Study on the relationship between Lampreys and ecosystem with variable sex ratio based on cellular automata

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Abstract. In this paper, cellular automata technology is used to build a model of the relationship between lampreys population and sex ratio, and further expand the model of the relationship between lam-preys and ecosystem to study the relationship between organisms with variable sex ratio and eco-system. The co-evolution model of lampreys and parasitic organisms was constructed by dou-ble-layer nested cellular automata to complement the relationship between lampreys and ecosystems. Sensitivity analysis of the model was performed to study the effects of pollution and fishing on lampreys. Finally, combined with the above model and simulation results, the advantages and dis-advantages of lampreys were evaluated, and the impact of lampreys on the ecosystem was summa-rized.

Keywords: Lampreys, sex ratio, cellular automata, ecosystem.

1. Introduction

Most species are substantially either male or female, and have a sex ratios of about 1:1. A few species such as Lampreys, however, have evolved to produce adaptive sex ratios variation[1].

Lampreys attach themselves to large fish to feed on body fluids[2]. For fishermen, lampreys are parasites that wreak havoc on the fishing industry. But for some indigenous people, lampreys are a source of food. Researching the dependence of adaptive sex ratios organisms such as lampreys on local conditions is important for both fisheries conservation and ecological construction.

Research has shown that the gender of lampreys depends on its growth rate, which depends on the environmental food resources[3]. The impact of growth environment on lampreys is shown in Figure 1.

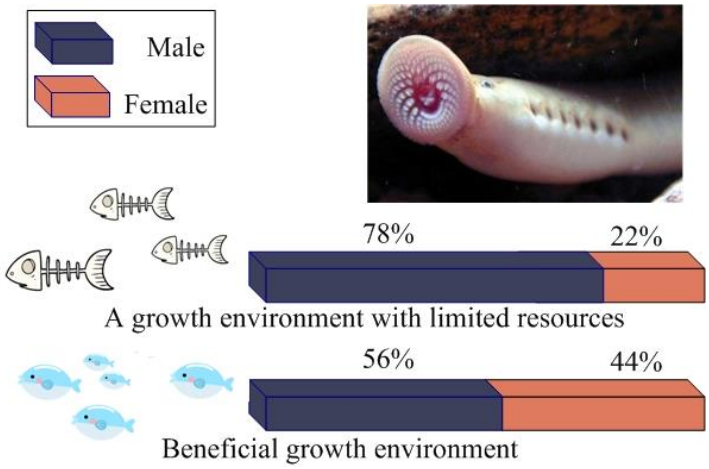


Figure 1. Adaptive sex ratios variation in lampreys

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems. Researching the impacts on ecological systems when the population of lampreys can alter its sex ratios.

Malthusian proposed an Exponential Growth Model in 1798, which suggested that population size grows exponentially. Pierre François Verhulst proposed the Logistic growth Model in 1838-1847. On the basis of the theory of interspecific competitive relationships, Lotka and Vito Volterra proposed the Lotka-Volterra Model (L-V Model) [4]. However, these models are not suitable for representing growth in the population of lampreys and other species with variable sex ratios.

There are many studies on lampreys currently, demonstrating characteristics of variable sex ratio, Predation, and habits of lampreys. However, research on the relationship of lampreys to other species is still lacking.

John von Neumann proposed the Cellular Automaton Model in the 1950s. It is able to simulate the evolution of various complex relationships. This model can be well used to research the evolution of lampreys and their relationships with other organisms.

2. A model of the interaction between sex ratios and population based on Cellular Automaton

For a certain carrying capacity, the higher the population, the worse the survival environment of the individuals, and the higher the male proportion in the population of Lampreys. In turn, sex ratios affect the variation of the population. Therefore, the population and sex ratios interact with each other, so we consider to establish a model of the interaction between sex ratios and the population.

2.1. Data Description

Data show that it takes three to six years for lampreys larvae to reach adulthood, and adults differentiate between the sexes and then enter the reproductive phase after one to two years, and die after reproduction (Figure 2).

When food is sufficient, i.e., when the population of lampreys is low in population, the MALE proportion is 56%; when food is scarce, i.e., when the population of lampreys is overpopulated, the male proportion is 78%.

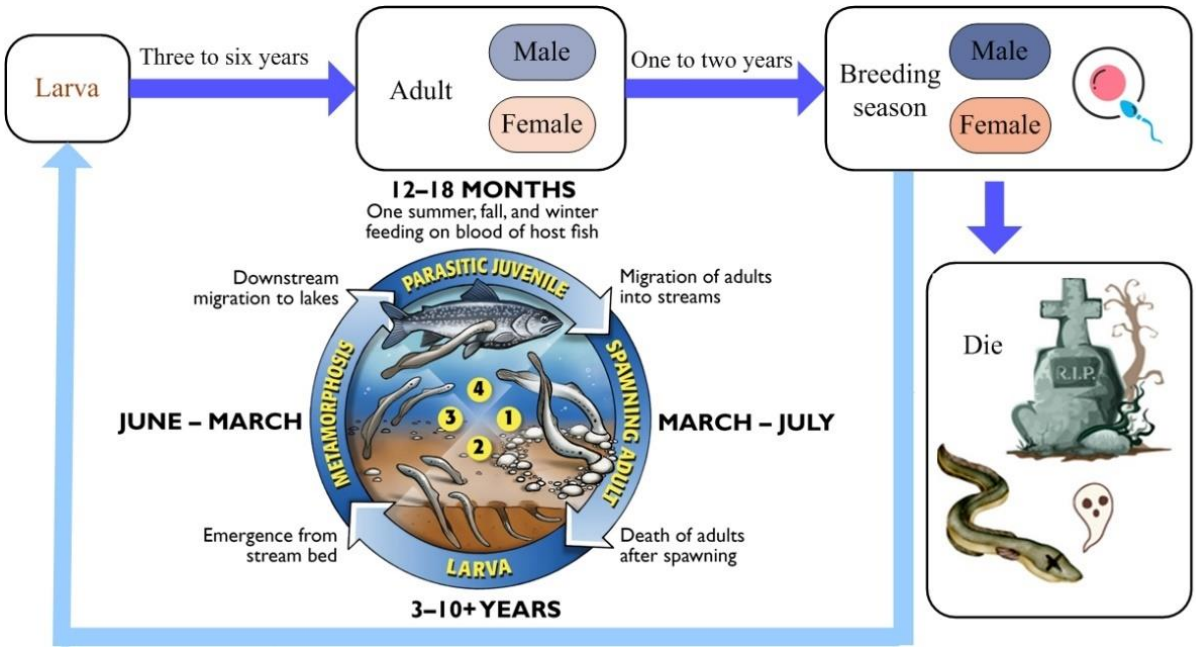


Figure 2. The life cycle of lampreys [5]

2.2. The Establishment of Model 1

In this paper, we refer to Conway's Game of Life and the application of metacellular automata in biology and chemistry to build metacellular automata([4][6][7][8]), to simulate the changes of population size and sex ratio of seven-gill eels.

2.2.1 Modeling the change of male proportion

Since the male proportion of lampreys increases exponentially with development time[4], the change of male proportion is modeled as

$$P_{male}\left(T_1\right)=Ae^{\gamma T_1} \tag{1}$$

Where A and γ are parameters to be solved.

According to Assumption 4, we got system of equations

$$\begin{cases} P_{male}\left(3\right)=0.56 \\ P_{male}\left(6\right)=0.78 \end{cases} \tag{2}$$

The solution yield processes $A=0.4$, $\gamma=0.11$.

2.2.2 A model of the interaction between sex ratios and population based on Cellular Automaton.

Cellular Automaton is a special lattice dynamics model that can simulate spatial and temporal evolution processes of complex systems. In this paper, a Cellular Automaton is established to simulate the spatial and temporal evolution of population populations and sex ratios of lampreys. The specific process is as follows.

A. Modeling Cellular Automaton model

Create an array of 30×30 squares representing the survival space of the lampreys population. Each square grid can survive up to one lamprey.

The ability of each individual lampreys to contribute to the population size depends on five factors: the location of the lampreys, the current age, the development time, the maturity interval, and the sex of the lampreys. In Cellular Automaton, we need to simulate these five factors in the initial state and during the evolutionary process.

B. Setting the rules for the Cell

a. Modeling the life cycle of lampreys

According to Assumption 4, development time is affected by the population of lampreys. Given that Cellular Automaton has 900 squares, the carrying capacity is set to 450. the closer the population of lampreys is to the carrying capacity, the longer the development time. Setting the development time to be a function of population N, i.e.

$$T_1\left(N\right)=\begin{cases} 3, N<169 \\ 4, 169\le N<225 \\ 5, 225\le N<282 \\ 6, N\ge 282 \end{cases} \tag{3}$$

Where development time is rounded to the nearest whole number for the sake of convenience (T_2 is the same).

After larvae develop into adults, set the male proportion of the lampreys equal to the male probability of lampreys, and obtain the probability model for the sex differentiation of hatchlings into males during evolution from the model for the change in male proportion.

$$P_{male}\left(T_1\right)=0.4e^{0.11T_1} \tag{4}$$

The maturity interval of lampreys is usually one to two years[5], so the maturity interval of lampreys in Cellular Automaton is set to be randomly taken as 1 or 2, that is, $T_2=random\left\{1,2\right\}$.

b. Specify iteration rules for Cell

Referring to Conway's Game of Life, set the Cell birth and survival rules as follows.

Male lampreys produce pheromones to attract nearby females to spawn[9]. Provide that in Cellular Automaton, for each blank square, a larva will be born in that square if the 5×5 neighborhood of each square contain both male and female that reached breeding conditions.

The survival probability of lampreys larvae in each square is determined by the population on the Moore neighborhood (3×3 neighborhood) of that square, and the following function is established.

$$P_{sur}(n)=\frac{1}{1+e^{0.5(n-5)}} \tag{5}$$

2.3. The Solution of Model 1

In Cellular Automaton, set the activity range of lampreys to 5×5 neighborhoods. Traversing through each square in CA, then we can get the distribution of locations of lampreys born in the next year.

2.3.1 Simulation of Cellular Automaton

In this paper, MATLAB is applied to solve Model 1.

We use MATLAB to build a 30×30 matrix, called CA matrix, to simulate Cellular Automaton, and set the initial data and the survival rules of the evolution process in the Cellular Automaton. The details are as follows.

Letting the CA matrix randomly distribute 245 lamprey individuals at the initial state. Referring to the life cycle of lampreys, setting the age of individuals in the initial state to be taken uniformly from 1 to 7, i.e., set 35 lampreys from 1 to 7 years old each. And the development time and maturity interval follow the rule, $T_1+T_2=6$ .The development time was taken according to eq.3 and the maturity interval was taken according to formula, $T_2=random\{1,2\}$, during the evolution process.

In terms of sex, the data show that the male proportion of lampreys population is generally larger than the female proportion. So according to the current automaton carrying capacity and the initial population, the initial male proportion was set to be 60%, i.e., the probability that the initial individual was male was 60%, and the probability of differentiating into male during the evolution process was taken as eq.4.

The initial state of Cellular Automaton and the influencing elements and specific settings of population during evolution are shown in Figure 3.

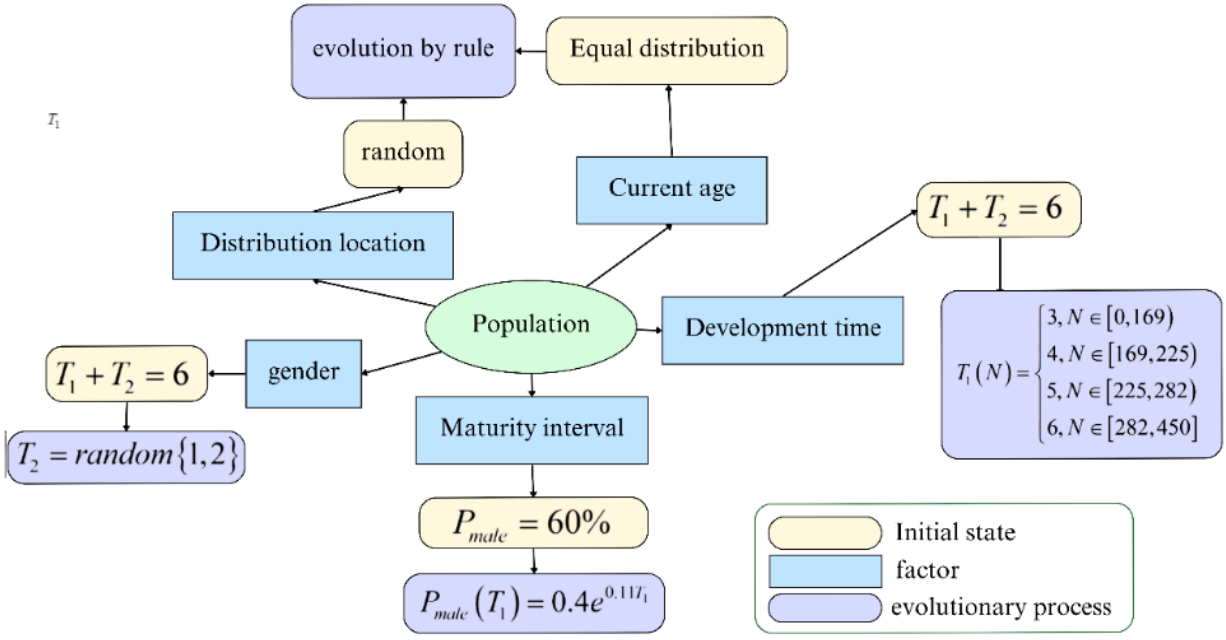


Figure 3. Rule Settings for Cellular Automaton

2.3.2 Modeling the evolution of lampreys in Cellular Automaton

Traverse through all squares in the CA matrix to determine if a lampreys larva is born in each square, using the survival rules as a basis. And calculate the Survival probability of each lamprey larvae.

The specific judgment method of whether lampreys larvae can survive is as follows.

Traverse through each lampreys larva, randomly take the judgment number between $[0,1]$, if the judgment number is less than the Survival probability, then the hatchling can survive, otherwise the larva dies. The specific simulation method is shown in Figure 4.

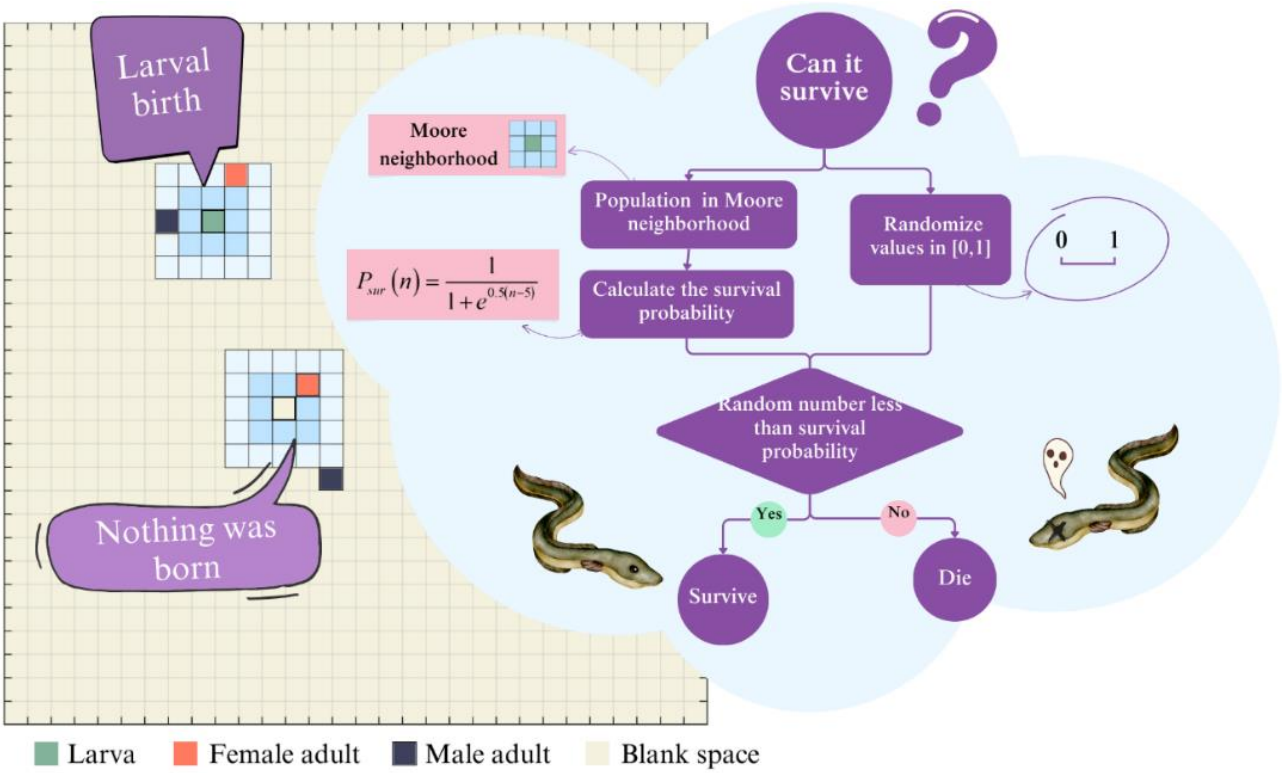


Figure 4. Schematic diagram of the simulation method for the iterative rules

The evolution of the lampreys population over the 20 years of the simulated Cellular Automaton is obtained with 20 iterations. One possible evolutionary outcome is shown in Figure 5.

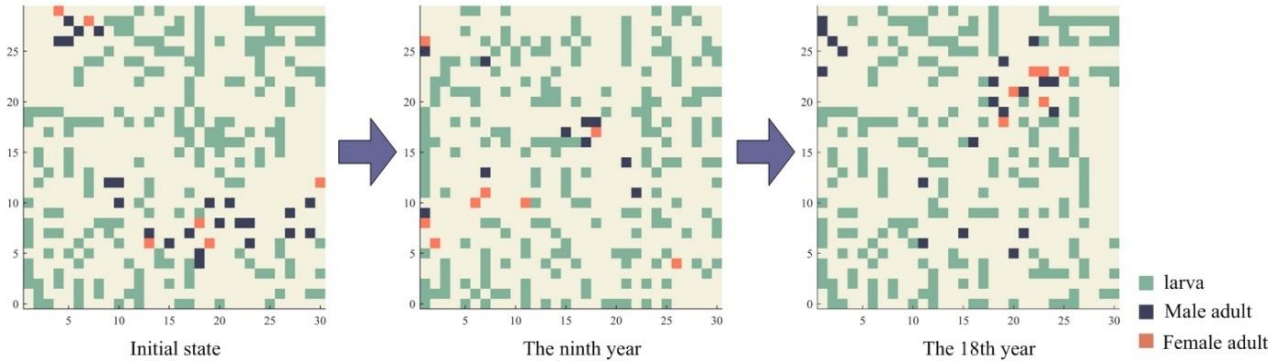


Figure 5. Schematic diagram of the evolution in Cellular Automaton.

2.3.3 Data processing

The data obtained from 20 iterations were analyzed and the evolution of lampreys' population in Cellular Automaton was depicted in a waterfall plot as shown in Figure 6.

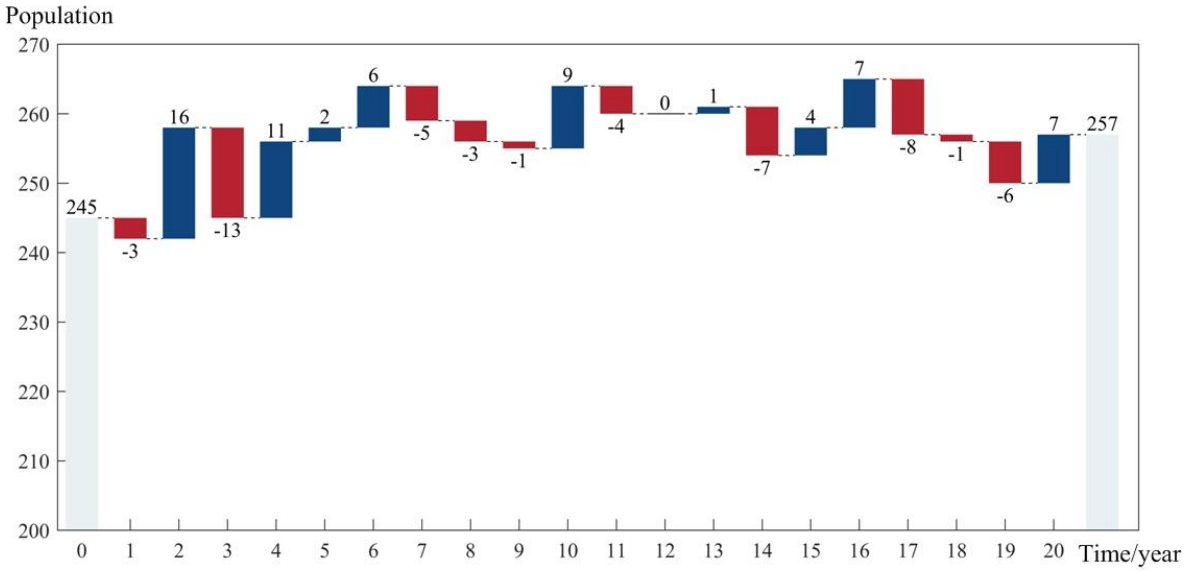


Figure 6. Waterfall plot of population change in lampreys

Data on population and male proportion of lampreys over time were obtained from the simulation of Cellular Automaton evolution process. Based on the above data, the annual growth rate of lampreys was calculated and plotted in a line graph as shown in Figure 7.

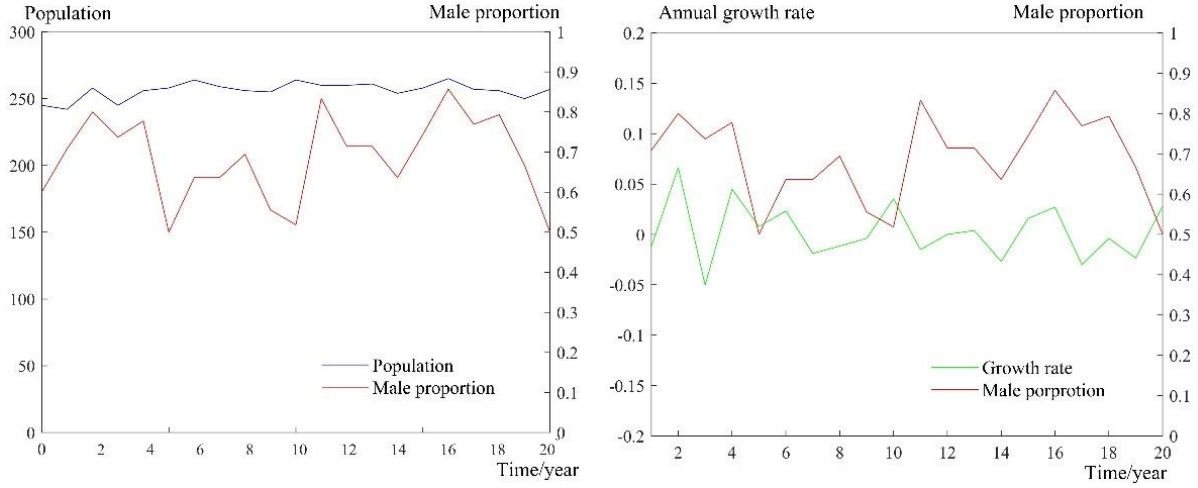


Figure 7. The change of lamprey's male proportion, population and annual growth rate over time

According to Figure 7, an increase in the male proportion of lampreys leads to a decrease or even a negative growth rate in the following year. Once the population decreases, it leads to a decrease in the male proportion.

The above results were analyzed and the conclusions were obtained as shown in Figure 8.

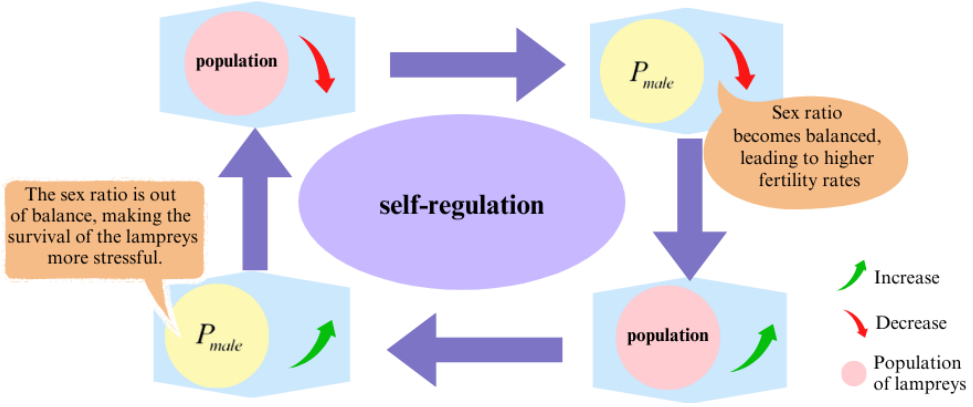


Figure 8. Conclusion from model I

3. Conclusion

In this paper, a model of the relationship between the number of lampreys and the sex ratio was established by using cellular automata technology, and the model of the relationship between lampreys and the ecosystem was further extended to study the relationship between organisms with variable sex ratio and the ecosystem. The co-evolution model of lampreys and parasites was constructed, and the effects of pollution and fishing on lampreys were analyzed. The results showed that as the population of lampreys increased, so did the proportion of males, leading to a decline or even negative growth in the following year. This finding has important implications for understanding and predicting the effects of changes in lamprey populations on ecosystems.

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