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第九届“认证杯”数学中国

数学建模国际赛

承　诺　书

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Research on Zero-sum Game Model of Network Evolution and Cooperative Evolution

Abstract:

The main problem to be solved in this paper is to establish a mathematical model to simulate the relationship between three or more participants, and perform sensitivity analysis on the model parameters, set up different parameter experiments to obtain the best parameters to design an adaptive biological system, even if it is subject to external interference and When the external environment changes, it can also automatically adjust the balance of the biological system, and then apply the mathematical model to solve other social dilemmas.

Aiming at problem 1: First, extend the "rock, paper, scissors" game model to the species May-Leonard model, and establish a network evolution zero-sum game model to simulate the relationship between more than three participants in the ecosystem. Compared with traditional games, networked games use the vertices in the network topology to represent species, and edges to represent the existence of game relationships between species. Pairs of species play games and obtain cumulative returns, which constitute a parameter return matrix, which is more consistent with social reality. In the limited network evolution game, each species has a limited number of strategies to choose from, and its dynamic evolution process is naturally related to the dynamics of the logical network.

In response to question 2: Combining the mathematical model established in question 1, first determine the model parameters: number of species x, population number N, design algorithm, introduce control variable method, use matlab programming to set different model parameters for single factor sensitivity analysis, and observe the results Variety. Then, introduce the interaction strength and Logistic population growth model to update the number of species, and design an adaptive biological system. The species can change the interaction strength to ensure its survival; finally, through matlab programming, change the corresponding parameters to analyze the impact of diseases and other predators Even if the biological system has other disturbances, it is possible to balance the imbalance between species by adjusting the interaction between organisms, so that the system reaches equilibrium.

Aiming at problem three: adjust the roles and parameters in the model, extend from problem two to design solutions for many social dilemmas, and realize dynamic games based on bounded rationality. In the process of the game, individuals will choose betrayal strategies in order to maximize their own interests. From this level, cooperative behavior seems impossible, but the phenomenon of cooperation can be seen everywhere. The application of evolutionary game analysis model to the actual problems of environmental pollution society reveals the cooperative behavior of government and enterprises in the process of environmental protection.

Addressing question 4: Use the established mathematical model ideas to explore the dynamics of COVID-19 infection, give the lowest achievable level of global epidemic prevention cooperation, and analyze the factors that may accelerate or hinder the goal in the current epidemic prevention process.

Keywords: zero-sum game; network evolution game model; adaptive biological system; dynamic game; social cooperation

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I. Problem restatement

1 . 1 Background analysis

Evolutionary game theory is a theory that combines biological evolution with classical game theory, and has become a hot topic in game theory research. Evolutionary game theory provides a dynamic interactive network with an environment that represents the decision-making and control problems of multiple participants, so that the strategic interaction of participants in the network can be modeled as a game between species in the ecosystem. In some game models, cooperative behavior in a group helps to maximize group benefits. However, for individuals, taking cooperative behavior often leads to loss of personal interests. This contradiction between individual interests and group interests Known as the social dilemma [1]. Maintaining cooperation in social dilemmas has become a research topic of concern in various fields. As one of the most widely used game models, the prisoner’ s dilemma game model has successfully portrayed the contradiction between individual and group interests in a social dilemma, and can help us study how cooperation can survive in a group of selfish individuals.

1 . 2 Issues that need resolving

Build a mathematical model to simulate the relationship with more than three participants. When implemented as an extended instance of the May-Leonard model, the model works differently from the original rock-paper-scissors model.

Through the sensitivity analysis of the model parameters, we design an adaptive biological system in which species can change the probability of interaction to ensure their survival, and explore how biological interactions balance the imbalance between species, as well as diseases and diseases. The influence of other predators.

Develop some analytical solutions for many other social dilemma games, such as rock-paper-scissors, battle of the sexes, stag hunting or exploring the dynamics of COVID-19 infection. The simulation model can also enable people to understand the real drivers of cooperative behavior in many other social dilemmas.

Write a two-page memorandum to ICM describing the minimum achievable level of a realistic global target epidemic prevention cooperation, a series of problems that must be resolved at present, and any circumstances that may accelerate or hinder the realization of the target.

II. Problem analysis

The main problem to be solved in this book is to establish a mathematical model to satisfy an adaptive biological system, which can automatically adjust the balance of the system even when affected by external factors. Apply the idea of establishing mathematical models to solve other social dilemmas.

2 . 1 Analysis of Problem 1

The purpose of this question is to understand the May-Leonard model through the "rock-paper-scissors" game model, and to establish an evolutionary game model based on zero-sum game to simulate the relationship between three or more participants in the ecosystem. First, starting from the topological structure of the network structure, the three-person "rock-paper-scissors" game analysis is carried out to construct the parameter return matrix; then, the "rock-paper-scissors" game model is used to simulate the ecological scene among the three species (May-Leonard model), and It is different from the original rock-paper-scissors model. Finally, a zero-sum game-based network evolution game model is established to simulate the relationship between more than three participants, and the profit matrix is modified according to the model selection strategy, and the participants are summarized in the equilibrium state. The parameter return matrix at x (x>3).

2 . 2 Analysis of Problem 2

On the basis of question 1, first determine the model parameters: the number of species x, the number of populations N, the design algorithm uses the control variable method to set different model parameters for single factor sensitivity analysis; then, to update the number of species to introduce the interaction strength and Population growth model, design an adaptive biological system, species can change the intensity of interaction to ensure their survival; finally, explore the impact of diseases and other predators, even if the biological system has other interference, it can also be adjusted by the interaction between organisms Balance the imbalance between species and make the system reach equilibrium.

2 . 3 Analysis of Problem 3

The third question is to adjust the roles and parameters of the model, and extend it to designing solutions for many social dilemmas, and to realize dynamic games based on bounded rationality. The evolutionary game analysis model is applied to the actual social problems of environmental pollution, revealing the cooperative behavior of government and enterprises in the process of environmental protection.

2 . 4 Analysis of Problem 4

Question 4 will propose a concept for the lowest level of global epidemic prevention cooperation and analyze the factors that may accelerate or hinder the goal in the current epidemic prevention process.

III. Symbol Description

Number of participants, number of species	x
Parametric return matrix	H_x
Graph node	v
Side	s
Species i dominates the cumulative income of species j	p_{ij}
Number of species i	$N_i(i = 1, 2, ..., x)$
Cycle	T
Maximum environmental capacity	K
Population growth rate	r
Reproduction cycle	g
Intrusion intensity	q
Maximum capacity of intruder environment	k
Government revenue	U
Government income investment	V
Business income	G
Penalty fees when the company fails to meet the standard	H
Species	SP

IV. Model assumptions

- Assume that there are more than three participants in the population, and the participants cannot simply be ranked from good to bad in the competition.
- Assume that the same dominance strategy is used for all species, and each species is both a dominator and a defender.
- The gain of the dominator is the loss value suffered by the defender; the gain of the defender is the loss suffered by the species, and the magnitude is the same as the value of the attacker's gain.
- The model is a zero-sum game.

V. Model building and solving

5.1 Model and solution of Problem 1

Game theory is a theory that studies multi-person decision-making problems, and has a wide range of applications in the economic, social and management fields. There are countless examples

Table 1 "Rock, Paper, Scissors" game

	x_1	x_2	x_3
x_1	*	1	-1
x_2	-1	*	1
x_3	1	-1	*

of game theory, such as "Prisoner's Dilemma" and "Wild Pig Game", as well as "Rock Paper Scissors" and "Chess" some common and well-known examples of game dynamics[2].

5.1.1 *"Rock Paper Scissors" game model*

The "rock, paper, scissors" game is a game often played in childhood. There are three participants in the game, called Participant 1, Participant 2, and Participant 3. Participants make a choice among rocks, scissors and cloth. They cannot compete in the competition. Simply sort participants from good to bad. The rules of the game are as follows: "Rock" defeats "Scissors", "Scissors" defeats "Cloth", and "Cloth" defeats "Rock".The network topology of the three participants is shown in Figure1.

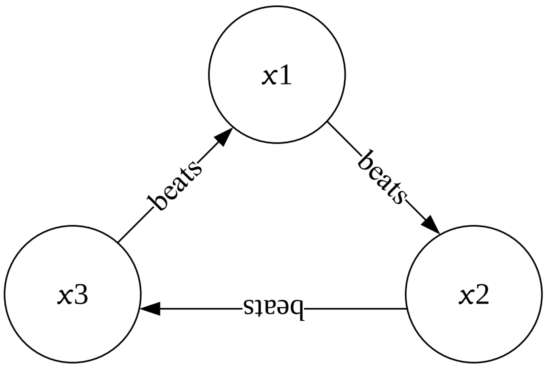


Fig. 1. Network topology model diagram

Each node represents a participant, and any two nodes have edges, that is, $S = C_3^2 = 3$. The direction of the arrow indicates loss (the arrow is toward oneself) and win (the arrow is toward the other side).

In Table 1, "*" means that the participant cannot compete with himself. Parameter 1 means that the participant in the row won the participant in the column, and the parameter -1 means the participant in the row lost to the participant in the column. . For example: the red 1 in Table 1 means that participant 1 wins participant 2, and participant 1' s profit is 1. On the contrary, participant 2' s profit is -1, that is, the yellow -1 in Table 1, which means participant 2 lost to participant 1.

Then the parameter return matrix of the "rock, paper, scissors" game of three participants can be expressed as:

$$H_{(x=3)} = \begin{pmatrix} * & 1 & -1 \\ -1 & * & 1 \\ 1 & -1 & * \end{pmatrix}$$

x represents the number of participants, and each element in the matrix (except the main diagonal) describes the profitability of both participants in each game. Parameter 1 represents the profit obtained when winning the game.

5.1.2 *Simulate the ecosystem with the "rock, paper, scissors" game model*

(1) May-Leonard model (three species)

In 1975, RMMay and WJ Leonard first used the rock-paper-scissors game to simulate the following ecological scenario (called the May-Leonard model): three species periodically dominate each other: one species dominates the second species, and the second species dominates the first. Three species, the third species dominates the first species. The game works well, for example, it can model different strains of circulating dominant E. coli bacteria. Figure 2 shows an example of the May-Leonard model.

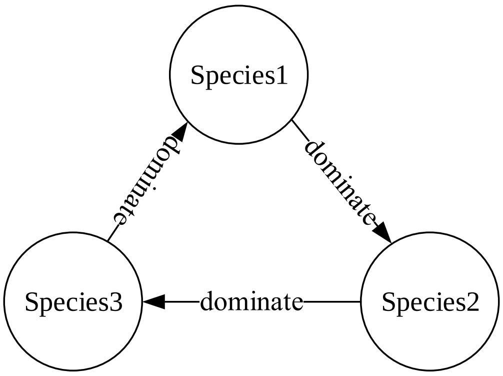


Fig. 2. Network topology M-L model diagram

This model is similar to the "Rock Paper Scissors" game model, but its working method is different from the original Rock Paper Scissors model. The difference is that the nodes of the model represent various species, and the power of the species is different, and there is a dominant relationship, that is The relationship between the predator and the predator, and the nodes of the rock-paper-scissors model represent each player. Each player can make three selection strategies (rock, scissors, and cloth), and the power of each player is equal.

(2) Network evolution game model based on zero-sum game (more than three participants)

When the number of participants x>3, a network evolution game model based on zero-sum game is established to simulate the relationship. A formal network evolution game model generally contains the following two basic elements[3]:

(i) Network Topology. It is represented by the one-way connected graph (V,S), where V represents the nodes (participants) in the network, and $S \subset V \cdot V$ represents the edges in the network (the interaction relationship between participants). There is a game relationship between any two species. The direction of the arrow indicates the relationship between dominance (the arrow points to another species) and the dominance (the arrow points to oneself).

(ii) Basic game unit $G = (X, S, H_x)$,where$X = \{1, 2, ..., x\}$ is the participant set,$S = \{s_1, s_2, ..., s_{x-1}\}$ is the selection strategy set, $H_x = (h_{ij})_{x \cdot x}$ is the parameter return matrix. h_{ij} represents the returned income matrix when species i (row i) ($i = 1, 2, ..., x$) selects strategy s_i to dominate species j (column j) ($j = 1, 2, ..., x$), and its opponent selects strategy s_j to dominate. $h_{ii}(i \not\equiv j)$ is -1 or 1.The parameter income matrix is inverted symmetric about the main diagonal, that is, the relationship between the upper triangular matrix and the lower triangular matrix is the inverted relationship.

Assuming that the game is repeated indefinitely, species i plays a game with other species, and obtains cumulative benefits p_i,

$$p_i(x = i, y = j | j \in \mathrm{N}_i) = \sum_{j \in \mathrm{N}_i} p_{ij}(x = i, y = j)$$

where p_{ij} represents the income obtained when species i and other species j play games. N_i represents the collection of other species except for species i.

The following simulates the relationship between more than three participants based on the established mathematical model:

① When $x = 4$, first, draw a four-node network topology diagram as shown in Figure 3 according to the zero-sum game relationship between species.

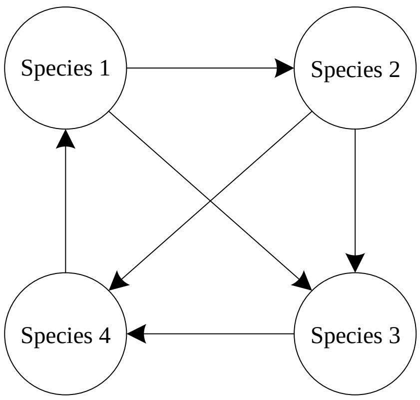


Fig. 3. Network topology model diagram

In the three-participant model, although a model that can simulate the competition between species has been established, an unbalanced relationship appears during the interaction of the four species. For example, species 2 can dominate both species 3 and 4. Only dominated by species 1; while species 4 is dominated by both species 2 and 3, but only dominates species 1. This leads to a certain imbalance, that is, six competitive strategies have emerged among the four species. Species 1 and 2 can dominate two species at the same time, and species 3 and 4 can only dominate one species. There is no doubt that species 1 and species 2 became the winners.

We found that when the number of species in the biological system is an even number, simply defining dominance as revenue 1, and defining dominance as revenue -1 will lead to an imbalance in the biological system, while odd numbers will not.

When there are four species in the biological system, in order to achieve a balance between species, the following strategy is adopted.

When species 1 dominates species 2, the gain is 2, and when species 3 is dominated, the gain is 1.

When species 2 dominates species 3, the gain is 1, and when species 4 dominates, the gain is 1.

When species 3 dominates species 4, the gain is 2.

When species 4 dominates species 1, the gain is 3.

It can be seen that when this strategy is adopted, the gains gained by each species when dominating other species are equal to the losses suffered when defending against other species. The offensive and defensive game model is a zero-sum game, and the biological system reaches equilibrium. According to this competitive strategy , There is no winner among the four species.

In order to make the expression more intuitive, a table is used to describe these 6 competitive strategies. It can be clearly seen in the table that the sum of the data in each row and column is 0.

Table 2: Game benefits between the four species

	SP1	SP2	SP3	SP4	Cumulative income p_i
SP1	*	2	1	-3	0
SP2	-2	*	1	1	0
SP3	-1	-1	*	2	0
SP4	3	-1	-2	*	0

Finally, the parameter income matrix is obtained as

$$H_{(x=4)} = \begin{pmatrix} * & 2 & 1 & -3 \\ -2 & * & 1 & 1 \\ -1 & -1 & * & 2 \\ 3 & -1 & -2 & * \end{pmatrix}$$

② When $x = 5$, according to the zero-sum game relationship between species, a five-node network topology is drawn as shown in Figure 4.

The game gains among the five species are shown in Table 3 below.

Table 3: Game benefits among the five species

	SP1	SP2	SP3	SP4	SP5	Cumulative income p_i
SP1	*	1	1	-1	-1	0
SP2	-1	*	1	1	-1	0
SP3	-1	-1	*	1	1	0
SP4	1	-1	-1	*	1	0
SP5	1	1	-1	-1	*	0

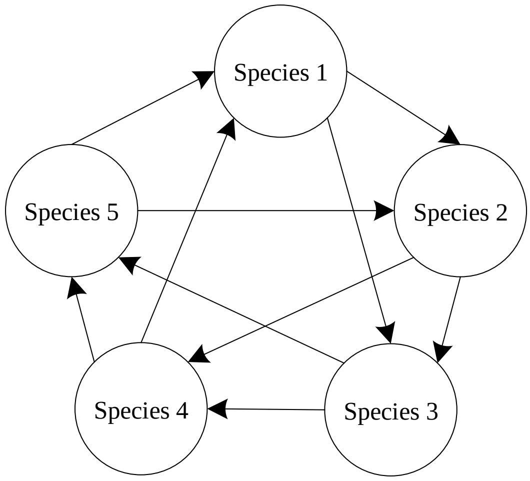


Fig. 4. Five-node network topology diagram

Finally, the parameter income matrix is obtained as

$$H_{(x=5)} = \begin{pmatrix} * & 1 & 1 & -1 & -1 \\ -1 & * & 1 & 1 & -1 \\ -1 & -1 & * & 1 & 1 \\ 1 & -1 & -1 & * & 1 \\ 1 & 1 & -1 & -1 & * \end{pmatrix}$$

③ When $x = 6$, according to the zero-sum game relationship between species, a six-node network topology is drawn as shown in Figure 5.

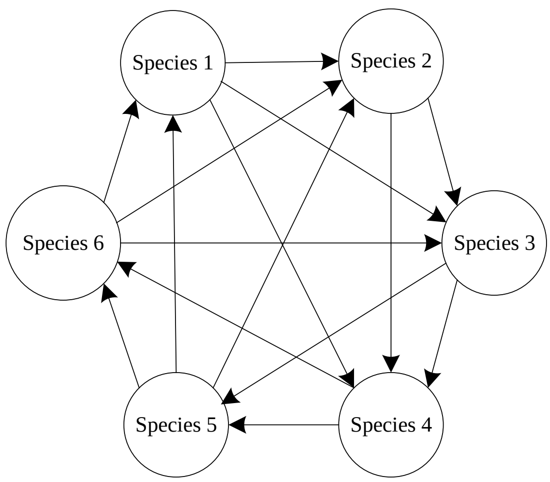


Fig. 5. Six-node network topology diagram

In order to achieve a balance between species, the following strategies are adopted.

When species 1 dominates species 2, the gain is 4, when species 3 is dominated, the gain is 1, and when species 4 is dominated, the gain is 1.

When species 2 dominates species 3, the income is 3, when species 4 is dominated, the income is 1, and when species 5 is dominated, the income is 1.

When species 3 dominates species 4, the income is 2; when species 5 is dominated, the income is 1, and when species 6 is dominated, the income is 1.

When species 4 dominates species 5, the gain is 3, and when species 6 dominates, the gain is 1.

When species 5 dominates species 6, the income is 4, and when species 1 is dominated, the income is 1.

When species 6 dominates species 1, the gain is 5, and when species 2 dominates, the gain is 1.

The game gains among the six species are shown in Table 4 below.

Table 4: Game benefits among the six species

	SP1	SP2	SP3	SP4	SP5	SP6	Cumulative income p_i
SP1	*	4	1	1	-1	-5	0
SP2	-4	*	3	1	1	-1	0
SP3	-1	-3	*	2	1	1	0
SP4	-1	-1	-2	*	3	1	0
SP5	1	-1	-1	-3	*	4	0
SP6	5	1	-1	-1	-4	*	0

Finally, the parameter income matrix is obtained as

$$H_{(x=6)} = \begin{pmatrix} * & 4 & 1 & 1 & -1 & -5 \\ -4 & * & 3 & 1 & 1 & -1 \\ -1 & -3 & * & 2 & 1 & 1 \\ -1 & -1 & -2 & * & 3 & 1 \\ 1 & -1 & -1 & -3 & * & 4 \\ 5 & 1 & -1 & -1 & -4 & * \end{pmatrix}$$

④ When $x = 7$, according to the zero-sum game relationship between species, a seven-node network topology is drawn as shown in Figure 6.

Then, we can draw the game gains among the seven species from the seven-node network topology as shown in Table 5 below.

Table 5: Game benefits among the seven species

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	Cumulative income p_i
SP1	*	1	1	1	-1	-1	-1	0
SP2	-1	*	1	1	1	-1	-1	0
SP3	-1	-1	*	1	1	1	-1	0
SP4	-1	-1	-1	*	1	1	1	0
SP5	1	-1	-1	-1	*	1	1	0
SP6	1	1	-1	-1	-1	*	1	0
SP7	1	1	1	-1	-1	-1	*	0

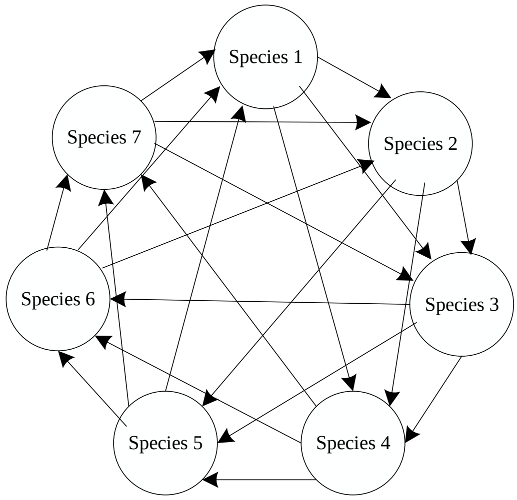


Fig. 6. Seven-node network topology diagram

Finally, the parameter income matrix is obtained as

$$H_{(x=7)}=\begin{pmatrix} * & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & * & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & * & 1 & 1 & 1 & -1 \\ -1 & -1 & -1 & * & 1 & 1 & 1 \\ 1 & -1 & -1 & -1 & * & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & * & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & * \end{pmatrix}$$

⑤ When $x = 8$, according to the zero-sum game relationship between species, a eight-node network topology is drawn as shown in Figure 7.

In order to achieve a balance between species, the following strategies are adopted.

When species 1 dominates species 2, the income is 6; when species 3 is dominated, the income is 1; when species 4 is dominated, the income is 1; when species 5 is dominated, the income is 1.

When species 2 dominates species 3, the income is 5, when species 4 is dominated, the income is 1, when species 5 is dominated, the income is 1, and when species 6 is dominated, the income is 1.

When species 3 dominates species 4, the income is 4, when species 5 is dominated, the income is 1, and when species 6 is dominated, the income is 1, and when species 7 is dominated, the income is 1.

When species 4 dominates species 5, the income is 3, when species 6 is dominated, the income is 1, and when species 7 is dominated, the income is 1 and when species 8 is dominated, the income is 1.

When species 5 dominates species 6, the income is 4, when species 7 is dominated, the income is 1, and when species 8 is dominated, the income is 1.

When species 6 dominates species 7, the income is 5, when species 8 is dominated, the income is 1, and when species 1 is dominated, the income is 1.

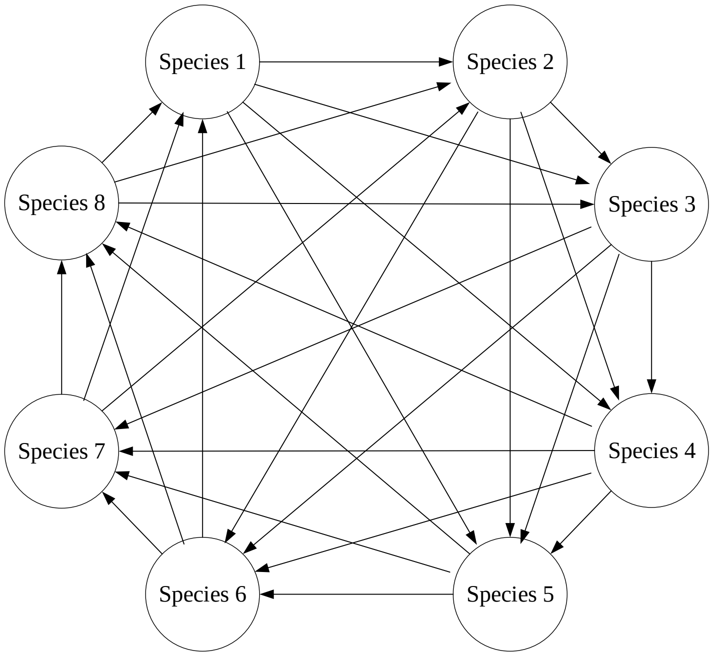


Fig. 7. Eight-node network topology diagram

When species 7 dominates species 8, the income is 6; when species 1 is dominated, the income is 1, and when species 2 is dominated, the income is 1.

When species 8 dominates species 1, the profit is 7, when species 2 is dominated, the profit is 1, and when species 3 is dominated, the profit is 1.

The game gains among the eight species drawn from the eight-node network topology are shown in Table 6 below.

Table 6: Game benefits among the eight species

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	Cumulative income p_i
SP1	*	6	1	1	1	-1	-1	-7	0
SP2	-6	*	5	1	1	1	-1	-1	0
SP3	-1	-5	*	4	1	1	1	-1	0
SP4	-1	-1	-4	*	3	1	1	1	0
SP5	-1	-1	-1	-3	*	4	1	1	0
SP6	1	-1	-1	-1	-4	*	5	1	0
SP7	1	1	-1	-1	-1	-5	*	6	0
SP8	7	1	1	-1	-1	-1	-6	*	0

Finally, the parameter income matrix is obtained as

$$H_{(x=8)}=\begin{pmatrix} * & 6 & 1 & 1 & 1 & -1 & -1 & -7 \\ -6 & * & 5 & 1 & 1 & 1 & -1 & -1 \\ -1 & -5 & * & 4 & 1 & 1 & 1 & -1 \\ -1 & -1 & -4 & * & 3 & 1 & 1 & 1 \\ -1 & -1 & -1 & -3 & * & 4 & 1 & 1 \\ 1 & -1 & -1 & -1 & -4 & * & 5 & 1 \\ 1 & 1 & -1 & -1 & -1 & -5 & * & 6 \\ 7 & 1 & 1 & -1 & -1 & -1 & -6 & * \end{pmatrix}$$

It can be deduced from this that if the number of species in the biological system is x,when x=2n

$$H_x=\begin{array}{c} \qquad\qquad\overbrace{\qquad\qquad\qquad\qquad}^{n-1}\quad\overbrace{\qquad\qquad\qquad\qquad}^{n-2} \\ \begin{pmatrix} * & x-2 & 1 & 1 & \dots & 1 & -1 & -1 & \dots & -1 & 1-x \\ 2-x & * & x-3 & 1 & 1 & \dots & 1 & -1 & -1 & \dots & -1 \\ -1 & 3-x & * & x-4 & 1 & 1 & \dots & 1 & -1 & \dots & -1 \\ \dots & \dots & 4-x & * & x-5 & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & * & \frac{x}{2}\text{-}1 & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & 1-\frac{x}{2} & * & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & * & x-4 & \dots & \dots \\ 1 & \dots & 1 & -1 & \dots & -1 & -1 & 4-x & * & x-3 & 1 \\ 1 & \dots & 1 & 1 & -1 & \dots & -1 & -1 & 3-x & * & x-2 \\ x-1 & 1 & \dots & 1 & 1 & -1 & \dots & -1 & -1 & 2-x & * \end{pmatrix} \\ \qquad\underbrace{\qquad\qquad\qquad\qquad}_{n-2}\quad\underbrace{\qquad\qquad\qquad\qquad}_{n-1}\qquad\qquad \end{array}$$

When $x = 2n + 1$,

$$H_x=\begin{array}{c} \qquad\overbrace{\qquad\qquad\qquad\qquad}^{n}\quad\overbrace{\qquad\qquad\qquad\qquad}^{n} \\ \begin{pmatrix} * & 1 & \dots & \dots & \dots & 1 & -1 & \dots & \dots & \dots & -1 \\ -1 & * & 1 & \dots & \dots & 1 & -1 & -1 & \dots & \dots & -1 \\ -1 & -1 & * & 1 & \dots & \dots & 1 & 1 & -1 & \dots & -1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ -1 & -1 & \dots & \dots & -1 & * & 1 & 1 & \dots & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ -1 & -1 & \dots & \dots & -1 & 1 & 1 & \dots & \dots & * & 1 \\ -1 & -1 & \dots & \dots & -1 & 1 & 1 & \dots & \dots & 1 & * \end{pmatrix} \\ \underbrace{\qquad\qquad\qquad\qquad}_{n}\quad\underbrace{\qquad\qquad\qquad\qquad}_{n}\qquad \end{array}$$

Therefore, according to this strategy, the established offensive and defensive game model is a zero-sum game, and the internal balance of the biological system can be maintained.

5.2 Model and solution of Problem 2

5.2.1 *Sensitivity analysis of model parameters*

Sensitivity analysis uses the method of changing external factors one by one to explain how the population is affected by changes in these factors. If a small change in a parameter can lead to a larger change in the result, then this parameter is called a sensitive factor, otherwise it is called an insensitive factor.

In question 1, the relationship between more than three participants is simulated by establishing a network evolution model based on zero-sum game. The parameters involved in this model are: the number of species x and the number of populations N. It is necessary to conduct a single-factor sensitivity analysis through the model parameters of the controlled variable analysis method, and design an adaptive biological system in which different parameters can be set to observe the changes in the results.

The specific process of the model is shown in Figure 8 below: When $x = 3, 4, 5$, and 6, it

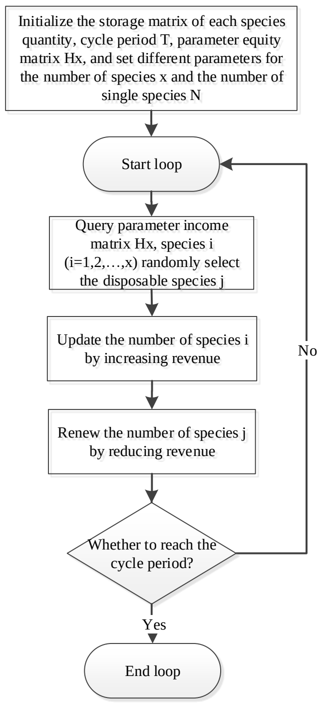
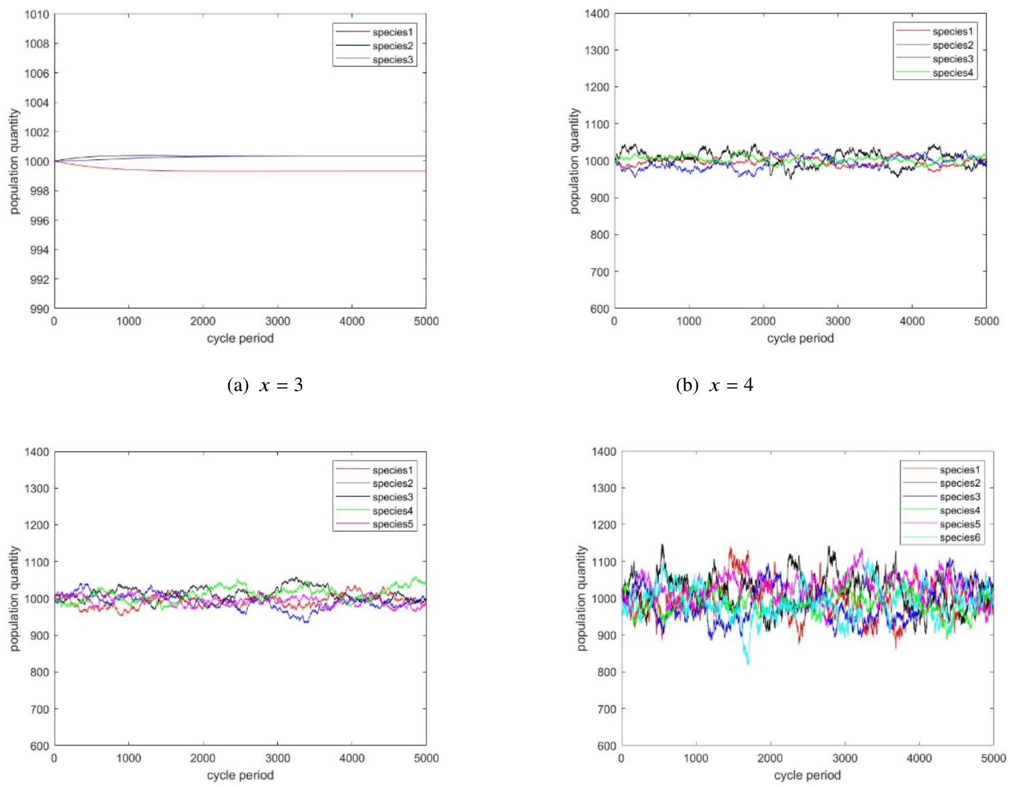


Fig. 8. Specific process of sensitivity analysis

is assumed that the number of individual species N is 1000, and the cycle period T is 5000. By writing a matlab program, setting the number of different species parameters, the following Figure 9 is obtained.

① The number of species x changes, other parameters remain unchanged

It can be seen from the figure that the analysis results are as follows: when the number of species is small, the competition between species is not obvious, and the fluctuation of the number of species



(a) $x = 3$ (b) $x = 4$

(c) $x = 5$ (d) $x = 6$

Fig. 9. The impact of the number of species on biological systems

is small. As the number of species (the number of participants) increases, the competition between species The game relationship is more obvious. The number of species will fluctuate with the competition relationship, and the stability of the entire biological system will increase. When the number of species is large, the extinction of a certain species may have little effect on the stability of the biological system during the same cycle, and the entire biological system is generally stable.

② The number of species N changes, other parameters remain unchanged

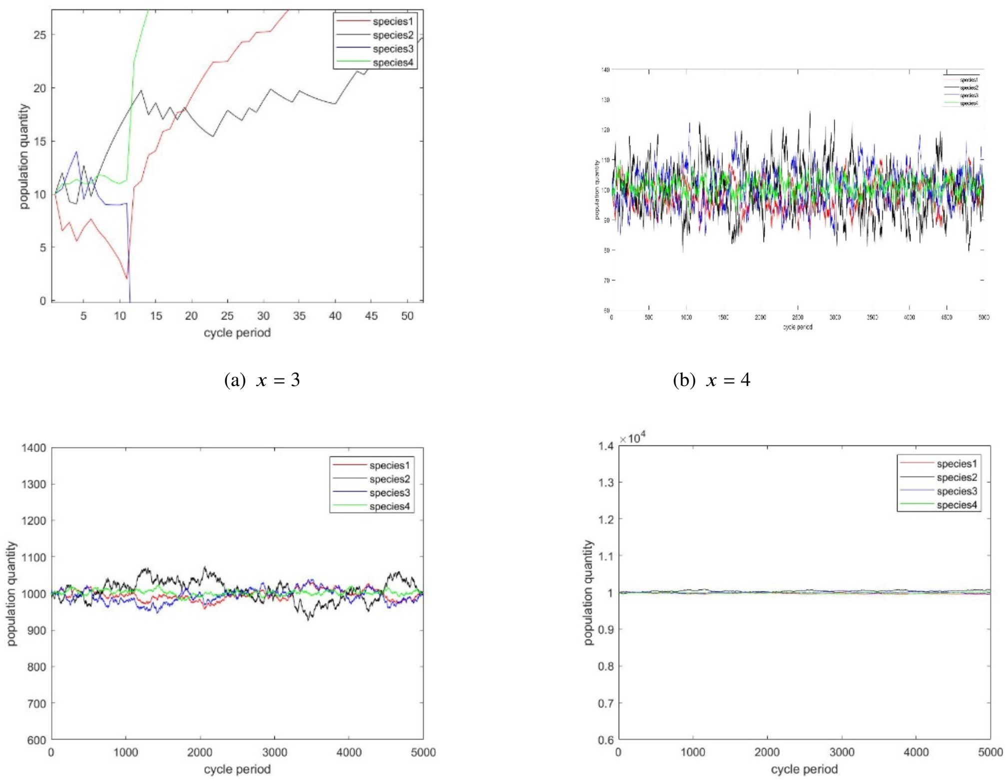
When $N = 10, 100, 1000, 10000$, suppose the number of species x is 4 and the cycle period T is 5000 unchanged. By writing a matlab program and setting different parameters for the number of a single species, the following Figure 10 is obtained.

As can be seen from the figure, the analysis results are as follows: When the number of species is small, after about 10 cycles, the number of species will drop sharply, leading to the extinction of this species. Because of the mutual domination of species, the extinction of one species will cause the entire organism The system crashes. As the number of species increases, the stability of the entire biological system will increase, and the degree of fluctuations will decrease.

5.2.2 *The effects of disease and other predators*

Two external factors, disease and other predators, are introduced to test the adaptability of the model.

(1) The impact of disease on biological systems



(a) $x = 3$ (b) $x = 4$

(c) $x = 5$ (d) $x = 6$

Fig. 10. The impact of the number of species on biological systems

Assuming that a certain disease spreads in species 1, the disease will lead to a sharp decrease in the number of species 1. As can be seen from Figure 11, after the decline in the number of species 1, the biological system loses balance and species 1 is extinct, eventually leading to all four species. Perish one after another.

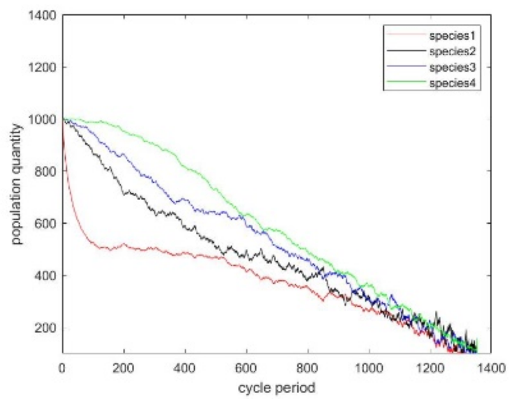


Fig. 11. The impact of disease on biological systems

(2) The impact of other predators on biological systems

Now suppose that there is another predator in the biological system. The predator feeds on species 1, but has no natural enemies. It can be seen from Figure 12 that the predator reproduced wantonly in the biological system, which caused the number of species 1 to decline. The biological system lost its balance, and species 1 died, which eventually led to the death of all four species.

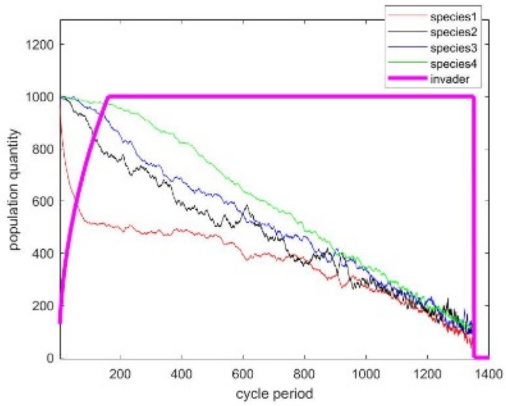


Fig. 12. The impact of other predators on biological systems

5.2.3 *Optimization of model parameters*

The arrival of diseases and the invasion of other predators will cause the number of species to continue to decrease. After a finite cycle, the number of species will drop to 0. To ensure the survival of species and the stability of biological systems, the Logistic population growth model[4] is introduced Optimal system model with interaction strength.

The specific process of the model is shown in Figures 13 and 14 below.

(1) Logistic population growth model

$$\frac{dN(t)}{dt} = r(1 - \frac{N(t)}{K})N(t)$$
$$N(t_0) = N_0$$

Among them,$N(t)$ represents the population at time t, K is the maximum population capacity of the environment, and r is the population growth rate.

Consider the discretization of this model

$$\frac{\Delta N}{\Delta t} = rN(1 - \frac{N}{K})$$

Taking the discrete step of time as 1, each generation (introducing the reproduction period g) is a time step.

$$N_t + 1 - N_t = rN_t(1 - \frac{N_t}{K})$$

(2) Interaction strength optimization system model

Due to the influence of diseases and other predators, there is an imbalance between species. In order to balance the imbalance between species, the system can change the interaction strength (to a certain extent, equivalent to the probability of interaction) to ensure the survival of species , To achieve ecological balance. That is, when the number of a certain species is less than a certain set value, an alarm will be triggered to increase the species’ predatory ability against other species to improve the balance performance of the biological system

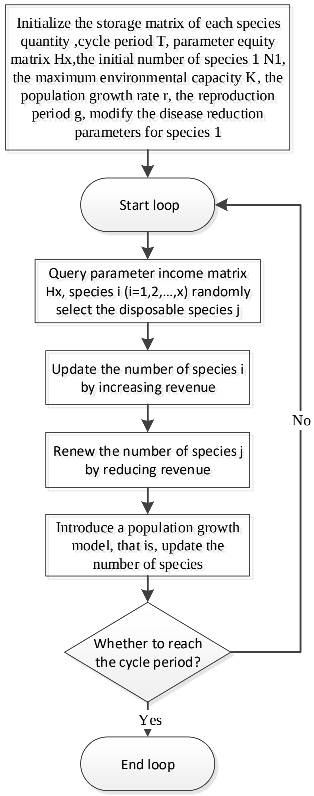


Fig. 13. Specific process of disease factor model introduced into population growth model

(3) The impact of disease and other predators (after the introduction of a balanced model)

To analyze the impact of diseases on biological systems, suppose the number of species $x = 4$, the initial number of species 1 $N1 = 1000$, the maximum environmental capacity $K = 1000$, the population growth rate $r = 0.01$, the reproduction period $g = 12$, and the cycle period $T = 5000$, discuss the impact of disease on species 1, and get the following Figure 15.

The results of the analysis are as follows: the initial number of species 1 is 1000, and the disease will reduce the number of species 1 to 80%, 60%, 20%, and 40% of the original number of species 1 each time an inter-species cycle is performed. As the disease affects the number of species 1 The more serious, the longer the cycle period required between species to restore the stability of the ecosystem.

In order to analyze the influence of the invaders on the biological system, the two parameters of the invasion intensity and the environmental capacity of the invaders are introduced. In the biological system with the number of species $x = 4$, one invader is added as the number of species, and the number of species becomes $x = 5$, assuming that the maximum environmental capacity $K = 1000$, the population growth rate $r = 0.01$, the reproduction period $g = 12$, set the cycle period $T = 5000$, and change the invasion intensity q or the intruder environmental capacity k to biological The influence of the system is shown in Figure 16 and Figure 17 below.

① When $k = 1000$, discuss the change of parameter q

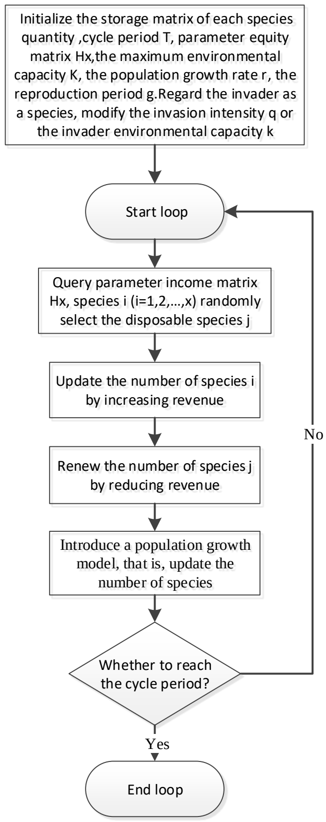


Fig. 14. The specific process of introducing the invader factor model of the population growth model

As the invasion intensity q continues to increase, although the balance of the biological system is gradually weakened, the biological system is still in an adaptive equilibrium state. But when the invasion intensity is too strong, the biological system will collapse.

② $q = 0.5$, discuss the change of parameter k

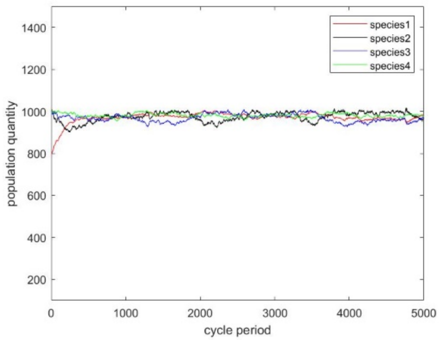
The invasion intensity q remains unchanged. With the continuous increase of the environmental capacity k of the intruder, the balance of the biological system is gradually weakened, and the biological system is still in an adaptive equilibrium state. But when the intruder's environment capacity k is too large, the biological system will also collapse.

Therefore, the two parameters of intrusion intensity q or intruder environment capacity k should be set appropriately.

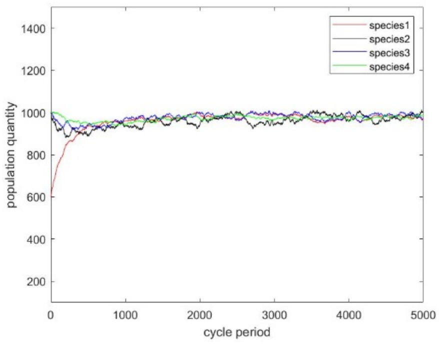
5.3 Evolutionary Game Analysis of Environmental Protection Policy Cooperation

Social dilemmas are common in human social and economic activities, such as rock-paper-scissors, war between the sexes, prisoner' s dilemma, and the dynamics of COVID-19 infection.

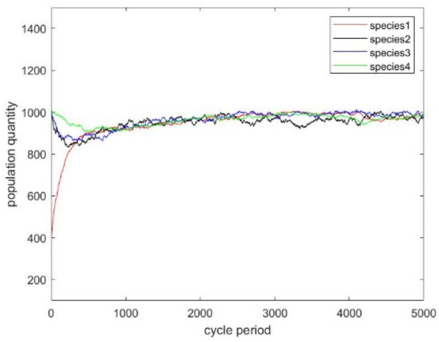
According to the analysis of these social dilemmas under the framework of classic game theory, cooperation is impossible to achieve. In particular, even if the game is repeated a limited number of times (repetitive games in reality cannot be an infinite number of times), cooperation is impossible by using the reverse recursion method. However, the phenomenon of cooperation in limited repeated



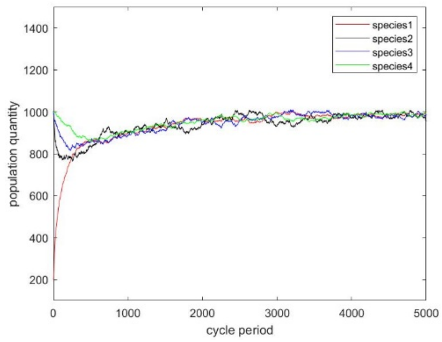
(a) $a(1,1) = 0.8 * N1$



(b) $a(1,1) = 0.6 * N1$



(c) $a(1,1) = 0.4 * N1$



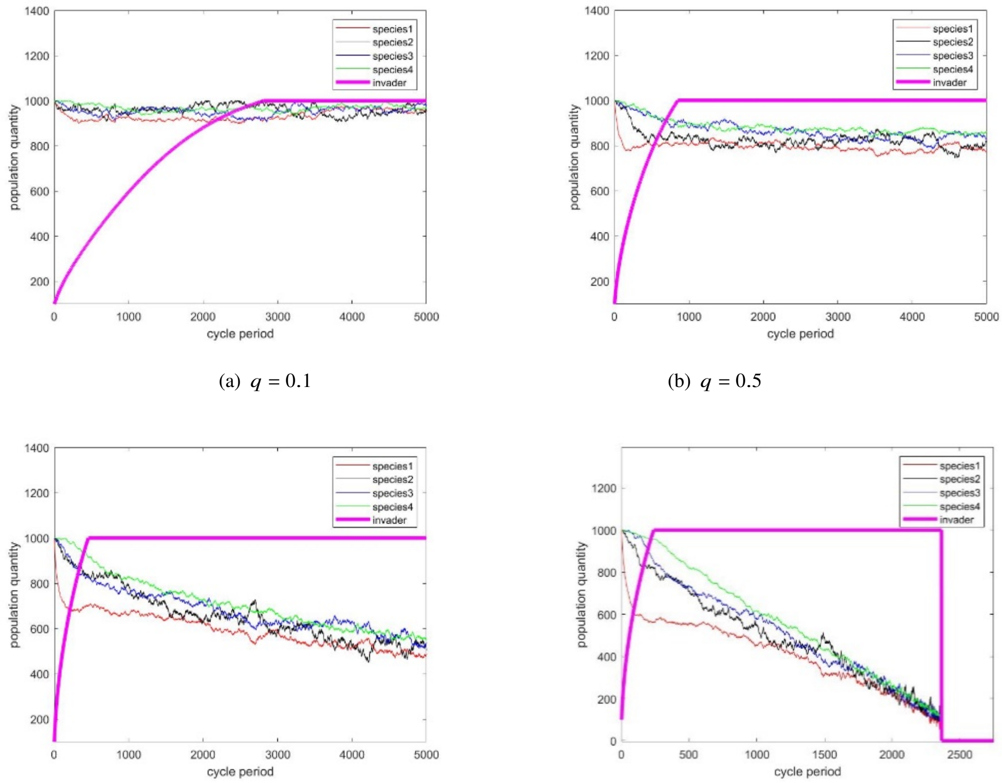
(d) $a(1,1) = 0.2 * N1$

Fig. 15. The impact of the number of species on biological systems

games is common in real society and various behavior experiments[5].This shows that individuals in reality do not act in accordance with the assumptions of classic game theory. When the result of an individual choosing a strategy depends not only on his own strategy choices, but also on the strategy choices of others, the final situation is much more complicated than the behavior predicted by the game under complete rationality. Therefore, to explain the spontaneous cooperation phenomenon among selfish groups in real society, it is necessary to break completely rational assumptions, while traditional game analysis methods are based on the analysis of rational reasoning and cannot reflect the learning process of participants. Therefore, the traditional static analysis framework is incapable of analyzing the game problem of bounded rational participants[6].

To solve the problem of social dilemma, it is necessary to seek the corresponding mechanism to make the cooperative strategy a systematic evolutionary stable strategy. Therefore, the evolutionary stability strategy (ESS) of analyzing the game in various situations has become the core issue. The concept of ESS was first proposed in a paper published by Maynard Smith and Price in Nature in 1973[7].The so-called ESS means that if the majority of individuals in the group choose this strategy, then any small mutant group that adopts other strategies cannot invade this group.

In recent years, social capital has increasingly participated in the construction of public projects, which has not only made up for the lack of a single source of government funding, but also brought investment income to social investors. During the game between the government and social capital, there are differences in the ability of the two parties to obtain information, decision-making



(a) $q = 0.1$ (b) $q = 0.5$

(c) $q = 1$ (d) $q = 1.5$

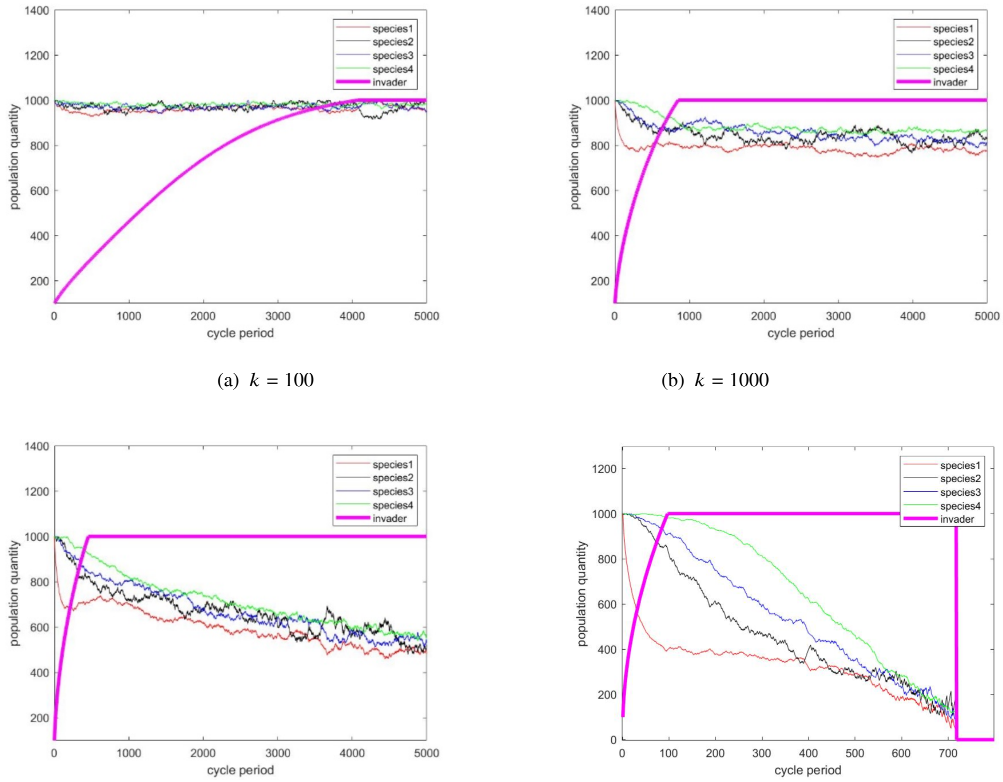
Fig. 16. The impact of the number of species on biological systems

capabilities, and risk preferences. Therefore, they cannot make optimal strategic choices at the beginning, but constantly adjust and adapt according to the environment and the changes in the other party’s behavior. It has undergone a dynamic evolution process. At the same time, the goals pursued by the government and social capital are not the same. Social capital pays more attention to the risks and economic benefits of the project. The government should not only pay attention to the safety and reasonable benefits of fiscal funds, but also the social benefits generated by the project. In order to attract social capital cooperation, the government may need the necessary "compromise", so the government is not completely rational in the decision-making process. Using the evolutionary game model can analyze the strategy selection process of the government and social capital more scientifically and rationally, and simulate the possible behavior of both parties, thus clearly showing the formation path of the evolutionary stable strategy of the government and social capital.

In life, because the government’s information about SMEs is not completely symmetrical, it is considered to use the idea of evolutionary game theory and use model assumptions at different stages to analyze environmental governance issues.

5.3.1 *The game between government and enterprise*

This stage occurs when the initial stage has developed to a certain extent. After the government purchases certain equipment and gives enterprises some preferential policies, it is assisted by command and control, which means that enterprises that do not deal with pollutants are punished.



(a) $k = 100$ (b) $k = 1000$

(c) $k = 2000$ (d) $k = 10000$

Fig. 17. The impact of the number of species on biological systems

Thus, the game payment matrix between the government and the enterprise in Table 7 can be obtained.W_d indicates the government fines for companies that do not handle pollutants.

Table 7: Game Payment Matrix between Government and Enterprise

		Enterprise	
		Deal with	Don't deal with
Government	Implement pollution reduction incentive policies	$U_a - V_a, S_a$	$U_d - V_d, S_d - W_d$
	No pollution reduction incentives	U_a, S_a	$U_d, S_d - W_d, S_d$

Assuming that among the government groups, the proportion of players who choose the strategy of "implementing economic incentive policies for pollution reduction" is p, then the proportion of parties that choose the strategy of "not implementing economic incentive policies for pollution reduction" is $1 - p$. At the same time, suppose that the proportion of players who choose the "processing" strategy in the enterprise group is q, then the proportion of the "no processing" strategy is $1 - q$.

Assuming that the government "implements pollution reduction economic incentive policies" and "does not implement pollution reduction economic incentive policies", the expected return of the two types of game players is u_{11}, u_{12}, and the group average return is $\overline{u_1}$, then there is

$$u_{21} = pS_a + (1-p)S_a = S_a$$

$$u_{22} = p(S_a - W_d) + (1-p)(S_a - W_d) = W_d - S_d$$

$$\overline{u_2} = qu_{21} + (1-q)u_{22} = qS_a + (1-q)(S_d - W_d)$$

The replication dynamics of the two types of group games are analyzed separately, and the government's replication dynamic equation is obtained as:

$$\frac{dp}{dt} = p(u_{11} - \overline{u_1}) = p(1-p)[qV_d - qV_a - V_d]$$

The dynamic equation of enterprise replication is:

$$\frac{dp}{dt} = q(u_{21} - \overline{u_2}) = q(1-q)[S_a - S_d + W_d]$$

The above equation describes the group dynamics of the evolution system. According to the method proposed by Frideman, the asymptotic stability of the system evolution strategy is analyzed, and the system has equilibrium points $A(0,0)$, $B(1,0)$,$C(0,1)$, $D(1,1)$ If $S_a - (S_d - W_d) > 0$, A(0,0), D(1,1) are saddle points, B(1,0) is an unstable node, and C(0,1) is stable The node is ESS) (see Figure 2.2 for the phase diagram of the system), that is, the government does not implement pollution reduction incentive policies and the enterprise treats pollutants.

From the above calculation results, it can be analyzed that with the increase in the profits made by the pollutant companies in the initial stage, in the mature stage of energy conservation and emission reduction, with the aid of government command and control, the violating companies will be punished only if the relationship of $S_d - (S_d - W_d) > 0$ is established Next, the above-mentioned evolutionary stability strategy can be achieved. That is to say, in the mature stage, the government does not implement economic incentive policies for pollution reduction, and is assisted by command and control. The income of enterprises from treating pollutants is greater than the income of not treating pollutants in order to achieve the purpose of active pollution discharge. An increase of W_d (the government's fine for companies that do not deal with pollutants) means that increased punishment can effectively control the profits of companies' illegal emissions, thus laying the foundation for the next stage.

5.3.2 *The game between environmental protection departments and enterprises*

The game has developed to a mature stage, enterprises voluntarily deal with pollutants, law enforcement agencies supervise the enterprises, and the government cancels preferential policies and supervises environmental protection agencies.

E means that the government requires the environmental protection department to supervise. If the supervision is not carried out, a certain amount of the environmental protection department will be deducted; G means the income of the enterprise; H means that the environmental protection department has been supervised to find that the company's pollution discharge is not up to the standard. So we get the game payment matrix of Table 8 between environmental protection departments and enterprises.

Table 8: Game payment matrix between environmental protection departments and enterprises

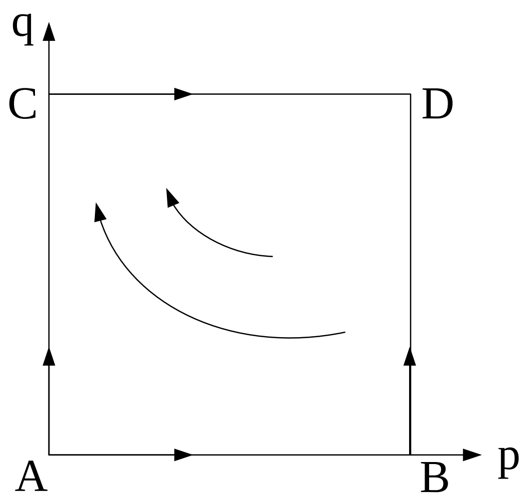


Fig. 18. Game phase diagram at maturity stage

		Enterprise	
		Up to standard	not to standard
Environmental protection department	Monitor	$0, G - H$	$-E, G$
	Do not monitor	$0, G$	$-E, G$

Assuming that among the environmental protection department group, the proportion of players who choose the "monitoring" strategy is p, then the proportion of the "non-monitoring" strategy is $1 - p$. At the same time, suppose that the proportion of players in the "standard" strategy in the enterprise group is q, then the proportion of the "non-standard" strategy is $1 - q$.

The replication dynamic analysis of the two types of group games is carried out, and the government's replication dynamic equation is obtained as

$$\frac{dp}{dt} = p(u_{11} - \overline{u_1}) = p(1 - p)E$$

The dynamic equation of enterprise replication is:

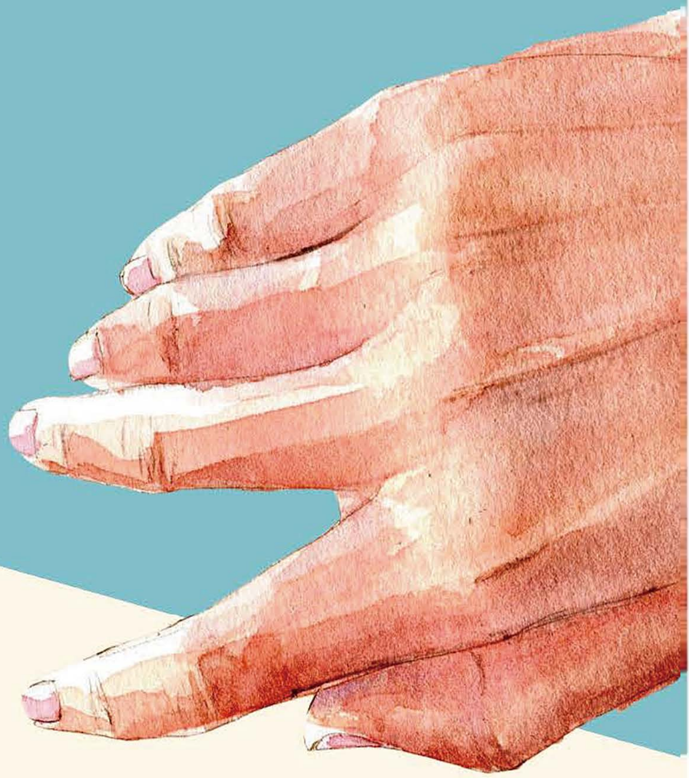
$$\frac{dq}{dt} = q(u_{21} - \overline{u_2}) = q(1 - q)pH$$

The above equation describes the group dynamics of the evolution system. The asymptotic stability analysis of the evolution strategy of the system shows that the stable node of the system is D(1,1), which is ESS, that is, the environmental protection department conducts supervision and inspection and discharges pollution. Enterprise purification treatment and compliance. In this process, whether the supervision department conducts supervision is related to the government's fines, and it is also related to the fines imposed when companies fail to meet the standards. Therefore, strengthening the disciplinary education of the supervision department is an inevitable decision of the government. If pollution accidents occur due to poor supervision, it is necessary to punish the supervisory authority. Therefore, increasing penalties will also help reduce pollution accidents caused by companies that do not meet the standards.

The behavior of enterprises in pursuit of the greatest self-interest often fails to truly realize their own greatest interests, and often they cannot fully realize the greatest interests of society. Environmental issues are a common problem faced by the world. In our country, various laws, regulations and related systems for environmental protection have not been established and perfected, and enterprises lack the motivation to actively deal with pollutants. The initial stage of the government' s implementation of pollution reduction economic incentive policies is The best choice. With the gradual maturity of corporate management and the increased enthusiasm of companies to deal with pollutants, the market will enter a mature stage. At this time, the government regulates the market in the form of command and control. Under the supervision of regulatory authorities, companies are driven by profits and responsibilities. Enterprises will choose the road of voluntary pollution reduction and advocate voluntary pollution discharge standards. In the mature stage, in accordance with the requirements of the market economy, the government adopts a policy of cooperating with enterprises. Energy conservation and emission reduction will become a matter for the participation of various market participants such as the government, enterprises, citizens, and follow the emission standards and monitoring technical specifications. The perfection of the market will eventually spontaneously adjust and develop in a positive direction.

5.4 Model and solution of Problem 4

our wills unite
like a fortress
Fight the epidemic



Customs entry requirements

1.Immigration inspection

Cooperate with staff

test for the virus

2.Isolation and Prevention

assigned to single room

self-isolation for 2 weeks

1. Natural history, transmission and diagnosis of viruses The research content includes understanding the natural history of the virus and how to separate it from the infected person; supporting the improvement of diagnostic technology and product iteration to promote clinical treatment; and exploring the infection models (including animal models) and transmission models of the disease; detecting the virus's apparent mutation and potential adaptability, and understand the immune response, etc.;	
2. The animal and environmental research on the origin of the virus, and the management practices of the interaction between humans and animals The research content includes determining animal reservoirs and searching for scientific evidence of animal viruses spilling into humans; understanding the socio-economic and behavioral risk factors of such spills, and designing a sustainable risk control plan;	
3. Epidemiological research The research content includes understanding the dynamic mechanism of virus transmission and the number of virus replication, incubation period, series interval, transmission model and environmental factors. The severity of the disease, including the fatality rate of symptomatic patients in hospitals and the high-risk groups of patients, etc.; understand the susceptible population, and conduct research on effective public health response measures;	
4. Clinical features and management Determine the natural history of the disease to support clinical and public health interventions, transmission prevention and control, and clinical trials; develop core clinical results (sharing) mechanisms to maximize the use of multiple clinical data; determine auxiliary and supportive measures to improve clinical treatment effects;	
5. Infection prevention and control, including the protection of health workers Specific research includes understanding how to effectively control the secondary transmission of hospital feelings and communities, optimize personal protective equipment (PPE), and reduce environmental risks during transmission;	

VI. Strength and Weakness

6.1 Strength

- The model building strategy strictly abides by the zero-sum game, the participants are evenly matched, and no one becomes a winner.
- The establishment of the model has undergone an evolutionary game and completed the transformation of income. Each species will encounter different opponents. The income of the species is the result of the interaction of a large number of different individuals.
- When external factors are added, the adaptability of the biological system will keep the system stable.

6.2 Weakness

- There is still a certain gap between the model and the real biological system in nature, such as mortality, extreme weather and other factors are not considered.
- When the intensity of diseases and invaders is too strong, the biological system will die.

VII. References

[1] Liu Danna. Research on the influence of individual diversity on the evolution of cooperation based on the prisoner' s dilemma game[D]. Beijing University of Posts and Telecommunications, 2019.

[2] Liu Zuhua, Feng Aifang. Solving matrix games with Mathematica software [J]. Advanced Mathematics Research, 2017, 20 (04): 71-74.

[3] Guo Peilian. Analysis, control and application of networked game based on semi-tensor product method [D]. Shandong University, 2016.

[4] Huang Wei, Song Wei, Li Yuefeng. Research on Influencing Factors of WeChat Message Forwarding Based on Logistic Population Growth Model[J]. Intelligence Theory and Practice, 2018, 41 (07): 78-86+98.

[5] Lugovskyy V, Puzzello D, Sorensen A, Walker J, Williams A. An experimental study of finitely and infinitely repeated linear public goods games[J]. Games and Economic Behavior, 2017, 102:286-302.

[6] Quan Ji, Zhou Yawen, Wang Xianjia. A review of the evolution of group cooperation behavior in social dilemma games[J]. Complex Systems and Complexity Science, 2020, 17(01):1-14.

[7] Maynard Smith J, Price G R. The logic of animal conflict[J]. Nature, 1973, 246:15-18

VIII. Appendix

Listing 1: The matlab Source code of Algorithm

```
sensitivity_a.m
clc;
close all;
x=4;
N=1000;
T=5000;

H3=[0,1,-1;
    -1,0,1;
    1,-1,0];
H4=[0 2  1 -3;
   -2 0 1  1;
   -1 -1 0 2;
    3 -1 -2 0];
H5=[0 1  1  -1  -1;
    -1 0 1  1   -1;
    -1 -1 0 1   1;
    1 -1 -1 0   1;
    1  1 -1 -1  0];
H6=[0   4   1   1  -1  -5;
    -4  0   3   1  1   -1;
    -1  -3  0   2  1   1;
    -1  -1  -2  0  3   1;
    1   -1  -1  -3  0  4
    5   1   -1  -1 -4 0];
a=zeros(x,T);
a(:,1)=N;
for t=2:T
    a(:,t)=a(:,t-1);
    for i=1:x
        if (x==3)
            H=H3;
           B = find(H3(i,:)>0);
        else if(x==4)
                 H=H4;
               B = find(H4(i,:)>0);
            else if (5==x)
                     H=H5;
                  B = find(H5(i,:)>0);
                else
                     H=H6;
                     B = find(H6(i,:)>0);
                end
            end
        end
```

```
        L = length(B);
        alp=randi([1,L],1,1);
        y=B(alp);
        temp=a(i,t);
        a(i,t) =a(i,t)+(N/temp)*L*H(i,y);
        a(y,t) =a(y,t)-(N/temp)*L*H(i,y);
    end
end
figure(1)
plot(1:T,a(1,:),"-r");
xlabel("cycle period");
ylabel("population quantity");
hold on
plot(1:T,a(2,:),"-k");
hold on
plot(1:T,a(3,:),"-b");
hold on
plot(1:T,a(4,:),"-g");
hold on
% plot(1:T,a(5,:),"-m");
% hold on
% plot(1:T,a(6,:),"-c");
% hold on
legend('species1','species2','species3');
legend('species1','species2','species3','species4');
legend('species1','species2','species3','species4','species5');
legend('species1','species2','species3','species4','species5','species6');
ylim([0.6*N,1.4*N])


disease.m
clc;
close all;
x=4;
r=0.01;
K=100;
T=5000;
gn=12;
W3=[0,1,-1;
    -1,0,1;
    1,-1,0];
W4=[0 2  1 -3;
   -2 0  1  1;
   -1 -1 0 2;
    3 -1 -2 0];
W5=[0 1  1  -1  -1;
    -1 0 1  1   -1;
    -1 -1 0 1   1;
    1 -1 -1 0   1;
```

```
   1  1 -1 -1  0];
W6=[0  4   1   1  -1  -5;
   -4  0   3   1  1   -1;
   -1  -3  0   2  1   1;
   -1  -1  -2  0  3   1;
   1   -1  -1  -3  0  4
   5   1   -1  -1 -4  0];
a=zeros(x,T);
a(:,1)=N;
a(1,1)=0.05*N;
for t=2:T
   a(:,t)=a(:,t-1);
   for i=1:x
      if (x==3)
         W=W3;
        B = find(W3(i,:)>0);
      else if(x==4)
             W=W4;
           B = find(W4(i,:)>0);
         else if (5==x)
                W=W5;
             B = find(W5(i,:)>0);
            else
                W=W6;
                B = find(W6(i,:)>0);
            end
         end
      end
        L = length(B);
        alp=randi([1,L],1,1);
        y=B(alp);
        temp=a(i,t);
        a(i,t) =a(i,t)+(K/temp)*L*W(i,y);
        a(y,t) =a(y,t)-(K/temp)*L*W(i,y);
   end
   if(0==mod(t,gn))
      for i=1:x
         if(a(i,t)<N)
            a(i,t)=a(i,t)+r*a(i,t)*(1-a(i,t)/N);
         else
            a(i,t)=N;
         end
      end
   end
end
figure(1)
plot(1:T,a(1,:),"-r");
hold on
plot(1:T,a(2,:),"-k");
```

```
hold on
plot(1:T,a(3,:),"-b");
hold on
plot(1:T,a(4,:),"-g");
hold on
xlabel("cycle period");
ylabel("population quantity");
\% plot(1:T,a(5,:),"-m");
\% hold on
\% plot(1:T,a(6,:),"-c");
\% hold on
legend('species1','species2','species3','species4');
ylim([0.1*N,1.5*N])
Invader.m
clc;
clear all;
x=5;
q=0.1;
r=0.01;
K=1000;
N=1000;
T=5000;
gn=12;
H3=[0,1,-1;
    -1,0,1;
    1,-1,0];
H4=[0 2  1 -3;
   -2 0 1  1;
   -1 -1 0 2;
    3 -1 -2 0];
H5=[0 2  1 -3 0;
   -2  0  1  1 0;
   -1 -1 0 2  0;
    3 -1 -2 0 0;
    q  0  0 0  0];
H6=[];
a=zeros(x,T);
a(:,1)=N;
a(5,1)=100;
for t=2:T
    a(:,t)=a(:,t-1);
    for i=1:x
        if(a(i,t)<=0)
                a(:,t)=0;
                continue;
        end
        if (x==3)
            H=H3;
           B = find(W3(i,:)>0);
```

```
      else if(x==4)
             H=H4;
           B = find(H4(i,:)>0);
         else if (5==x)
                H=H5;
             B = find(H5(i,:)>0);
            else
                H=H6;
                B = find(H6(i,:)>0);
            end
         end
      end
        L = length(B);
        alp=randi([1,L],1,1);
        y=B(alp);
        temp=a(i,t);
        if(i<x)
           if(a(y,t)-(N/temp)*L*H(i,y)>0)
           a(i,t) =a(i,t)+(N/temp)*L*H(i,y);
           a(y,t) =a(y,t)-(N/temp)*L*H(i,y);
           else
           a(i,t) =a(i,t)+a(y,t);
           a(y,t) =0;
           end
        else
           if((a(y,t)-(K/temp)*L*H(i,y))>0)
           a(i,t) =a(i,t)+(K/temp)*L*H(i,y);
           a(y,t) =a(y,t)-(K/temp)*L*H(i,y);
           else
           a(i,t) =a(i,t)+a(y,t);
           a(y,t) =0;
           end
        end
        if(a(i,t)<=0)
            a(i,t)=0;
        elseif(a(i,t)>N)
            a(i,t)=N;
        end
   end
   if(0==mod(t,gn))
      for i=1:x
         if((a(i,t)<N) && (a(i,t)>0))
             a(i,t)=a(i,t)+r*a(i,t)*(1-a(i,t)/N);
         end
      end
   end
end
figure(1)
plot(1:T,a(1,:),"-r");
```

```
hold on
plot(1:T,a(2,:),"-k");
hold on
plot(1:T,a(3,:),"-b");
hold on
plot(1:T,a(4,:),"-g");
hold on
plot(1:T,a(5,:),"-m","linewidth",3);
hold on
xlabel("cycle period");
ylabel("population quantity");
legend('species1','species2','species3','species4','invader');
ylim([0.1*N,1.4*N])
```