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Coexistence or Mutual Loss?

—Evidence from China

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Abstract

How to assess the health status of China's coastal ecosystems and establish a comprehensive ocean observation plan to support the assessment of ecosystem health status are major scientific issues that urgently need to be addressed by the Chinese government and local coastal governments. Based on the Lotka-Volterra, a symbiosis model is applied to calculate symbiosis degree between the coastal socio-economic system and marine ecosystem in Beibu Gulf. It is found that the marine ecological pressure in Beibu Gulf has not been reversed in the past 20 years. Most cities are in the stage when socio-economic development and marine ecological damage coexist. We use the Lotka-Volterra model to discuss the dynamic process of the evolution and development of marine ecosystem and coastal socio-economic system in an environment of mutual influence. It is urgent to improve marine ecological security by cultivating ecological industrial system and industrial clusters, establishing a land-sea ecological restoration, and to promote joint protection and co-governance across different administrative regions.

Keywords

Marine Ecosystem, Lotka-Volterra Model, Beibu Gulf, Coastal Socio-Economic System

1. Background and Issues

The development of the economy and society requires a healthy and beautiful marine ecosystem, and effectively assessing the health status of marine ecosystems is a major scientific issue of global concern. Taking New Zealand as an example, the country is located in the southern Pacific Ocean with a coastline of 6900 kilometers. It is renowned for its beautiful environment and is known as the "last pure land in the world". The country attaches great importance to the protection and management of the health status of marine ecosystems. In order to limit overfishing and destructive fishing practices, the country protects its unique marine ecosystem through laws, regulations, and policies. In contrast, another example that is not satisfactory is the Beibu Gulf. The Beibu Gulf is located in the northwest of the South China Sea, bordering the Leizhou Peninsula and Hainan Island in Guangdong Province to the east, the Guangxi Zhuang Autonomous Region to the north, and Vietnam to the west. It is connected to the Qiongzhou Strait and the South China Sea, and is surrounded by the land of China and Vietnam and Hainan Island in China. The total area of the sea is about 128,000 square kilometers, making it a beautiful and rich bay in the northwest of the South China Sea. The Beibu Gulf was once one of the best and cleanest natural marine ecosystems in China. However, in recent years, with the continuous acceleration of development and construction in coastal areas, the phenomenon of land reclamation is widespread, and chemical and heavy metal pollution is increasing. Land non-point source pollution is showing an upward trend. As important indicators for measuring marine ecology, mangroves and nearshore fish are constantly decreasing, and the protection pressure on the Beibu Gulf marine ecosystem is rapidly increasing. Humans do not live in the ocean, so it is impossible to understand the state of the ocean through our own feelings and observations. Our deep understanding of the ocean can only come from observing it. The observation of marine ecosystems driven by the major scientific goal of conducting health assessments of marine ecosystems is an important measure to support the coexistence and coordinated development of healthy marine ecosystems and coastal social ecosystems.

The Beibu Gulf is a precious large shallow sea marine ecosystem along the coast of the South China Sea, renowned worldwide for its unique resource and environmental characteristics. The water quality in the Beibu Gulf is clear and the ecological environment is beautiful. It is considered one of the most suitable marine ecological environments for human habitation and tourism in the future worldwide. Its resource environment has two characteristics: firstly, a diverse ecosystem. The Beibu Gulf is a diverse and rich marine ecosystem, including coral reefs, seagrass beds, seaweed, and other marine ecosystems, providing unique habitats and breeding grounds for various marine organisms. Secondly, abundant fishery resources. The marine life in the Beibu Gulf area is diverse, mainly including various fish, shrimp, shellfish, algae, etc. The shallow waters of the Beibu Gulf are rich in shrimp resources and are one of the most important shrimp fishing bases in the world.

If viewed from the perspective of the Gulf economy, the shortcomings of the Beibu Gulf are exposed. China has six large bays geographically, from north to south, namely Liaodong Bay, Bohai Bay, Laizhou Bay, Haizhou Bay, Hangzhou Bay, and Beibu Gulf. According to the statistics at the end of 2023, the annual throughput ranking of ports in the six major bays is as follows: Bohai Bay ranks first with 1.4 billion tons, Hangzhou Bay ranks second with 1.2 billion tons, Haizhou Bay ranks third with 690 million tons, Liaodong Bay ranks fourth with

370 million tons, Beibu Gulf ranks fifth with 250 million tons, and Laizhou Bay ranks sixth with 230 million tons. The GDP rankings of major cities around the six major bays are as follows: Bohai Bay ranks first at 2.4 trillion yuan, Hangzhou Bay ranks second at 2.23 trillion yuan, Laizhou Bay ranks third at 1 trillion yuan, Haizhou Bay ranks fourth at 500 billion yuan, Liaodong Bay ranks fifth at 450 billion yuan, and Beibu Gulf ranks sixth at 330 billion yuan.

Why is the southernmost Gulf of Tonkin the most underdeveloped one? Based on the unique features of the Lotka Volterra model, in this paper, we constructed a differential dynamics model by using the Lotka Volterra model, and used differential dynamics research methods to establish a symbiotic model of marine ecology and coastal social economy. Taking the Beibu Gulf as an example, the dynamic equilibrium relationship between the two is studied.

2. Literature Review

The existing literature can be roughly divided into the following two categories. The first type of literature starts with the main ecological indicators of the Beibu Gulf, and through in-depth investigation and professional analysis, conducts comprehensive and three-dimensional investigation and professional cause decomposition of the Beibu Gulf ecology, and puts forward targeted governance suggestions.

The Beibu Gulf of Guangxi is an important part of the Beibu Gulf Economic Zone. However, since the 21st century, the marine ecological environment in the Beibu Gulf has shown a serious deterioration trend. By using Ecopath with Ecosim 5.1 software, Chen and Qiu (2008) [1] constructed the Ecosim model of Beibu Gulf marine ecosystem in 1959-1960, which included about 20 functional groups such as fishery, marine mammals, sea-birds, sharks, pelagic fishes, demersal fishes, and benthic crustaceans, etc. Through the comparison with the investigation data in 1997-1999, the effects of fishing on the structure and function of Beibu Gulf marine ecosystem were analyzed. Their research results indicated that with the increasing fishing pressure over the past forty years, the ecosystem structure and function shifted drastically, with the biomass of long-lived, high trophic level and piscivorous fishes declined while short-lived and small fishes and benthic invertebrates dominated gradually. The biomass of piscivorous species in 1999 was only 6% of that in 1960, while cephalopods increased 2.7 times or more. The trophic level of the catch declined from 3.2 in 1960 to 2.98 in 1999, which fitted the rule of "fishing down the food web" and suggested that the present exploitation patterns were unsustainable. Based on the data of the 1990s, the changes in the ecosystem under decreasing fishing pressure were predicted. This study validated the feasibility of Ecosim model in predicting the effects of fishing pressure on marine ecosystem. Their predicted results are basically consistent with the changes in the Beibu Gulf ecosystem after 2008.

There may be moderate pollution or disturbance in the northern waters of the Beibu Gulf, especially in the autumn when the stability of the biological community structure is poor (Miu *et al.*, 2024) [2]. Scholars have tried to use bottom trawl surveys to evaluate the spatial distribution and diversity changes of fish resources in the northern coastal waters of the Beibu Gulf. They have found that the quantity and diversity index of fishery resources in the northern coastal waters of the Beibu Gulf showed a downward trend compared to historical levels, and the community structure has undergone significant changes (Luo *et al.*, 2023) [3]. The fish community in the Beibu Gulf has shifted from bottom-dwelling species to upper-middle-dwelling species and from large, commercially significant high trophic species to small, low-value, low-trophic species (Peng *et al.*, 2023) [4]. Some scholars have constructed an ecological risk assessment system for the Beibu Gulf of Guangxi based on the PSR model, exploring the ecological risk status of the Beibu Gulf, and also indicating that the ecological risks in the Beibu Gulf are in a warning state (Wu *et al.*, 2023) [5]. In order to explore the sources of pollutants caused by ecological deterioration, some scholars have studied the current discharge status of water pollutants in the key bay catchment areas of the Beibu Gulf Economic Zone in Guangxi through comprehensive environmental pollution assessment and cluster analysis (Fan *et al.*, 2024) [6]. Their results have shown that domestic and agricultural sources are the main sources of water pollutants in the key bay catchment areas.

In order to develop marine ecological restoration technology in the Beibu Gulf of Guangxi, Ning and Chen (2021) [7] studied the data in the marine ecological environment from 2008 to 2018, and analyzed the variation trend in the Beibu Gulf of Guangxi. The purpose was to provide theoretical reference for improving the marine ecological environment. The results showed that the water quality, marine ecosystem health, and ecological environment of ocean management had been improved. The sediment quality kept steady. Marine pollutants remained the main source of pollution. Combined with the characteristics of Guangxi marine environment, the coordinated prevention and control of pollutants from land and sea, and the support of ecological restoration funds should be strengthened, to promote the ecological restoration of marine ecosystem and provide theoretical reference for improving marine ecological environment.

The second type of literature starts from an ecological perspective, focusing on the mutual influence and evolutionary process between the Beibu Gulf ecosystem and the coastal socio-economic system.

A single research perspective may not be able to explain the true reason for the serious deterioration of the marine ecological environment in the Beibu Gulf. Many studies have shown that the destruction of the marine ecological environment is due to overfishing of marine resources, especially since the implementation of policies such as the Guangxi Pilot Free Trade Zone and the opening up to the outside world. The Beibu Gulf urban agglomeration in Guangxi has achieved rapid development towards the sea economy, but with it comes the overexploitation of marine resources, excessive discharge of marine pollutants, and a series of other marine resource and environmental problems. Therefore, special attention should be paid to the construction of marine ecology in the Beibu Gulf while achieving development in the offshore economy. Improving the carrying capacity of marine resources and environment, achieving sustainable development of marine resources and environment, and injecting momentum into the world's sustainable development have become hot issues of social concern (Li *et al.*, 2022) [8]. In response to the deterioration of the marine environment, the Guangxi Institute of Oceanography in China has comprehensively analyzed the contradictions and conflicts between various offshore development and utilization activities and ecological protection from three levels: two-dimensional compatibility of sea area management, feasibility of three-dimensional layered property rights confirmation, and coordination of four-dimensional temporal zoning management (Cao *et al.*, 2024) [9]. The institute has proposed principles for determining the priority of marine functions to promote the balance and coordination between the Beibu Gulf economy and the ocean.

The purpose of establishing a multi-factors dataset for coastal zones is to provide data support for the ecological environment of the coast. Therefore, Zhang (2024) [10] proposed remote sensing dynamic monitoring of mangroves, aquaculture ponds, and coastlines in the Beibu Gulf. Dr. Chen (2022) [11] constructed the Beibu Gulf Spatial Durbin Model to study the spatial relationship between environmental regulation, high-quality economic development, and ecological capital utilization, indicating that environmental regulation, high-quality economic development, and ecological capital are interrelated and mutually influential, and the interactive effect formed by the coordination of the three effectively promotes the sustainable development of marine terrestrial ecosystems. Ye (2019) [12] conducted an empirical analysis about the problems existing in the marine industry of the Beibu Gulf Economic Zone and the driving effect of the marine industry on the local economy. He proposed countermeasures and suggestions to enhance the competitiveness of the marine industry in the Beibu Gulf Economic Zone of Guangxi, particularly highlighting the importance of marine environmental protection. Feng *et al.* (2024) [6] analyzed the functional relationship based on the evaluation index system of the "Three Lives" function using a coupled coordination model, and explored the spatiotemporal heterogeneity of the influencing factors of the "Three Lives" functional coordination using a spatiotemporal geographically weighted regression model. The results showed that the production, living, and economic functions of the counties in the Beibu Gulf Economic Zone gradually improved, while the ecological functions declined. Some scholars have further analyzed the measurement of marine environmental efficiency in the Beibu Gulf through an improved Durbin model. Based on the previous model used by scholars, they considered unexpected outputs and constructed a Super SBM model to measure the marine ecological efficiency in coastal areas (Zhang, 2022) [13]. Their research showed that the marine ecological efficiency is relatively low and the growth rate is slow in the Beibu Gulf region, and the marine environmental efficiency has negative spatial spillover. The investment in marine science and technology, the level of marine scientific research, and the activity of ports significantly inhibit the marine environmental efficiency in the Beibu Gulf.

The research of these scholars has shown the problem of balance disruption between marine ecology and coastal ecology. However, few scholars have been able to explore the balance change relationship between the two from the perspective of differential dynamics.

While American ecologist Lotka (1921) studied chemical reactions and Italian mathematician Volterra (1923) studied the fish competition, they proposed a classic biological, mathematical model which is called the Lotka-Volterra model. The model describes the evolution of population changes in organisms, which are constrained by their own population self-restraint laws and influenced by the number of other populations. This kind of model is a classical mathematical framework used in ecology to describe the interaction between two species, especially when these two species are in a predator-prey relationship. This model consists of two first-order nonlinear differential equations used to express the dynamic behavior of two populations over time. After continuous in-depth research, the Lotka Volterra model has now been applied in many fields, such as economics and social sciences, to explore competition and cooperation issues between different entities.

3. Model and Analysis

The Beibu Gulf used to be a blue ocean in the South China Sea, but in recent years, due to excessive economic development, the marine ecology has shown signs of deterioration, as shown in **Table 1** and **Table 2**.

Table 1. Comparison of coastal marine ecosystems in China.

Bay	major port	Bay length (kilometers)	Bay water area (square kilometers)	Annual port throughput (trillion tons)
Bohai Bay	Port of Tianjin, Port of Tangshan, Port of Qinhuangdao	300	10,590	14.0
Hangzhou Bay	Port of Shanghai, Ningbo Port	90	350	12.0
Haizhou Bay	Lianyungang Port	40	876	6.9
Liaodong Bay	Yingkou Port, Panjin Port, Jinzhou Port	300	13,283	3.7
Beibu Gulf	Qinzhou Port, Beihai Port, Fangchenggang Port	1000	128,000	2.5
Laizhou Bay	Weifang Port, Longkou Port	100	6966	2.3

Table 2. Comparison of coastal socio-economic system in China.

Bay	Major Surrounding Cities	Population of Major Cities (in ten thousand)	GDP of Major Cities (in trillion RMB)
Bohai Bay	Tianjin, Tangshan	2321	2.40
Hangzhou Bay	Hangzhou, Ningbo	1890	2.23
Laizhou Bay	Weifang, Yantai	1649	1.00
Haizhou Bay	Lianyungang	466	0.50
Liaodong Bay	Dalian, Shenyang	1577	0.45
Beibu Gulf	Nanning, Beihai	1059	0.33

In order to achieve more rational resource allocation and more efficient medical services, in this section, we use the Lotka-Volterra model to discuss the dynamic process of the evolution and development of marine ecosystem and coastal socio-economic system in an environment of mutual influence.

The main methods for marine ecological security assessment are including ecological carrying capacity model (Odum and Barrett, 1971) [14], ecological footprint method (Rees, 1992) [15], causal chain analysis method (Belausteguigoitia, 2004) [16], AD-AS (aggregate demand-aggregate supply) model (Su *et al.*, 2014) [17], dynamics model (Wang *et al.*, 2021) [18], Lotka-Volterra model (Mohan, 2021; Wenhan Ren & Yuhan Xu, 2024; Shuhong Wang and Suisui Chen, 2021; Chenfei Ma & Xiaofeng Zhang, 2025) [18]-[21]. Among them, Lotka-Volterra model and dynamics model are better at analyzing the interaction between systems and factors, can more clearly know the causes and paths of ecological security problems. However, dynamics model is mainly used for system simulation and prediction, which is inconsistent with the purpose of this study. Therefore, the Lotka-Volterra model has been selected to explain the coordinated symbiotic relationship between the coastal socio-economic system and the marine ecosystem to comprehensively reveal the state of marine ecological security.

Based on the exchange laws of energy flow, material flow, information flow, and value flow between marine ecosystem and coastal socio-economic system, the issue of marine ecological security is regarded as the result of the complex interaction between these two systems. At first, the rapid population growth, production pollution, engineering construction brought by the socio-economic development of coastal areas has broken the natural balance mechanism of the marine ecosystem. However, the forces of artificial restoration will make the marine ecosystem evolve for the purpose of socio-economic development in the coastal areas, such as the construction of marine ranches and the delineation of ecological protection zones. Meanwhile, the status of marine ecosystem plays a moderator role in population aggregation, capital flow, production efficiency and life quality, which promotes or restricts the developing process of coastal socio-economic system. According to the description of the symbiosis theory (Can Chen *et al.*, 2024) [22], marine ecosystem and coastal socio-economic system can be regarded as two kinds of biological populations competing for ecological resources and environment in the same living space. A virtuous cycle of socio-economic development and ecological protection will be formed if the relationship of both systems is adjusted properly, which will bring mutual benefits, symbiosis, and joint expansion. Lotka (1925) and Volterra (1928) used the Lotka-Volterra symbiosis model to explain the competitive or mutually beneficial relationship between two groups. This model is introduced here and will then be further modified into a symbiosis model of marine ecosystem and coastal socio-economic system to assess the marine ecological security level of the Great Bay Area. The model is constructed as follows:

$$\begin{cases} \dfrac{dx}{dt} = r_1 x\left[1-\dfrac{x+\alpha_1 y}{K_1}\right] \\ \dfrac{dy}{dt} = r_2 y\left[1-\dfrac{y+\alpha_2 x}{K_2}\right] \end{cases} \tag{3.1}$$

Assuming that the same coastal area (spatial scope: from the coastline to the territorial sea baseline, from the land side to the outer boundary of the city) has a coastal socio-economic system x and a marine ecosystem y, r_1 and r_2 respectively represent the growth rate of the coastal socio-economic system and the marine ecosystem. $x(t)$ and $y(t)$ respectively represent the comprehensive development index of coastal socio-economic system and marine ecosystem. K_1 represents marine ecological capacity index, which is the marine resources guarantee provided by the marine ecosystem to the coastal socio-economic system; K_2 represents coastal socio-economic system index, which is the coastal socio-economic resources guarantee provided by the coastal socio-economic ecosystem to the marine system. t represents time. α_1 represents the force coefficient of the marine ecosystem on the coastal socio-economic system, and α_2 represents the force coefficient of the coastal socio-economic system on the marine ecosystem. $\alpha_1 > 0$ means that the coastal socio-economic system is restricted by the marine ecosystem (negative effect); $\alpha_1 < 0$ means that the marine ecosystem has expanded the development space for the coastal socio-economic system (positive effect); $\alpha_1 = 0$ means that marine ecosystem has no impact on coastal socio-economic system. $\alpha_2 > 0$ means that the marine ecosystem is infringed by the coastal socio-economic system (negative effect); $\alpha_2 < 0$ means that the coastal socio-economic system has optimized the marine ecosystem (positive effect); $\alpha_2 = 0$ means that the coastal socio-economic system has no impact on the marine ecosystem.

Firstly, in the first scenario, $\alpha_1 = \alpha_2 = 0$. we discuss the independent development paths of the coastal socio-economic system that has no impact on the marine ecosystems without any exchange of resources. In this idealized scenario, it is easy to prove that the changes in the number of coastal socio-economic systems and marine ecosystems develop in the form of the logical function described in Proposition 1.

Proposition 1. If $\alpha_1 = \alpha_2 = 0$, Then solution of the dynamic system (3.1) is:

$$x(t) = \frac{K_1}{1+C_1 e^{-r_1 t}} \tag{3.2}$$

$$y(t) = \frac{K_2}{1+C_2 e^{-r_2 t}} \tag{3.3}$$

where C_1 and C_2 are constants determined by the initial conditions of coastal socio-economic system and the marine ecosystem in system (3.1).

In the second scenario, $\alpha_1 \neq 0$, $\alpha_2 \neq 0$, we argue that the mutual influence between the nearshore ecosystem and the socio-economic ecosystem cannot be ignored, as there are resource-related factors affecting both parties

Proposition 2. For arbitrary constant α, there exists the following form of integral along plane $y - k_1 x = 0$ in the system (3.1)

$$\frac{\alpha}{x} + \frac{\beta}{y} + \frac{A}{\rho_1} = Ce^{\rho_1 t} \tag{3.4}$$

where

$$\beta = -k_1\alpha\,,\quad \rho_1 = \frac{r_1 - r_2 k_1^2}{1 + k^2}\,,\quad A = \left(\frac{r_1}{K_1} - \frac{r_2}{K_2}k_1\right)\alpha$$

Proof: By taking arbitrary real numbers α and β, Construct the following differential combination of the system (3.1):

$$\alpha\frac{\dot{x}}{x^2} + \beta\frac{\dot{y}}{y^2} + \rho_1\left(\frac{\alpha}{x} + \frac{\beta}{y}\right) = -A + \rho_1\left(\frac{\alpha}{x} + \frac{\beta}{y}\right) + \left(\alpha\frac{r_1}{x} + \beta\frac{r_2}{y}\right) - \frac{\alpha K_2 a_1 r_1 (y + k_2 x)(y - k_1 x)}{K_1 K_2 xy}$$

Let $\beta = -k_1\alpha$, $A = \left(\frac{r_1}{K_1} - \frac{r_2}{K_2}k_1\right)\alpha$.

Then above differential combination can be transformed into the following first-order ordinary differential equation:

$$\frac{d}{dt}\left(\frac{\alpha}{x} + \frac{\beta}{y}\right) - \rho_1\left(\frac{\alpha}{x} + \frac{\beta}{y}\right) = A$$

After solving the first-order differential Equation (3), we can immediately draw the following conclusion:

$$\frac{\alpha}{x} + \frac{\beta}{y} = e^{\rho_1 t}\left[\int e^{-\rho_1 t}\cdot A dt + C\right]$$

After simple integration and organization, the conclusion of Proposition 2 can be obtained.

Similarly, it can be proven that the conclusions of Proposition 3 and Proposition 4 are also correct.

Proposition 3. For arbitrary constant α, there exists the following form of integral along plane $y + k_2 x = 0$ in the system (3.1):

$$\frac{\alpha}{x} + \frac{\beta}{y} + \frac{B}{\rho_2} = Ce^{\rho_2 t} \tag{3.5}$$

where

$$\beta = -k_2\alpha\,,\quad \rho_2 = \frac{r_1 + r_2 k_2^2}{1 - k^2}\,,\quad B = \left(\frac{r_1}{K_1} - \frac{r_2}{K_2}k_2\right)\alpha$$

Proposition 4. For arbitrary constant α, there exists the following form of integral along spatial surface $x^2 + y^2 + b_1 x + b_2 x = 0$ in the system (3.1):

$$\frac{\alpha}{x} + \frac{\beta}{y} = Ct \tag{3.6}$$

where

$$\beta = k\alpha\,,\quad b_1 = -\frac{K_1}{a_1}\,,\quad b_2 = -\frac{K_2}{a_2}\,,\quad k = \frac{K_2 a_1 r_1}{K_1 a_2 r_2}$$

4. Conclusion and Recommendations

Proposition 1 states that if the Beibu Gulf ecosystem is completely isolated from the nearshore socio-economic system, the evolution and development of each system will only be constrained by internal factors within the system, and the two systems will move forward according to their respective logical function curves (3.2) or (3.3). Proposition 2 states that if the Beibu Gulf ecosystem and the nearshore social ecosystem are in a mutually beneficial evolutionary state, then according to the integral (3.4), it is easy to see that the development of the two systems will result in a win-win ideal state compared to a completely isolated state. Proposition 3 states that if the Beibu Gulf ecosystem and the nearshore social ecosystem are in a state of double damage evolution, then according to the general integral (3.5), it can be inferred that even if the nearshore social ecosystem develops rapidly, it is due to malicious fishing of marine organisms that the marine ecosystem deteriorates rapidly. This worrying situation of double losses has emerged. Proposition 4 states that under normal circumstances, according to the general integral (3.6), it can be inferred that the marine ecosystem and the coastal socio-economic system will be in a complex situation of coexistence or mutual loss. At this time, the influence of both parties plays a decisive role in the final evolutionary outcome of both parties.

By innovatively combining Lotka-Volterra model into the field of marine ecological security assessment, this study indicates that the coastal socio-economic system and marine ecosystem have evolved into a severely uncoordinated phase of mutual infringement in the Beibu Gulf. From the statistical data in **Table 1** and **Table 2**, it can be seen that there are signs of adverse trends in the socio-economic system and marine ecosystem evolution along the Beibu Gulf coast. It is mainly caused by the excessive consumption of limited marine resources in the Beibu Gulf by the coastal socio-economic system due to the pursuit of rapid GDP growth, which proves the important role of the Lotka Volterra model in enriching marine ecological security assessment methods and tracking the causes of marine ecological problems. Based on the above analysis, this study draws the following conclusions: Due to the long-term state of marine ecological destruction in the Beibu Gulf, its relatively harsh marine environment and limited marine resources have begun to limit the coastal socio-economic system. The symbiotic index has always been very inconsistent, so local authorities must remain vigilant. The approach of the New Zealand government is worth learning from, that is, strict marine ecological protection and restoration policies can make its marine ecosystem relatively safe. New Zealand has actually provided a good reference for other cities.

The model proposed in this article makes some theoretical judgments on the evolution results of the Beibu Gulf ecosystem from a qualitative perspective. However, the assumptions and parameters of our model may not accurately reflect the current situation of Beibu Gulf at present. In future research, we need to collect a large amount of raw empirical data to verify the prediction results of the model.

Suggestions:

It is foreseeable that the rigid demand for marine resources and the environmental capacity in the Beibu Gulf will continue to rise. In order to promote sustainable development in this region, based on the idea of gaining mutual benefit from coordinated development of economic society and marine ecology, it is important to speed up the ecological restoration project and carry out land-sea comprehensive governance.

1) Establish a new pattern of land-sea ecological restoration

Considering the interlinked and superimposed features of marine ecological problems in the Beibu Gulf, it is necessary to make unified planning, three-dimensional monitoring, comprehensive supervision, and joint action with human resources, finance, material, and technology for marine ecological governance. First, it needs to set up the protective par close to the red line of coastal ecology and implement integrated coastal zone management. With the overall consideration of sea and land protection, the local authorities in Guangxi should focus on the comprehensive restoration of estuaries, coastlines, wetlands, bays and islands to achieve "mountain top to ocean" traceability and governance. Second, it needs to implement construction projects for the protection of coastlines, wetlands, and islands. A marine protected area system with marine protected areas and parks shall be comprehensively arranged.

2) Strengthening the long-term mechanism for marine ecological environment protection

Guangxi implements the "Key Points for the 2024 Work of the Autonomous Region Bay Chief System", strengthens the control of marine and coastal land space, strictly controls land reclamation, strengthens the control of land and sea pollutant emissions, promotes the supervision of marine aquaculture ecological environment, strengthens the supervision and management of river and sea discharge outlets, etc., in order to build a beautiful Beibu Gulf with "clear water and clear beaches, fish and gulls gathering, and harmonious human sea".

3) Optimize the regional coordinated development layout

The Beibu Gulf Economic Zone includes administrative areas under the jurisdiction of Nanning, Beihai, Qinzhou, and Fangchenggang, as well as administrative areas under the jurisdiction of Yulin, Chongzuo, and other cities included according to development needs. The economic zone is based in the Beibu Gulf, facing Southeast Asia, serving Southwest, South China, and Central South, with the goal of building a logistics base, commercial base, processing and manufacturing base, and information exchange center that is open and cooperative with ASEAN (Association of Southeast Asian Nations).

4) Advocate joint protection and governance of multiple subjects

By reconciling conflicts of interest among multiple parties based on the principles of balance, sharing, and innovation, a more transparent mechanism for interest games and a more reasonable system for rights allocation will be formed, ensuring the common interests of Beibu Gulf marine governance, fairness, and social justice. Set up technology information and trading platforms for marine ecological governance and promote open-market transactions of technology in marine monitoring and evaluation, marine pollution treatment, as well as marine ecological restoration.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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