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The Evaluation Method of the Marine Spatial Suitability for Islands from the Perspective of Sustainable Development: A Case Study of the Pingtan Islands

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Abstract: Due to the special geographical location and unique ecosystem of islands, appropriate development and protection of islands is important for promoting the sustainable development of islands. By using the Pingtan Islands as an example, this study constructed a system of suitability evaluation indexes for marine ecological space, marine agricultural production space and marine construction space under the principle of land–sea coordination. To evaluate the spatial suitability of the sea area around islands, a GIS spatial analysis method and a hierarchical analysis method (AHP) were used, which provided useful references for the integration of land and sea and for developing islands sustainably. The research results showed that the suitability area of ecological space in the Pingtan Islands accounted for around 64.3%, the construction space accounted for around 2.1% and the agricultural production space accounted for 33.5%.

Keywords: Pingtan Islands; spatial suitability evaluation; marine spatial planning; sustainable development

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1. Introduction

Since islands are geographically isolated and have a unique ecosystem and fragile natural environment, the high density of exploration and development will be irreversible in the short term [1–3]. Developing and protecting islands and the surrounding sea areas in a sustainable manner requires a rational allocation of spatial resources. Marine spatial planning of the sea area around islands can standardize the protection and utilization of islands and facilitate the coordination between their ecological safety and economic development [4–6]. The evaluation of marine spatial suitability is a critical element of marine spatial planning of the sea area around islands [7,8] since it can provide scientific support. Although it is a comparatively important subject, it has not been adequately studied for islands in China to date; there are still problems with evaluating the marine spatial suitability of islands, such as insufficient theoretical support and a lack of detailed technical information.

Chinese territorial spatial planning is currently in the formation process, and coastal zone planning has become a special planning project with binding and guiding effects on the sea as part of this process. Given that the characteristics of the spatial and ecological environment of islands in spatial planning are particularly important, this study proposed a method for evaluating the marine spatial suitability of islands. It evaluated the spatial suitability of the sea area around the Pingtan Islands in order to provide useful references for land–sea coordination and the sustainable development of island spaces.

2. Literature Review

Due to the special characteristics of islands [9–11], the sea area around islands is different from other sea areas and presents new challenges when it comes to assessing marine spatial suitability. According to the characteristics of islands, a unique evaluation method should be proposed [12–16]. The sustainable development and land–sea coordination fields have been extensively researched by experts and scholars in recent years, including connotations [17,18], strategies [19,20] and frameworks [21–23], as well as relevant evaluation indexes of land–sea coordination or sustainable development [24], which have been applied to coastal cities [25,26], ports [27] and spatial planning [28]. As a special spatial element of land and sea, research on the land–sea integration of islands, particularly inhabited islands, has focused on the opportunities and challenges associated with the land–sea integration [29–31], network governance [32–34] and ecological protection of islands [35,36]. A conceptual theory and framework study of sustainable development has gradually been extended to the measurement of island classification management and the evaluation of marine space suitability. For example, based on sustainable development, Zheng et al. [37] studied the classified development and management of islands from the perspective of ecological suitability. Taking Weizhou Island, Guangxi, as an example, Liu et al. [38] considered the traffic data and stock of ecological assets in a holistic manner and constructed an evaluation index system of ecological assets for land–sea coordination. Liu et al. [39] proposed strategic suggestions for the land–sea coordinated development in the Zhoushan Archipelago New Area in terms of the concepts and connotations of land–sea coordination and sustainable development. Huang et al. [40] analyzed how to carry out the construction of Hainan International Tourism Island while adhering to the development strategies of sustainable development and land–sea coordination. From the perspective of sustainable development, O'Hagan et al. [21] discussed the suitable treatment method for land–sea interaction by analyzing how the EU members that implement the EU marine spatial planning directive considered the land–sea interaction. Taking South Africa as an example, Linda et al. [41] studied how to consider the land and marine ecosystem comprehensively and divided the cross-domain precise scale ecosystem maps in order to promote sustainable development. Schlüter et al. [19] believed that sustainable development in coastal zone governance called for multi-layer governance and new forms of policy integration through a comprehensive analysis of the literature.

In China, "Double evaluation", which is the term given to the evaluation of the resource and environmental carrying capacity and territorial development suitability, is the important basis and prerequisite for the implementation of spatial planning [42]. It is an effective way to promote the sustainable development of space resources. The suitability evaluation of marine space development is an important aspect of resource and environment carrying capacity evaluation and suitability evaluation. Some experts and scholars have done a lot of research on the evaluation of spaces' development suitability, which has had an enlightening effect on the development suitability evaluation of islands. For example, Wang et al. [43] believed that "double evaluation" provides important references for optimizing the spatial structure of the land and controlling the intensity of land development. Jia [44] and Zhou [42] argued that the optimization of the spatial land pattern based on "double evaluation" should consider the scale and regional discrepancies, as well as optimize the technical methods in light of local circumstances.

Some experts and scholars tend to classify areas based on the suitability of development and utilization. For example, Ma et al. [45] analyzed suitability with two typical sea categories, namely, sea for fishery and sea for construction, and conducted an empirical study taking Wenzhou as an example. Liu et al. [46] evaluated the suitability of the development and utilization of uninhabited islands based on the index system of resources–ecological environment–social development framework. Liu et al. [47] constructed the coastal zone "potential-limitation" evaluation index system to evaluate suitability based on environmental profits and losses.

Some scholars evaluated and zoned from the perspective of ecological protection. For example, Li et al. [48] proposed the suitability evaluation method for small-scale marine space development and zonning within the framework of ecosystem services. Tian et al. [49] analyzed the ecological suitability of the habit quality index, biodiversity index and biological vulnerability index. Jiang et al. [50] updated the evaluation system of marine ecology suitability to the complex system of nature–society–economy–ecology. Xiang et al. [51] referred to the ecological suitability of a sea area in terms of the habitat structure, habitat function, economic and social conditions, and use of the sea area.

Some scholars assessed marine space suitability and zones from different aspects, such as ecology and the economy. For example, Ye et al. [52] evaluated the suitability of the exploration and development of uninhabited islands in light of the importance of ecological protection and the feasibility of economic development. Based on a comprehensive assessment and development of ecology–economy–industry, Li et al. [53] proposed the zoning of island exploration and development. To construct the evaluation index system, 12 indexes were selected based on the geographic location, terrain and landforms, and protection and development status. Huang et al. [54] zoned and evaluated island space suitability using GIS. An et al. [55] zoned the functions of the coastal zone according to the space development suitability. Lai et al. [56] constructed the suitability evaluation index system of "ecological, production and living spaces" of Southwest Guangxi and North Bay and zoned the ocean and land into "three spaces".

The above studies have enriched the theoretical connotations and applications of "double evaluation", "suitability evaluation" and "marine spatial suitability evaluation" and have steadily expanded from the land suitability evaluation to the sea and even to islands. Different from the study of the above scholars, more attention was paid to the marine spatial suitability for islands in this research, and a suitability evaluation model was constructed to evaluate the spatial suitability of waters around islands.

3. Date and Methods

3.1. Study Area and Date

The Pingtan Comprehensive Pilot Zone is located in the central coastal region of Fujian Province and west of the northern entrance of the Taiwan Strait (Figure 1). The land area is 371 square kilometers, the sea area is 2873 square kilometers, the mud flats area is 62.93 square kilometers and the coastline area is 447 square kilometers. Known as "a county with thousands of islands", the Pingtan Comprehensive Pilot Zone consists of 126 islands, including Haitan Island and 702 rocks, with an area of 371 square kilometers. With twists and turns along with coastline, there are 283 gulfs and harbors. The main island, namely, Haitan Island, covers an area of 271 square kilometers, which is the 5th largest island in China and the largest in Fujian Province.

Under the territorial spatial planning system, land–sea coordination is the most effective method of resolving conflicts between land and sea in the Pingtan Islands. Besides effectively managing the relationship between the islands' land area and marine space, it also is capable of promoting the efficient use of land and sea resources and optimizing their allocation. In view of the natural resource endowment and characteristics of the sea area around the Pingtan Islands, this research conducted a comprehensive suitability evaluation of the marine space of the waters around the Pingtan Islands with the data from the *Marine Function Delineation of Pingtan Comprehensive Pilot Zone*, *China Marine Statistical Yearbook*, *Bulletin of Marine Ecology and Environment Status of China*, *Environmental Quality Bulletin of China's Coastal Waters*, *Fuzhou Statistical Yearbook*, *Bulletin of Ecological Environment Status in Fuzhou* [57] and the right confirmation data of the sea area in Pingtan.

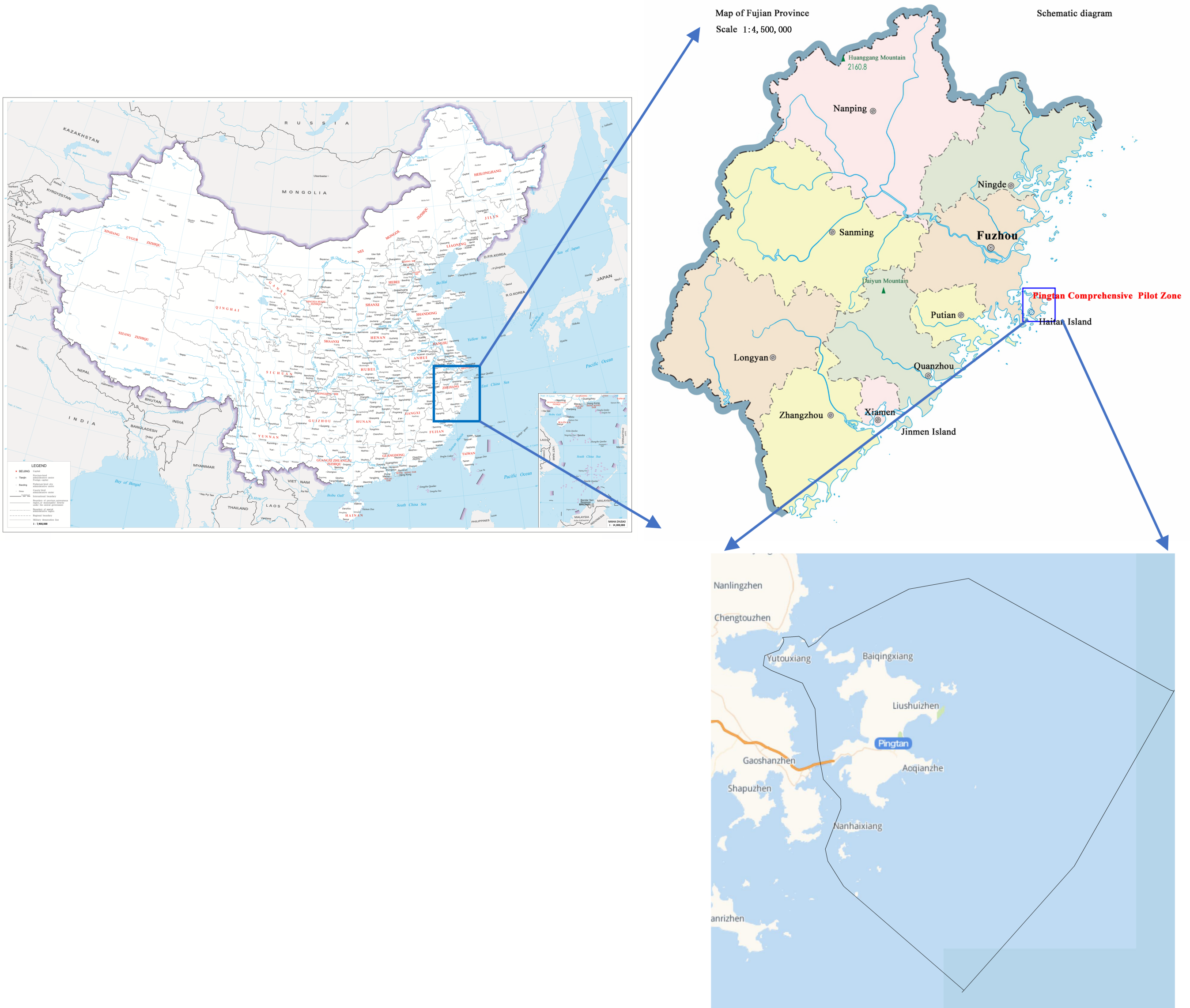

Figure 1. Location map of the Pingtan Comprehensive Pilot Zone.

3.2. Methods

Spatial suitability evaluation for islands refers to the evaluation of the suitability of the sea area around islands for marine ecology, agricultural production and urban construction. Three types of marine spaces are clearly defined, including marine ecological space, marine agricultural production space and marine construction space.

Through the results of the spatial suitability evaluation, an overlay analysis of each layer was carried out, and an appropriate proportion of three types of marine space was determined in light of the requirements of local economic development and development intensity. Meanwhile, a preliminary scheme of three types of marine spaces was outlined using a boundary treatment, the connection between the status quo and planning, cross-regional coordination, and upper and lower coordination. Based on the actual situation, the importance of marine ecology functions and the marine main functional areas, the preliminary scheme was checked to ensure the scientific and reasonable delineation of various spaces. The spatial suitability evaluation method for the sea area around the islands is shown in Figure 2.

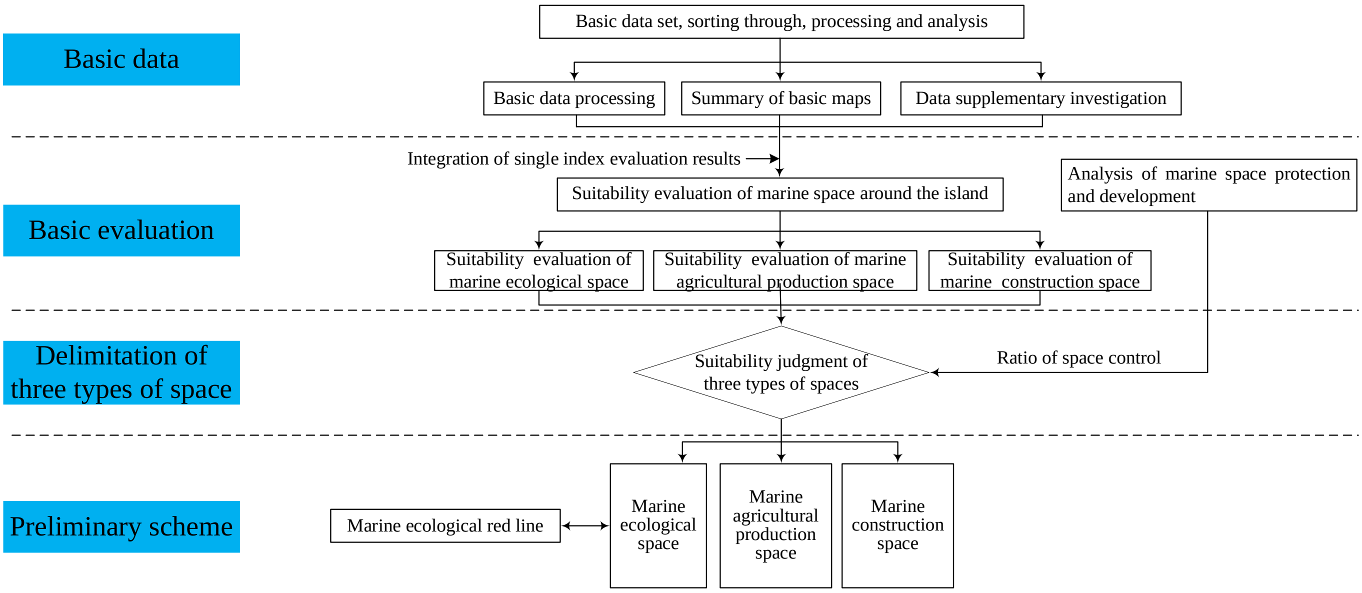

Figure 2. Evaluation methods of the island space suitability.

3.2.1. Classification of the Sea Area Space around the Islands

Based on the planning of marine main functional areas and the background conditions of marine space, the marine space was divided into "two spaces and one red line" for the study of the zoning. Among them, the "two spaces" refers to marine utilization space and marine ecological space, where the marine utilization space includes the marine agricultural production space and marine construction space, while the "one red line" refers to the marine ecological red line.

(1) Marine construction space

Marine construction space refers to the marine space that undertakes the main functions of marine development and construction activities [58–64], such as the development of ports and industries around ports and major infrastructure construction, including the sea space for the construction of ports, channels and anchorages; the sea area for the coastal industry and the coastal town construction; and the sea area for ocean engineering, resource development and energy exploitation.

(2) Marine agricultural production space

A marine agricultural production space is defined as sea areas with a higher level of marine primary productivity and a better-quality marine environment [65]. It is used to provide seafood and pharmaceutical ingredients to marine organisms and is primarily responsible for maintaining fishery stability and developing marine biomedicine. It includes the space for the cultivation and proliferation of marine products [66], the construction of marine ranch and fishery infrastructure, high-quality mariculture and the protection of marine biological resources [67].

(3) Marine ecological space

Marine ecological space refers to an ocean space with marine natural attributes that is carrying out the main functions of ecological services [68,69], ecosystem protection and maintenance [70–76], including the areas defined by the red line of marine ecological protection, marine protected areas, marine tourism, leisure and creation, reconstruction and restoration of the marine resources and environment, and the area for sustainable development.

The red line of marine ecology in China refers to the areas delimited for the mandatory strict protection of prohibited development areas [77,78], important ecological function areas at the national and provincial levels [79], ecologically fragile areas, and sensitive areas that are deemed by various departments and regions to be in need of strict protection and other areas of mandatory and strict protection [80].

3.2.2. Construction of the Spatial Suitability Evaluation Index System

(1) Evaluation indexes and weights

The purpose of this study was to investigate the different attributes and characteristics of marine ecological space, marine agricultural production space and marine construction space from the perspective of marine spatial classification. Meanwhile, it also draws upon the "double evaluation" index system [46], considers the data accessibility and representativeness of the indexes and, finally, selects appropriate evaluation indexes scientifically, as illustrated in Table 1, for the construction of the zoning suitability evaluation index system.

Table 1. Evaluation index system for the suitability of marine spatial planning zoning.

Theme	Criteria	Explanation
Marine ecological suitability (G1)	Marine resources evaluation (G11) Marine environment evaluation (G12)	Resource effect index Water quality
Marine town construction suitability (G2)	Evaluation of marine space resources (G21)	Shoreline development intensity Sea area development intensity
	Marine resources evaluation (G22)	Resource effect index Development effect index
	Dominance of maritime traffic (G23)	Offshore distance
Suitability of marine agricultural production (G3)	Evaluation of marine biological resources (G31) Marine environment evaluation (G32)	Marine biological resources evaluation index Water quality
	Marine resources evaluation (G33)	Resource effect index Development effect index

Considering the type, source and nature of the index data, the AHP method was adopted to determine the index weights. Twenty experts were selected from the marine think tank of the National Marine Data and Information Service based on their authoritativeness and study fields. Among them, 5 experts were in the field of marine management, 5 experts were in the field of marine economy and 10 experts were in the field of spatial planning. In this study, these 20 experts were invited not only to select the primary indexes and finally determine the index system but also to score the secondary indexes with a 1–9 scoring method and check the consistency by Python, with CR lower than 0.1.

$$CI = \frac{\lambda max - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

In the formula, CI is the consistency index, RI is the mean random consistency index, CR is the consistency ratio and n is the judgment matrix order.

(2) Measurement of the index data

1) Marine resources evaluation

The marine resources evaluation indexes (Z) included the resource effect index and the development effect index, which were mainly used to characterize the different levels of comprehensive influence on the marine space resources by different types of sea areas, and its formula was as follows:

$$Z = \alpha P + \beta R \quad (3)$$

where P is the marine resource effect index, R is the development effect index, α is the weight of the marine resource effect index P and β is the weight of development effect index R. The marine resource effect index was evaluated based on the effect of marine development activities in the main functional marine areas for marine space resources. Referring to the technical method in the Monitoring and Early-warning Technical Methods of Resources and Environment Carrying Capacity (Trial) [25], consumption coefficients of different types of functional areas for marine space resources were established, as shown in Table 2. The formula for calculating the marine resource effect index (P) was as follows:

$$P = \frac{\sum_{i=1}^{n} k_i A_i}{S} \tag{4}$$

where n is the number of marine functional area types, k_i is the consumption coefficient of the ith marine functional area, A_i is the area of the ith marine functional area and S is the total area.

Table 2. Consumption coefficients of different types of functional areas for marine space resources [25].

Type of Marine Functional Areas	Consumption Coefficients
Marine areas for industrial and town development	1
Ports and shipping area	0.8
Mineral and energy area	0.6
Agricultural and fishery area	0.6
Area for tourism, leisure and creation	0.4
Area for special utilization	0.2
Marine protected area	0.2
Reserved area	0.2

The development effect index was evaluated based on the area of various sea activities and influence weight to construct the spatial influence coefficients of different sea activities, as shown in Table 3. The formula for the development effect index (R) was as follows:

$$R = \frac{\sum_{i=1}^{n} l_i B_i}{T} \tag{5}$$

where n is the number of marine functional area types, l_i is the consumption coefficient of the ith marine functional area, B_i is the area of the ith marine functional area and T is the total area.

Table 3. Spatial influence coefficients of different sea activities [25].

Primary Sea Use	Secondary Sea Use	Influence Coefficients
Sea area for industrial use	Sea area for shipbuilding	1.0
	Sea area for solid mineral exploitation	0.2
	Sea area for other industries	0.2
Sea area for submarine engineering	Sea area for cable duct	0.6
Sea area for transportation	Sea area for ports	0.8
	Sea area for roads and bridges	0.4
Sea area for tourism and recreation	Sea area for tourism infrastructure	1.0
Special sea use	Sea area for coastal protection engineering	0.1
	Sea area for scientific research and teaching	0.5
Sea area for fisheries	Sea area for open cultivation	0.8
	Sea area for sea enclosing cultivation	0.8
	Sea area for fishery infrastructure	1.0
Sea area for land reclamation engineering	Sea area for land reclamation of town construction	1.0

2) Evaluation of the marine environment

As the carrier of the marine ecosystem, seawater is crucial for maintaining the health of marine ecology [81]. Pollutions caused by seawater eutrophication, oil spills, and seawater exploration and development can be reflected through water quality indexes. The *Bulletin of Marine Ecology and Environment Status of China* reflects the state of the marine ecological environment primarily through water quality. Therefore, the marine environment evaluation index was mainly measured using the sea area water quality, and the data were obtained from the local marine environment monitoring data.

3) Evaluation of the marine space resources

The evaluation of the marine biological resources was characterized by the shoreline and sea area development intensity, and was calculated using the following formula:

$$Q = \frac{\sum_{i=1}^{n} S_i}{S} \tag{6}$$

where n is the number of types of shorelines (sea area), S_i represents the length (area) of the ith developed shoreline (sea area) and S is the total length (area) of shoreline (sea area).

4) Evaluation of the marine biological resources

The evaluation of marine biological resources mainly considered the number of individuals of phytoplankton, zooplankton and benthos, as well as the changes in marine ecological protection objects, and was obtained using the marine biodiversity carrying index and change rate of marine ecological protection objects. The marine biodiversity change index combined the phytoplankton index, zooplankton index and benthos index. Among them, the number of species reflected the species richness of phytoplankton, zooplankton and benthic communities within a unit, the density reflected the total number of organisms per unit volume within a unit, and the species diversity index reflected the distribution of species richness and number of individuals in the biological community. The evaluation index of the marine biological resources (E_1) was calculated by averaging the weight of the single index evaluation results of the phytoplankton index (E_{1-1}), zooplankton index (E_{1-2}) and benthos index (E_{1-3}), and the formula was as follows:

$$E_1 = \left(E_{1-1} + E_{1-2} + E_{1-3}\right)/3 \tag{7}$$

When $E_1 < 1.5$, marine ecology will be overloaded; when $1.5 \leq E_1 < 2.5$, marine ecology will be critically overloaded; when $E_1 \geq 2.5$, the marine ecology will be loadable. The phytoplankton index was calculated with the monitoring data of shallow water type III net phytoplankton in the marine biodiversity/ecological monitoring area as follows:

$$E_{1-1} = \frac{D_1 + R_1}{3} \tag{8}$$

where E_{1-1} is the change in phytoplankton; D_1 and R_1 are the density and the number of species of phytoplankton in the past decade, respectively; and the number of species is the total population of different biological species in the evaluation unit. The density is the average annual biological density of each monitoring station divided by the number of stations in the evaluation unit. The zooplankton index was calculated with the net monitoring data of type I zooplankton in the marine biodiversity or ecological monitoring area as follows:

$$E_{1-2} = \frac{D_2 + R_2}{3} \tag{9}$$

where E_{1-2} is the change in zooplankton, and D_2 and R_2 are the zooplankton density and the changes in the current value and average value of the number of species in the past decade respectively. The benthos index was calculated with the quantitative monitoring data of macrobenthos in the marine biodiversity or ecological monitoring area as follows:

$$E_{1-3} = (D_3 + R_3)/3 \tag{10}$$

where E_{1-3} is the change in benthos, and D_3 and R_3 are the density and number of benthos species and the changes in the current value and average value of species diversity index, respectively. When E_{1-1} or E_{1-2} or E_{1-3} > 50%, the changes are significant, and the value is 1. When 25% < E_{1-1} or E_{1-2} or $E_{1-3} \leq$ 50%, fluctuation appears and the value is 2. When E_{1-1} or E_{1-2} or $E_{1-3} \leq$ 25%, it is largely stable and the value is 3.

5) Dominance of the maritime traffic

Since islands have a small spatial scale, the closest distance from the grid center point in the evaluation unit to the shoreline was taken as a measure of the marine traffic dominance. In addition, the evaluation results were categorized into five levels with the assignments shown in Table 4.

Table 4. Spatial influence coefficients of different sea activities.

Closest Distance to the Shoreline (km)	0–6	6–12	12–18	18–24	24–30	≥20
Assignment	1	0.8	0.6	0.4	0.2	0

3.2.3. Calculation and Classification of the Evaluation Unit

The evaluation unit is the basic spatial unit for the suitability evaluation of spatial development [82]. As the leading method, dominant factor determination was used, supplemented by the superposition method and dynamic grid method [83]. Taking into account the data availability of the evaluation parameters, a reasonable grid cell size was chosen as the basic evaluation cell, and the base map of the target area was divided into 2 km by 2 km grid cells using ArcGIS10.1. In accordance with the suitability evaluation index of marine space zoning, data required in the index system were collected, analyzed and calculated between layers with ArcGIS10.1.

The graphical and attribute data of valuation factors at each index layer were standardized to form a data grid for each evaluation factor layer [84]. Partially, the values at the center of the grid represented the scores of the evaluation unit. According to each index score in the evaluation unit, relevant standardization was carried out using the extremum method in this study. The formula of the extremum method is as follows:

$$B_i = \frac{A_i - \min A_i}{maxA_i - \min A_i} \tag{11}$$

where B_i is the evaluation value of index i; A_i is the actual value; and $maxA_i$ and $\min A_i$ are the upper and lower limits of the actual value, respectively.

By weighting and summing the standardized index scores of each evaluation unit and overlaying the data grid of each layer with the corresponding index weights to calculate, the comprehensive score of the unit and the evaluation result layer were obtained.

The multi-factor comprehensive determination method was used to calculate the score of the evaluation index using the formula below [85]:

$$Y_i = \sum_{k=1}^{n} W_k \times Y_{ik} \tag{12}$$

where Y_i is the comprehensive score of evaluation unit i, W_k is the weight of index k and Y_{ik} is the score of index k in the evaluation unit i.

The natural discontinuity grading method was used in Arcgis for the division of grades in light of the distribution of scores. The grading score for each evaluation unit was used to determine the grading results. Based on local circumstances, the cluster grading was made up of three levels: "high", "medium" and "low". Meanwhile, the marine space with continuous attributes value was divided into several areas with uniform attributes to obtain the evaluation results of regional marine ecology suitability, marine town construction suitability and marine agricultural suitability. The boundary of the merged areas was smoothed and regulated to make the outline of the suitability evaluation result boundary smoother and clearer. At the same time, the vector data were extracted according to the "high", "medium" and "low" suitability levels. The specific calculation process of the spatial suitability evaluation method to form the preliminary scheme for dividing the three types of space is shown in Figure 3.

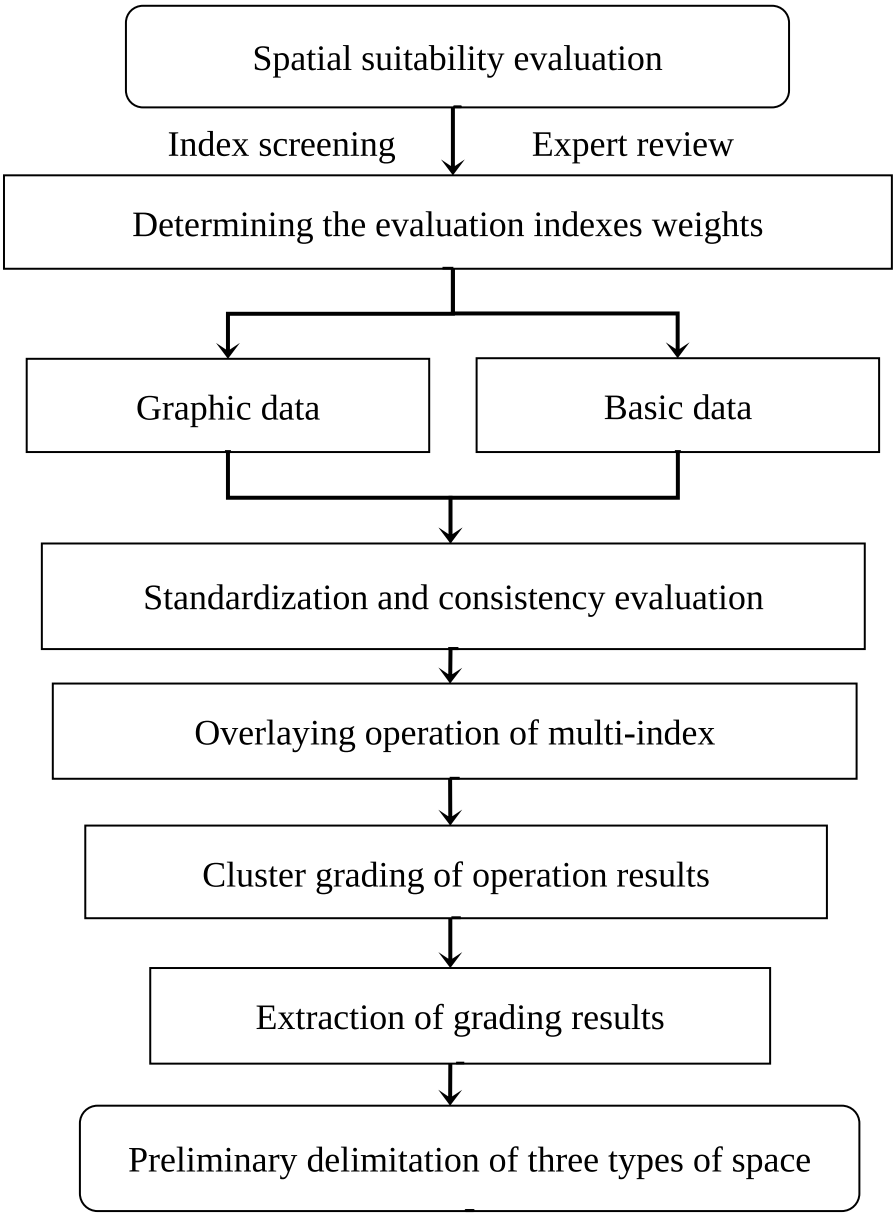

Figure 3. Calculation process of the suitability evaluation.

3.2.4. Determination Method for the Three Types of Space

Based on the analysis of suitability evaluation results of marine space zoning and the relevant research achievements of Gao et al. (2019) [86] and Gao (2018) [87], the zoning method was formed in accordance with the below criteria (Table 5).

(1) In the evaluation results of marine space zoning, only one area with a high degree of suitability will be divided into this type of space. Under the principle of ecological priority, two areas with a high degree of suitability, including one with a high degree of suitability for marine ecology suitability, will be classified into a marine ecological space. Otherwise, it will be classified as a marine agricultural production space according to the priority principle. If all three suitability levels are high, it can be classified as a marine ecological space according to the principle of ecological priority.

(2) For the divided areas above, if the marine ecology suitability or the agriculture and fishery production suitability in the evaluation results of marine space zoning suitability are medium, they will be divided into this type of space. When both are medium, the type of space with low suitability in the main functional orientation can be determined based on the priority of the marine ecological space, marine agricultural production space and marine construction space. As an alternative, the concentration of space types can be determined according to the principle of space concentration. Otherwise, it will be divided into the space type consistent with its main functional orientation according to the principle of implementing the main functional orientation. If all three suitability levels are medium, the area will be divided into the space type consistent with its main functional orientation under the principle of main functional orientation. If all three suitability levels are low, it can be divided into a marine ecological space under the principle of ecological protection priority.

Table 5. Determination criteria for the suitability evaluation of marine space zoning.

Marine Ecological Suitability	Suitability of Marine Agricultural Production	Suitability of Marine Town Construction	Recommended Types
High	*	*	Marine ecological space
Medium	High	*	Marine agricultural production space
Medium	Medium	High	Marine construction space
Medium	Medium	Medium	Marine ecological space
Medium	Medium	Low	Marine ecological space
Medium	Low	High	Marine construction space
Medium	Low	Medium	Marine ecological space
Medium	Low	Low	Marine ecological space
Low	High	*	Marine agricultural production space
Low	Medium	High	Marine construction space
Low	Medium	Medium	Marine agricultural production space
Low	Medium	Low	Marine agricultural production space
Low	Low	High	Marine construction space
Low	Low	Medium	Marine construction space
Low	Low	Low	Marine ecological space

Note: * represents any evaluation result.

4. Results

4.1. Single Evaluation of the Important First-Level Indexes

4.1.1. Evaluation Results for the Marine Resources

(1) According to the characteristics of the marine environment and its natural resources, the status of marine exploration and development, and the strategic demand for environmental protection and economic development, the Pingtan marine functional areas were classified into eight types. Among them are agriculture and fishery areas, port shipping areas, industrial and town sea areas, mineral and energy areas, tourism, leisure and recreational areas, marine protected areas, special utilization areas and reserved areas. Furthermore, there were 31 basic functional areas in total [88].

(2) Based on the judgment of the impact of marine development activities on the marine space resources in the major marine functional areas [89], the marine resource effect index of each unit was evaluated, as shown in Figure 4.

(3) According to the area and influence weights of the secondary sea area exploitation [90], the development effect index of each unit was evaluated and is shown in Figure 5.

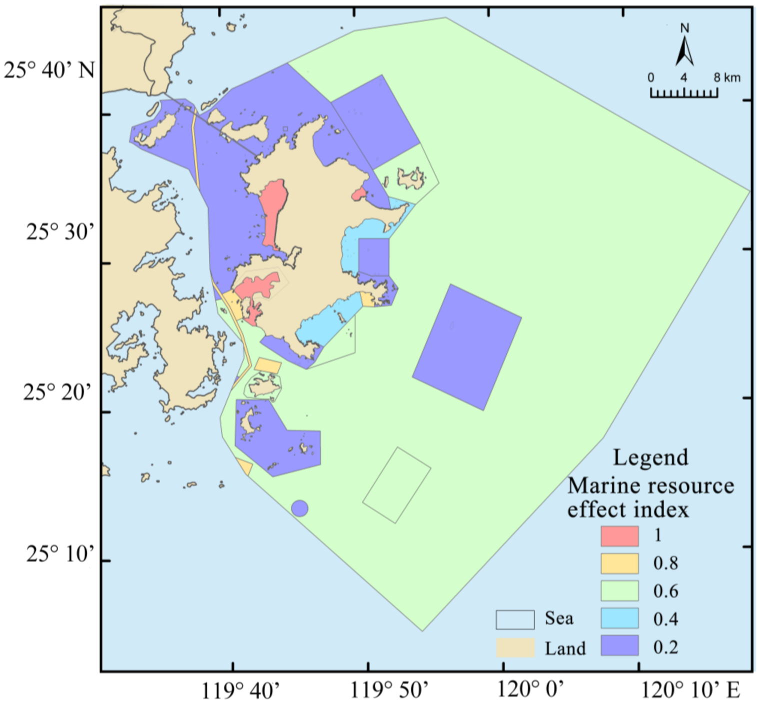

Figure 4. Evaluation results for the marine resource effect indexes.

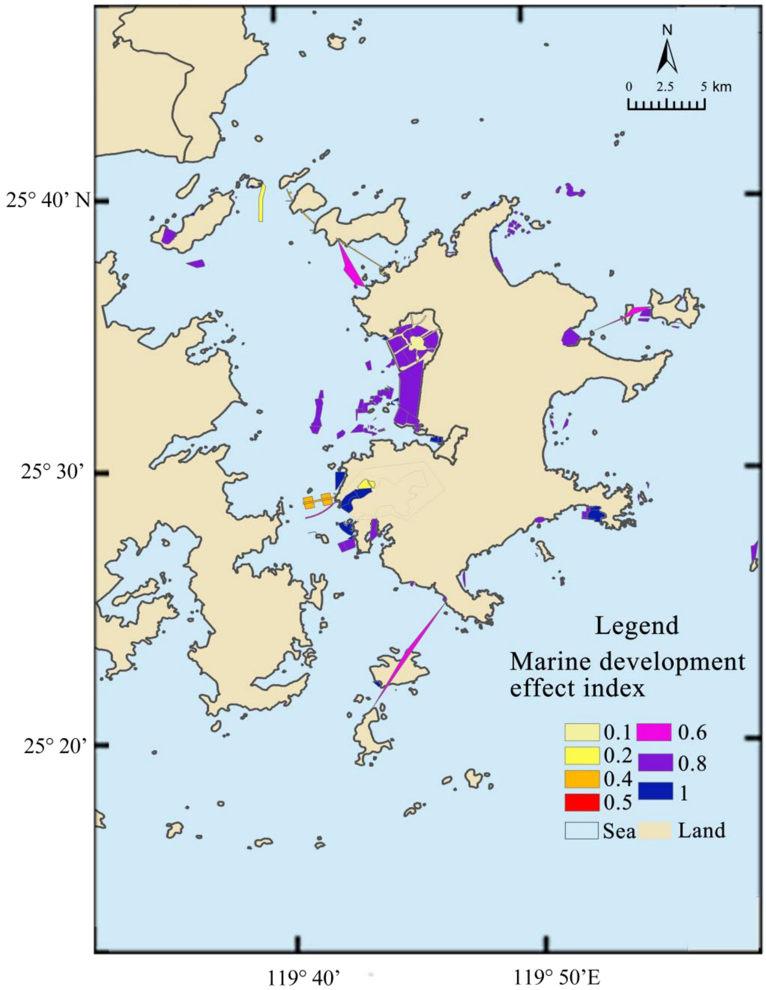

Figure 5. Evaluation results for the marine development effect index.

4.1.2. Evaluation Results for the Marine Environment

The seawater in Pingtan's offshore marine areas basically met the first and second levels of the seawater quality standards in the Sea Water Quality Standard (GB3097-1997), in which the excellent water quality rate throughout the area reached 99.6%. The first-level water quality accounted for 73.3%, the second-level water quality accounted for 26.3% and the third-level water quality accounted for 4%. According to the monitoring data of the marine environment monitoring station in the four quarters in the Pingtan Islands, the marine environment evaluation results were obtained with the comprehensive evaluation method of seawater quality and are shown in Figure 6.

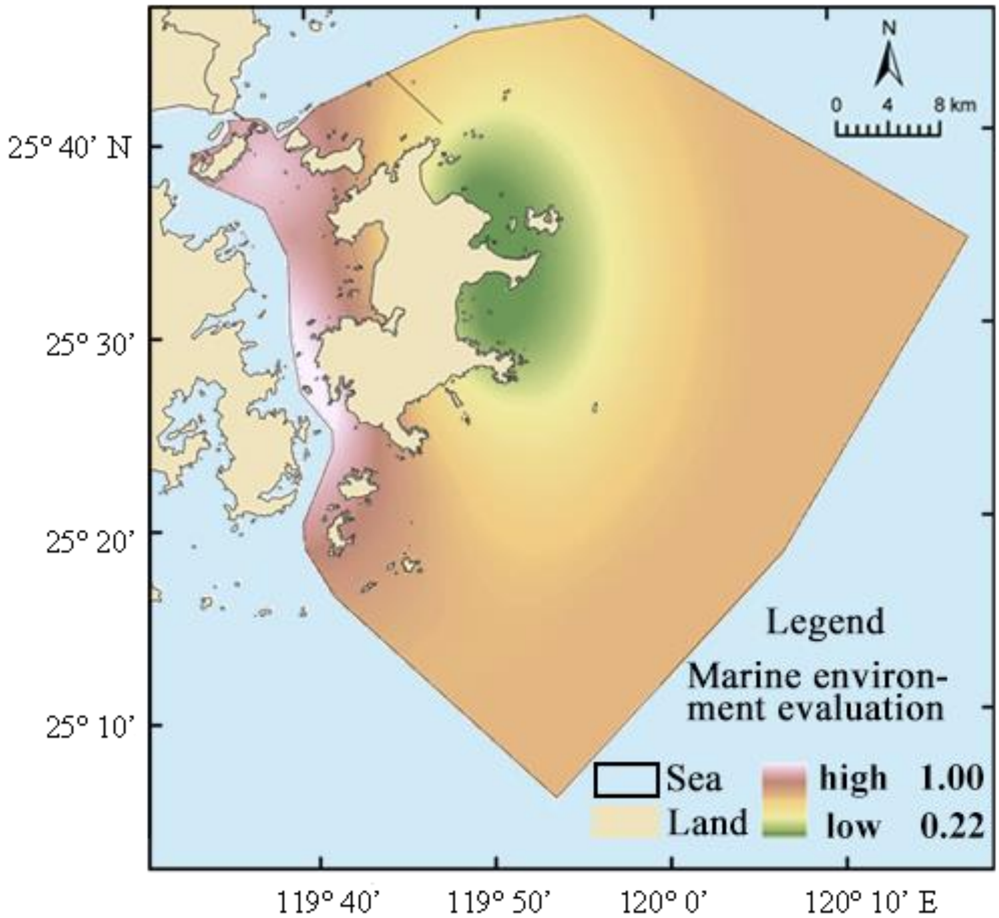

Figure 6. Evaluation results for the marine environment.

4.1.3. Evaluation Results for the Marine Biological Resources

In accordance with the distribution of phytoplankton, zooplankton and benthos, marine biological resources were comprehensively analyzed, as shown in Figure 7. According to the monitoring results, marine organisms in offshore areas were at risk of overfishing and the concentration of zooplankton and phytoplankton was decreasing due to the influence of the sea area development and environmental changes. In some fishing grounds, the species and number of new organisms have fluctuated significantly due to the influence of "killer" fishing nets. Meanwhile, the yield of the Chinese horseshoe crab, which is a typical species in Pingtan, has continued to drop and the typical protected has fluctuated drastically in recent years. The evaluation results show that the marine biological resources in the offshore areas of Pingtan were in a recession. The marine biological resources outside the sea area were better and the carrying capacity of marine biological resources was average.

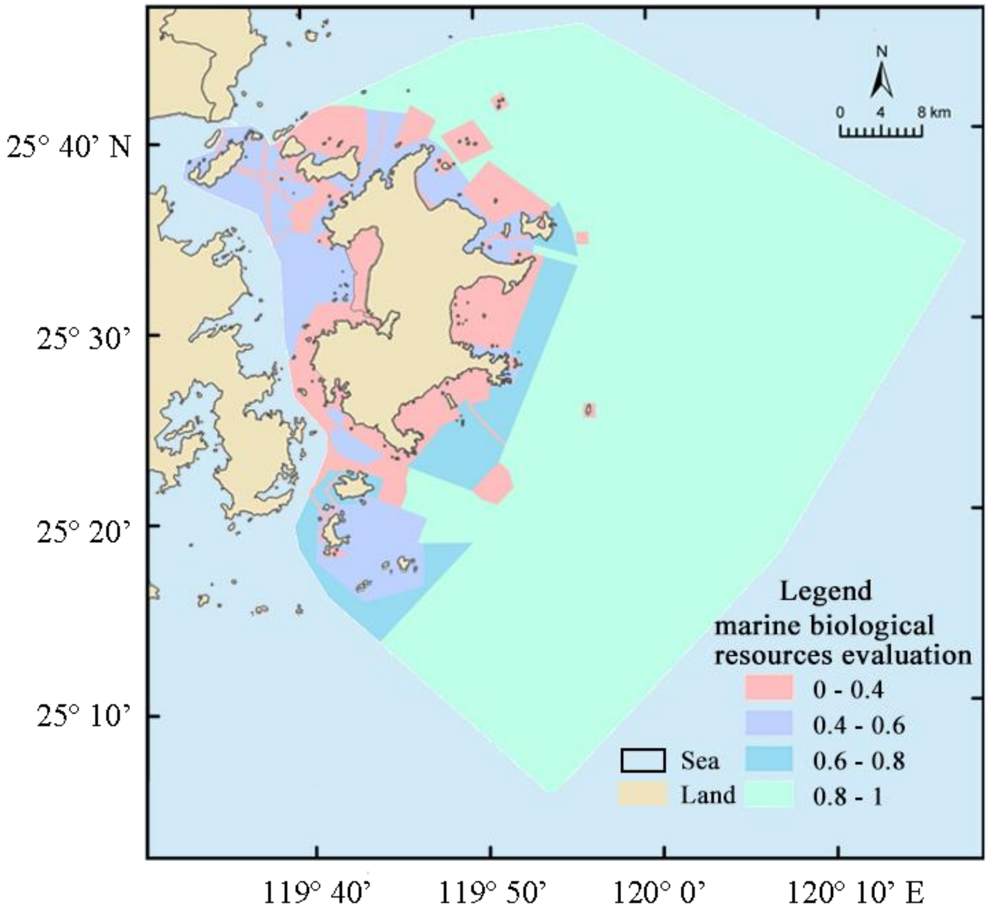

Figure 7. Evaluation results for the marine biological resources.

4.2. Suitability Evaluation

4.2.1. Evaluation Results for the Marine Ecological Suitability

The suitability evaluation of marine ecology focused on the ecological environment evaluation. Based on the evaluation of marine resources and the marine environment, the concentration in the ecological sector was weighted, and the comprehensive evaluation results of the marine ecology suitability [91–94] was obtained by overlaying the marine functional zoning in the Pingtan Islands. In combination with the above aspects, based on the conditions of using sea areas, the tourism development and environmental protection in Pingtan were considered to make the suitability evaluation map of marine ecological space (see Figure 8).

The suitable marine ecological area highlights the regulative effect of the natural ecosystem. The areas where their natural ecology needs to be protected should be protected in a manner of natural reserves, scenic spots and ocean parks, which are mainly distributed in the eastern sea area under the jurisdiction of Pingtan County and coastal waters in Tannan Bay, Haitan Bay, Shanqi Gulf, Changjiang Gulf, Shipaiyang and Nanhai Town. There is a good endowment of natural resources and good environmental conditions in Pingtan, as well as unique natural and cultural resources. With a total of 70 km of high-quality sand beach, its harbors and shorelines are excellent. The marine erosion landforms are also widespread throughout the region, and there are numerous uninhabited islands that contain an abundance of marine and island resources. Haitan Scenic Attraction and Pingtan Islands National Forest Park are among its attractions. However, most of the ecological suitability areas are located in areas or islands far away from towns, and there are problems such as insufficient infrastructure, incomplete tourism elements, weak port traffic capacity, sensitivity to seasonal natural factors and a fragile ecological environment.

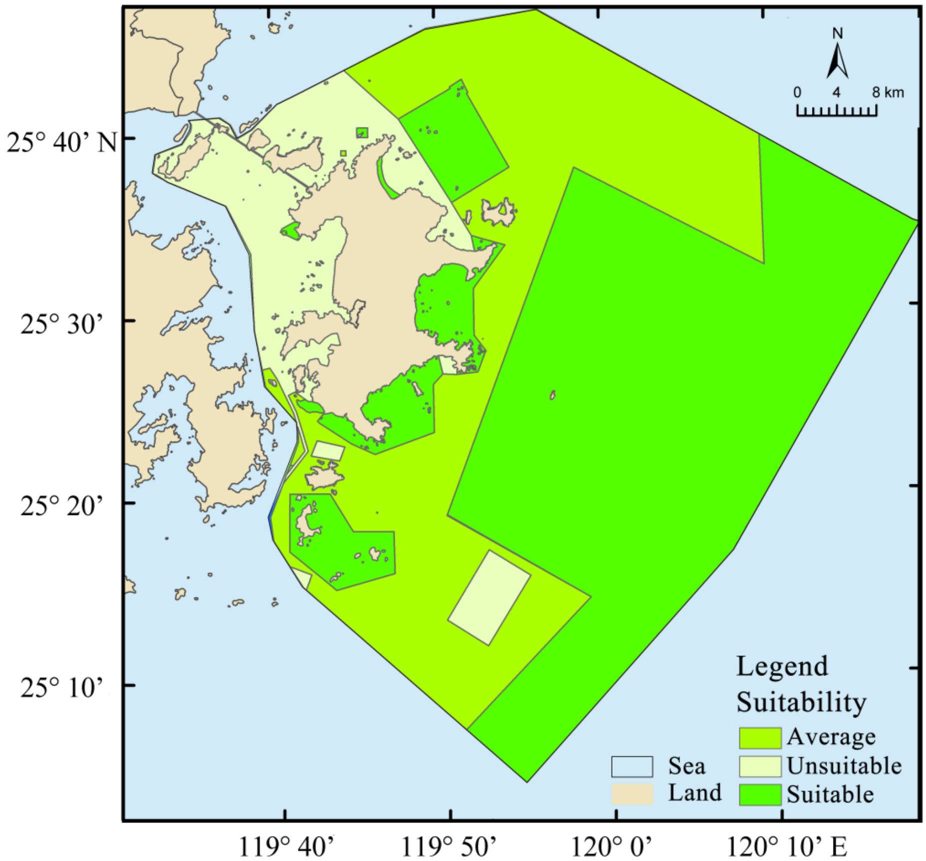

Figure 8. Map of the marine ecology suitability evaluation.

4.2.2. Suitability Evaluation Results for the Marine Agricultural Production

The planning of tourism development, environmental protection and fishery farming was coordinated based on the utilization conditions of Pingtan sea areas. Furthermore, the suitability of marine agriculture production was evaluated comprehensively through overlaying analyses of the index results, including the evaluation of marine biological resources, the evaluation of the marine environment and the connectivity of sea areas, as shown in Figure 9.

The suitable areas for agricultural production were heavily concentrated in offshore waters in Tannan Bay, Haitan Bay and Dongxiang Island. The development conditions of agricultural production in the offshore waters along the eastern coast of the Pingtan Islands and eastward extended areas were better. As a whole, the traditional agricultural space in Pingtan was divided into two major regions in the east and west. Due to the discontinuity of the sea area spatial location, it is difficult to realize a large and contiguous aquaculture area and unified management.

4.2.3. Suitability Evaluation Results for the Marine Town Construction

Based on experience regarding the suitability of town construction, the spatial distance from the reclaimed built-up area, the spatial location characteristics of residential areas, and the proximity to ports and main roads were selected. Furthermore, construction should avoid terrain-restricted areas, such as high-slope coasts that are difficult to reclaim and use for construction. By analyzing the superposition of indicators, such as comprehensive advantages, marine spatial resources evaluation and marine resources evaluation, the suitability of construction of the entire sea area was comprehensively evaluated. We can draw the following conclusions in light of the current situation of the use of sea areas, the development of tourism and environmental protection in Pingtan, and the suitability evaluation map for the construction of marine cities (Figure 10).

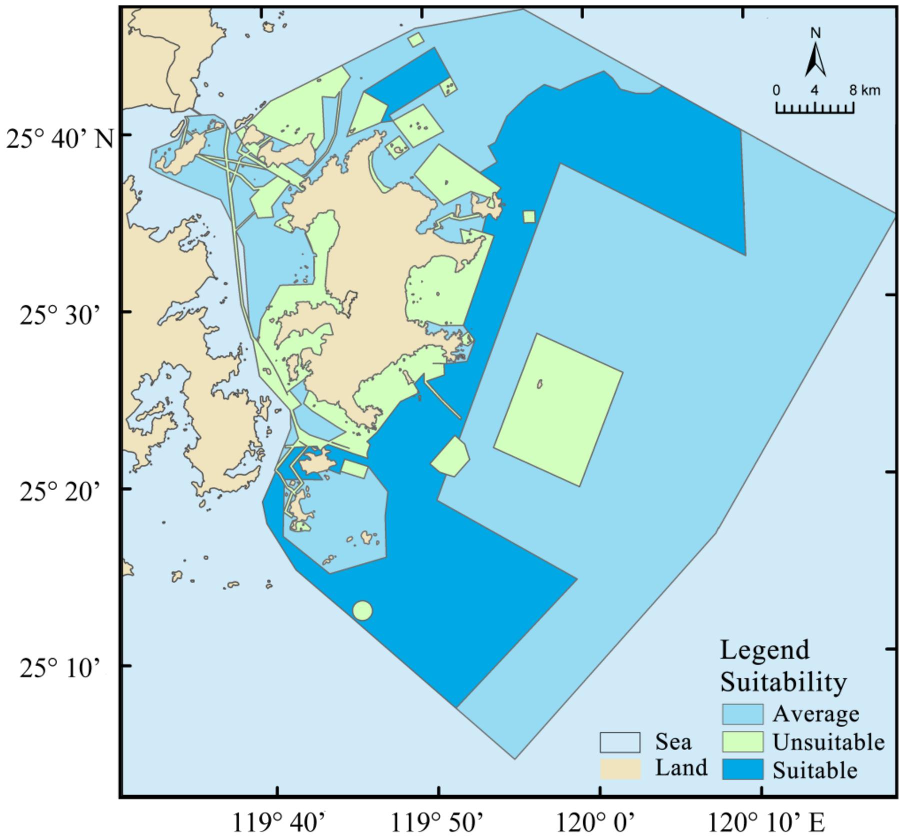

Figure 9. Map of the suitability evaluation of marine agricultural production.

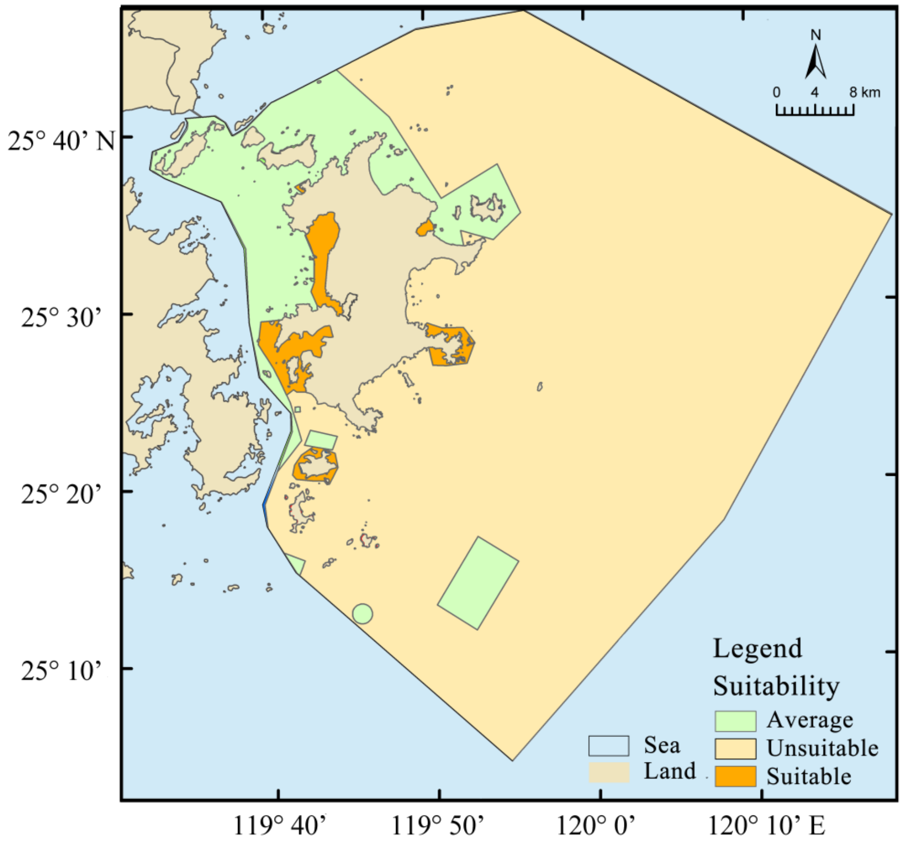

Figure 10. Map of the suitability evaluation of town construction.

The suitable areas for urban construction were mainly located in the coastal areas of Jinjing Bay, Xingfuyang, Shanmen, Houyu, Su'ao Port Area and Nanhai Town Island. In addition, during the evaluation, as opposed to the marine functional zoning, the current sea areas for urban construction were not suitable for town construction. The sea areas for town construction with a small area and limited future potential in the current marine functional zoning should gradually exit from such a function. Furthermore, according to the latest reclamation control measures, projects and plans for reclamation should be canceled. Inbuilt sea reclamation programs and projects should be adjusted according to the national policy and processed promptly.

4.3. Results of the Suitability Zoning

According to the determination method of the three types of space, the evaluation results of the three types of space were overlaid to obtain the result shown in Figure 11. The suitable area of marine ecological space was 1847.58 square kilometers, accounting for 64.47%, which was concentrated in the southeastern waters far from the islands. The suitable area of marine agricultural production space was 964.58 square kilometers, accounting for 33.64%, which was located around the main island. The suitable area of marine construction space was 60.87 square kilometers, accounting for 1.89%, which was located around the main island. According to the ecological protection area and the marine ecology red line in the Marine Function Zoning of Pingtan Comprehensive Pilot Zone (2013–2020), the ecological protection red line was delineated. The ecological protection red line refers to the area with especially important functions that must be strictly and compulsively protected within the scope of ecological space, where development activities with greater impact on the marine ecology functions are prohibited or those failing to meet the objective of marine ecological environment protection are strictly limited. On this basis, combined with the above areas, the zoning map was obtained as shown in Figure 12. Among them, the marine utilization space was 1847.58 square kilometers, accounting for 64.3% of the total sea area, and the marine utilization space was 1025.42 square kilometers, accounting for 35.7%.

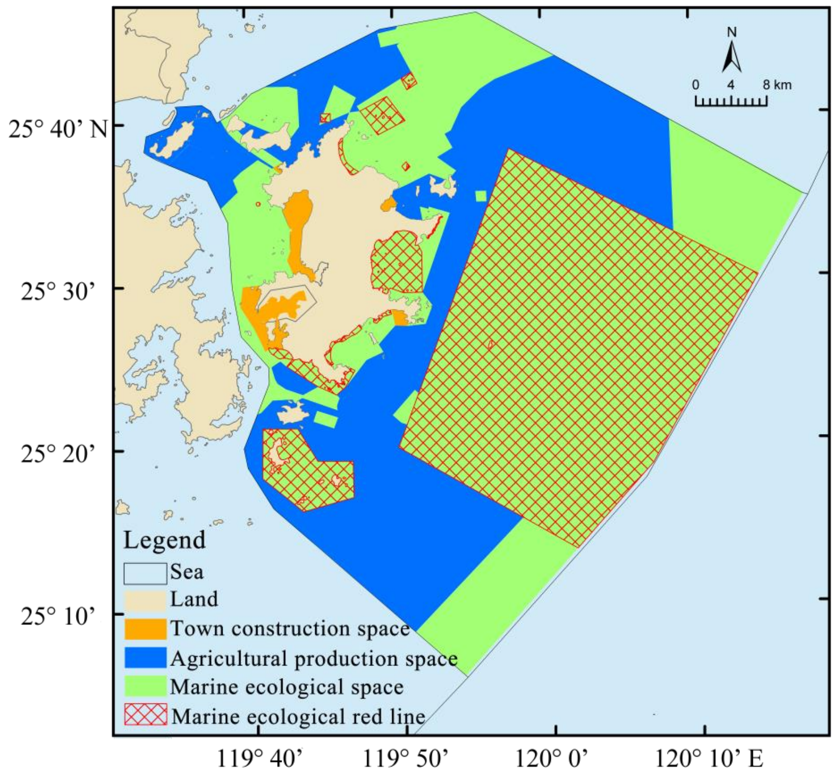

Figure 11. Scheme of three types of space zoning in the Pingtan marine space.

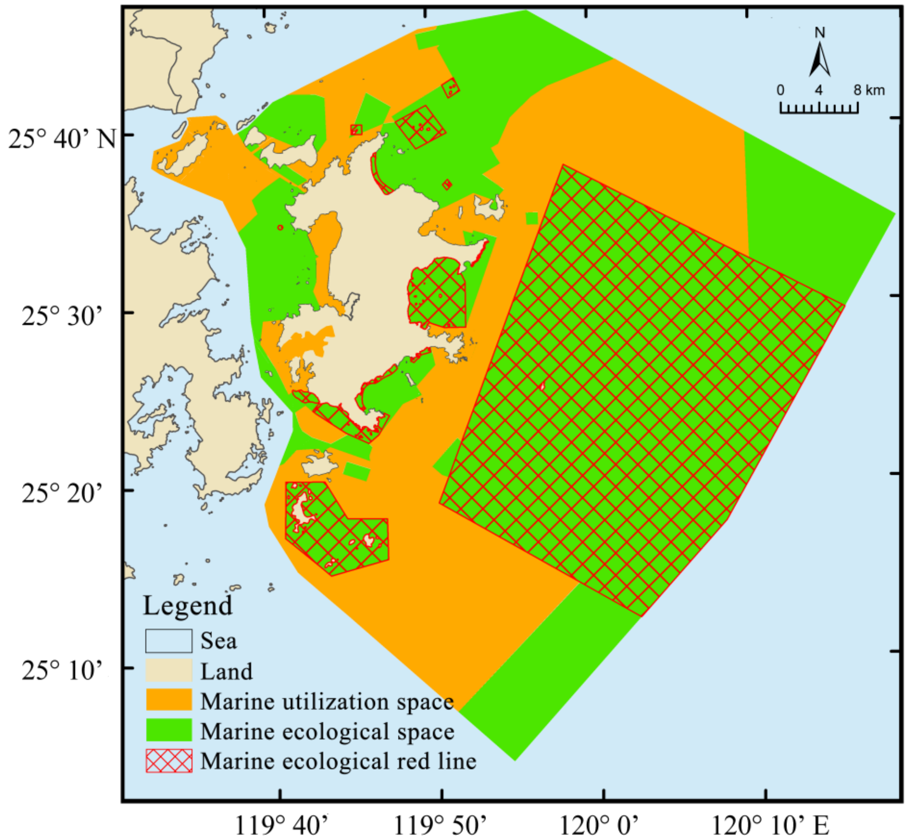

Figure 12. "Two spaces and one red line" of the Pingtan marine space.

5. Discussion

The thought of marine sustainable development in China has gradually expanded from focusing simply on the management of marine utilization to multi-dimensional fields, such as marine space utilization, marine economic development and marine ecological protection. The majority of studies on marine spatial suitability adopted different methods to apply to marine space, rather than the surrounding island sea area. Some experts and scholars tended to classify areas based on the suitability of development and utilization [46–48]. Some scholars assessed the marine space suitability and zones from different aspects, such as ecology and economy [49–57].

Different from the above studies, this study took into account the unique characteristics of the sea area around the islands and the natural environment from the perspective of the islands rather than the marine space. Its advantage was that by considering the characteristics of the island itself, it puts forward a unique evaluation and spatial zoning method according to local conditions. This method was more targeted for the island, and the research results were more accurate. In this research, taking into account the ecology, resources, and conditions of exploration and development of the surrounding island sea area, an index system consisting of suitability evaluation of marine ecological space, suitability evaluation of sea area for construction and suitability evaluation of marine agricultural production space was constructed to more reasonably consider the effect of background conditions of the surrounding island sea area on the space zoning. In this article, through the study of the marine spatial suitability for islands, it considered that the spatial suitability evaluation of the surrounding island sea area should be the basis for space zoning and the sustainable development of the islands.

However, due to the lag and lack of statistical data at the small spatial scale, this study only chose 2 km × 2 km grid cells, which requires further research and improvement. On the one hand, the spatial scale of the study needs to be refined, and several islands were selected for empirical studies and time series analysis to further demonstrate the adaptability and scientificity of the evaluation method of the marine spatial suitability and index system for islands in a small-scale space. On the other hand, through the refinement of the spatial scale and more empirical studies, the main influencing factors and their mechanisms of sustainable development for islands were analyzed. The positive and negative influencing factors were determined according to the spatiotemporal evolution characteristic.

6. Conclusions

The suitable area of the Pingtan Islands was 1847.58 square kilometers, the marine agricultural production space was 764.15 square kilometers and the marine construction space was 60.84 square kilometers. "Two spaces and one red line" were delineated. Among them, the marine utilization space was 1847.58 square kilometers, accounting for 64.3% of the total sea area, and the marine utilization space was 1025.42 square kilometers, accounting for 35.7% (Figure 12). Overall, the marine ecological space area was larger and was located in the southeastern sea area of the Pingtan Islands, and the marine utilization space was located around the Pingtan Islands, which can meet the needs of the exploration and development of Pingtan.

Different islands have different ecological and resource endowments [95–99]. In the future, in terms of evaluation techniques and methods, more research work is needed to refine the evaluation indicators, evaluation content and technical methods to objectively reflect the resource and ecological [95] attributes of islands and provide a scientific basis for zoning and sustainable development. At the level of zoning methods, more consideration should be given to the relationship between suitability and adaptability. Differences between the current background conditions and future background conditions that will change with economic and social development can be considered, and suitability management strategies can be proposed to allow for the zoning's dynamic adjustment in order to realize the sustainable development [100,101] of the island space and resources.

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