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Evolutionary Game and Sustainable Development of Environmental Pollution Control in Erhai Lake Basin

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***Abstract*—With the acceleration of urbanization, industrialization and agricultural modernization, the rapid development of tourism, the increase of population and the further development of economy and society has caused the environment of Erhai Lake Basin to face a severe test. Based on evolutionary game theory, this paper establishes the evolutionary game model that takes the relationship between fishermen and fishermen, between the government and enterprises, and between the water source government and the local government downstream as an example by means of taking the understanding and policy evolution of three development stages of pollution control in Erhai Lake Basin as clue. According to the replication of dynamic equation, this paper analyses the strategic evolution relationship among the main bodies of pollution control in Erhai Lake Basin and gives the influencing factors and strategies of environmental sustainable development in Erhai Lake Basin to put forward policy recommendations for improving the governance of Erhai Lake by means of evolutionary stable strategy.**

Keywords—Erhai Lake Basin; evolutionary game; evolutionary stable strategy; sustainable development

I. INTRODUCTION

Erhai Lake, as the second largest freshwater lake in Yunnan Province, is the core of Dali's main drinking water source and Cangshan Erhai national nature reserve and tourist attraction. With the acceleration of urbanization, industrialization and agricultural modernization in the lake basin, the rapid development of tourism, the increase of population and the further development of economy and society has caused the water environment of Erhai Lake Basin to face a severe test. Erhai Lake belongs to public goods, and Erhai pollution belongs to public problems, which must be inseparable from human benefit-chase behavior, and is the result of game between different main bodies. [1] Under the influence of the game of interests of different main bodies, the government is continuously governing the environment of Erhai Lake, which experiences the stages from "lake surface governance" to "source governance", and then from "source governance" to "ecological governance". Each stage is a game process of relevant interest groups. Each interest game promotes the continuous enrichment and improvement of government governance policies and practices; meanwhile, it also deepens the development of the government's concept of ecological environment governance.

II. EVOLUTIONARY GAME THEORY

In recent years, more and more scholars have begun to adopt this theory to analyze and solve water pollution problems in the applied research of evolutionary game theory. Evolutionary game theory, which is also translated into evolutionary game theory in China, originates from the biological evolutionism. Unlike traditional game theory, it does not require the participants to be completely rational, nor does it require the conditions of complete information, however, it requires the participants in the game are limited rationality. Limited rationality means that the players do not always find the best strategy at the beginning, they will learn the game in the process of the game, and they must find better strategies through trial and error. Limited rationality also means that at least some of the players will not adopt the equilibrium strategy of entirely rational game, which means that the equilibrium is the result of constant adjustment and improvement rather than one-time selection, and even if it arrives to equilibrium it may deviate again. Therefore, one of the core concepts of evolutionary game is evolutionary stable strategy, which is the equilibrium in evolutionary game. It must satisfy two conditions: one is the stable state that will be achieved in the dynamic strategy adjustment of evolutionary game players, and the other is the robustness to a small amount of deviated disturbances.

The key of evolutionary game analysis is to determine the mechanism of learning and strategy adjustment of game players. Because evolutionary game players have many bounded rational levels, the way and speed of learning and strategy adjustment are very different, so different mechanisms must be used to simulate the process of strategy adjustment of game players. For example, different dynamic mechanisms are needed to simulate repeated games of random matching between small group members with fast learning ability and large group members with slow learning

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speed. In view of the repeated game of random matching of large groups composed of members with slow learning speed, strategy adjustment uses replicator dynamics mechanism1 to stimulate. The evolutionary game of both sides can be divided into symmetric evolutionary game and asymmetric evolutionary game: the former is a game between two groups of bounded rational players, whose members are similar, and whose positions are not different; the latter is a game in which members of two groups of bounded rational players randomly match with each other. [2] [3] [4] [5]

In the environmental management of Erhai Lake Basin, we should not only explore temporary management methods, but also explore a mode of coordination between governance and development, which requires the relevant stakeholders to constantly adjust their strategies to achieve a stable state in the dynamic adjustment, which is in line with the requirements of environmental sustainable development in Erhai Lake Basin. The main bodies of environmental governance and protection in Erhai include local governments, enterprises, practitioners, farmers, residents and fishermen. Local governments refer to environmental protection departments, fishery departments and health supervision departments in Dali Prefecture, Dali city and Eryuan city. Enterprises refer to big, small and medium-sized enterprises in Erhai Basin and businesses such as inns and restaurants around Erhai Lake Basin. Farmers refer to farmers living on agriculture in Erhai Lake Basin. Fishermen refer to those farmers who live on the fishery resources of Erhai Lake Basin. Based on evolutionary game theory, this paper establishes the evolutionary game model that takes the relationship between fishermen and fishermen, between the government and enterprises, and between the water source government and the local government downstream as an example by means of taking the understanding and policy evolution of three development stages of pollution control in Erhai Lake Basin as clue. According to the replication of dynamic equation, this paper analyses the strategic evolution relationship among the main bodies of pollution control in Erhai Lake Basin and gives the influencing factors and strategies of environmental sustainable development in Erhai Lake Basin to put forward policy recommendations for improving the governance of Erhai Lake by means of evolutionary stable strategy.

III. GOVERNANCE OF LAKE SURFACE: GAME BETWEEN FISHERMEN AND FISHERMEN

Erhai Lake enjoys rich fishery resources. In order to make profits from it, the local residents developed fishing motor boats for fishing in the 1970s and 1980s. However, fishing motor boats emit a large amount of oil pollution to Erhai Lake in the process of fishing, which causes huge pollution to Erhai Lake. In the early 1990s, the local fishermen also began to spring up the fish culture in net pen. In order to pursue high yield and obtain higher economic benefits, fishermen used a large number of chemical fertilizers to feed fish, which directly increased the nitrogen and phosphorus content in Erhai Lake. At the same time, in order to improve the survival rate of autotrophic fish, fishermen caught fish in large quantities that ate other fishes, which led to the imbalance of the ecosystem of Erhai Lake. By 1996, there were more than 2500 fishing motor boats and 158 mu of fish culture in net pen on Erhai Lake surface. In September of the same year, the "cyanobacteria incident" broke out in Erhai Lake that the sea water emitted a foul odor, and the water transparency decreased from 4 meters to 0.7-1.5 meters. Faced with such a situation, the people's government of Dali Prefecture made the decision to cancel the power facilities for fishing motor boats and fish culture in net pen of Erhai. Until July 1997, 9507 cages were removed, 2576 sets of power facilities of fishing motor boats were removed, and about 120,000 bamboo and wooden poles (piles) were pulled out, involving 2966 households. The policy of "double cancellation" is the government's "lake governance" to Erhai Lake, which aims at the direct main body of Erhai Lake pollution, and is the result of the game of interests between the government and fishermen, fishermen and fishermen. This paper mainly analyses the symmetrical evolutionary game between fishermen and fishermen.

Hypothesis 1: There are two groups of fishermen I and fishermen II. There are two strategies for fishermen to choose, that is, the mode of aquaculture by fishing motor boat and fish culture in net pen and the mode of aquaculture by "double cancellation" that responds positively to the government's "double cancellation" policy. Assuming that the proportion of the fishermen raised by the "double cancellation" method is x, the proportion of the fishermen raised by the fishing motor boat and fish culture in net pen method is $1-x$ in this group composed of fishermen. In this fishermen group, each fisherman may encounter either a fisherman who raises in the way of "double cancellation" or a fisherman who raises in the way of fishing motor boat and fish culture in net pen when the fishermen are randomly matched to play the game. The former probability is x, and the latter probability is $1-x$.

Hypothesis 2: when fishermen breed aquatics in the way of fishing motor boat and fish culture in net pen, the profit of fishermen selling aquatic products is p: when fishermen breed aquatics in the way of "double cancellation", their aquatic products will get more profit a; when fishermen breed aquatics in the way of "double cancellation", they need to pay extra cost b; therefore, fishermen will buy less chemical fertilizer, feed and so on that cost is c; when one party adopts fishing motor boats and fish culture in net pen while the other party adopts "double cancellation" cultivation, the government will give financial subsidies d to the fishermen who feed in the mode of "double cancellation"; at the same time, the price of aquatic products farmed in the mode of fishing motor boats and fish culture in net pen will decrease e because of the advantage of "double cancellation"

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[1] Duplicator dynamics is a mechanism that describes the dynamic strategy adjustment of a game player with low rationality and limited rationality that only has the ability to simply imitate the dominant strategy. The core of duplicator dynamics is that more successful strategies adopted in groups will gradually increase, and dynamic differential equations or differential equations can be used to describe the dynamic change speed. Its basic principle is that in the group composed of bounded rationality (with very low rationality), the strategy with higher earnings than average will be gradually adopted by more players, so that the proportion of players who adopt various strategies in the group will change.

of farmers receiving government subsidies. Based on the above hypothesis, the game payment matrix is shown in "Table I".

TABLE I. BENEFIT MATRIX OF SYMMETRIC EVOLUTIONARY GAME AMONG FISHERMEN IN ERHAI LAKE BASIN

		Fishermen II	
		Aquaculture of "double cancellation" mode	***Aquaculture of fishing motor boats and fish culture in net pen***
Fishermen I	***Aquaculture of "double cancellation" mode***	$p+a-b+c, p+a-b+c$	$p+a-b+c+d, p-e$
	Aquaculture of fishing motor boats and fish culture in net pen	$p-e, p+a-b+c+d$	p, p

Then, the expected benefits u_s, u_c of the fishermen who adopt the two strategies of "double cancellation" aquaculture and motor boat and net pen aquaculture are as follows:

$$u_s = x\,(p + a - b + c) + (1 - x)\,(p + a - b + c + d)$$

$$u_c = x\,(p - e) + (1 - x)\,p$$

Consequently, the average benefits $\bar{u}$ of members of the fishermen group are:

$$\bar{u} = x u_s + (1 - x)\,u_c$$

According to the above expected benefits, the dynamic change speed of the proportion of the game players who adopt "double cancellation" aquaculture can be expressed by the following replication dynamic equation:

$$\frac{dx}{dt} = F(x) = x\,(u_1 - \bar{u}) = x\,(1 - x)\,(u_s - u_c) = x\,(1 - x)\,(-xd + xe + a - b + c + d)$$

For a given value of a, b, c, d, e, $\frac{dx}{dt}$ is a unit function. If $F(x) = 0$, all stable states of the replicator dynamics can be obtained, $x^* = 0$, $x^* = 1$, $x^* = \frac{a-b+c+d}{d-e}$ respectively. In addition to its own equilibrium state, $x*$ point must have the property that if some players deviate from them by accidental mistakes, the replicator dynamics will still make x return to x^*. This is equivalent to the requirement that when the interference makes x lower than x, $\frac{dx}{dt} = F(x)$ must be greater than 0, and when the interference makes x higher than x^*, $\frac{dx}{dt} = F(x)$ must be less than 0. [10]

When $x^* = \frac{a-b+c+d}{d-e}$, the fixed points of the above replicator dynamic equation are only $x^*=0$ and $x^*=1$ that are in line with the requirements. However, only $x^*=0$ is an evolutionary stable strategy, that is, all fishermen adopt fishing motor boats and net pen for aquaculture. In other words, if all fishermen start with the use of fishing motor boats and net pen for aquaculture, even if a small number of "double cancellation" fishermen are appeared, they will soon return to the use of fishing motor boats and net pen for aquaculture.

When $0 < \frac{a-b+c+d}{d-e} < 1$, the three fixed points of the above replicator dynamic equation are reasonable. However, only $x* = \frac{a-b+c+d}{d-e}$ is an evolutionary stable strategy. In fact, this means that once a small number of fishermen change from fishing motor boats and net pen for aquaculture to "double cancellation" aquaculture, the number of "double cancellation" aquaculture fishermen will continue to increase until the proportion of the total number of fishermen is $x* = \frac{a-b+c+d}{d-e}$. If the proportion of "double cancellation" aquaculture in fishermen exceeds this ratio, or even all of them adopt "double cancellation" aquaculture, then a small number of fishermen using fishing motor boats and net pen for aquaculture will spread in the population and eventually return to the equilibrium ratio of $x* = \frac{a-b+c+d}{d-e}$.

When $\frac{a-b+c+d}{d-e} > 1$, the fixed points of the above replicator dynamic equation are only $x^*=0$ and $x^*=1$ that are in line with the requirements. However, only $x^*=1$ is an evolutionary stable strategy, that is, all fishermen use the "double cancellation" method for aquaculture. In other words, if all fishermen start with "double cancellation" for aquaculture, even if there are a small number of fishermen using fishing motor boats and net pen for aquaculture, they will soon return to using fishing motor boats and net pen for aquaculture. [2]

The above analysis shows that the government's governance to Erhai Lake is only on the surface. From the game strategy between fishermen and fishermen, it is also concluded that the optimal strategy between fishermen is to adopt fishing motor boats and net pen. Although the government has adopted the policy of "double cancellation", fishermen can find other forms to replace the operation of fishing motor boats and net pen.

IV. SOURCE GOVERNANCE: GAME BETWEEN GOVERNMENT AND ENTERPRISE

The policy of "double cancellation" has not fundamentally effectively harnessed Erhai Lake, which

[2] In this paper, the evolutionary stable strategy analysis of symmetric game between fishermen and fishermen only refers to Xie Shiyu's analysis of frog song game.

indicates that the government should not only tackle the direct causes of pollution in Erhai Lake, but also start from the source of pollution in Erhai Lake. Therefore, in the beginning of 21st century, the government will extend from the pollution control of Erhai Lake itself to the pollution control of Erhai Lake Basin, and find out the causes from the source of pollution in Erhai Lake Basin, so as to form a more comprehensive governance pattern.

Erhai Lake Basin has jurisdiction over 16 townships and 167 administrative villages in Dali and Eryuan counties (cities), with a total population of 837,400. As for the pollution regulation of Erhai Lake, the government should not only take corresponding measures for fishermen, but also take measures for agricultural non-point source pollution around the lake basin. Therefore, following the "two cancellations", the government carried out the "three withdrawals and three returns" for Erhai bottom land. By returning ponds to lakes, farmlands to forests and houses to wetlands, the ecosystem of Erhai Lake saw periodic recovery in July 2002. During the period of "three withdrawals and three returns", more than 15,000 people were invested in labor, more than 13 million yuan was invested, and 300,000 yuan was invested by two counties and municipalities. 4,550 mu of pond return to lake was carried out, 169 agreements were signed, 1500 fish ponds were opened, 36,000 cubic meters of earth and rock were excavated, 510 sets of ancillary facilities of fish pond were removed such as aerator, pole wiring, 347 fish pond detention rooms were removed, with removal area of 6940 square meters, accounting for 100% of the area to be withdrawn. The implementation of conversion of farmland to forestry is 4726.2 mu, of which the contracted area is 3621.9 mu, the reserved area is 1104.3 mu, accounting for 100% of the returnable area. 8315 contracts for termination of contracts have been signed, 8313 contracts for land have been cancelled, 11 174 contracts for compensation agreement have been signed, 5,000 mu of trees have been planted and 480,000 willows have been planted, accounting for 100% of the area of cultivated land. All have achieved "three pairs of evidence". 200 mu of wetland is returned after checking out, accounting for 100% of the area to be returned. For 657 households that have been approved to build and build, 420 mu of land use certificate has been renewed. [6] [7] Compared with the "two cancellations", the government invested heavily about the "three withdrawals and three returns", involving a large number of people, including local fishermen, local farmers and herdsmen and related enterprises. The work of "three withdrawals and three returns" is the government's management of the whole basin area of Erhai Lake Basin. It is the result of the game between the government and the residents and enterprises of the basin, and between the residents and residents of the basin.

The goals pursued by the government and the practitioners in Erhai Lake Basin are different. These practitioners pursue profit maximization and choose sewage treatment before discharge. Meanwhile, they need to invest in purchasing corresponding sewage treatment equipment and invest in environmental protection, which will certainly reduce their profits. In order to avoid the high cost of pollution control, they prefer to be fined rather than treated. The government should not only pursue economic interests but also take public interests into account. On the one hand, the government should get tax revenue from these commercial tenants; on the other hand, it should also consider the impact of Erhai environment on the public and the assessment of environmental protection. Therefore, it is necessary to analyze the asymmetric evolutionary game between the government and the practitioners (enterprises) around Erhai Lake Basin. The framework of our analysis is to repeatedly select a pair of members randomly from two groups of government and enterprise to play games. The learning and strategy imitation of the two players are confined to their own group. The mechanism of strategy adjustment is still similar to the replicator dynamics in the two-person symmetric game.

Hypothesis 1: There are two groups of government and enterprise. Enterprises have two strategic choices for sewage treatment, that is, to discharge sewage after treatment (i.e. discharge after treatment) and to discharge sewage directly without treatment (discharge direct). The government has two strategic choices for enterprises, that is, the government supervises and not supervises enterprises. It is assumed that the probability of government that chooses supervision is x, the probability of government that not chooses supervision is $1-x$ in the group composed of the government; and the probability of the enterprise discharging the sewage after treatment is y, the probability that the enterprise still discharges the sewage directly without treatment is $1-y$ in the group composed of the enterprise.

Hypothesis 2: The basic revenue r of the government concerned in Erhai Lake Basin comes from the tax revenue of the enterprise; the cost of implementing supervision is $r1$; if the enterprise chooses discharge the sewage directly without treatment, the government needs to control the pollution of Erhai Lake Basin at the cost of $r2$; Enterprises will reduce costs and increase their profits due to the direct discharge of sewage without treatment, which will make the government increase taxes $r3$.

Hypothesis 3: The normal income of enterprises in Erhai Lake Basin is q: the cost of purchasing sewage treatment equipment is q_1; the cost of not purchasing sewage treatment equipment is used to expand the scope of business, which can increase the income q_2; if enterprises do not carry out sewage treatment, they will be fined q_3 after being found by the government regulatory authorities. Based on the above hypothesis, the game payment matrix is shown in "Table II".

TABLE II. BENEFIT MATRIX OF ASYMMETRIC EVOLUTIONARY GAME BETWEEN GOVERNMENT AND ENTERPRISES IN ERHAI LAKE BASIN

		Enterprise	
		Discharge after treatment	***Discharge direct***
Government	***Supervision***	$r-r_1,\ q-q_1$	$r-r_1-r_2+r_3+q_3,\ q+q_2-q_3$
	Non-supervision	$r,\ q-q_1$	$r-r_2+r_3,\ q+q_2$

Then, the expected benefits $u1j$, $u1n$ of the government that adopts the two strategies of "supervision" and "non-supervision" in the government groups are as follows:

$$u_{1j} = y\,(r-r1) + (1-y)\,(r-r_1-r_2+r_3+q_3)$$

$$u_{1n} = yr + (1-y)\,(r-r_2+r_3)$$

Therefore, the average benefits $\bar{u1}$ of members in the government group are:

$$\bar{u_1} = xu_{1j} + (1-x)\,u_{1n}$$

Then, the expected benefits u_{2c}, u_{2n} of the government that adopts the two strategies of "discharge after treatment" and "discharge direct" in the enterprise group are as follows:

$$u_{2c} = x(q-q_1) + (1-x)(q-q_1)$$
$$u_{2n} = x(q+q_2-q_3) + (1-x)(q+q_2)$$

Therefore, the average benefits $\bar{u2}$ of the members in the enterprise group are as follows:

$$\bar{u_2} = yu_{2c} + (1-y)\,u_{2n}$$

The probability of government and enterprise choosing a specific strategy varies with the time t. When the average revenue $\bar{u_1}$ of the government is higher than that u_{1j} of the government that carry out supervision, some regulated governments begin to imitate the strategy of the non-regulated government with higher revenue, that is, to join the non-regulated ranks. Similarly, when the average income $u2c$ of enterprises is higher than that u_{2c} of enterprises that discharge sewage after treatment, enterprises that discharge sewage after partial treatment begin to imitate the strategy of enterprises that discharge sewage directly with higher income, that is, to join the ranks of sewage of direct discharge. Evolution speed is expressed by replicator dynamic equation. The replicator dynamic equation of government and enterprise is respectively:

$$\frac{dx}{dt} = x(u_{1j}-\bar{u}_1)$$
$$= x(1-x)(u_{1j}-u_{1n})$$
$$= x(1-x)(q_3-r_1-yq_3)$$

$$\frac{dy}{dt} = y(u_{2c}-\bar{u}_2)$$
$$= y(1-y)(u_{2c}-u_{2n})$$
$$= y(1-y)(xq_3-q_1-q_2)$$

When $y=\frac{q_3-r_1}{q_3}$, $\frac{dx}{dt}$ is always 0, which means that when the probability of enterprise "discharging after treatment" is $\frac{q_3-r_1}{q_3}$, the game process is in stable state no matter what measures the government takes. When $y\neq\frac{q_3-r_1}{q_3}$, $x^*=0$ and $x^*=1$ are two stable states, that is, for the two strategies of enterprise "discharge after treatment" or "direct discharge", which one is the choice of enterprise's stability strategy needs to be further discussed. When $y>\frac{q_3-r_1}{q_3}$, $x^*=0$ is the evolutionary stable strategy, and when $y<\frac{q_3-r_1}{q_3}$, $x^*=1$ is the evolutionary stable strategy.

Similarly, when $y<\frac{q_3-r_1}{q_3}$, $\frac{dy}{dt}$ is always 0, which means that when the probability of government "supervision" is $\frac{q_1+q_2}{q_3}$, the game process is in a stable state no matter what measures enterprises take. When $x\neq\frac{q_1+q_2}{q_3}$, $y^*=0$ and $y^*=1$ are two stable states, that is, as for the two strategies of "supervision" or "non-supervision" of the government, which one is the choice of the stable strategy of the government needs to be further discussed. When $x>\frac{q_1+q_2}{q_3}$, $y^*=1$ is an evolutionary stable strategy, and when $x<\frac{q_1+q_2}{q_3}$, $y^*=0$ is an evolutionary stable strategy.

In order to visually represent the replicator dynamic equation of government and enterprise, the relationship between the two can be expressed by plane graphics (see "Fig. 1").

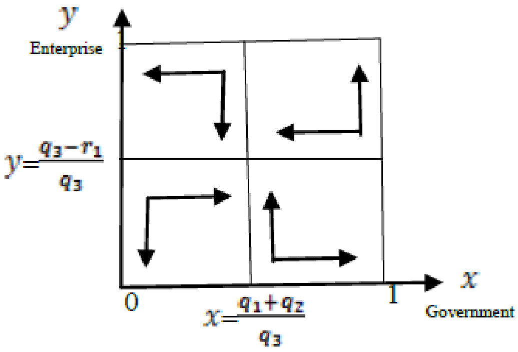

Fig. 1. Copy dynamic relationship and stability of two-group game between government and enterprise.

As can be seen from "Fig. 1", there is no evolutionary stable strategy at the four vertices. When the initial state falls in the upper left corner area, the game converges to x=0 and y=0, that is, the government does not regulate, and enterprises directly discharge sewage. When the initial state falls in the upper right corner region, the game converges to x=0 and y=1, that is, the government does not supervise, and the enterprise discharge sewage after treatment. When the initial state falls in the lower left corner area, the game converges to x=1 and y =0, that is, government is in supervision and enterprises can discharge sewage directly. When the initial state falls in the lower right corner area, the game converges to x=1 and y=1, that is, government is in supervision, enterprises can discharge sewage after treatment.

From the above analysis, we can see that the most ideal strategy is government is in supervision, and enterprises discharge sewage after treatment. However, even so, the fundamental problem has not been solved, and the sewage is still discharged into Erhai Lake. After the government's policy of "two cancellations" and "three withdrawals and three retreats", the water quality of Erhai Lake has only been improved in stages. From the general trend, the water quality of Erhai Lake is still polluted continuously. From 1993 to 1999, the quality of Erhai Lake was maintained in class II, but in the 17 years from 2000 to 2016, the quality of Erhai Lake was only class II for 4 years, and in the other 13 years, it was class III. At this time, a new way of thinking is put in front of everyone: the governance of Erhai Lake should not only stay on "point" and "face", but also take "maintenance" to drive "governance". That is to say, it is necessary to find ways to restore the original state of Erhai Lake and try to restore the state of Erhai Lake that is not polluted, which requires the government to make up its mind to build the ecological construction of Erhai Lake.

V. Ecological Governance: Game Between the Government of Water Source and the Government of Downstream Areas

In order to make more comprehensive governance to the Erhai Lake, in 2005, Dali began to implement the "six major projects" for the protection of the Erhai Lake, namely, ecological project of the Erhai Lake, sewage treatment and sewage interception project, non-point source pollution control project, rubbish treatment project in rivers and villages entering the lake, greening and soil erosion control project in mountain areas, and environmental management engineering of the Erhai Lake. The "six major projects" is an important measure for the comprehensive management of Erhai Lake. However, in 2013, large-scale blue-green algae broke out in Erhai Lake, and the quality of water once affected the lives of local residents, which fully shows that the management of Erhai Lake should not only be comprehensive, but also try to proceed from the root, and continue until the pollution problem of Erhai Lake is completely solved. In January 2017, Dali comprehensively implemented the "seven actions", namely, the "two violations" rectification action of the lake basin, the "two pollutants" rectification action of villages and towns, the action of reducing non-point source pollution, the action of water-saving and ecological restoration, the action of speeding up pollution interception and pollution control projects, the action of river basin law enforcement and supervision, and the action of protecting Erhai Lake by the whole people. The major "seven actions" are not to control pollution, but to achieve sustainable pollution control effect by re-establishing a new ecological environment. This is not only "governance", but also "cultivation", in order to cultivate the ecology to achieve the effect of pollution control. The "seven actions" is the government's "ecological governance" of Erhai Lake and the result of the game of mutual interests among the government, residents, enterprises, traders and tourists.

"Eco-governance" is a more comprehensive governance action, involving a wider range of stakeholders, which requires the linkage between local governments at all levels. Therefore, this part will analyze the asymmetric evolutionary game between water source government and downstream government.

Erhai Lake Basin flows through Eryuan County and Dali City. Eryuan County is the source of Erhai Lake and the source of Erhai Lake. The main lake body of Erhai Lake is in the downstream area, namely Dali City. Obviously, the water quality of Erhai Basin in Eryuan County is better than that of the main lake in Dali City. At the same time, the governance and protection of Erhai basin must depend on the government of the water source area, which will directly aggravate the pollution of Erhai Basin. However, for the governance and protection of Erhai Lake Basin, if the upstream and downstream governments invest as much as the downstream governments, it will form a situation that the revenue of the downstream governments is higher than that of the water source governments. Eryuan county government has two choices for Erhai basin: protection or non-protection. Therefore, if the government of the water source area wants to devote all its efforts to the protection of the Erhai Lake Basin, the government of the downstream area should make appropriate compensation to the government of the water source area. Of course, downstream governments have two choices: compensation or non-compensation.

Hypothesis 1: There are two groups of water source government and downstream government. The probability of water source government chooses protection is x, and chooses non-protection is 1-x. The probability that the downstream government chooses compensation is y, and chooses non-compensation is 1- y.

Hypothesis 2: The normal benefits of the water source government is t; the additional benefits of the water source government's choice of protection is t_1; the cost of the water source government's choice of protection is t_2; the opportunity cost that the water source government's choice of protection will be lost is t_3; when the downstream government chooses to compensate the water source government, the water source government will be punished $w1$ by the higher government if it does not protect.

Hypothesis 3: The total revenue of the downstream government is s due to the choice of protection by the water source government; the total revenue of the downstream government is s_1 due to the choice of non-protection by the water source government; the downstream government compensates s for the water source government; and the downstream government will be punished w_2 by the higher government if it does not compensate for the choice of protection by the water source government.

Based on the above hypothesis, the game payment matrix is shown in "Table III".

TABLE III. BENEFIT MATRIX OF ASYMMETRIC EVOLUTIONARY GAME BETWEEN WATER SOURCE GOVERNMENT AND DOWNSTREAM GOVERNMENTS

		Downstream Government	
		Compensation	***Non-compensation***
Water Source Government	***Protection***	$t + t_1 - t_2 - t_3 + s_2, s - s_2$	$t + t_1 - t_2 - t_3, s - w_2$
	Non-protection	$t + s_2 - w_1, s - s_2$	t, s_1

Then, the expected benefits u_{3b}, u_{3n} of the two strategies of "protection" and "non-protection" in the government groups of water sources are as follows:

$$u_{3b} = y(t + t_1 - t_2 - t_3 + s_2) + (1 - y)(t + t_1 - t_2 - t_3)$$
$$u_{3n} = y(t + s_2 - w_1) + (1 - y)t$$

Therefore, the average benefits $\bar{u}_3$ of members of government groups in water sources are as follows: $\bar{u}_3 = xu_{3b} + (1 - x)\, u_{3n}$

Then, the expected benefits u_{4b}, $u4n$ of the government groups in the downstream areas that adopt the two strategies of "compensation" and "non-compensation" are as follows:

$$u_{4b} = x\,(s - s_2) + (1 - x)\,(s - s_2)$$
$$u_{4n} = x\,(s - w_2) + (1 - x)\,s_1$$

Therefore, the average benefits $\bar{u}4$ of members of government groups in downstream areas are as follows:

$$\bar{u}_4 = yu_{4b} + (1 - y)\,u_{4n}$$

Similarly, the rate of evolution is expressed by the replicator dynamic equation. The replicator dynamic equations of water source government and downstream government are respectively:

$$\frac{dx}{dt} = x(u_{3b} - \bar{u}_3)$$
$$= x(1 - x)(u_{3b} - u_{3n})$$
$$= x(1 - x)(yw_1 + t_1 - t_2 - t_3)$$
$$\frac{dy}{dt} = y(u_{4b} - \bar{u}_4)$$
$$= y(1 - y)(u_{4b} - u_{4n})$$
$$= y(1 - y)(xw_2 - s_2)$$

When $y = \frac{t_2 + t_3 - t_1}{w_1}$, $\frac{dx}{dt}$ is always 0, which means that when the probability of downstream government that carries out "compensation" is $\frac{t_2 + t_3 - t_1}{w_1}$, regardless of the measures taken by the water source government, the game process is in a stable state. When $y \neq \frac{t_2 + t_3 - t_1}{w_1}$, x^*=0 and x^*=1 are two stable states, that is, for the downstream governments to "compensate" or "not compensate" two strategies, which one is the choice of enterprise's stability strategy needs to be further discussed. When $y > \frac{t_2 + t_3 - t_1}{w_1}$, x^*=1 is an evolutionary stable strategy, and when $y < \frac{t_2 + t_3 - t_1}{w_1}$, x^*=0 is an evolutionary stable strategy.

Similarly, when $x = \frac{s_2}{w_2}$, $\frac{dy}{dt}$ is always 0, which means that the probability of water source government to "protect" is $\frac{s_2}{w_2}$, the game process is stable no matter what measures the downstream government takes. When $x \neq \frac{s_2}{w_2}$, y^*=0 and y^*=1 are two stable states, i.e. the two strategies of "protection" or "non-protection" for the government of water sources, which one is the choice of the government's stability strategy needs to be further discussed. When $x>\frac{s_2}{w_2}$, $y^*=1$ is an evolutionary stable strategy, and when $x<\frac{s_2}{w_2}$, $y^*=0$ is an evolutionary stable strategy.

In order to visually represent the replicator dynamic equation of government and enterprise, the relationship between the two can be expressed by plane graphics (see "Fig. 2").

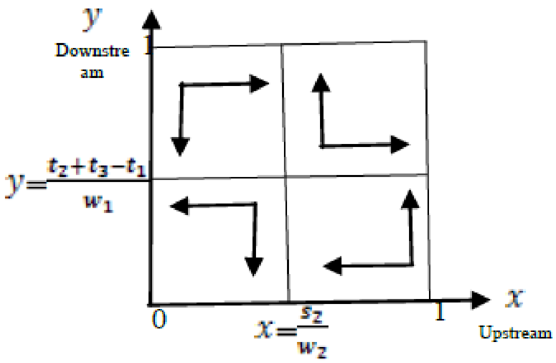

Fig. 2. Copy dynamic relations and stability of two group game between water source government and downstream government.

As can be seen from "Fig. 2", the game has two evolutionary stable strategies: $x^*=0$ and $y^*=0$; $x^*=1$ and $y^*=1$. When the initial state falls in the lower left corner area, it will eventually converge to $x^*=0$ and $y^*=0$, that is, the government of the water source area does not protect, and the government of the downstream area does not compensate. When the initial state falls in the upper right corner, it will eventually converge to $x^*=1$ and $y^*=1$, that is, the water source government will protect, and the downstream government will compensate. When the initial state falls in the upper left corner, if the convergence rate of $x^*=1$ of the government group in the water source area is faster than that of $y^*=0$ of the government in the downstream area, the final evolutionary stable strategy is the $x^*=1$ and $y^*=1$; otherwise $x^*=0$ and $y^*=0$. When the initial state falls in the lower right corner area, if the convergence rate of $x^*=0$ of the government group in the water source area is faster than that of $y^*=1$ of the government in the downstream area, the final evolutionary stable strategy is $x^*=0$ and $y^*=0$; otherwise, $x^*=1$ and $y^*=1$.

The above analysis shows that the government's solving idea of taking maintenance to drive is correct. Compared with the policies of the first two stages, the "six major projects" and "seven major actions" not only solve the problem more comprehensively, but also restore the Erhai Lake ecology from the perspective of sustainable development.

VI. Stable Strategy of Environmental Sustainable Development in Erhai Lake Basin

Through the symmetrical evolutionary game analysis of fishermen groups, in order to achieve the sustainable development of the environment in Erhai Lake Basin, of course, it is hoped that all fishermen will adopt the "double cancellation" mode for aquaculture. Therefore, under the previous hypothesis, to ensure that fishermen adopt the "double cancellation" aquaculture method as an evolution stable strategy, it needs to be ensured that $\frac{a-b+c+d}{d-e}>1$, namely $a+c>b-e$. Under these conditions, all fishermen adopt the "double cancellation" mode for aquaculture.

Through the asymmetric evolutionary game analysis of the government and enterprises, in order to achieve the sustainable development of the environment in Erhai Lake Basin, it is hoped that enterprises can choose the strategy of disposal before sewage discharge, whether the government adopts the strategy of supervision or not, that is $x>\frac{q_1+q_2}{q_3}$. Therefore, in order to realize the government's strategy of supervision or non-supervision, all enterprises can choose the strategy of disposal before sewage discharge. It is necessary to make $x>\frac{q_1+q_2}{q_3}$ as small as possible, that is to say, to reduce the cost of sewage treatment q_1 and increase the benefits q_2 of the cost of unauthorized sewage treatment equipment, and to increase the intensity of fines q_3.

Based on the asymmetric evolutionary game analysis between the water source government and the downstream government, when $x^*=1$ and $y^*=1$ are evolutionary stable strategy, that is, the water source government adopts protection strategy and the downstream government adopts compensation strategy. Therefore, whether the game between the two groups can evolve into the protection strategy adopted by the water source government and the compensation strategy adopted by the downstream government, which are mainly affected by the additional benefits t_1 of the water source government's choice of protection, the cost t_2 of the water source government's choice of protection, the opportunity cost t_3 of the water source government's choice of protection, and the compensation s_2 of the downstream government to the water source government. In order to achieve the protection strategy adopted by all water source governments and all downstream governments, $\frac{s_2}{w_2}$ and $\frac{t_2+t_3-t_1}{w_1}$ should be made as small as possible, namely, to minimize the cost of water source governments' choice of protection and the opportunity cost of loss due to the choice of protection, increase the additional benefits of water source governments' choice of protection, increase the unprotected water source areas and the penalty amount of downstream areas' non-compensation. Rationally determine the compensation quota of the downstream government to the water source government.

VII. Conclusion

To sum up, the governance of Erhai Lake needs people to deepen their understanding, and the degree of understanding determines what kind of policies the government will introduce. The introduction of policies must also consider the game situation among the stakeholders of all parties. The government must find the best strategy in accordance with the game analysis. The introduction of new policies will produce new games, and the recognition, policy and game will continue to proceed in a contradictory movement. This is a process of approaching truth and essence from vagueness to clarity, so today's governance is not finished, and new understanding, policy and game need to be highlighted in the process of governance. In short, under the guidance of scientific and sustainable development concept, it will be a priority strategy for all parties for actively building the ecological Erhai Lake.

References

[1] Jin Shuai, Du Jianguo, Sheng Zhaoying. Analysis on Evolutionary Game of Regional Environmental Protection Action. System Engineering Theory and Practice, 2015, (12): 3107-3118. (in Chinese)

[2] Xie Shiyu. Economic Game Theory (Third Edition) [M]. Shanghai: Fudan University Press, 2007. (in Chinese)

[3] Lewontin R C. Evolution and the theory of games [J] . Journal of Theoretical Biology, 1960, (1): 382-403.

[4] Maynard S J. The theory of games and the evolution of animal conflict [J]. Journal of Theoretical Biology, 1974, (47): 209-223.

[5] Taylor P D, Jonker L B． Evolutionarily stable strategy and game dynamics[J]. Mathematical Bioscience, 1978, (40): 145-156.

[6] Zhao Jin, Zhang Ying, Liu Liu, Duan Peican. The Successful Way of Lake Conservation and Governance — "Erhai Experience" News Survey (I) [N]. Yunnan Daily, 2007.09.26. (in Chinese)

[7] Zhao Jin, Zhang Ying, Liu Liu, Duan Peican. Sample of Sustainable Development — "Erhai Experience" News Survey (II) [N]. Yunnan Daily, 2007.09.27. (in Chinese)

[8] Li Changfeng, Zhang Luanying, Zhao Guangchuan, Mo Lijuan. Research on watershed ecological compensation based on Evolutionary Game Theory — Take Taihu Lake Watershed as an Example. Chinese Population, Resources and Environment of China, 2014, (1): 171-176. (in Chinese)