspection type	Inspection method	Test items	Statistical values	P-value
Formal inspection	LM	LM-error	42.02***	0.000
		LM-lag	51.856***	0.000
		Robust LM-error	0.796	0.372
		Robust LM-lag	10.632***	0.001
	Wald	Wald-error	156.35***	0.002
		Wald-lag	170.23	0.001
Effectiveness test	Hausman	Random effects	298.35***	0.000
	LR	Spatial effects	28.71***	0.000
		Time effect	35.97***	0.000

*, **, *** represent significant at the 10%, 5% and 1% levels, respectively, the same below

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Spatial Durbin model regression results analysis

As can be seen from *Table 5*, the spatial autoregressive coefficient rho is 0.126 and is significantly positive at the 1% level, indicating that there is a significant positive spatial spillover effect of the carbon sink efficiency of marine fisheries in this region on the carbon sink efficiency of marine fisheries in neighboring regions, i.e., the carbon sink efficiency of marine fisheries in neighboring provinces will have a positive impact on the carbon sink efficiency of marine fisheries in this province, while the carbon sink efficiency of marine fisheries in this province will also have a positive impact on the carbon sink efficiency of neighboring At the same time, the efficiency of marine fisheries carbon sinks in the province will also have a positive impact on the efficiency of marine fisheries carbon sinks in the neighboring provinces. All the regions are “prosperous together, and lose together”.

The spatial autoregressive coefficient of the gross output value of mariculture economy is 0.547, which is significantly positive at the 10% level, and the regression coefficient of per capita income of residents is 0.081, which is significantly positive at the 1% level, while other factors are not significant, indicating that the gross output value of mariculture economy and per capita income of residents have positive effects on the carbon sink efficiency of marine fisheries. The increase of the gross economic output value of mariculture and the carbon sink efficiency of marine fisheries have a direct relationship, and the increase of the gross economic output value of mariculture will promote the carbon sink efficiency of marine fisheries significantly; the increase of the per capita income of residents can enable marine fisheries to obtain larger output with less production factor input and realize the improvement of the carbon sink efficiency of marine fisheries.

Table 5. *SDM model regression results*

Variables	SDM	Spatial	Variance
lnLI	-0.095 (0.15)		
lnPI	-0.006 (0.38)		
lnES	0.547* (0.08)		
lnEG	0.018*** (0.00)		
lnFD	-0.004 (0.67)		
rho		0.126*** (0.00)	
sigma2_e			0.001*** (0.00)

Analysis of spatial spillover effects

Table 6 shows the decomposition results of the spatial Durbin effect obtained by referring to the LeSage and Pacebias matrix method decomposition, including the direct, indirect and total effects of each explanatory variable on the carbon sink efficiency of marine fisheries.

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***Table 6.** Decomposition results of spatial spillover effects of carbon sink efficiency of marine fisheries*

Variables	Direct	Indirect	Total
lnLI	0.119**	0.15	0.269
lnPI	-0.025*	0.006	-0.031
LnES	-0.738***	-1.171**	-1.909***
lnEG	0.046**	0.018	0.064
lnFD	-0.088***	-0.109***	-0.197***

In terms of direct effects, the number of fishermen, the power of fishing vessels, the economic output value of mariculture, the per capita disposable income of residents and the area affected by disasters all have significant effects on the carbon sink efficiency of marine fisheries in this region. Among them, the number of fishery workers and per capita disposable income have significant positive effects on the carbon sink efficiency of marine fisheries in this region, while the total economic output value of mariculture, the power of fishery vessels and the area of affected fishery have significant negative effects on the carbon sink efficiency of marine fisheries in this region. The increase in the number of fishery employees can make more advanced ideas and advanced technologies introduced into the marine fishery field, reduce the level of fishery pollution and realize the improvement of marine fishery carbon sink efficiency. The higher the level of per capita income of residents reflects the higher economic level, the better the level of fishery development, the higher the economic output value of shellfish and algae, and the more it can promote the improvement of carbon sink efficiency of marine fisheries. The impact of the total economic output value of mariculture on the carbon sink efficiency of marine fisheries is negative, probably because the total economic output value of mariculture mainly comes from fish, shrimps and crabs and other species with high economic value, while the production value of shellfish and algae is relatively small, and at the same time, the larger the total economic output value of mariculture, the greater the input of bait and fishing medicine leads to the pollution of the water environment, which is unfavorable to the growth of shellfish and algae and cannot achieve the carbon sink efficiency of marine fisheries. The higher the power of aquaculture vessels, the higher the power of aquaculture vessels. The higher the power of aquaculture vessels, the greater the intermediate consumption of marine fisheries, the more carbon dioxide greenhouse gases are released, and the degree of fisheries pollution increases, which is not conducive to the improvement of carbon sink efficiency of marine fisheries. The larger the affected aquaculture area makes the aquaculture area of shellfish reduce, and at the same time the yield of shellfish will be affected, which directly leads to the reduction of the carbon sink efficiency of marine fisheries.

In terms of spatial spillover effects, the number of fishery employees, the power of farmed fishing vessels and the per capita disposable income of residents have positive spatial spillover effects on the carbon sink efficiency of marine fisheries in neighboring areas. The total economic output value of mariculture and the affected culture area have a significant negative spatial spillover effect on the carbon sink efficiency of marine fisheries in neighboring areas. The increase in the number of fishermen can produce a “spillover effect” and promote the training of personnel and the introduction of advanced technology in the neighboring areas, thus promoting the production of

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shellfish and algae culture and the improvement of the carbon sink efficiency of marine fisheries. The increase in the power of fishing vessels in the region will increase the pollution level of the fisheries in the region, compared with the decrease in the pollution level in the neighboring regions, which will improve the carbon sink efficiency of marine fisheries in the neighboring regions. The increase in per capita disposable income of residents will spread the economic benefits of the region to neighboring areas, so that neighboring areas can optimize the layout of production, which will lead to the improvement of marine fisheries carbon sink efficiency. The affected farming area will have an impact on neighboring areas through factor flow and policy influence, which is not conducive to the improvement of shellfish production, and then affects the improvement of marine fisheries carbon sink efficiency. The growth of gross economic output value of marine fisheries may lead to the inflow of factors such as capital and labor from neighboring areas, which may compete for resources used for shellfish culture in neighboring areas, thus unfavorable to the growth of shellfish production in neighboring areas and the improvement of carbon sink efficiency of fisheries.

Conclusion and policy recommendations

Based on the measurement and spatial autocorrelation analysis of the carbon sink efficiency of marine fisheries in nine coastal provinces of China from 2012 to 2021, this study uses the spatial Durbin model to analyze the influencing factors and spatial spillover effects on the carbon sink efficiency of marine fisheries, and obtains the following conclusions: from the overall perspective, the carbon sink efficiency of marine fisheries in China is high and on the rise, with significant regional differences; from the global perspective, there is a significant spatial positive correlation between regions and the agglomeration effect. From the direct effect, the number of fishery workers and the per capita disposable income of residents have a positive effect on the carbon sink efficiency of marine fisheries, while the total economic output value of mariculture, the power of fishery vessels and the affected area have a negative effect on the carbon sink efficiency of marine fisheries; from the spatial effect, the number of fishery workers, the power of fishery vessels and the per capita disposable income of residents have a positive effect on the carbon sink efficiency of marine fisheries. In terms of spatial effects, the number of fishery workers, the power of fishery vessels and the area of affected fishery have positive spatial spillover effects, while the total economic output value of mariculture and the area of affected fishery have negative spatial spillover effects.

In response to these findings, this study makes the following recommendations:

(1) There are significant spatial correlations and spillover effects in the carbon sink efficiency of marine fisheries, so when formulating policies, we should take into full consideration the resources, policies and economic development levels of neighboring regions and other elements. Through the corresponding comprehensive marine spatial planning to carry out comprehensive coordination, accelerate the spatial layout and structural adjustment in the marine aquaculture industry, promote the implementation of policies such as spatial control of marine aquaculture and total control of pollutants, and promote the formation of a comprehensive management model and control policies for marine aquaculture that are compatible with the high-quality development of the marine economy in the new era, so as to meet the requirements of the high-quality development

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of the marine economy in the new era and achieve The "mountain, water, forest, lake, grass and sea" life community of the system of governance.

(2) To address the positive spillover effect of the number of fishery employees on the efficiency of carbon sinks in marine fisheries, strengthen professional education and training for farming personnel engaged in carbon sink fisheries, comprehensively improve their comprehensive quality, ensure sufficient labor required for carbon sink fisheries farming, encourage enterprises to establish long-term and stable cooperative relationships with sea-related universities, jointly carry out cultivation of carbon sink fisheries professionals, provide them with knowledge reserves and practical exercises platform, and combine human capital in mariculture input factors with capital factors for resource allocation to achieve maximum output.

(3) The state should strengthen support for the aquaculture industry, increase funding for scientific research and programs, and should especially strengthen support for the carbon sink aquaculture industry for shellfish and seaweed to promote the development of the aquaculture industry and the level of production processes. All regions should strengthen technical exchanges, establish a platform for technical research and development of new species of carbon sink aquaculture, continuously increase the proportion of investment in carbon sink aquaculture science and technology, focus on innovation in carbon sink aquaculture science and technology, and improve the level of research on new species of aquaculture and aquatic disease prevention and control technology in order to enhance the output value of carbon sink aquaculture. To stimulate the enthusiasm of marine carbon sink fishery operators, turn marine carbon sink fishery into a promising industry and realize the goal of rural revitalization strategy of "strong fishery, beautiful fishing village and rich fishermen".

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REFERENCES

[1] Cao, H., Fang, Z. (2022): Green efficiency assessment of marine fisheries based on the principle of material balance. – Statistics and Decision Making 38(04): 106-111.

[2] Cerrato, R. M., Caron, D. A., Lonsdale, D. J., et al. (2004): Effect of the northern quahog Mercenaria mercenaria on the development of blooms of the brown tide alga Aureococcus anophagefferens. – Marine Ecology Progress Series 281: 93-108.

[3] Cheng, N., Chen, C. (2021): Ocean carbon sink, carbon tax and green technology: a combination strategy to achieve the goal of "double carbon". – Journal of Shandong University (Philosophy and Social Science Edition) 249(06): 150-161.

[4] Fay, R. A., McKinley, A. G. (2021): Observed regional fluxes to constrain modeled estimates of the ocean carbon sink. – Geophysical Research Letters 48(20).

[5] Gao, K., Mckinley, K. R. (1994): Use of marine biomass production and CO2 remediation: a review. – Journal of Applied Phycology 6(1): 45-60.

[6] He, Y. X., Zhang, F. X. (2023): A game study on the implementation of marine carbon sink fisheries in the context of carbon neutrality—analysis of the tripartite behavior of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_001015

fishery practitioners, research institutions, and the government. – Marine Policy 147:105365.

[7] Huguenin, J. E., Rothwell, G. N. (1979): The problems, economic potentials and system design of large future tropical marine fish cage systems. – Journal of the World Aquaculture Society 10(1-4): 162-181.

[8] Ji, J. Y., Wang, P. P. (2016): Study on carbon sink decomposition of mariculture shellfish--based on modified Laspeyres index decomposition method. – China Fisheries Economy 34(05): 79-84.

[9] Rodríguez-Martínez, R., Leonard, G.. S., Milner, D. S. et al. (2020): Controlled sampling of ribosomally active protistan diversity in sediment-surface layers identifies putative players in the marine carbon sink. – The ISME Journal 14: 984-998.

[10] Shao, G., Liu, B., Li, C. (2019): Assessment of mariculture carbon sink capacity and its impact effect in major sea areas in China--based on panel data of nine coastal provinces in China. – Journal of Ecology 39(07): 2614-2625.

[11] Tang, Q., Jiang, Z., Mao, Y. (2022): The definition of fishery carbon sink and carbon sink fishery and its related issues. – Progress in Fisheries Science 43(05): 1-7.

[12] Tone, K. (2002): A slacks-based measure of super-efficiency in data envelopment analysis. – European Journal of Operational Research 143(1): 32-41.

[13] Xu, J., Qin, T., Han, L. (2018): Review of research on marine "carbon sink fisheries". Resource Science 40(01): 161-172.

[14] Xu, J., Zhang, J., She, C. (2020): Evaluation of spatial spillover effects of green development of marine carbon sink fisheries. – China Population-Resources and Environment 30(02): 99-110.

[15] Yang, L., Hao, X., Shen, C. et al. (2022): Assessment of carbon sink capacity and potential of China's marine fisheries under carbon neutrality target. – Resource Science 44(04): 716-729.

[16] Yu, L. H., Zheng, S., Gao, Q. (2023): Independent or collaborative management? Regional management strategy for ocean carbon sink trading based on game theory. – Ocean and Coastal Management 235:106484.

[17] Yun, J. M., Jeong, S. J., Gruber, N., et al. (2022): Enhance seasonal amplitude of atmospheric CO2 by the changing Southern Ocean carbon sink. – Science advances 8:41.

[18] Zhang, H., Wang, K., Fan, G. F. et al. (2023): Feedbacks of $CaCO_3$ dissolution effect on ocean carbon sink and seawater acidification: a model study. – Environmental Research Communications 5:021004.

[19] Zhang, J. H., Fang, J. G., Tang, Q. S. (2005): Contribution of shallow sea shellfish aquaculture to the ocean carbon cycle in China. – Advances in Earth Sciences 3: 359-365.

[20] Zhang, X., Zheng, S., Yu, L. (2020): Measurement of green efficiency of marine carbon sink fisheries in China and its spatial spillover effect. – China Rural Economy 10: 91-110.

[21] Zhao, Y., Shan, X., Yang, T., Jin, X., Wei, C. (2022): Contribution of potential carbon sources to the autumn benthic food web in the adjacent waters of Miaodao Islands and thoughts on carbon sink fisheries. – Progress in Fisheries Science 43(05): 132-141.

[22] Zhou, C., Mao, Q., Xu, X., Fang, C., Luo, Y., Li, B. (2016): Preliminary analysis of the carbon sink potential of blue carbon ecosystems in China's coastal zone. – China Science: Life Sciences 46(04): 475-486.

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