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Evaluation on deep-water cage culture suitability of Changhai County based on GIS

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Evaluation on deep-water cage culture suitability of Changhai County based on GIS

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Abstract. For the scientific planning of deep-water cage culture sea, this paper constructs a comprehensive suitability evaluation index system for deep-water cage culture, uses AHP to determine index weights, and calculates the Comprehensive weighted suitability index. Based on GIS the spatial statistics and analysis of the suitability results were carried out, and the Changhai sea area was taken as an example for case study. The results show that the suitable sea area for deep-water cage culture is 7045.81 km^2, accounting for 65.31% of the total sea area of Changhai county. The most suitable sea area for deep-water cage culture is distributed around Guanglu and Gexian Island, the southern part of Zhangzi Island, the sea area between the Shicheng Island and Wumang Island and the southern part of the Haiyang island, with an area of 1248.38 km^2, accounting for 11.57%. The higher suitability sea area is widely distributed around Zhangzi Island, Haiyang Island, Wumang Island and Xiaochangshan Island, covering an area of 2279.56km^2, accounting for 21.13%. Due to the combined effects of chlorophyll concentration and distance from town areas, it is not suitable for deep-water cage culture area mainly distributed in sea areas far away from land and islands, with an area of 814.81 km^2, accounting for 7.56%. The study can provide reference for the sea planning and sea area management of aquaculture in Changhai county.

1. Introduction
The rigid constraints of the marine environment and the fierce competition from the sea use of various industries have led to the continuous extrusion of marine aquaculture areas [1], especially in coastal waters. Therefore, deep-water cage culture has gradually become an emerging industry in mariculture. Thus the spatial planning of deep-water cage culture has become a necessary research topic. Suitability evaluation is a process of grading for a certain type of development or utilization, based on analyzing its suitability [2], which is often used in planning. Its application is very extensive and gradually becomes an important method for spatial planning.

At present, there are relatively few studies on the suitability evaluation of sea area utilization and marine resource spatial planning. The existing researches include: Yu Yonghai et al. [3] evaluated the suitability of coastal reclamation in Liaoning Province; Wang Fang et al. [4] discussed the development model of coastal beach resources in Jiangsu Province. However, there are few special studies on the suitability evaluation of aquaculture. Liu Yang [5] considered coastal type, ecology, intertidal width, water exchange capacity and sediment conditions in the study of marine functional zoning layout technology and application. Seven indicators, such as seawater quality and disaster conditions, established a relatively simple fishery resource environmental suitability evaluation index system; C. Silva et al. [6] based on GIS from the legal, planning perspective, multi-criteria suitable evaluation of the Chilean Valdivia estuary about the suitability of Pacific oyster culture was studied.

Lin Yong et al. Used chlorophyll a concentration, seawater surface temperature, water depth, transparency, and distance indicators from the evaluation unit to fishing port, town, tourist area and nature reserve to evaluate the suitability of scallop culture in the Changshan Island[7]. Wang Peng et al. Used a comprehensive evaluation method to evaluate the suitability of aquaculture seas in Jinzhou [8]. The research has provided a reference for the sea suitability evaluation and spatial planning for deep-water cage culture.

This paper constructs the suitability evaluation index system for deep-water cage culture and takes Changhai sea area as the case to study the spatial distribution of the suitability of deep-water cage culture based on GIS technology.

2. Study area and data sources

Changhai county is affiliated to Dalian, Liaoning Province, China. Changhai sea area(38°55′47″ N~39°34′10″ N) is located in the northern part of the Yellow Sea. The geographical location is shown in Figure 1. There are 195 islands in Changhai county with a land area of 142 km^2. The sea area is 10,324km^2 with the water depth between 10 and 40 meters.

The data used in this paper mainly comes from "the environmental quality status of coastal waters issued by the Liaoning Provincial Environmental Protection Department (quarterly report)", the Dalian Ocean and Fisheries Bureau released monitoring data of aquaculture companies, and the "Assessment Report on the Use of Sea Areas for Aquaculture in Changhai county, Dalian" And the maritime matrix size classification results obtained by the "908 survey project"[9]. The study area is shown in Figure 1.
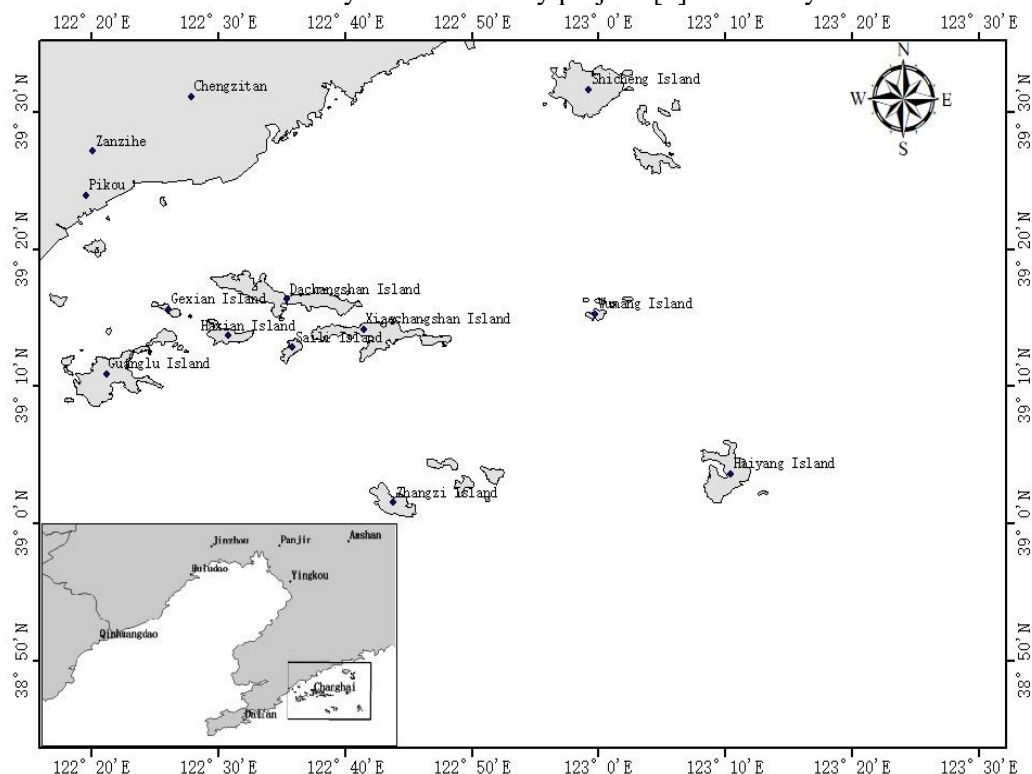

Figure 1. Geographical location of study area.

3. Method

3.1. Deep-water cage culture suitability evaluation index system

The factors affecting the suitability of aquaculture are complex and diverse. This paper selects indicators from the two aspects of natural environment and society. Natural factors include water

physical factors such as water depth, temperature, salinity, hydrodynamic conditions, chemical factors including dissolved oxygen, pH, COD, nutrients, heavy metal concentrations, etc., biological factors including chlorophyll concentration, enemies, etc., substrate factors including the type of sediment, sediment quality, etc.; social factors include functional zoning, compatibility with other sea types, ecological protection requirements, and convenient transportation conditions. According to the guiding principle, difference, data availability and comprehensive construction principle of the evaluation index system, 11 indicators were selected to establish a system framework based on natural factors and social factors. In order to simplify and comprehensively reflect the impact of water quality and sediment quality on marine aquaculture, this paper will use comprehensive pollution index of water quality, eutrophication index and sediment pollution index as evaluation indicators. The index calculation method is presented in the paper "GIS-based analysis of environmental information in the Changhai sea area" [10]. The index system for sea suitability evaluation for deep-water cage culture is constructed, which consists of three levels, which are represented by layers A, B and C. See Figure 2 for details.
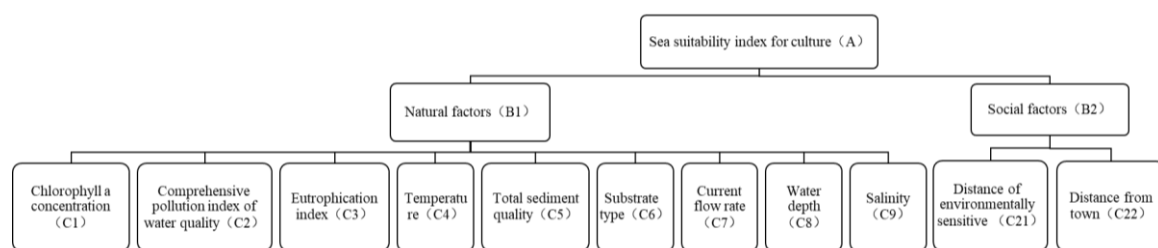

Figure 2. Suitability evaluation index system for deep-water cage culture.

3.2. Suitability evaluation criteria

In the evaluation index system, the units of each indicator are different, and the numerical differences are large, and direct comparison cannot be made. After literature research and expert consultation, the grading standards for each index of deep-water cage culture are formulated. See Table 1 for details. According to the scoring system of the table, the indicator data is standardized, and the raster data of each indicator is reclassified to obtain the standardized value of the index, wherein "5" is the most suitable and "1" is the most inappropriate

Table 1. Seawater suitability assessment index grading standard for deep-water cage culture.

Index	Standard score				
	1	2	3	4	5
Chlorophyll a concentration (mg/m3)	<1	>30	1~10	20~30	10~20
Comprehensive pollution index of water quality	>5	2.6~5	1~2.6	0.6~1	<0.6
Eutrophication index	>9	6~9	3~6	1~3	<1
Temperature(℃)	<8	>20	8~12	16~20	12~16
Total sediment quality	>5	3~5	2~3	1~2	<1
Substrate type	<-8φ	-1~-8φ	>8φ	4~8φ	-1~4φ
Current flow rate(m/s)	<0.2	>1.1	0.8~1.	0.2~0.5	0.5~0.8
Water depth(m)	<5	>50	5~15	15~25	25~50
Salinity	<15	15~20	>30	20~25	25~30
Distance from environmentally sensitive area(km)	<3	3~5	5~7	7~9	>9
Distance from town (km)	>9	7~9	5~7	3~5	<3

3.3. Method of Index weight determination
The numerical value of the evaluation index weight reflects the degree of influence of the indicator in the evaluation index system. The weight of this paper is determined by the analytic hierarchy process.

3.4. Calculation of comprehensive evaluation indexes
This paper uses the weighted comprehensive index method, the specific formula is as follows:

$$SSI = \sum_{i=1}^{n} W_i \times X_i$$

Where: W_i is the weight of the i-th indicator, X_i is the score of the i-th indicator, and n is the number of evaluation indicators.

According to the compatibility of marine functional areas, ports, nature reserves, and waterway areas are not compatible with deep-water cage culture. According to the status of marine functional zoning and sea area use, the suitability of deep-water cage culture is unified in the calculation of suitability index. The index is assigned a value of zero.

4. Results

4.1. Index weights
The analytic hierarchy process is used to determine the index weights. The judgment matrix is constructed first. To construct the judgment matrix, it is necessary to sort the importance of each index. Refer to the Saaty proposal, the value of the matrix elements was assigned, taking the value between 1 and 9 and its reciprocal. According to the suitability evaluation index system, the degree of importance of each index to the upper layer, the A-B, B1-Ci, B2-C2i judgment matrix was established (see Tables 2-4). The λmax of each matrix and the corresponding eigenvector w were calculated, obtaining the weight value of each element.

In order to verify whether the judgment matrices are coordinated, the scale of each indicator is reasonable and logical, and it is necessary to perform consistency check on each judgment matrix. Consistency test was performed using CR=CI/RI, CI is the consistency index, RI is the average random consistency index of the judgment matrix, and CR is the consistency ratio. If CR < 0.1 is satisfied, it is considered to pass the consistency test. The judgment matrix passes the consistency test. The weights of each indicator are calculated as shown in Table 5.

4.2. Natural suitability of deep-water cage culture
According to the scoring standard Table 1 the indicators were standardized and the grid operation was carried out according to the formula of suitability index calculation, which can obtain the suitability of natural factors, social factors suitability and comprehensive suitability for the deep-water cage culture. According to the natural discontinuity method, the suitability level is divided into five grades, and the results of comprehensive evaluation of the suitability of deep-water cage culture are generated by reclassification.

For natural suitability, some unsuitable area for deep-water cage culture are mainly caused by the low concentration of chlorophyll a and high comprehensive pollution index of water quality. In most other sea areas are suitable for the development of deep-water cage culture, but only a few of sea area belongs to a highly suitable sea area. According to the distribution of natural suitability index, the suitability index is the highest in the sea area near Wumang Island, Zhangzi Island, Gexian Island and Guanglu Island, followed by the sea area between Xiaochangshan Island, Wumang Island and Haiyang Island. The suitability of the outer seas of the southeastern part of Changshan Island is higher than that of the northwestern part of the coastal waters. The details are shown in Figure 3.

4.3. Social suitability of deep-water cage culture
For the social suitability, the distance from town will affect the convenience of aquaculture operations. From the perspective of social suitability index distribution, the degree of suitability is centered on land and islands, and is concentrically distributed to the sea. In addition, considering the compatibility

of different sea types, the environmental sensitive areas are not compatible with the aquaculture sea, the suitability index is assigned 0. The distribution of environmentally sensitive areas in the Changhai sea area will affect the suitability of culture in local areas. The spatial distribution of the social suitability index is shown in Figure 4.

4.4. Comprehensive suitability of deep-water cage culture
The comprehensive evaluation index were obtained through weighted calculating natural suitability and social suitability. The distribution of different suitability grades is shown in Figure 5.

Table 2. A-B judgment matrix.

A	B1	B2	W
B1	1	2	0.67
B2	1/2	1	0.33
	RI = 0(n≤2)		

Table 3. B1-Ci judgment matrix.

B1	C1	C2	C3	C4	C5	C6	C7	C8	C9	W
C1	1	2	3	4	9	8	5	6	7	0.31
C2	1/2	1	2	3	8	7	4	5	6	0.22
C3	1/3	1/2	1	2	7	6	3	4	5	0.16
C4	1/4	1/3	1/2	1	6	5	2	3	4	0.11
C5	1/9	1/8	1/7	1/6	1	1/2	1/5	1/4	1/3	0.02
C6	1/8	1/7	1/6	1/5	2	1	1/4	1/3	1/2	0.02
C7	1/5	1/4	1/3	1/2	5	4	1	2	3	0.07
C8	1/6	1/5	1/4	1/3	4	3	1/2	1	2	0.05
C9	1/7	1/6	1/5	1/4	3	2	1/3	1/2	1	0.03

CI = 0.0502 RI = 1.45 CR = 0.0344<0.1

Table 4. B2-C2i judgment matrix.

B2	C21	C22	W
C21	1	2	0.67
C22	1/2	1	0.33
	RI = 0(n≤2)		

Table 5. The weight of evaluation index.

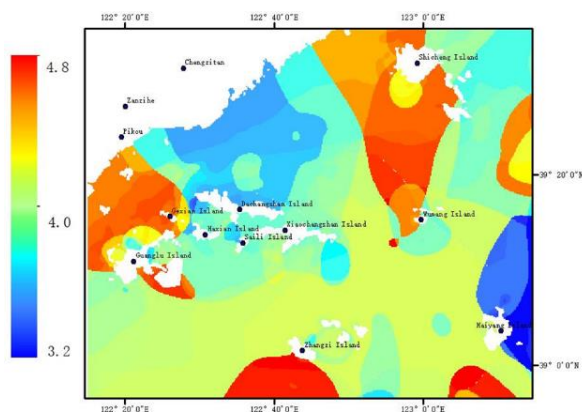|	Criteria layer	Weights	Solution layer	Weights
Suitability index system (A)	Natural factors(B1)	0.67	Chlorophyll a concentration C1	0.21
			Comprehensive pollution index of water quality C2	0.15
			Eutrophication index C3	0.10
			Temperature C4	0.07
			Total sediment quality C5	0.01
			Substrate type C6	0.02
			Current flow rate C7	0.05
			Water depth C8	0.03
			Salinity C9	0.02
	Social factors(B2)	0.33	Distance from environmentally sensitive area C21	0.22
			Distance from town C22	0.11

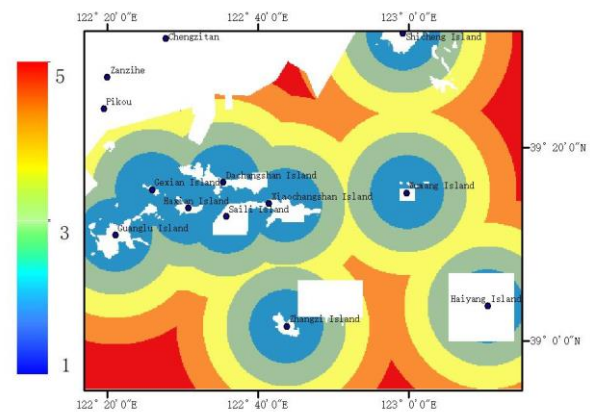**Figure 3.** distribution of natural suitability index.   **Figure 4.** distribution of social suitability index.

The comprehensive evaluation results show that the sea area suitable for the Changhai Sea is 7045.81 km², which accounts for 65.31% of the total sea area of Changhai county. The most suitable for deep-water cage culture is 1248.38 km², accounting for 11.57% of the total area of the sea. It is distributed in the sea area of Guanglu Island and Gexian Island, the southern part of Zhangzi Island, the part of the sea area between Shicheng Island and Wumang Island and the southern part of the Haiyang island. The higher suitability sea area is 2279.56km², accounting for 21.13%, which is distributed in the sea area around Zhangzi Island, Haiyang Island, Wumang Island and Xiaochangshan Island. The water quality conditions in this part of the sea area are slightly worse than the most suitability area, and the water depth is shallow, which reduces the suitability of deep-water cage culture. The medium suitability sea area is 3517.88 km², accounting for 32.61%, which is distributed in most sea areas outside the higher suitability sea area.

The chlorophyll concentration in the sea area is slightly lower, the distance from the town is far, and the nutrient salt concentration is low. The multi-factor comprehensive effect reduces the suitability of deep-water cage culture. The area of lower suitability and low suitability is 786.81 km² and 28 km², respectively, accounting for 7.29% and 0.27%, and it is far from land and islands. The main reasons for the low suitability are: the part of the sea area is far from the island, affecting the transportation of aquatic products; the water depth is too deep, and the chlorophyll concentration is low.
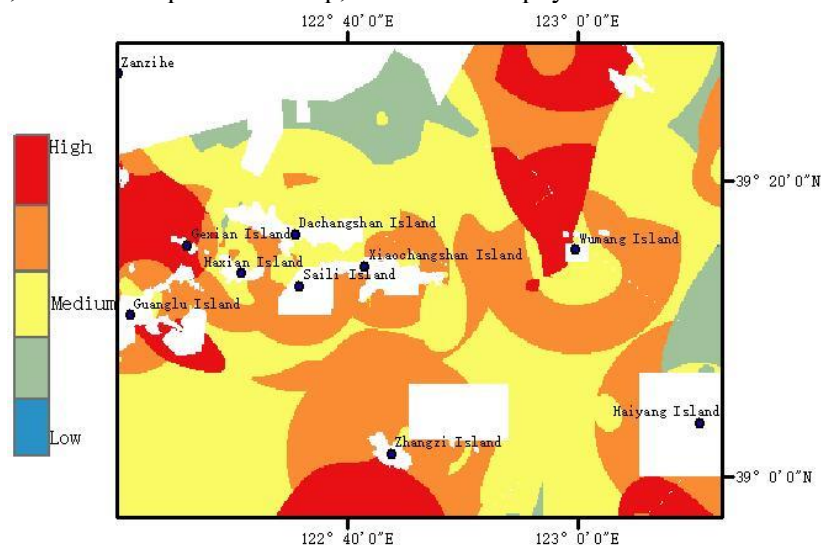

Figure 5. Sea suitability for deep-water cage culture.

5. Conclusions

With the perspective of society and nature, the paper constructs suitability index system for deep-water cage culture including chlorophyll a comprehensive pollution index, sediment type, current velocity, etc. Based on GIS, the suitability for deep-water cage culture in Changhai sea area is caculated and mapped. The evaluation results show that the suitable sea area for deep-water cage culture in the Changhai is 7045.81 km^2, accounting for 65.31% of the total sea area of Changhai county. The high suitability is distributed in the sea area of Guanglu Island and Gexian Island, the southern part of Zhangzi Island, sea area between the Shicheng island and Wumang Island and the southern part of the Haiyang island, with an area of 1248.38 km^2, accounting for 11.57%. The higher suitability sea areas are widely distributed in the sea area around Zhangzi Island, Haiyang Island, Wumang Island and Xiaochangshan Island, covering an area of 2279.56km^2, accounting for 21.13%. The moderately suitable sea area is distributed in most sea areas outside the higher suitability sea area. The low suitable sea area is distributed sea areas far away from land and islands, with an area of 814.81 km^2, accounting for 7.56%. The research can provide reference for management and use of sea space resources to achieve optimal allocation of marine resources.

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