

*Original Paper*

Game Analysis on the Evolution of Summer Fishing  
Moratorium System Strategy Under Ecological Compensation  
Mechanism

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**Abstract**

*Ecological compensation mechanism, as an effective means to resolve the contradiction between sustainable development of fisheries and poverty alleviation of fishermen, plays its role effectively through an in-depth exploration of game strategies of relevant subjects. Based on the hypothesis of bounded rationality, the relevant game matrix is constructed by invoking the mathematical model of the evolutionary game in this paper, by which the differential equilibrium results of the fishery ecological compensation game are analyzed. Furthermore, MATLAB software is employed to simulate and analyze the evolutionary stable strategy under different parameters by combining the relevant data. The study shows that: i) In the case of ecological compensation payments by local governments to fishermen, the enthusiasm of fishermen to conduct fishing moratorium increases with the increase of ecological compensation payment. Excessive ecological compensation payments will reduce the willingness of local governments to carry out ecological compensation. ii) In the case of political rewards from superior governments to local governments, neither excessively low political rewards nor insufficient penalties help improve the enthusiasm of local governments for ecological compensation. When political rewards are greater than a certain limit, local governments' willingness to make ecological compensation will increase with the increase of political rewards from superior governments. Fishermen's willingness to choose to conduct fishing moratorium, influenced by the enthusiasm of local governments, will also increase.*

**Keywords**

*evolutionary game, ecological compensation, withdrawal from fishing, strong reciprocity theory, simulation analysis*

## 1. Introduction

Since the 1980s, ecological compensation has been highly valued by academic circles at home and abroad, and studies related to it have been carried out. Costanza et al. published the estimated results of global ecosystem service value in the journal *Nature*, marking a new era in the study of ecological compensation mechanisms. With this impetus, theoretical research on ecological compensation mechanisms has made great strides toward systematization and in-depth development. In terms of ecological compensation, foreign scholars Gao et al. have studied the concept, theoretical basis, principles, approaches, standards and methods of ecological compensation respectively. As for the earliest form of ecological compensation, it can be traced back to 1996, when Costa Rica introduced the “Payment for Ecosystem Service” in the Forestry Law. Moreno-Sanchez et al. regarded “Payment for Ecosystem Service” as an efficient means to protect the environment by transforming unpaid externalities into the economic stimulus. Then Gao et al. further demonstrated that ecological compensation stands out by its advantage of coordinating different administrative agencies and uniting them as a whole to solve cross-bouder pollution problems, rather than dealing with pollution problems in different regions alone. More recent studies by Yuan Weiyan et al. analyzed and compared the differences of ecological compensation at home and abroad, and revealed the basic consistency between the concept of “Payment for Ecosystem Service” abroad and that of China. The two differ in terms of starting points, key points, background and conditions, and the direction of policy implementation.

Ecological compensation, a concept introduced to China in the 1980s and 1990s, refers to the realization of ecological protection and effective use of ecosystem services through some policy instruments, so that the externality of ecological protection can be transformed into internality as much as possible. In comprehensive consideration of ecological protection costs, development opportunity costs, ecological products and ecological service values, government and market instruments should be utilized to coordinate the interests of all stakeholders, and financial transfer payments or market transactions should be adopted to give reasonable compensation to ecological protectors through institutional innovation, and the problem of “hitchhiking” in the consumption of ecological products should be solved. Ecological compensation should include the following main contents: 1) compensation for the cost of protecting (restoring) or destroying the ecosystem itself; 2) internalization of the externalities of economic benefits through economic means; 3) economic compensation for individual or regional inputs to protect the ecosystem and environment or the loss of giving up development opportunities; and 4) conservation investment to areas or objects with great ecological value.

China has a vastly different natural environment, with the population ranking first in the world and the per capita natural resources far below the world average. Since the reform and opening up, China has witnessed continuous rapid economic growth, which has accordingly led to excessive environmental load, prominent contradiction between the supply and demand of natural resources, and severe

ecological environment situation. Complemented by the twin sister-like correlation between ecological degradation and poverty, it contributes to the very prominent contradiction between improving the ecological environment and getting rid of poverty. Therefore, it is of great necessity and rationality to establish an ecological compensation mechanism. Li Wenhua et al. analyzed the specific practices of compensation for forest ecological benefits in China, and summarized the aspects that need to be improved in the compensation system for forest ecological benefits in China. Further, Fei Shimin et al. carried out an in-depth analysis on the necessity, principle, way and compensation standard for the establishment of a compensation mechanism for forest ecological benefits, providing a scientific basis for further improving the compensation mechanism for forest ecological benefits in China. In terms of watershed ecological compensation, Qian Shuimiao et al. carried out research from the aspects of system and market, and made clear the principle, standard, method and source of funds of watershed ecological compensation as well as the importance of establishing and perfecting watershed ecological compensation. Similarly, Zhou Dajie et al. expounded on the essence, principle, classification and mode of ecological compensation in watershed water resources management, as well as the importance of developing an operable compensation mechanism and a supervision and guarantee system for this mechanism. Cao Mingde, taking the legal system as the breakthrough point, provided useful suggestions for the problems existing in the theory and actual operation of ecological compensation for mineral resources in China. More studies by Cheng Linlin et al. summarized the present situation of the construction of an ecological compensation mechanism for mineral resources development in China, made a policy design for the ecological compensation mechanism of mineral resources development in China on the basis of drawing lessons from foreign experience, and proposed to establish the regulations for ecological compensation for mineral resources development and a special management department for ecological environment management in mining areas. Up to now, a large amount of theoretical and practical research has been carried out in the ecological fields such as forests, watersheds and minerals, and certain research results have been made in the subject and object, standard and way of ecological compensation. These played an indelible role in the environmental and social problems caused by ecological degradation in the early stage. But unfortunately, the research on ecological compensation of fishery resources started late and is in the exploratory stage. On May 13, 2016, the General Office of the State Council of the People's Republic of China issued the Implementation Opinions on Improving the Ecological Protection Compensation Mechanism, which clearly stated that the ecological compensation mechanism should be developed in the fields of forest, grassland, wetland, desert, ocean, water flow and cultivated land. With the implementation of the ecological compensation mechanism, a series of problems such as ecological environment have been effectively improved, and various studies on ecological compensation have emerged in an endless stream. Moreover, the mechanism has also been widely used in the protection and restoration of ecosystems and achieved remarkable practical results.

With the gradual decline of marine fishery resources and the continuous degradation of the marine environment since the 1990s, the protection of fishery resources has attracted more and more attention and likewise, academics have gradually devoted themselves to the study of it, from the exploration of the concept and legal positioning of ecological compensation to the gradual discussion of fishery compensation methods and compensation mechanisms. Ecological compensation of fishery resources is a means and institutional arrangement to adjust the interest relationship between fishery resources and the behavior subjects of damage and protection. Specifically, it can be used to compensate for the behavior of protection and restoration of fishery resources ecosystem through diversified adjustment of society, market and government and combined with the relevant standards of fishery resources. As a consequence, the income of the behavior subjects can be improved. As regards the cost of ecological protection and repairing the subjects, it is shared by the beneficiary subjects of fishery ecological benefits according to the benefit ratio, so as to facilitate the internalization of external costs of fishery resources economic development activities. In this way, the fishery resources and ecosystem services can be protected, restored and improved.

## 2. Literature Review

In terms of the fishery ecological compensation system, Zhu Jianzhen held the view that bringing the fishery into an orderly track needs to be achieved in three ways: improving fishing licenses and limited licenses, setting objective fishery production indicators, and establishing a declaration system for catches and catch yield. Li Wenhua et al. argued for an institutional arrangement of ecological restoration by relying on administrative and market compensation methods to coordinate ecological stakeholders<sup>[24]</sup>. There are also different views on the fishery ecological compensation system. Jia Xin et al. harbored the idea that an incentive mechanism of ecological compensation should be formed through institutional innovation and external policy adjustment to achieve the internalization of positive externalities of ecological protection, thus realizing the rational allocation of marine resources. Gao Qiang et al. believed that the ecological imbalance of marine fishery was formed under the action of natural and human factors through the analysis of the ecological imbalance mechanism of the marine fishery.

In terms of fishery ecological compensation methods, Zheng Miao Zhuang et al. took the attitude that in the practice of marine fishery ecological compensation, compensation methods such as policy compensation and material compensation should be brought into play to improve the efficiency of the implementation of compensation measures. Yang Wenbo et al. believed that it is essential to actively implement the job transfer of fishing fishermen, accelerate the proliferation of fishery resources, and safeguard fishery resources. Zhang Jiping et al. advocated that the establishment of a marine ecological compensation system is an important way to solve the deterioration of the marine ecological environment and the decline of fishery resources. The core is to strengthen legislation on marine ecological compensation, increase investment in fishery compensation funds, and establish a set of

effective marine ecological restoration and compensation mechanisms. However, Yang Zhengyong et al. hold different views. They agreed that governmental and market instruments should be combined to improve the efficiency of ecological compensation for fisheries. Vertically, the government should gradually clarify property rights and reduce transaction costs through macro-control, while horizontally, the market compensation mechanism should be brought into play.

In terms of fishery ecological compensation measures, Gao Qiang et al. believed that the research on the ecological restoration technology of marine fisheries in China should focus on the ecological imbalance mechanism of marine fisheries, and related technical means including control technology and reconstruction technology should be utilized to achieve the goal of marine ecological restoration. According to the study by Wang Miao et al, the loss of fishery ecological value should be analyzed from several aspects such as marine fishing, mariculture pollution, and industrial domestic sewage pollution, which should be used to assess the fishery ecological compensation. More studies have also suggested ecological compensation measures for fisheries. Yang Wenbo et al. believed that a sound environmental assessment and compensation system should be established, and the damaged marine resources should be compensated and repaired as soon as possible. Moreover, an ecological compensation mechanism should be formed for the protection of fishery resources. Bai Fuchen proposed to improve the Hague ecological value assessment system and, on this basis, to build a review system for marine ecological compensation value. In terms of the raising and effective use of fishery ecological compensation funds, Tong Chunfen et al. proposed to complete as soon as possible the government compensation means mainly based on financial transfer payment and the market compensation means mainly based on market transactions and ecological taxes and fees. Besides, the marine fishery ecological compensation fund should be established to ensure adequate compensation resources and effective management.

Research on ecological compensation theory and fishery ecological compensation has been conducted from different perspectives, including compensation systems, compensation methods and compensation measures, but they still remain theoretical and lack the support of mathematical and theoretical models. Moreover, there is limited research on the implementation of a fishery ecological compensation system, the way to achieve social equilibrium spontaneously, and the factors affecting the implementation of the ecological compensation system. According to Mao Weixi's analysis, China's fishery resources still showed a deteriorating trend after the implementation of the fishing moratorium, which was mainly due to institutional and non-institutional reasons. Therefore, the mathematical model of the evolutionary game is helpful to further explore the application of ecological compensation in related fields and the analysis of influencing factors.

Evolutionary game theory, according to Samuelson, is one of the most active and rapidly developing research fields in economics. Unlike traditional game theory models, which assume that all participants are perfectly rational and fully aware of the details of the game, the evolutionary model assumes that people choose strategies through a trial-and-error learning process in which they gradually discover

that certain strategies are more effective than others. A number of studies have explored the problems related to ecological compensation using evolutionary games and explored their optimal solutions. Taking Zhu Xiao et al.'s study as an example, the evolutionary game model was applied to discuss the strategy selection of the three parties including the central government, the local government and the enterprises in the process of mineral resource exploitation. Tan Wanbing constructed a mathematical model of evolutionary game with the upper and lower reaches of the Xiangjiang River basin as the main body under the intervention of superior strong reciprocal government. In the study of Li Jiqing et al., an evolutionary game model of ecological compensation for cross-basin water transfer projects was constructed to analyze the interest demands and compensation behaviors among local governments in water source areas, in water receiving areas and superior governments. Relying on the evolutionary game model, Li Yunyan et al. discussed the strategic choice and evolution direction of the two main game players of the central government and the local government by analyzing the interrelationship and function of various interest parameters that affect the regional joint prevention and control strategy. Further, Zhang Weiwei et al. put forward the evolutionary game of ecological compensation for cross-regional forest protection, and analyzed the interest relationship and logical relationship among the three game players of government, enterprises and residents. The research on ecological compensation by evolutionary game mostly focuses on upstream and downstream compensation of river basins, ecological compensation for cross-regional forest protection, ecological compensation for air pollution and ecological compensation for mineral resources development, etc. Little research has been conducted on the ecological compensation system of the marine fishing moratorium and the relationship between balancing the sustainable development of China's fisheries and poverty alleviation of fishermen, and there is a lack of application of evolutionary game theory in ecological compensation of marine fishery.

To further investigate the impact of fishery ecological compensation measures on the implementation of the fishing moratorium system, a superior strong reciprocal type of government regulation is introduced in this study based on the hypothesis of bounded rationality and using an evolutionary game mathematical model. A tripartite evolutionary game model is constructed and simulation analysis is carried out to solve the problems encountered by ecological compensation measures when they converge to the optimal strategy combination expected by the society. In addition, the effects of different external factors on the strategic equilibrium point are analyzed to better approximate the reality and provide effective suggestions.

### **3. Model Construction**

#### *3.1 Game Subject and Action Strategy*

An ecological compensation system is a crucial means to realize the sustainable development of fisheries, improve the marine ecological environment and lift fishermen out of poverty. Only through the joint efforts of local fishermen, local governments and superior governments can it achieve the goal

of fishing moratorium and maximize fishermen's income simultaneously. In this way, two levels of ecological compensation relationship have been formed, on the one hand, the political compensation relationship between superior governments and local governments, on the other hand, the ecological compensation relationship between local governments and local fishermen.

In the process of implementing the ecological compensation system, fishermen will choose the most suitable strategy according to the principle of maximizing their own benefits. In other words, the willingness of fishermen to opt for a moratorium increases when the benefits from fishing moratorium outweigh the losses from fishing moratorium, and conversely, the incentive to choose an illegal fishing strategy increases; According to the principle of maximizing their own performance or local economic growth, local governments will choose the goals that best meet their local development. That is to say, the basis for local governments to choose ecological compensation is the difference between their own benefits and their implementation costs. When the benefits outweigh the costs, local governments prefer positive compensation strategies and vice versa for strategies that deny compensation. Superior governments, as strong reciprocal governments, insist to a certain extent on punishing the non-cooperators and cooperative saboteurs in the group even if they themselves need to pay a relatively high price. In the process of choosing whether to conduct strict supervision, superior governments will choose the most suitable supervision strategy according to the principle of maximizing social welfare and promoting the effective implementation of ecological compensation measures. That is to say, the basis for superior governments to choose strict supervision is determined by their own probability of implementing ecological compensation to local governments and the probability of fishermen choosing to conduct fishing moratorium. If superior governments perceive that local governments are less willing to actively compensate or fishermen are less willing to conduct fishing moratorium, they will intervene in strict supervision and correct the behavior of local governments or fishermen through punitive measures.

There are two strategies that can be adopted by superior governments under the above mechanism. One is strict supervision. In order to promote local governments to implement ecological compensation measures and urge fishermen to consciously abide by the summer fishing moratorium system, superior governments need to strictly supervise local governments or fishermen; The second is loose supervision. When local governments actively implement ecological compensation measures and fishermen do not violate the rules of fishing, superior governments choose loose supervision to reduce unnecessary costs for the principle of maximizing social welfare. There are also two strategies for local fishermen to choose from. One is to conduct fishing moratorium, i.e., to abide by the arrangement of the fishing moratorium and suspend fishing activities; The second is illegal fishing, i.e., not obeying the arrangement of the fishing moratorium and continuing fishing activities. Similarly, there are two strategies available to local governments. One is positive compensation, i.e., fully implement ecological compensation measures and supervise them; The second is a refusal of compensation, i.e., not fully implementing or not implementing ecological compensation measures at all.

According to the above situation, a tripartite game relationship including superior governments, local governments and local fishermen has been formed, as shown in Table 1.

**Table 1. Tripartite Game Strategy**

Game subject	Strategy	Selection probability
Local fishermen	Fishing moratorium	$x$
	Illegal fishing	$1-x$
Local governments	Positive compensation	$y$
	Refusal of compensation	$1-y$
Superior governments	Strict supervision	$z$
	Loose supervision	$1-z$

### 3.2 Model Hypothesis

Based on the above analysis, the following hypotheses are made in this paper:

Hypothesis 1: local fishermen are participants 1, local governments are participants 2, and superior governments are participants 3. The goal of fishermen is to maximize their own benefits, that of local governments is to maximize their own performance or local economic growth, while superior governments are strong reciprocal governments with the goal of maximizing social welfare and promoting the effective implementation of ecological policies. Because of the strong information and behavior ability of strong reciprocal governments, their fixed existence can standardize meaningful cooperation and altruism among groups by policies, thus realizing the effective allocation of social resources. All three parties are participants of bounded rationality, and the strategy choice gradually evolves and stabilizes at the optimal strategy with time.

Hypothesis 2: When local fishermen choose to conduct fishing moratorium, the ecological benefits obtained by fishermen from improving the marine ecological environment are  $H$ , and the income of fishermen is reduced by  $t\%$  due to the suspension of fishing activities. Assuming that the expected income of fishermen before the suspension of fishing system is  $M$ , the income reduced by fishermen due to the suspension of fishing activities is  $t*M$ .

Hypothesis 3: When local governments choose to make positive compensation for fishermen, they will issue ecological subsidies  $S$  to fishermen and supervise their behavior of going out for fishing. The fishermen who illegally fish during the fishing moratorium will be fined  $P$  and local governments will suffer ecological loss  $L$  (such as environmental governance costs) with regulatory costs of  $C$ . Local governments will gain ecological benefits  $E$  from the improvement of marine ecological environment. Given the critical importance of economic development to local governments, fishermen's cessation of fishing behavior will cause local governments to suffer local economic growth losses  $G$ .

Hypothesis 4: Superior governments will regulate the behavior of both local governments and fishermen when they impose strict regulations, with a regulatory cost of  $T_c$ . Superior governments will give political rewards  $R$  to local governments that make positive compensation and effectively improve the marine environment, and penalties  $T_3$  to local governments that refuse to compensate. Moreover, superior governments will fine fishermen for illegal fishing. When the policy is fully implemented, superior governments will gain political benefits  $T_1$ . When local governments choose to make positive compensation and fishermen choose illegal fishing, the recovery of marine ecological environment is limited and the expected goal cannot be achieved, and superior governments can only get limited political gains  $(1-a)T_1$ , where  $a$  means the percentage of lost political gains. In addition, when local governments choose the strategy of refusing compensation and fishermen choose the strategy of illegal fishing, by default, the state at this time is equivalent to the state where the marine environment suffered great damage before the implementation of ecological compensation. At this time, superior governments will suffer corresponding losses  $T_2$  (such as reputation loss, and environmental governance costs).

Hypothesis 5: Local governments and local fishermen can know each other's decision-making choices in advance or that the information costs are minimal and negligible. Whether or not superior governments choose a strict supervision strategy is unknowable to local governments and local fishermen in advance or at great cost to information, which they can only know afterward.

Therefore, the benefit matrix of ecological compensation game among local fishermen, local governments and superior governments is constructed, as shown in Table 2.

**Table 2. Benefit Matrix of Ecological Compensation Game among Local Fishermen, Local Governments and Superior Governments**

		Local governments				
		Positive compensation (y)	Refusal of compensation (1-y)	of	Positive compensation (y)	Refusal of compensation (1-y)
Local fishermen	Fishing	$S+(1-t)M+H;$	$(1-t)M+H; E-G-T_3;$		$S+(1-t)M+H;$	$(1-t)M+H; E-G; T_1$
	moratorium (x)	$E+R-C-S-G; T_1-T_c$	$T_1-T_c+T_3;$		$E+R-C-S-G; T_1$	
	Illegal fishing (1-x)	$-P+M-T_4; -C+P-L-G;$	$M;-L-T_3;$		$-P+M; -C+P-L-G;$	$M; -L; -T_2$
		$(1-a)T_1-T_c+T_4$	$-T_2-T_c+T_3$		$(1-a)T_1$	
		Strict supervision(z)			Loose supervision (1-z)	
		Superior governments				

Note. For each pure strategy combination, the first one is the benefit of local fishermen, the second is the benefit of local governments, and the third is the benefit of superior governments.

### 4. Analysis of Evolutionary Stable Strategy

#### 4.1 Analysis of Local Fishermen's Stability Strategy

Let and represent the expected benefits of local fishermen when they choose the strategy of stopping fishing and illegal fishing, respectively, and let represent the expected benefits of local fishermen.

$$\pi_{11} = yz(H+S-M(t-1)) + (y-1)(z-1)(H-M(t-1)) - z(y-1)(H-M(t-1)) - y(z-1)(H+S-M(t-1)) \quad (1)$$

$$\pi_{12} = -yz(P-M+T4) + (y-1)(z-1)(M) - y(z-1)(M-P) - z(y-1)(M) \quad (2)$$

$$\pi_1 = x\pi_{11} + (1-x)\pi_{12} \dots\dots\dots (3)$$

According to the principle of replication dynamic equation, the replication dynamic equation of local fishermen is constructed:

$$F(x) = \frac{\partial x}{\partial t} = x(\pi_{11} - \pi_1) = x(1-x)(H-M \cdot t + P \cdot y + S \cdot y + T4 \cdot z \cdot y) \dots\dots\dots (4)$$

The strategic evolution phase diagram of local fishermen is shown in Fig. 1. Fig. 1 shows that the probability of fishermen choosing illegal fishing is volume  $V_{A1}$  of A1, while that of stable fishing moratorium is volume  $V_{A2}$  of A2. The following conclusions are drawn based on the stability theorem of the differential equation and the analysis result of evolutionary stable strategy:

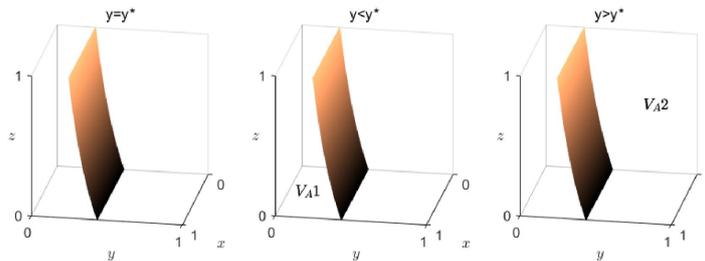


Figure 1. Strategic Evolution Phase Diagram of Local Fishermen

Conclusion 1: The probability of local fishermen choosing the strategy of fishing moratorium increases with the increase of the probability of positive compensation by local governments.

It is proved that if  $y = \frac{M-t-H}{P+S+T4z} = y^*$ ,  $F=0$ , then the probability  $x$  of fishermen choosing fishing moratorium is a stable strategy regardless of any value, i.e., the strategy of fishermen does not change with time; Let  $F(x)=0$ , then  $x=0$  or  $1$ , and only when  $\frac{\partial F(x)}{\partial x} < 0$ , this point is an evolutionary stable point.

Let and use to find the partial derivative of  $x$ , then  $\frac{\partial F(x)}{\partial x} = (1-2x)(H-M \cdot t + P \cdot y + S \cdot y + T4 \cdot z \cdot y)$ . When  $y < y^*$ ,

$$\left. \frac{\partial F(x)}{\partial x} \right|_{x=0} < 0, \text{ at which time is an evolutionary stable strategy; When } y > y^*, \left. \frac{\partial F(x)}{\partial x} \right|_{x=1} < 0, \text{ at}$$

which time is an evolutionary stable strategy.

Conclusion 2: The probability of fishermen choosing fishing moratorium is positively related to the ecological benefits obtained from the improvement of the ecological environment, the fines imposed by

superior governments, the fines imposed by local governments and the ecological compensation, while negatively related to the expected income of fishermen.

It is proved that the probability of fishermen choosing illegal fishing is volume  $V_{A1}$  of A1, while that of the stable fishing moratorium is volume  $V_{A2}$  of A2. The equations for both are as follows:

$$V_{A1} = \int_0^1 \int_0^1 \frac{M \cdot t - H}{P + S + z \cdot T4} dz dx = \frac{M \cdot t - H}{T4} \cdot \ln \left( 1 + \frac{T4}{P + S} \right) \dots \dots \dots (5)$$

$$V_{A2} = 1 - V_{A1} \dots \dots \dots (6)$$

According to the expression of the probability of local fishermen choosing fishing moratorium, the first-order partial derivatives of each factor are found to yield  $\partial V_{A2} / \partial M < 0$ ,  $\partial V_{A2} / \partial H > 0$ ,  $\partial V_{A2} / \partial S > 0$ ,  $\partial V_{A2} / \partial P > 0$ ,  $\partial V_{A2} / \partial T4 > 0$ .

4.2 Analysis of Local Governments' Stable Strategy

Let and represent the expected benefits of local governments when they choose active and passive implementation strategies, respectively, and let represent the expected benefits of local governments.

$$\pi_{21} = z(x-1)(C+G+L-P) - xz(C-E+G-R+S) + x(z-1)(C-E+G-R+S) - (x-1)(z-1)(C+G+L-P) (7)$$

$$\pi_{22} = z(x-1)(L+T3) - (x-1)(z-1)(L) - xz(C-E+T3) - x(z-1)(E-G) (8)$$

$$\pi_2 = y\pi_{21} + (1-y)\pi_{22} (9)$$

According to the principle of replication dynamic equation, the replication dynamic equation of local governments is constructed:

$$F(y) = \frac{\partial y}{\partial t} = y(\pi_{21} - \pi_2) = y(y-1)(G+C-P+x \cdot (P+S-G-R)-T3 \cdot z) (10)$$

The strategic evolution phase diagram of local governments is shown in Fig. 2. Fig. 2 shows that the probability of local governments choosing refusal of compensation is volume  $V_{B1}$  of B1, while that of stable positive compensation is volume  $V_{B2}$  of B2. The following conclusions are drawn based on the stability theorem of the differential equation and the analysis result of evolutionary stable strategy:

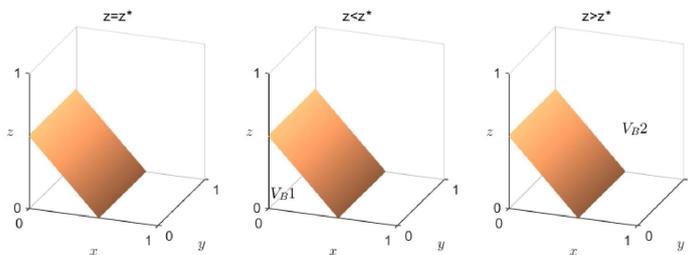


Figure 2. Strategic Evolution Phase Diagram of Local Governments

Conclusion 3: The probability of local governments choosing active implementation strategies increases with the increase of the probability of strict supervision by superior governments.

It is proved that if  $z = \frac{C+G-P+x \cdot S-x \cdot G-x \cdot R-x}{T3} = z^*$ ,  $F \equiv 0$ , then the probability y of local governments choosing positive compensation is a stable strategy regardless of any value, i.e., the strategy of local

governments does not change with time; Let  $F(y)=0$ , then  $y=0$  or  $1$ , and only when  $\frac{\partial F(y)}{\partial y} < 0$ , this point is an evolutionary stable point. Let and use to find the partial derivative of  $y$ , then  $\frac{\partial F(y)}{\partial y} = (2y-1)(G+C-P-G \cdot x + P \cdot x - R \cdot x + S \cdot x - T3 \cdot z)$ . When  $z < z^*$ ,  $\frac{\partial F(y)}{\partial y} \Big|_{y=0} < 0$ , at which time is an evolutionary stable strategy; When  $z > z^*$ ,  $\frac{\partial F(y)}{\partial y} \Big|_{y=1} < 0$ , at which time is an evolutionary stable strategy.

Conclusion 4: The probability of local governments choosing positive compensation is positively related to the fine imposed on fishermen, the fine imposed by superior governments and the political gains obtained by local governments, while negatively related to the loss of local economic growth and the cost of supervision.

It is proved that the probability of local governments choosing refusal of compensation is volume  $V_{B1}$  of B1, while that of stable positive compensation is volume  $V_{B2}$  of B2. The equations for both are as follows:

$$V_{B1} = \int_0^1 \int_0^{\frac{P-C-G}{P+S-G-R}} \frac{C+G-P+x \cdot P+x \cdot S-x \cdot G-x \cdot R}{T3} dx dy = \frac{(C+G-P)^2}{2 \cdot T3 \cdot (G-P+R-S)} \dots \dots \dots (11)$$

$$V_{B2} = 1 - V_{B1} \dots \dots \dots (12)$$

According to the expression of the probability of local governments choosing active implementation, the first-order partial derivatives of each factor are found to yield  $\partial V_{B2} / \partial P > 0$ ,  $\partial V_{B2} / \partial G < 0$ ,  $\partial V_{B2} / \partial C < 0$ ,  $\partial V_{B2} / \partial T3 > 0$ ,  $\partial V_{B2} / \partial R > 0$ .

4.3 Analysis of Superior Governments' Stable Strategy

Let and represent the expected benefits of superior governments when they choose strict supervision and loose supervision strategies, respectively, and let represent the expected benefits of superior governments.

$$\pi_{31} = y(x-1)(Tc-T4+T1(a-1)) - x(y-1)(T1+T3-Tc) + yx(T1-Tc) - (x-1)(y-1)(T2-T3+Tc) \dots (13)$$

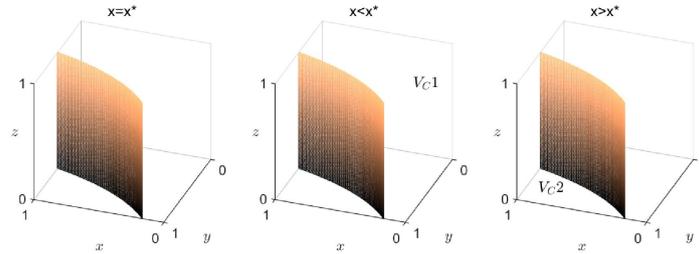
$$\pi_{32} = yx(T1) - (x-1)(y-1)(T2) - x(y-1)(T1) + y(x-1)((a-1)T1) \dots \dots \dots (14)$$

$$\pi_3 = y\pi_{31} + (1-y)\pi_{32} \dots \dots \dots (15)$$

According to the principle of replication dynamic equation, the replication dynamic equation of superior governments is constructed:

$$F(z) = \frac{\partial z}{\partial t} = z(\pi_{31} - \pi_3) = z(z-1)(Tc-T3-T4 \cdot y + T3 \cdot y + T4 \cdot x \cdot y) \dots \dots \dots (16)$$

The strategic evolution phase diagram of superior governments is shown in Fig. 3. Fig. 3 shows that the probability of superior governments choosing strict supervision is volume  $V_{C1}$  of C1, while that of loose supervision is volume  $V_{C2}$  of C2. The following conclusions are drawn based on the stability theorem of the differential equation and the analysis result of evolutionary stable strategy:



**Figure 3. Strategic Evolution Phase Diagram of Superior Governments**

Conclusion 5: The probability of superior governments choosing strict supervision strategy decreases with the increase of the probability of fishing moratorium by fishermen.

It is proved that if  $x = \frac{T3+T4 \cdot y - Tc - T3 \cdot y}{T4 - y} = x^*$ ,  $F=0$ , then the probability  $z$  of superior governments choosing strict supervision is a stable strategy regardless of any value, i.e., the strategy of superior governments does not change with time; Let  $F(z)=0$ , then  $z=0$  or  $1$ , and only when  $\frac{\partial F(z)}{\partial z} < 0$ , this point is an evolutionary stable point. Let and use to find the partial derivative of  $z$ , then  $\frac{\partial F(z)}{\partial z} = (2z-1)(Tc-T3-T4 \cdot y+T3 \cdot y+T4 \cdot x \cdot y)$ . When  $x < x^*$ ,  $\frac{\partial F(z)}{\partial z} \Big|_{z=1} < 0$ , at which time is an evolutionary stable strategy; When  $x > x^*$ ,  $\frac{\partial F(z)}{\partial z} \Big|_{z=0} < 0$ , at which time is an evolutionary stable strategy.

Conclusion 6: The probability that superior governments chooses strict supervision is positively related to the fines imposed on local fishermen and local governments, while negatively related to the supervision cost of superior governments themselves.

It is proved that the probability of superior governments choosing compensation is volume  $V_{C1}$  of  $C1$ , while that of non-compensation is volume  $V_{C2}$  of  $C2$ . The equations for both are as follows:

$$V_{C1} = \int_0^1 \int_{\frac{T4-Tc}{T4}}^1 \frac{T3-Tc}{T3-T4+T4 \cdot x} dx dz + \frac{T4-Tc}{T4} = \frac{T3-Tc}{T4} \cdot \ln\left(\frac{T3}{T3-Tc}\right) + \frac{T4-Tc}{T4} \dots \dots \dots (17)$$

$$V_{C2} = 1 - V_{C1} \dots \dots \dots (18)$$

According to the expression of the probability of superior governments choosing strict supervision, the first-order partial derivatives of each factor are found to yield  $\partial V_{C1} / \partial T3 > 0$ ,  $\partial V_{C1} / \partial T4 > 0$ ,  $\partial V_{C1} / \partial Tc < 0$ .

**4.4 System Stable Analysis**

In the system, the subjects interact with each other, and the change of one factor will lead to the change of one subject's strategy, which in turn will affect the behavior strategies of other subjects. As a result, the behavior strategies of all three parties will be adjusted and changed. Therefore, on the basis of

analyzing the stable strategy of game subjects, it is necessary to further analyze the conditions for the system to achieve stability.

Let 0, then the 8 local equilibrium points of the solvable equation are  $E_1(0, 0, 0)$ ,  $E_2(1, 0, 0)$ ,  $E_3(0, 1, 0)$ ,  $E_4(0, 0, 1)$ ,  $E_5(1, 1, 0)$ ,  $E_6(1, 0, 1)$ ,  $E_7(0, 1, 1)$ ,  $E_8(1, 1, 1)$ . Where, are equations with respect to time t, and the replica dynamic equation is the derivative of with respect to time t. According to the geometric meaning of derivative, the replication dynamic equation reflects the direction and speed of local fishermen, local governments and superior governments' strategic choices changing with time. When the replication dynamic equation is equal to zero, the strategies of local fishermen, local governments and superior governments reach a relatively balanced state. At this time, the strategies of the three parties do not change with time, but this balanced state does not mean that this is a stable state, so it is necessary to discuss whether this local equilibrium point is a stable strategy of the three parties.

According to evolutionary game theory (Frieman, 1991; Ritzberger et al., 1995), when all eigenvalues in Jacobian matrix are non-positive, the equilibrium point is the evolutionary stable strategy point (ESS) of the system. The Jacobian matrix of the replication dynamic equation is:

$$J = \begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} \dots\dots\dots (19)$$

$$J_1 = (1-2 \cdot x) \cdot (H - M \cdot t + P \cdot y + S \cdot y + T4 \cdot y \cdot z) \dots\dots\dots (20)$$

$$J_2 = (P+S+T4 \cdot z) \cdot x \cdot (1 - x) \dots\dots\dots (21)$$

$$J_3 = x \cdot (T4 \cdot y) \cdot (1 - x) \dots\dots\dots (22)$$

$$J_4 = y \cdot (1 - y) \cdot (G - P+R-S) \dots\dots\dots (23)$$

$$J_5 = (2 \cdot y - 1) \cdot (G+C - P - G \cdot x + P \cdot x - R \cdot x + S \cdot x - T3 \cdot z) \dots\dots\dots (24)$$

$$J_6 = T3 \cdot y \cdot (1-y) \dots\dots\dots (25)$$

$$J_7 = z \cdot (T4 \cdot y) \cdot (z - 1) \dots\dots\dots (26)$$

$$J_8 = (T3 - T4 + T4 \cdot x) \cdot z \cdot (z - 1) \dots\dots\dots (27)$$

$$J_9 = (2 \cdot z - 1) \cdot (Tc - T3 + T3 \cdot y - T4 \cdot y + T4 \cdot x \cdot y) \dots\dots\dots (28)$$

By substituting the equilibrium points into the matrix, the eigenvalues of each equilibrium point are obtained (Table 3).

**Table 3. Eigenvalues of Each Equilibrium Point**

Equilibrium point	Eigenvalue $\lambda_1$	Eigenvalue $\lambda_1$	Eigenvalue $\lambda_1$
$E_1(0, 0, 0)$	$H - M \cdot t$	$P - G - C$	$T3 - Tc$
$E_2(1, 0, 0)$	$M \cdot t - H$	$R - C - S$	$T3 - Tc$
$E_3(0, 1, 0)$	$H + P + S - M \cdot t$	$C + G - P$	$T4 - Tc$

$E_4(0, 0, 1)$	$H-M-t$	$P-G-C+T3$	$Tc-T3$
$E_5(1, 1, 0)$	$M-t-P-S-H$	$C-R+S$	$-Tc$
$E_6(1, 0, 1)$	$M-t-H$	$R-C-S+T3$	$Tc-T3$
$E_7(0, 1, 1)$	$H+P+S+T4-M-t$	$G+C-P-T3$	$Tc-T4$
$E_8(1, 1, 1)$	$M-t-H-P-S-T4$	$C-R+S-T3$	$Tc$

Since all the parameters are positive values, and is unstable. The positive and negative of the characteristic roots corresponding to other equilibrium points cannot be directly judged, so it needs to be discussed in different situations. Comparing and  $E_5$ , when certain conditions are met, is unstable when is a stable point, and is stable when is a stable point. The same is true of  $E_1$  and  $E_4$ , and  $E_7$ , and  $E_8$ , and so on. Therefore, the following discussion is divided into four cases.

Case 1: ① When  $H-M-t < 0$ ,  $P-G-C < 0$  and  $T3-Tc < 0$ , is a stable point, i.e., (illegal fishing, refusal of compensation, negative supervision). In this case, superior governments punish local governments with low or no punishment measures, and adopt loose supervision measures, which lacks binding force. Local governments' strategic choice behavior is related to its illegal fines for fishermen, regulatory costs and local economic growth losses. Because it is costly for local governments to take ecological compensation measures (greater than the sum of their own regulatory costs and local economic growth losses), local governments refuse to make ecological compensation for fishermen. For local fishermen, due to the lack of ecological compensation from local governments, their strategic choice behavior is only related to their own losses and the gains from the improvement of the ecological environment. In this case, the loss of fishermen's expected benefits is greater than those from their compliance with the fishing moratorium system, so fishermen adopt illegal fishing strategies. Due to the passive supervision strategy, superior governments have low rewards and punishments for local governments or fishermen, which eventually leads to the failure to implement ecological compensation measures in this area and further affects the summer fishing moratorium system. Therefore, in the absence of strong supervision and ecological compensation measures from superior governments, the implementation of the fishing moratorium system is vulnerable to resistance from both local governments and local fishermen. ② When  $H-M-t < 0$ ,  $P-G-C+T3 < 0$  and  $Tc-T3 < 0$ , is a stable point, i.e., (illegal fishing, refusal of compensation, strict supervision). The sum of local governments' economic growth losses and their own regulatory costs is far greater than the sum of the rewards and fines of superior governments, and local governments lack the motivation to actively implement ecological compensation measures, so they adopt the strategy of refusal of compensation. Furthermore, local fishermen's benefits from implementing the summer fishing moratorium system are less than their economic losses, and there is no local government to make ecological compensation. Fishermen also lack the motivation to abide by the summer fishing moratorium system, and fishermen adopt overfishing strategies. The system of fishing moratorium in summer is met with resistance from both local governments and local fishermen. At this time, superior governments will ensure the implementation of ecological compensation

measures and promote the implementation of the summer fishing moratorium system by intervening in strict supervision and high punishment.

Case 2: ① When  $M \cdot t - H < 0$ ,  $R - C - S < 0$  and  $T_3 - T_c < 0$ , is a stable point, i.e., (fishing moratorium, refusal of compensation, negative supervision). At this time, superior governments adopt the strategy of loose supervision, and impose a small fine or no punishment on local governments. Fishermen's benefits from improving the ecological environment are greater than their economic losses from suspending fishing activities, so fishermen choose the strategy of fishing moratorium. For local governments, because the political reward they get is less than the sum of the ecological compensation value and supervision cost for fishermen, local governments adopt the strategy of refusing compensation. Therefore, in the absence of strict supervision by superior governments, local governments lack the motivation to make ecological compensation for fishermen for their own consideration. However, the local fishermen's expected income loss is small (less than the gains from their fishing moratorium), and fishermen will consciously to conduct fishing moratorium for the sake of maximizing their own gains.

(2) When  $M \cdot t - H < 0$ ,  $R - C - S + T_3 < 0$  and  $T_c - T_3 < 0$ , is a stable point, i.e., (fishing moratorium, refusal of compensation, strict supervision). Because the sum of the supervision cost of local governments and the cost of ecological compensation is relatively large (greater than the sum of the fines imposed by superior governments and the rewards given by superior governments to local governments), local governments still prefer to choose the strategy of refusing compensation. At this time, it is necessary for superior governments to take long-term strict supervision measures, correct local governments' behaviors through appropriate rewards and punishments, ensure the implementation of ecological compensation measures and promote the implementation of the fishing moratorium system.

Case 3: ① When  $H + P + S - M \cdot t < 0$ ,  $C + G - P < 0$  and  $T_4 - T_c < 0$ , is a stable point, i.e., (illegal fishing, positive compensation, negative supervision). At this time, superior governments adopt the strategy of loose supervision, and impose a small fine or no punishment on local governments. The benefits brought by local fishermen's suspension of fishing activities (the sum of the benefits obtained from the improvement of ecological environment, the ecological compensation value and the fines imposed by local governments) are less than their economic losses, and fishermen have the motivation to fish illegally. For local governments, because their fines for fishermen are greater than the sum of local economic growth losses and regulatory costs, they have enough enthusiasm to make ecological compensation for fishermen.

② When  $H + P + S - M \cdot t < 0$ ,  $G + C - P - T_3 < 0$  and  $T_c - T_4 < 0$ , is a stable point, i.e., (illegal fishing, positive compensation, strict supervision). Due to the lack of initiative and enthusiasm of local fishermen to adopt the strategy of stopping fishing, it is necessary for superior governments to carry out long-term strict supervision and regulate fishermen's behavior by raising the fines imposed on fishermen by superior governments, so as to effectively implement the system of stopping fishing in summer.

Situation 4: When and  $C - R + S < 0$ , is a stable point, i.e., (fishing moratorium, positive compensation, loose supervision). When the political reward of superior governments to local governments is greater

than the sum of local governments' own supervision cost and the ecological compensation to the fishermen, and local governments are not affected by the loss of local economic growth (or the loss of local economic growth is minimal), local governments adopt the positive compensation strategy. For local fishermen, the economic loss of fishermen is less than the sum of ecological compensation, ecological benefits and local government fines. At this time, fishermen adopt the strategy of stopping fishing. Because ecological compensation measures are enough to correct the strategic choices of local governments and local fishermen, at this time, superior governments do not need to maintain a long-term strict supervision strategy.

## 5. Numerical Analysis

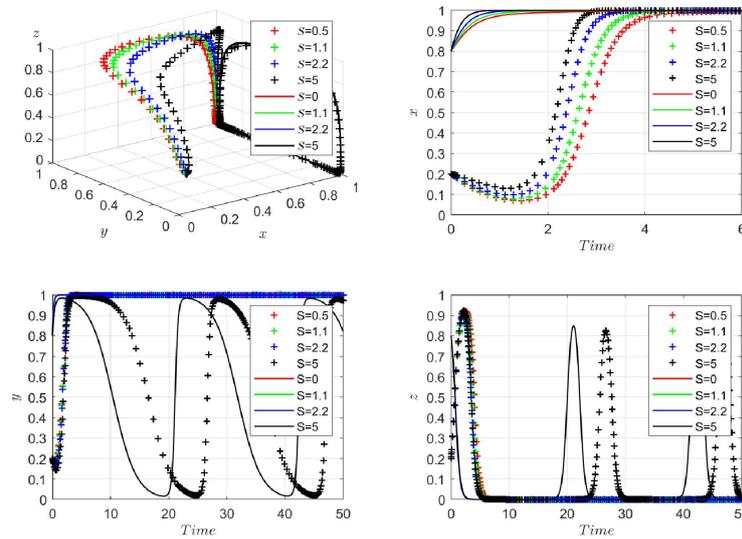
According to the discussion of system stability analysis above, the influence law of each parameter change on the final stable state of the system is further analyzed by numerical simulation, that is, the influence law of each parameter changes on the three-way strategy selection. Among them, the influence laws of C, M, H, L and other parameters are similar to the research results of Lili Ding et al. (2021), because under the analytical framework, the research on the influencing factors of summer fishing moratorium system is similar to the research on ecological compensation measures in this paper, and the existing research results on the influencing factors of seasonal fishing moratorium system can be directly extended to the game analysis framework of ecological compensation mechanism, so the influence laws of relevant parameters on fishermen and local governments are similar to those of summer fishing moratorium system. In this study, the effects of political incentives and penalties from superior governments to local governments, ecological subsidies and penalties from local governments to fishermen, and initial probabilities on the choice of tripartite strategies are analyzed.

### *5.1 Ecological Subsidies and Penalties for Local Fishermen and the Influence of Initial Probability on Tripartite Strategy Selection*

Firstly, the influence of the change of ecological compensation on fishermen's evolutionary game is studied. Referring to the research results of Lili Ding et al. (2021), the numerical value 1:

$E=10$ ;  $H=2.5$ ;  $R=7$ ;  $L=5$ ;  $C=2.5$ ;  $S=0.5$ , 1.1, 2.2, 5;  $P=1.8$ ;  $M=17$ ;  $t=0.25$ ;  $G=2$ ;  $T1=5$ ;  $Tc=2.5$ ;  $T2=10$ ;  $T3=5$ ;  $a=0.25$ ;  $T4=3$

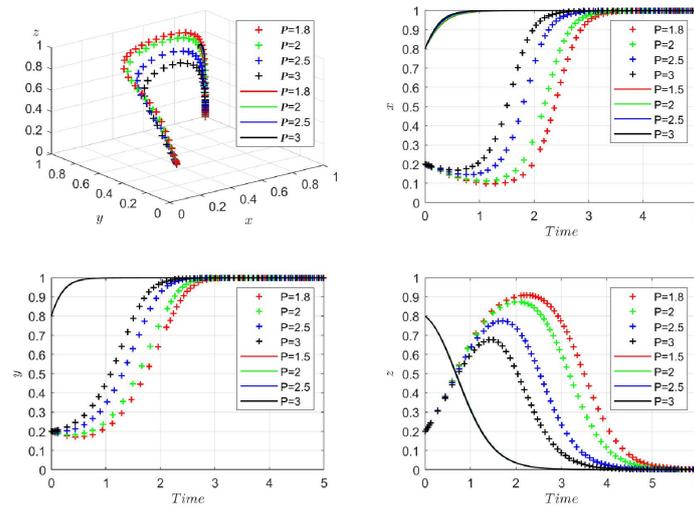
is selected. The initial value is and  $x=0.8$ ,  $y=0.8$ ,  $z=0.8$ . By analyzing its changing trend, the simulation results of replicating dynamic equations evolving 50 times with time are shown in Fig. 4:



**Figure 4. Influence of Ecological Compensation Value on Fishermen's Strategic Choice**

It can be seen from Fig. 4 that, on the one hand, when the ecological compensation value is within a proper range, the higher ecological subsidies given by local governments to fishermen will help them to converge to the strategic choice of stopping fishing, and the higher the initial probability of fishermen choosing to conduct fishing moratorium, the shorter the evolution process of fishermen's stable strategy of stopping fishing. For local governments and superior governments, when the ecological compensation value is within a certain range, for different initial points, both local governments and superior governments converge to the strategic choice of (positive compensation and loose supervision), and the evolution rate of local governments converging to the steady state increases with the decrease of ecological compensation value, while the evolution rate of superior governments converging to the steady state increases with the increase of ecological compensation value. On the other hand, when the ecological compensation value exceeds a certain range, the excessive ecological compensation value is enough to make up for all the losses caused by fishermen's suspension of fishing, which makes fishermen converge on the strategic choice of fishing moratorium at a faster evolutionary speed. On the contrary, compared with local governments, the excessive ecological compensation value has the motivation to refuse compensation for different initial points based on the principle of maximizing its own benefits. Therefore, local governments will choose the strategy with the strict supervision of superior governments or not. As shown in Fig. 4, the strategy choices of local governments and superior governments are both presented as waveforms.

Then, the influence of the change of local governments' punishment measures on fishermen on evolutionary game is discussed, and the numerical value 2: is selected. The initial value is and  $x=0.8$ ,  $y=0.8$ ,  $z=0.8$ . By analyzing its changing trend, the simulation results of replicating dynamic equations evolving 50 times with time are shown in Fig. 5:



**Figure 5. Influence of Local Government Fines on Fishermen's Strategic Choice**

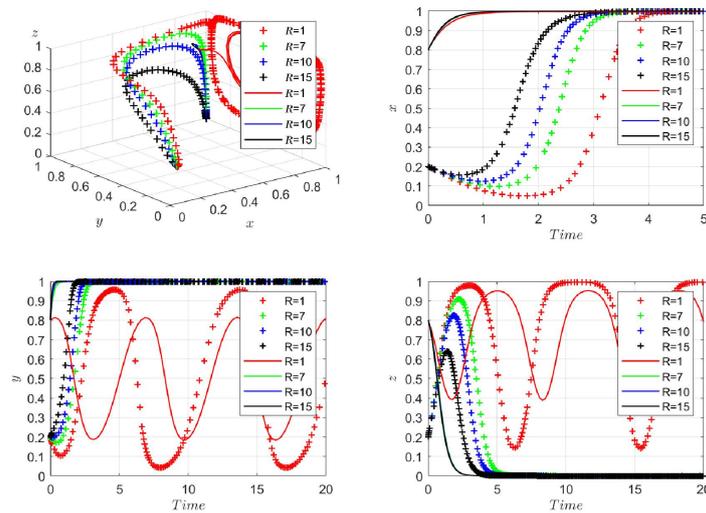
According to the analysis in Fig. 5, no matter how the initial point is selected, when local governments actively carry out ecological compensation, the harsher the local governments punish the fishermen, the more helpful it is for the fishermen to choose the strategy of stopping fishing, and the evolution rate of the fishermen's stable strategy of stopping fishing increases with the increase of local government punishment. For local governments, the increase of punishment for fishermen means that the cost of local governments' active compensation strategy is reduced, which is also helpful to improve the enthusiasm of local governments for ecological compensation. For superior governments, with the increase of fines imposed by local governments on fishermen, the rate of convergence and stability of local governments and local fishermen in the strategy of stopping fishing and the strategy of active compensation has accelerated, so the cycle of superior governments from strict supervision to loose supervision has been shortened with the increase of fines imposed by local governments on fishermen.

### 5.2 Political Rewards and Punishments to Local Governments and the Influence of Initial Probability on Tripartite Strategy Selection

The influence of the change of political reward to local governments on evolutionary game is studied, and the numerical value 3:

$E=10$ ;  $H=2.5$ ;  $R=1, 7, 10, 15$ ;  $L=5$ ;  $C=2.5$ ;  $S=2.2$ ;  $P=1.8$ ;  $M=17$ ;  $t=0.25$ ;  $G=2$ ;  $T1=5$ ;  
 $Tc=2.5$ ;  $T2=10$ ;  $T3=5$ ;  $a=0.25$ ;  $T4=3$

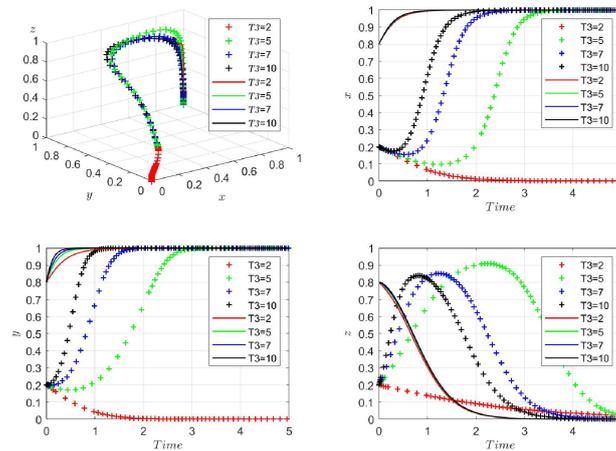
is selected. The initial value is  $x=0.2, y=0.2, z=0.2$  and  $x=0.8, y=0.8, z=0.8$ . By analyzing its changing trend, the simulation results of replicating dynamic equations evolving 50 times with time are shown in Fig. 6:



**Figure 6. Influence of Political Incentives on the Strategic Choice of Local Governments**

From the analysis of Fig. 6, it can be seen that on the one hand, when the value of the political reward given by superior governments to local governments is greater than a certain condition, the higher the value of the political reward, the more helpful it is for local governments to choose the positive compensation strategy. At the same time, the higher the initial value of the positive compensation strategy, the faster it will converge and stabilize. For local fishermen, the fishermen's enthusiasm for choosing fishing moratorium is influenced by local governments' enthusiasm for choosing ecological compensation strategy, and the rate at which their strategic choices converge and stabilize on fishing moratorium will also accelerate with the improvement of political incentives from superior governments to local governments. On the other hand, when the political reward from superior governments to local governments is low, no matter what the initial point is, there is no stable strategy point for superior governments and local governments, and the strategy choice of local governments fluctuates inversely with the strategy choice of superior governments. Therefore, superior governments need to maintain the implementation of the ecological compensation measures by local governments through periodic strict supervision measures.

To further discuss the influence of superior governments' punishment on local governments on evolutionary game, the numerical value 4: is selected. The initial value is and  $x=0.8$ ,  $y=0.8$ ,  $z=0.8$ . By analyzing its changing trend, the simulation results of replicating dynamic equations evolving 50 times with time are shown in Fig. 7:



**Figure 7. Influence of Superior Governments' Fines on Local Governments' Strategy Choice**

It can be seen from Fig. 7 that for different initial points, when the fine imposed by superior governments on local governments is greater than a certain value, the evolution rate of local governments' convergence to the positive compensation strategy is accelerated with the increase of the fine imposed by superior governments on local governments. Under the influence of local governments, the evolution rate of the fishermen's choice to conduct fishing moratorium is also accelerated with the increase of the fine imposed by superior governments on local governments. On the other hand, when the fine imposed by superior governments on local governments is less than a certain value, a high initial point value is beneficial for local governments to stabilize the strategic behavior of positive compensation and the fishermen can converge and stabilize with the strategic choice of fishing moratorium. In contrast, with a lower initial point value and a lower fine from superior governments to local governments, local governments are more inclined to choose the strategy of refusing compensation because of the strict supervision by superior governments, and the fishermen converge on the illegal fishing behavior affected by the motivation of local government compensation. According to the different initial points, when the fines imposed by superior governments on local governments are low, the evolution dynamics will eventually converge to two strategic combinations (fishing moratorium, positive compensation, loose supervision) and (illegal fishing, refusal of compensation, loose supervision).

## 6. Conclusion

Ecological compensation measures are one of the effective initiatives to ensure the successful implementation of the fishing moratorium system, which ensures mutual coordination and cooperation among local fishermen, local governments, and superior governments during the fishing moratorium. To successfully implement ecological compensation measures, it is necessary to find the optimal incentives that satisfy all stakeholders, i.e., reducing fishermen's poverty, maximizing local economic

growth, maximizing social welfare, and restoring fishery resources. This means that superior governments should not only coordinate the interests of fishermen and local governments, but also maximize the welfare of the whole society and effectively implement the fishing moratorium system in summer. Therefore, ecological compensation can effectively restore fishery resources and maximize social welfare by using the motivation of individuals or organizations to maximize benefits. Based on the above-mentioned tripartite evolutionary game model and simulation analysis, the results show that:

(1) The reward and punishment method consisting of ecological subsidies and illegal fines can effectively encourage local governments and fishermen to cooperate to abide by the summer fishing moratorium system. However, in no way can the improper design and combination of ecological subsidies and punishment measures make the evolutionary game achieve the expected incentive effect. Therefore, designing a reasonable subsidy system and punishment intensity is an important factor for the game to achieve long-term equilibrium, that is, moderate subsidy and severe punishment. Furthermore, appropriate external environmental factors are the basis of stimulating the expected effect. Specifically, fishermen will support this policy when they will not lose too much income or gain enough ecological subsidies because of this policy. In the process of implementing ecological compensation measures, fishermen's strategic choices are not only related to their own factors, but also influenced by local governments and superior governments. The higher the enthusiasm of local governments to implement ecological compensation and the higher the probability of superior governments choosing strict supervision, the higher the probability of fishermen choosing to conduct fishing moratorium will be.

(2) The reward and punishment method consisting of political reward and illegal fine is equally effective for local governments. When the political performance is greater than a certain value, with the improvement of political reward, the enthusiasm of local governments to take ecological compensation measures will also increase. Besides, the amount of fines imposed by superior governments on local governments will also affect the enthusiasm of local governments to take ecological compensation measures, and will increase with the increase of fines. For superior governments, designing reasonable political reward and punishment intensity plays a crucial role in promoting local governments to actively take ecological compensation measures. Given that local economic development is of great importance for national economic growth, and that local governments are more concerned about local economic growth and have incentives to refuse ecological compensation, political rewards from superior governments to local governments can effectively promote local governments' assessment method of local GDP growth to a more diversified evaluation system of green comprehensive development.

The selective and strict supervision by superior governments will help local governments and fishermen to implement ecological compensation measures better and faster and abide by the summer fishing moratorium policy. When the fishermen's goal is to maximize their own interests and local governments' goal is to maximize local economic growth, the intervention of the superior strong

reciprocal government can provide strong enough constraints and incentives for both parties, which is helpful to accelerate the evolution rate of expecting the best strategy from the society. In addition, because superior governments are involved as strong reciprocal governments with strong information and behavioral capabilities, their fixed existence can make meaningful cooperation and altruistic behavior among groups standardized by policies, thus realizing the effective allocation of social resources and having a stable effect on the final result of strategic evolution.

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