The spatial spillover effect of technical efficiency and its influencing factors for China's mariculture — based on the partial differential decomposition of a spatial durbin model in the coastal provinces of China

Ji J.[23]; Sun Q.[2]; Ren W.[1*]; Wang P.[4]

Abstract

Using mariculture data from China's nine coastal provinces from 2003 to 2015, this paper first evaluates the technical efficiency through data envelopment analysis (DEA). Then, this paper analyses the spatial spillover effect of technical efficiency and its influencing factors with a spatial panel Durbin model (SDM). The results indicate that there are obvious regional differences in the technical efficiency of China's mariculture, and there is a great room for improvements in the technical efficiency of most areas. The results evidence a significant positive spatial correlation in the technical efficiency of China's mariculture. The technology promotion factor is beneficial for improving technical efficiency, and at the same time, this factor can produce a positive spatial spillover effect on the surrounding areas. The level of economic development clearly has a positive effect on the technical efficiency of the region, and the surrounding area has a negative spatial spillover effect. Moreover, the labor input has a negative effect on technology efficiency. The negative impact of the degree of disaster on technical efficiency is not significant.

Keywords: Mariculture, China, Technical efficiency, Influencing factors, Spatial spillover effects.

1-Institute of B&R, Qingdao University, Qingdao, China.
2-School of Economics, Ocean University of China, Qingdao, China.
3-Institute of marine development, Ocean University of China, Qingdao, China.
4-College of Economics and Management, China Agricultural University, Beijing, China.
*Corresponding author's Email: qdrenwenhan@163.com

Introduction

In recent years, the rapid development of mariculture has become the main channel for the incremental supply of aquatic products in the world, and developing countries have become the major contributors to the growth of mariculture production (Yang *et al.*, 2004; Campbell and Pauly, 2013). China, as a country with strong mariculture, has obvious advantages in its marine resources. In recent years, the development of China's mariculture has made great progress (Li *et al.*, 2017; Sun *et al.*, 2018). However, the space for China's mariculture development is also become increasingly constrained (Wang and Ji, 2017). On the one hand, coastal beaches are requisitioned, resulting in a large reduction in the area of mariculture. On the other hand, the development of industrialization and the deterioration of the water environment have resulted in a further reduction in high-quality breeding waters (Liang *et al*., 2018). Therefore, under the current conditions, determining how to continuously improve the technical efficiency of mariculture and increase mariculture output has become very important. Furthermore, with the increasing communication among regions, there has been a spatial spillover effect of technical efficiency in inter-regional industries and a spatial interaction among the factors affecting efficiency levels (Zhao *et al*., 2017a; Li *et al*., 2018), therefore, the spatial spillover effect must be considered when analysing the technical efficiency of mariculture and its influencing factors,

which is of great significance to the coordinated development of regional efficiency of China's mariculture.

Many scholars have studied the efficiency of aquaculture. Based on the Cobb-Douglas production function, Karagiannis *et al.* (2000) and Dey *et al.* (2000) calculated the production efficiency of the Greek perch and snapper and the technical efficiency of tilapia farming in the Philippines, respectively. Singh (2008) used the stochastic frontier approach (SFA) method to evaluate the economic efficiency of fish production in the southern region of Tripura and decomposed it into pure technical efficiency and allocated efficiency. Moreover, some scholars have realized regional differences in the efficiency of aquaculture. Zhang *et al.* (2014) used DEA and the Malmquist index to evaluate the efficiency of aquaculture based on data from China's twenty-nine provinces from 2006 to 2012. Due to the regional imbalance in the efficiency of aquaculture, some scholars began to study the main factors affecting this efficiency. Cinemre *et al*. (2006) used the DEA method to calculate technical efficiency, allocated efficiency and cost efficiency of the Tilapia culture industry in the Black Sea region in Turkey. In another study, Asche *et al.* (2009) calculated technical efficiency and analysed the factors (including experience, education level, capital intensity, and scale) contributing to the technical efficiency of salmon in Norway. Wang (2013) studied the factors affecting aquaculture efficiency in China by using multiple linear

regression. Furthermore, Ji and Kong (2013) selected five listed companies in the aquaculture industry in China and analysed their efficiency and influencing factors based on the DEA-Tobit two-stage model.

Scholars have conducted many studies on the technical efficiency of aquaculture. However, studies on the spatial spillover effect of technical efficiency and its influencing factors are limited. In addition, most of these studies remain in the field of aquaculture and ignore one of its important branches, mariculture. Based on the above considerations, this study used the DEA method to measure the technical efficiency of China's mariculture and described its spatial-temporal evolution characteristics. Furthermore, based on the relevant literatures (Mansfield *et al*., 1977; Pan *et al*., 2011; Zhao *et al*., 2017 b), this paper uses the spatial Durbin model (SDM) to study the spatial spillover effect of technical efficiency and its influencing factors for China's mariculture.

Materials and methods
Method for calculating mariculture technical efficiency
The parameter method has many disadvantages for the evaluation of efficiency; for example, it is necessary to use an input-output model, which entails many restrictions, and it is easy to make the model incorrectly. However, nonparametric methods have been widely used in the study of mariculture efficiency, which does not require a production function and can

be used to measure the efficiency of multiple inputs and outputs (Yang and Lin, 2016). Therefore, this paper uses the DEA method to measure the technical efficiency of China's mariculture. The technical efficiency of China's mariculture is measured using the input-oriented model based on constant returns to scale (CRS). The basic models are as follows:

$$\begin{cases} Min\left[\theta - \varepsilon(e^T s^+ + \hat{e}^T s^-)\right] \\ s.t. \sum_{j=1}^{n} X_{jm}\lambda_j + s^- = \theta X_0 \\ \sum_{j=1}^{n} Y_{jm}\lambda_j - s^+ = Y_0 \\ \lambda_j \geq 0, s^+ \geq 0, s^- \geq 0 \end{cases}$$

$$(1)$$

The model evaluates the technical efficiency of mariculture in j areas and regards each area as a decision-making unit (j=1, 2, n). Each region (DMU) includes m input variables and r output variables, among which X_{jm} stands for the total amount of m input in region j, Y_{jr} stands for the total amount of r output in region j, λ_j stands for the weighted variables to ensure that all valid points are connected to form the efficiency frontier and to determine the technical efficiency of regional mariculture, and θ represents the mariculture technical efficiency index ($0<\theta\leq1$). The greater the θ value, the higher efficiency is; $\theta=1$ is the optimal efficiency. s^+ is the residual variable, s^- is the relaxation variable, and ε is the non-Archimedean infinitesimal. $e^T = (1, 1, …) \in E^r$ and $e^T = (1, 1, …) \in E^m$ are unit space vectors.

At present, China has 8 coastal provinces, 1 autonomous region and 2 municipalities, namely, Liaoning, Hebei, Shandong, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan, respectively. Due to the serious lack of data in Tianjin and Shanghai, nine of them are selected as the study sample. According to the China Statistical Yearbook, the coastal provinces are divided into three regions: the Bohai region, the Yangtze River Delta and the Pearl River Delta. The Bohai region includes three provinces, namely, Liaoning, Hebei and Shandong. The Yangtze River Delta includes Jiangsu and Zhejiang, and the Pearl River Delta includes four provinces, namely, Fujian, Guangdong, Guangxi and Hainan.

According to the Cobb-Douglas production function, the input variables mainly include labour, land and capital. Adapted from present research (Ji and Zeng, 2017; Zhang *et al.*, 2017), the output includes the total economic output value of mariculture (O_1) and the total production of mariculture (O_2). Labour in mariculture (I_1), mariculture area (I_2) and mariculture fishing boat (I_3) are the input variables. All the data are from the China Fishery Statistical Yearbook and the China Statistical Yearbook (2004-2016).

Method of analysing the influencing factors for technical efficiency

The advantages of using the SDM in this paper are as follows: 1. Elhorst (2014) confirmed that the SDM is more comprehensive and that all spatial analyses should be based on this model.

2. The SDM allows the explanatory variables to be included in the spatial analysis system, which can effectively control variables that may have spatial spillovers, thereby improving the robustness of estimation (Yu *et al.*, 2013).

Based on the traditional panel data model, the spatial weighting matrix was introduced by Lesage and Pace (2009), and the SDM was established as follows:

$$Y = \alpha I_n + \rho WY + \beta X + \theta WX + \varepsilon$$

(2)

Where Y represents the interpreted variable, X represents the explanatory variable, I_n is a unit matrix of n×1 order and n is the number of cross-sections (space unit). Nine provinces are involved in this survey, so n equals 9; α is a constant; and β is the coefficient of the independent variables in the local region. θ explains the coefficients of the independent variables in other areas. ρ is the spatial autoregressive coefficient; ε is a residual term. W is a 9×9 spatial weight matrix. This paper selects the adjacency matrix of the spatial geographic unit. If the region is adjacent, the element is 1; otherwise, it is 0. Then, the matrix is standardized, making the sum of the elements of each line equal to 1.

In this paper, the interpreted variable is technical efficiency, represented by (E); X includes technology promotion funds (T_1), the number of technology promotion agencies (T_2), per capita GDP (G), the degree of disaster (D) and labour input (L). Based on the study reported in this paper, the SDM model

is set as follows:

$$E = \alpha I_n + \rho WE + \beta_1 T_1 + \beta_2 T_2 + \beta_3 G + \beta_4 L + \beta_5 D + \theta_1 WT_1 + \theta_2 WT_2 + \theta_3 WG + \theta_4 WL + \theta_5 WD + \varepsilon$$

(3)

If ρ does not equal zero, then the regression coefficient of each explanatory variable cannot be directly used to explain the degree of influence, resulting in bias in the regression. To solve the coefficient bias problem, Lesage and Pace (2009) proposed the partial differential method of a spatial regression model. With this method, the equation can be rewritten as follows:

$$(I_n - \rho W)Y = \alpha I_n + \beta X + \theta WX + \varepsilon$$

(4)

$$Y = \sum_{r=1}^{k} S_r(W)X_r + V(W)I_n\alpha + V(W)\varepsilon$$

(5)

$$S_r(W) = V(W)(I_n\beta_r + W\theta_r)$$

(6)

$$V(W) = (I_n - \rho)^{-1}$$

(7)

Where k is the number of explanatory variables, β_r is the estimation coefficient of X_r ($r=1, 2, 3, \dots K$), and θ_r is the regression coefficient of WX_r. Therefore, Y_i ($i=1, 2, 3, \dots n$) can be expressed as follows:

$$Y_i = \sum_{r=1}^{k}(S_r(W)_{i1}X_{1r} + S_r(W)_{i2}X_{2r} + \dots + S_r(W)_{in}X_{nr} + V(W)_i I_n\alpha + V(W)_i\varepsilon$$

(8)

According to this formula, the partial derivatives of Y_i to X_{ir} and X_{jr} are as follows:

$$\frac{\partial Y_i}{\partial X_{ir}} = S_r(W)_{ii}$$

(9)

$$\frac{\partial Y_i}{\partial X_{jr}} = S_r(W)_{ij}$$

(10)

Where $S_r(W)_{ii}$ is the influence of X_{ir} (independent variable r in area i) on Y_i (the dependent variable in area i) and is called the direct effect; $S_r(W)_{ij}$ is the influence of X_{jr} (independent variable j in area i) on Y_i (the dependent variable in area i), and it is called the indirect effect.

The technical efficiency of mariculture is mainly affected by research investment, the level of economic development, natural conditions and so on. Based on the relevant research, this paper selects technology promotion funds (Wang and Ji, 2017), technology promotion institution, the number of labour (Gai *et al*., 2013), per capita GDP (Zhang *et al*., 2017) and the degree of disaster as the influencing factors for technical efficiency.

Technology promotion funds reflect the regional government's attention to promoting technology and the status of the technical service system. Therefore, the theoretical hypothesis is that the more funds are extended to technology, the more conducive they are to full implementation of technological levels and to improvement of technological efficiency. Thus, there is a positive correlation between these variables.

Technology promotion institutions, as a fixed place to provide technical advisory services for fishermen, provide useful assistance for fishermen in solving all kinds of the problems and difficulties. At the same time, it is beneficial to promote new technology

and training for fishermen. The preliminary theoretical hypothesis is that the more technical extension institutions are, the more conducive they are to improvement of technical efficiency. Thus, there is a positive correlation between the variables.

Some scholars have found that the labour market in China is distorted and that there is a serious imbalance between the size of the labour force in the agricultural sector and that in the non-agricultural sector, with no tendency for this imbalance to decrease over time. The distortions in the labour market resulted in excessive agricultural labour, while agriculture is a labour-intensive industry with less technological innovation than the non-agricultural sector, which brings significant efficiency loss. Mariculture belongs to the category of agriculture, so the theoretical hypothesis is that labour input and efficiency improvement are negatively correlated. Per capita GDP reflects the level of economic development in the region. In areas with a high level of economic development, scientific research is more developed, human capital is more abundant, and more funds are invested in policy support. Therefore, the theoretical assumption is that per capita GDP and efficiency are positively correlated.

Finally, the level of technical efficiency is also affected by natural disasters. The disaster factors mainly include typhoons, flooding, disease, drought and pollution. The more serious the disaster is, the greater the losses of output and the reduction in technical

efficiency. Therefore, a negative correlation between these variables is postulated. The original data for the above indices are from "the China Fishery Statistical Yearbook" (2004-2016) and "the China Statistical Yearbook" (2004-2016).

Results
The technical efficiency and characteristics of temporal-spatial evolution

This paper used DEA to calculate the technical efficiency of mariculture for China's nine provinces from 2003 to 2015, and the efficiency differences among three regions and nine provinces are analysed as follows.

Table 1 shows the results of comparing the means and rankings of technical efficiency in each province. First of all, based on the static absolute value comparison, Guangxi's technical efficiency ranked first, with a mean technical efficiency of up to 0.9485 during the period 2003-2015. The lowest was observed for Hebei, whose mean technical efficiency was only 0.4973. Second, based on a comparison of the range of dynamic changes in absolute value, the highest increase in technical efficiency was observed for Jiangsu, with an increase of 49.61%. The province with the lowest growth rate was Guangxi, which was at a relatively high level of efficiency. Despite fluctuations in the period, the amplitude of the change was not large, and it was relatively stable.

Table 1: The mean and ranking of technical efficiency in each region.

Region	Province	Mean of technical efficiency	Regional ranking	Growth range
Bohai Region	Hebei	0.4973	9	6.48%
	Liaoning	0.6646	7	11.28%
	Shandong	0.8774	3	34.69%
Yangtze River Delta	Jiangsu	0.6928	6	49.61%
	Zhejiang	0.6440	8	1.83%
	Fujian	0.9413	2	18.48%
Pearl River Delta	Guangdong	0.8535	5	35.69%
	Guangxi	0.9485	1	0
	Hainan	0.8769	4	4.49%

Table 2 shows the average technical efficiency of mariculture in each area from 2003 to 2015. Through a comparison of the technical efficiency of the three zones, the following conclusions can be drawn. First, the overall efficiency of the Pearl River Delta was the highest, followed by the Bohai region. The efficiency of the Yangtze River Delta was the lowest before 2010. After 2010, the technical efficiency of the Yangtze River Delta was higher than that of Bohai. Second, from 2003 to 2015, the average increase in technical efficiency in the three zones was 15.68%. In a comparison of the three regions, the largest increase was in the Yangtze River Delta (40.80%), followed by the Bohai (12.85%) and then the Pearl River Delta with the lowest growth rate (8.81%). Furthermore, to study the trend of efficiency more intuitively, this paper depicts the changes in efficiency over time (Fig. 1) for the Bohai region, Yangtze River Delta and Pearl River Delta. In addition to the decline from 2006 to 2009, the efficiency of mariculture in various regions was rising in most years, which may result from technology progress and improvement in the level of economic development.

Table 2: The average technical efficiency from 2003 to 2015.

| Years	Bohai	Yangtze River Delta	Pearl River Delta	Overall
2003	0.7110	0.6225	0.9190	0.7838
2004	0.7357	0.6125	0.8980	0.7804
2005	0.7373	0.6405	0.8765	0.7777
2006	0.7013	0.7420	0.9015	0.7993
2007	0.6470	0.7305	0.9215	0.7876
2008	0.5443	0.5115	0.8475	0.6718
2009	0.5640	0.5370	0.8295	0.6760
2010	0.5930	0.5875	0.8858	0.7219
2011	0.6637	0.5830	0.8650	0.7352
2012	0.6623	0.6250	0.9005	0.7599
2013	0.7073	0.7915	0.9413	0.8300
2014	0.7680	0.8295	0.9803	0.8760
2015	0.8023	0.8765	1.0000	0.9067
Growth range (%)	12.85	40.80	8.81	15.68
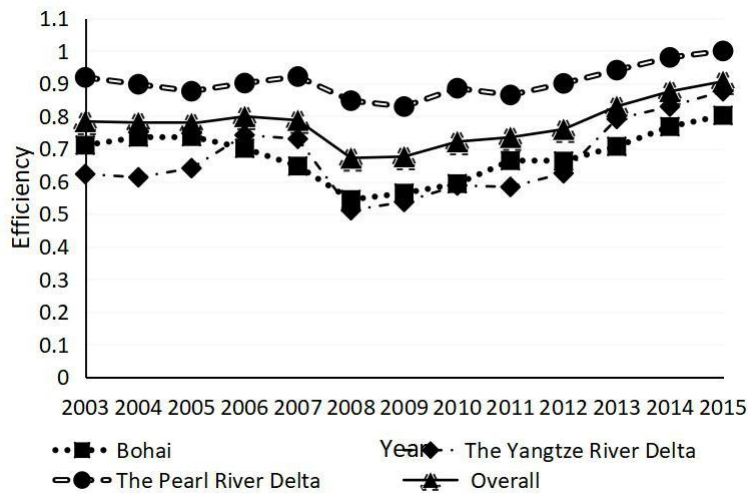
Figure 1: The changes in technical efficiency of mariculture.

The spatial spillover effect of technical efficiency

This paper uses Stata 12.0 to regress the panel data from China's nine coastal provinces from 2003 to 2015, and the SDM results are shown in Table 3.

The Hausman test is used in the table to test the random effects and fixed effects models. The Hausman statistic is equal to -116.03, which is negative and thus supports the use of the random effects model for the original hypothesis.

Table 3: Estimation of the spatial Durbin model.

Variable	Coefficient	Random effect	Fixed effect
con	α	45.178***	
WE	ρ	0.315***	0.050***
T_1	β_1	0.339**	0.292**
T_2	β_2	0.027*	0.021
G	β_3	6.922*	7.729*
L	β_4	-0.197***	-0.217***
D	β_5	-0.082*	-0.069
WT_1	θ_1	0.659**	0.661**
WT_2	θ_2	0.024	0.030
WG	θ_3	-5.813*	-6.748
WL	θ_4	0.060	0.094
WD	θ_5	0.005	-0.003
Hausman		-116.03	

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

In Table 3, coefficient ρ is 0.315, with a 1% level of significance; hence, the technical efficiency of the surrounding area is beneficial for improving the level of local efficiency. This result reveals an obvious geographical spatial dependence or spatial spillover effect of the interpreted variable (technical efficiency of mariculture).

Discussion

Due to the significant spatial correlation among regions, the regression coefficient of independent variables cannot accurately reflect the spatial spillover effect of efficiency. Therefore, the effect must be decomposed into direct or indirect effects.

The effect of technology promotion funds on the technical efficiency of mariculture

The direct and indirect effects of technology promotion funds for technical efficiency are positive, and the coefficients are 0.459 and 1.011, respectively, and are significant at the 5% level. Every additional ¥ 1 million of investment in the region would increase the efficiency by 0.459. In the surrounding area, the efficiency would increase by 1.011. These results show that, on the one hand, the more investment in technology promotion there is in the region, the more perfect the technology service system is (Wang, 2013) and the more that scientific research personnel can guide the training of fishermen, provide more comprehensive and timely consulting services, popularize scientific research and practical techniques for the entire process of prenatal aquaculture production and achieve the combination of theory and practice of scientific research that reduces technical risk, increases output and improves technical efficiency. On the other hand, increasing funds for investing in technology promotion in the surrounding areas is beneficial to enhance regional technical exchanges, contribute to enhancing the technological level of the region, result in technological progress spillover, and achieve common progress and coordinated development among all regions.

The effect of technology promotion agencies on the technical efficiency of mariculture

The direct and indirect effects of the number of technology extension agencies on efficiency are all positive, and the coefficients are 0.032 and 0.043, respectively. The direct effect had a significant level of 5%, but the indirect effect failed to pass the significance test, which indicated that an increase in technology promotion agencies in some regions would increase efficiency by 0.032. This result occurs because the technology promotion agency as a fixed institution had a higher dependence on fishermen. When a new technical problem or difficulty is encountered, it can be consulted and solved in a timely manner to reduce unnecessary losses due to improper handling or inconsistency. Therefore, an increase in the number of technology promotion institutions is beneficial for improving efficiency. The increase in the number of technology extension agencies in the surrounding areas has not significantly improved the efficiency of the region. There was no obvious spatial spillover effect, perhaps because of the fixed nature of the technical promotion institution, which mainly solves the problems encountered by fishermen in the area of the organization. Therefore,

efficiency improvements in other provinces are not significant.

The effect of economic development levels on the technical efficiency of mariculture

The direct effect the coefficient of economic development levels on technical efficiency is 6.476, with a 5% significance level; namely, when the region's per capita GDP increases by ten thousand, the technical efficiency will increase by 6.476% (Zhang *et al.*, 2017). Thus, the economic development level of the region has a strong effect on the improvement of technical efficiency. On the one hand, the higher level of economic development is, the more conducive it is to the improvement of technology levels and the more funds are available for policy support. At the same time, it is beneficial to attract outstanding talent from other areas, which is beneficial to the inflow of human capital, thus promoting the improvement of technical efficiency. On the other hand, the indirect effect of coefficient of the economic development level in surrounding area on the region's technical efficiency is -4.838, with a 10% significance level, showing that the economic development in the surrounding area has caused a negative spillover effect on the improvement of technical efficiency in the region. This effect may occur because the level of economic development is higher in surrounding areas; talent will seek better places with better development, and thus, the outflow of talent from this region to the surrounding area results in

a negative spillover effect. In general, the direct effect is greater than the negative spillover effect, so improving the level of economic development is beneficial for improving the level of technical efficiency.

The effect of labour input on the technical efficiency of mariculture

The direct effect of labour input on technical efficiency is -0.195, with a 1% level of significance; thus, an increase in labour input significantly inhibits the improvement of the technological efficiency of mariculture. This result may occur because China is devoting too much labour to mariculture at the present time, resulting in improper allocation of labour resources, which is not conducive to industrial economic development. At the same time, due to the excessive labour force in mariculture, the lack of technology innovation makes it impossible to play the most important role, resulting in low efficiency, consistent with the theoretical hypothesis. The indirect effect is -0.002, but it is not significant, indicating that the labour input in the surrounding area does not significantly impact the improvement of technical efficiency in the region.

The effect of natural disasters on the technical efficiency of mariculture

The direct and indirect effects of disaster ratio on technical efficiency of mariculture are -0.084 and -0.026, respectively, but the coefficients are not significant at the 10% level. Although the effect is not obvious, it can also be

observed that natural disasters are not conducive to improving the technical efficiency of mariculture (Table 4).

Table 4: Spatial effect decomposition (random effects model).

	Variable	Coefficient	Z Statistic	P
Direct effect	T_1	0.459**	2.38	0.017
	T_2	0.032**	2.02	0.044
	G	6.476**	1.99	0.047
	L	-0.195***	-2.78	0.005
	D	-0.084	-1.16	0.245
Indirect effect	T_1	1.011**	2.5	0.012
	T_2	0.043	0.92	0.357
	G	-4.838*	-1.71	0.088
	L	-0.002	-0.01	0.988
	D	-0.026	-0.15	0.879

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Through the above empirical research, the following conclusions can be obtained. First, there are obvious regional differences in the technical efficiency of China's mariculture, and there is great room for improvements in the technical efficiency of most areas. Second, the results evidence a significant positive spatial correlation in the technical efficiency of China's mariculture. Third, the technology promotion factor is beneficial for improving technical efficiency, and at the same time, this factor can produce a positive spatial spillover effect on the surrounding areas. The level of economic development clearly has a positive effect on the technical efficiency of the region, and the surrounding area has a negative spatial spillover effect. Moreover, the labour input has a negative impact on technology efficiency. The negative impact of the degree of disaster on technical efficiency is not significant. In view of the above conclusions, the following suggestions are proposed:

First, the government should pay attention to technology promotion while considering technological research and development. Only by applying scientific and technologic achievements to the mariculture production process can improve the technical efficiency of mariculture. Second, the government should increase the employment of talent and improve the level of science and technology in order to achieve sustainable development. Third, the government should control the input quantity of mariculture and strengthen the allocation of labour market resources to ensure that it plays the most important role. Fourth, the state should set up a policy support system to establish a mechanism for disaster protection and reduce the losses caused by natural disasters and other force majeure factors.

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