Intelligent Promotion Mechanism of the Sustainable Aquaculture from the Perspective of Game Theory

Zhao Chang*
China Institute of Marine Affairs, Ministry of Natural Resources, P.R China Beijing, China
*Corresponding author: zhaochang2019@cso.org.cn

Abstract. China has always attached great attention to aquaculture development, but some inappropriate aquaculture modes have brought a series of marine resources waste and environment problems. In order to solve these problems more effectively and lead to a sustainable aquaculture mode, based on stakeholder analysis, this paper constructs evolutionary game models on both supply side and demand side of aquaculture, and puts forward some suggestions for sustainable aquaculture development. The results indicate that in initial stage of promoting sustainable aquaculture, mandatory control measures and economic subsidies of the government are needed to the promotion. After gradually forming a mature management mode, the market should play a decisive role in resource allocation, so as to realize the sustainable development of aquaculture with the tripartite win-win interests in the game.

1. Introduction
Currently, aquaculture supplies about half of global consumption and is expected to increase from 66.6 million metric tons in 2012 to 932 tons by 2030 [1]. According to statistics in 2018, China's total aquaculture output exceeded 50 million tons, accounting for more than 78% of the total output of aquatic products in China, which makes China the only country that the total amount of aquaculture aquatic products exceeds the total catch. Aquatic products could not only be an important source of protein in people's daily diet, but also rich in omega-3, which is very important to promote the health of heart and brain [2]. According to a survey by the global aquaculture Alliance (GAA), although the food retail industry has been affected by the outbreak of COVID-19, the consumption of aquatic products has increased rather than decreased [3]. In addition, the development of aquaculture has also brought about continuous promotions of seafood processing, feeding and equipment manufacturing, creates a large number of employment opportunities for the society.

China's aquaculture has a long history with various function forms. While problems caused by fecal waste, interactions with predators, invasion of non-native/exotic species, excess food and antibiotics, and habitat destruction pose threat to the development. A traditional aquaculture mode both brings serious pollution to water environment, and seriously affects the quality of aquatic products as well. Therefore, in order to achieve long-term development of aquaculture, the development of sustainable aquaculture is very important.

A sustainable aquaculture mode needs to meet the following conditions: first, environmental sustainability, that is, no impact on marine ecosystem and biodiversity; second, economic sustainability,
which means to have a good prospect for development; third, social responsibility, which is to produce aquatic products with guaranteed good quality [4]. The development of sustainable aquaculture requires not only scientific improvement in breeding, disease control, bait delivery and sewage post-treatment technologies of aquaculture enterprises, but also better planning and layout of aquaculture sea areas by the government. At the same time, economic means such as low interest loans and tax-free measures should be provided to help aquaculture enterprises to choose to adopt improved technologies in realizing sustainable aquaculture. As part of green transformation of enterprises, the sustainable transformation of aquaculture conforms to the theory of transformation and upgrading [5], which refers to the initiative and all-round reform to achieve win-win coexistence of economic, social and environmental benefits [6]. Based on the "Hypothesis of Rational Man", their choices are based on the maximization of their own interests, for example the goal of aquaculture enterprises is to get maximum economic profits. Therefore, it is difficult to fundamentally solve the problem of aquatic sustainable transformation solely by the continuous supervision of the government in a cost-effective way. A two-way promotion on both the supply side and user side would be valid to solve the current problems of aquaculture, which encourages the market to play a key role in the allocation of resources.

This paper analyzes the strategies and choices of all stakeholders in the process of realizing the sustainable transformation of aquaculture under the incomplete information game to explore the optimization of resource allocation, so as to provide policy suggestions for the establishment of sustainable development model of aquaculture with government regulation, market orientation and public participation.

2. Game model construction

2.1. Stakeholder Analysis

Combined with Ostrom's social ecosystem research framework [7], the sustainable transformation process of aquaculture enterprises is analyzed. Sustainable transformation of aquaculture is a process in which aquaculture enterprises and consumers, as users of the system, produce and consume sustainable aquatic products under the influence of government regulation and the economy, or resources in the system. Within the framework constructed above, the interactions and results of a certain period of time are affected by the direct causal relationship and feedback of the internal core subsystem. Among them, the key stakeholders in stimulating the sustainable transformation of aquaculture include the government, aquaculture enterprises and consumers. The objectives of the three are different. The government's goal is to "implement the policies of the superior government departments and take into account the economic development and ecological environment protection in the jurisdiction area"; the enterprise's purpose is "to obtain the maximum economic benefits"; and the consumers want to "purchase aquatic products that meet the needs of consumption". According to their own goals, the three parties formulate their own strategies and actions in the system.

![Fig 1. Interactions among three stakeholders.](image-url)
Considering that the formation of sustainable aquaculture model is a constantly changing process, three stages are included in the study. During the three stages, the main utilization demands of the government, aquaculture enterprises and consumers are as follows:

| Stage      | Government                                    | Aquaculture Enterprise                  | Consumer                                      |
|------------|-----------------------------------------------|-----------------------------------------|-----------------------------------------------|
| First Phase| Loose taxation policy and active fiscal support| Try to understand sustainable aquaculture, but the cost of technology transformation is high | Know Sustainable aquatic products, but almost buy normal ones |
| Second Phase| Gradually reduce subsidies| Begin sustainable transformation, and the cost of transformation reduce | Buy more sustainable aquatic products than normal ones |
| Third Phase| Withdraw from management| Choose sustainable aquaculture | Buy sustainable aquatic products |

In order to reflect the process of policy implementation more clearly, the model is divided into supply side and user side.

2.2. Game model by the supply side
Without considering the influence of consumers, both government and aquaculture enterprises are limited rational with limited information. It is assumed that the probability of enterprises choosing sustainable aquaculture technology transformation is \( x \) and the probability of maintaining the original state is \( 1-x \); the probability of promoting sustainable aquaculture by the government is \( Z \), and the implementation of general policies is \( 1-Z \).

It is assumed that \( R_1 \) is the incremental income obtained by the aquaculture enterprises by adopting the sustainable aquaculture mode; \( C_1 \) represents the additional cost required for the sustainable aquaculture transformation; \( R_3 \) is the social incremental income obtained by the government due to the development of sustainable aquaculture; and \( -R_3 \) represents the loss caused by the government's failure to attach importance to the sustainable development of aquaculture.

### Table 2. Payoff matrix in supply side evolution game.

| Government Enterprises | Sustainable Aquaculture Policy | General Policy |
|------------------------|-------------------------------|----------------|
| Sustainable Transformation | \( (R_1 - C_1 + M_1, R_3 - M_1) \) | \( (R_1 - C_1, R_3) \) |
| Original Production Mode | \( (-M_2, -R_3 + M_2) \) | \( (0,0) \) |

The average quantitative benefit of the enterprise and the government in the statistical sense are as follows:

\[
\pi_E = [(R_1 - C_1 + M_1) * z + (R_1 - C_1) * (1 - z)] * x + (-M_2 * z) * (1 - x)
\]  
\[
\pi_G = [(R_3 - M_1) * x + (-R_3 + M_2) * (1 - x)] * z + R_3 * x * (1 - z)
\]

The variation of the probability of the analysis will be changed according to the evolutionary direction as determined by the replication dynamic equation [8]. Replication dynamic equation could be obtained as follows:

\[
S(x) = \frac{dx}{dt} = (M_1 z + R_1 - C_1 + M_2 z) * x * (1 - x)
\]
\[ S(z) = \frac{dx}{dt} = (R_3x - M_1x + M_2 - R_3 - R_3x) * z * (1 - z) \] 

(4)

The equilibrium point of the above replication dynamic equation is established by the formula, there \( S(x) = S(z) = 0 \), the equilibrium points a(0,0), b(0,1), c(1,0), d(1,1) and e\((\frac{R_3 - M_2}{R_3 - M_1 - M_1 + M_2}, \frac{C_1 - R_1}{R_3 - M_1 - M_1 + M_2})\).

Evolutionary game theory partial equilibrium point stability analysis by analyzing the local stability analysis of the system Jacobi matrix. The Jacobi matrix \( \text{Det}(J) \) and the trace \( \text{Tr}(J) \) as follows:

\[ \text{Det}(J) = \begin{vmatrix} \frac{\partial G(x)}{\partial x} & \frac{\partial G(x)}{\partial z} \\ \frac{\partial G(z)}{\partial x} & \frac{\partial G(z)}{\partial z} \end{vmatrix} \]

(5)

\[ \text{Tr}(J) = \frac{\partial G(x)}{\partial x} + \frac{\partial G(z)}{\partial z} \]

(6)

| Equilibrium points \(e\) | \(\text{Det}(J)\) \(e\) | \(\text{Tr}(J)\) \(e\) |
|--------------------------|-----------------|-----------------|
| a\(+(R_1 - C_1)(M_2 - R_3)^e\) | \(R_1 - C_1 + M_2 - R_3\) | \(R_1 - C_1 + M_2 - R_3\) |
| b\(- (M_2 - R_3)\) | | \(C_1 - R_1 - M_1 - R_3\) |
| c\((R_1 - C_1)M_1\) | \(C_1 - R_1 - M_1\) | \(C_1 - R_1 - M_1\) |
| d\(- (M_1 + R_1 - C_1 + M_2)\) | \(C_1 - R_1 - M_1\) | \(C_1 - R_1 - M_1\) |
| e\(-\) | \(0\) | \(0\) |

Table 3. \(\text{Det}(J)\) and \(\text{Tr}(J)\) of five equilibrium points.

In order to make enterprises and the government run normally, let \(R_1 - C_1 + M_1 > 0\), \(M_1 > 0\), \(M_2 > 0\), and \(-R_3 + M_2 > 0\). According to the local stability analysis method of the Jacobi matrix, local stability of five equilibrium points is analyzed under different constraints as follows.

| Condition | Equilibrium points | \(\text{Det}(J)\) | \(\text{Tr}(J)\) | Outcome |
|-----------|-------------------|-----------------|-----------------|---------|
| \(R_1 - C_1 > 0\) | a \(+\) | \(+\) | Instability point |
| b \(-\) | \(-\) | Instability point |
| c \(+\) | \(-\) | ESS |
| d \(-\) | \(-\) | Instability point |
| e \(+/-\) | 0 | Saddle point |

| \(R_1 - C_1 < 0\) \(R_1 - C_1 > -M_2\) | a \(+\) | \(+/-\) | Instability point |
| b \(-\) | \(-\) | Instability point |
| c \(-\) | \(-\) | Instability point |
| d \(-\) | \(-\) | Instability point |
| e \(+/-\) | 0 | Saddle point |

| \(R_1 - C_1 > 0\) \(R_1 - C_1 < -M_2\) | a \(-\) | \(-\) | Instability point |
| b \(+\) | \(-\) | ESS |
| c \(-\) | \(-\) | Instability point |
| d \(-\) | \(+\) | Instability point |
| e \(+/-\) | 0 | Saddle point |

Table 4. Local stability analysis of the evolutionary game in supply side.
As can be seen from table 2 and 3, when \( R_1 - C_1 < 0 \), enterprises would not choose to do sustainable transformation unless enough economic subsidies from the government (\( R_1 - C_1 > -M_2 \)); when \( R_1 - C_1 > 0 \), enterprises would choose to do sustainable transformations, at this time, the government does not need more stimulus.

2.3. Game model by the user side

Without considering the influence of enterprises, both government and customers are limited rational with limited information. The probability of customers participating in sustainable aquatic products is \( y \), and the probability of purchasing general aquatic products is \( 1-y \); the probability of government implementing policies to promote sustainable aquaculture is \( Z \), and the probability of implementing general policies is \( 1-z \).

\( R_2 \) Means the earnings (like elegant marine environment and access to healthy seafood with the best freshness etc.) buyers get when buying sustainable aquatic products. \( C_2 \) Is the additional cost of purchasing such products; \( R_3 \) is the social incremental benefits obtained by the government because of the promotion of sustainable aquaculture, and \(-R_3\) is the loss lost by the government due to the failure to popularize sustainable aquaculture. Suppose \( \alpha M_1 \) \((0 < \alpha < 1)\) is the indirect benefit of government incentive subsidies to enterprises. While the buyer does not participate in the decision-making of sustainable aquaculture, because all taxes or fines imposed by the government on enterprises that do not use sustainable breeding technology would be completely transferred to consumers in the form of increasing product prices, and the benefits of buyers are recorded as \(-M_2\).

**Table 5.** Payoff matrix in user side evolution game.

| Government | Sustainable Aquaculture Policy | General Policy |
|------------|--------------------------------|---------------|
| Buy Sustainable Aquatic Products | \(( R_2 - \alpha M_1, R_2 - C_2 + \alpha M_1 )\) | \(( R_3, R_2 - C_2 )\) |
| Buy Normal Aquatic Products | \((-R_3 + M_2, -M_2 )\) | \((0,0)\) |

The average quantitative benefit of consumers and the government in the statistical sense are as follows:

\[
\pi_C = [(R_2 - C_2 + \alpha M_1) * z + (R_2 - C_2) * (1 - z)] * y + (-M_2 * z) * (1 - y) \quad (7)
\]

\[
\pi_G' = [(R_3 - \alpha M_1) * y + (-R_3 + M_2) * (1 - y)] * z + (R_3 * y) * (1 - z) \quad (8)
\]

Replication dynamic equation could be obtained as follows:

\[
D(y) = \frac{dy}{dt} = (\alpha M_1 z + R_2 - C_2 + M_2 z) * y * (1 - y) \quad (9)
\]

\[
D(z) = \frac{dz}{dt} = (R_3 y - \alpha M_1 y - R_3 + M_2 - M_2 y) * z * (1 - z) \quad (10)
\]

Let \( D(x) = D(z) = 0 \), the equilibrium points A(0,0), B(0,1), C(1,0), D(1,1)and E(\( \frac{R_3 - M_2}{R_3 - \alpha M_1 - M_2}, \frac{C_2 - R_2}{R_3 - \alpha M_1 - M_2} \)). The Jacobi matrix \( \text{Det}(J) \)and the trace \( \text{Tr}(J) \) as follows:

\[
\text{Det}(J) = \begin{vmatrix}
\frac{\partial g(x)}{\partial x} & \frac{\partial g(x)}{\partial z} \\
\frac{\partial g(z)}{\partial x} & \frac{\partial g(z)}{\partial z}
\end{vmatrix}
\]

(11)
Tr(J) = \frac{\partial g(x)}{\partial x} + \frac{\partial g(z)}{\partial z} \tag{12}

Table 6. Det (J) and Tr (J) of five equilibrium points.

| Equilibrium points | Det(J) | Tr(J) | Outcome |
|--------------------|--------|-------|---------|
| A\textsuperscript{c3} | (R_2 - C_2)(M_2 - R_c)\textsuperscript{c3} | R_2 - C_2 + M_2 - R_c\textsuperscript{c3} | Instability point |
| B\textsuperscript{c3} | -(C_2 + R_2 + \alpha M_1 + M_2)(M_2 - R_c)\textsuperscript{c3} | C_2 - R_2 - \alpha M_1 - R_c\textsuperscript{c3} | Instability point |
| C\textsuperscript{c3} | (R_2 - C_2)M_4\textsuperscript{c3} | C_2 - R_2 - \alpha M_1\textsuperscript{c3} | ESS |
| D\textsuperscript{c3} | -(-C_2 + R_2 + \alpha M_1 + M_2)\alpha M_1\textsuperscript{c3} | C_2 - R_2 - M_2\textsuperscript{c3} | Instability point |
| E\textsuperscript{c3} | -\alpha M_1\textsuperscript{c3} | 0\textsuperscript{c3} | Saddle point |

When R_2 - C_2 > 0, consumers would choose to buy sustainable aquatic products no matter what is choice of the government; when R_2 - C_2 < 0, only if R_2 < C_2 - M_2, consumers would choose to buy sustainable aquatic products.

Table 7. Local stability analysis of the evolutionary game in user side.

| Condition | Equilibrium points | Det(J) | Tr(J) | Outcome |
|-----------|--------------------|--------|-------|---------|
| R_2 - C_2 > 0 | A | + | + | Instability point |
| | B | - | - | Instability point |
| | C | + | - | ESS |
| | D | - | - | Instability point |
| | E | +/- | 0 | Saddle point |
| R_2 - C_2 < 0 | A | + | +/- | Instability point |
| R_2 > C_2 - M_2 | B | - | - | Instability point |
| | C | - | - | Instability point |
| | D | - | - | Instability point |
| | E | +/- | 0 | Saddle point |
| R_2 - C_2 > 0 | A | - | - | Instability point |
| R_2 < C_2 - M_2 | B | + | - | ESS |
| | C | - | - | Instability point |
| | D | - | + | Stability point |
| | E | +/- | 0 | Saddle point |

3. Conclusions
Based on the model in part II, we offer some suggestions on every phase of sustainable aquaculture policy implementation. The strategies and choices at different time is showed as follows:

3.1. First Phase
At the start, the incremental profits of both aquaculture enterprises and consumers are negative. At this stage, the transformation efficiency is higher than the financial efficiency, and the operation efficiency is low. It is necessary to strengthen policy guidance and enhance government's financial support.

From the supply side, due to the problem of cost control of technical improvement, transformation investment is generally higher than income caused by the transformation. At this period, because of insignificant economic benefits, aquaculture enterprises would face more financial pressure and feel
difficult to maintain normal operations. Government should make the incremental profits of enterprises after technical improvement more than zero by means of tax relief and other subsidies. Secondly, high taxes should be imposed on the enterprises using unreasonable original aquaculture ways or strict environmental supervisions to promote sustainable transformation of enterprises. Third, more support would be given to research and innovation of aquaculture technology, which could give help to aquaculture enterprises to solve the technical problems using lower transformation costs.

From the user side, consumers need to spend more money when buying sustainable aquatic products, and the incremental cost is generally higher than the income. Therefore, it is necessary to strengthen the publicity and guidance of marine environmental protection and healthy aquatic products for buyers, and also certain economic incentives for them, such as promotional activities.

**Table 8. Strategies and choices of the three phases.**

| Time         | Supply side | User side | Choice         |
|--------------|-------------|-----------|----------------|
| First phase  | $R_1 - C_1 < 0$ | $R_2 - C_2 < 0$ | $(0,0,1)$       |
|              | $R_1 - C_1 < M_1$ | $R_1 - C_1 + aM_1 > 0$ |                |
| Second phase | $R_1 - C_1 < 0$ | $R_2 - C_2 < 0$ | $(0-1,0-1,1)$  |
|              | $R_1 - C_1 + M_1 < 0$ | $R_2 < M_2 + C_2$ |                |
| Third phase  | $R_1 - C_1 > 0$ | $R_2 - C_2 > 0$ | $(1,1,0)$       |

### 3.2. Second Phase

In the second stage, due to the continuous improvement of the industrial chain of sustainable aquaculture, the loss margin of both supply and demand sides is reduced, while the overall incremental profit is still negative. The financial efficiency firstly increases and then decreases but always higher than the conversion efficiency, while the operational efficiency rises steadily. Through policy guidance, the final strategy combination tends to be the combination of government incentives and consumers' purchase of sustainable high-quality aquatic products.

From the supply side, the government should still vigorously support independent R & D and technology innovations, further cost reduction of transformation and upgrading of aquaculture technology to increase the incremental economic benefits earn from sustainable aquatic products. In terms of economic policy, the results of supply side evolutionary game show that high tax policy has no substantial guiding effect on the promotion of sustainable breeding mode. From the user side, the government's goal is to promote the transformation and upgrading of aquaculture enterprises, and advocate consumers to transform to purchase sustainable and high-quality sustainable aquatic products. Therefore, the evolution result would to any combination of strategies, enterprises and customers make their choices randomly.

### 3.3. Third phase

In the third stage, sustainable aquaculture industry has formed scale benefit after the development of the first two stages, and the incremental profit of both supply and demand is positive. At this time, the whole aquaculture and sales system is highly efficient. Through dynamic game analysis, the system has evolved into a combination of strategies for sustainable aquaculture enterprises, consumers participating in the purchase of high-quality sustainable seafoods and government gradually withdrawing from incentive. From the supply side, with the gradual improvement of the breeding and marketing market, the government should establish an effective sustainable breeding supervision system. For example, raise the aquaculture industry standards and aquatic product market access system. From the user side, the market plays a decisive role in resource allocation, realizes the optimization of the market resources allocation from production to consumption, brings about the whole process of market allocation from production to consumption.
4. Reflections
This paper analyzes and discusses the stable evolutionary equilibrium of the evolution strategy by constructing the evolutionary game model of stakeholders on the supply side and user side of sustainable aquaculture.

From the supply side, in the early stage of the policy, we should adopt the way of high economic subsidies to the breeding enterprises that choose sustainable transformation and raise taxes on the enterprises that do not transform to promote the formation of sustainable breeding mode. In the second and third stage of the policy, it would be promoted to vigorously support the independent research and innovations of new and cost-effective aquaculture technology, and improve the evaluation and supervision system of sustainable aquaculture. From the user side, the role of market in resource allocation need to be taken more seriously.

References
[1] https://fish.cgiar.org/research-areas/sustainable-aquaculture#:~:text=Sustainable%20aquaculture%20breeds%20and%20genetics.%20Nutrition%20and%20health.%20Aquaculture%20systems.
[2] https://www.fisheries.noaa.gov/feature-story/aquaculture-supports-sustainable-earth
[3] https://www.aquaculturealliance.org/advocate/special-report-retail-demand-reduces-covid-19-pain-for-seafood-industry/
[4] https://www.worldbank.org/en/topic/environment/brief/sustainable-aquaculture
[5] Kotter J P. Leading Change: Why Transformation Efforts Fail[J]. IEEE Engineering Management Review, 2007, 37(3):42-48.
[6] SUN Liwen, REN Xiangwei. Research on the Driving Factors and Mechanism of Manufacturer Green Transformation——An Integrated Analysis Framework of Cross-layer Interaction Factors [J]. Modernization of Management, 2020, 40(02):67-70.
[7] Ostrom, E., 2007: Going beyond panaceas special feature: a diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Science, Vol.104, No.39.
[8] R. Olfati-Saber, Evolutionary dynamics of behavior in social networks, Proceedings of 46th IEEE Conference on Decision and Control, New Orleans, LA, USA, December 2007, pp. 4051–4056.