Research on the Impact of Sex Adaptive Change Abilities in Lampreys on Their Population and Ecological Environment

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Abstract. With the rapid change in the ecological environment, the adaptive mechanism of specific species and its impact on the stability of the ecosystem has become an important field of ecological research. This study took Lampreys as the research object to explore the effects of their sex-adaptive changeability on the ecosystem and its population. Sex adaptation in lampreys means that the sex ratio of lamprey changes in response to changes in the external environment. In this study, we used the Lotka - Volterra population competition model to predict the change in the lamprey population and the corresponding ecological impact. Comparing the predicted results of the two scenarios with and without sex change, we found that the sex-adaptive changeability of lampreys plays an important role in maintaining the stability of the ecological environment and improving the survival ability of the population. This study is of great significance for protecting the ecological environment and maintaining the stability of the ecosystem.

Keywords: Lamprey, Ecosystem, Sex ratio, Lotka-Volterra model.

1. Introduction

With the change in the global ecological environment, the adaptability of biological populations has become an important field of ecological research. Lampreys, as organisms living in a specific water environment, have attracted the attention of many scientists for their unique sexual adaptability. The ability of sex adaptation to change refers to the ability of organisms to change their sex ratio to adapt to the environment when they encounter changes in the external environment. This study explores the effects of the sex adaptation of lampreys on the ecological environment and its population, which is of great significance for maintaining the stability of the global ecological environment.

In this study, we created a sex-driven function $g(M, F)$ to reflect the sex adaptation of lampreys. Using the Lotka - Volterra model, we set up the population equation of Lampreys with the ability of sex adaptive change and the ecosystem impact equation. At the same time, we assumed the absence of this ability for comparison. By comparing the two cases, we can determine the effect of the sex adaptation of lampreys on the ecological environment and its population.

2. Impact on the ecosystem

We hypothesize that the impact of lampreys on the larger ecological environment can be reflected based on the number of prey populations of lampreys, while only considering biological factors and ignoring abiotic factors such as water quality. At the same time, the effect of human activities on the population of lampreys was negligible compared to the natural population of lampreys.

We used the Lotka - Volterra model to analyze this problem. The sex ratio of sea lampreys was determined by the number of male and female populations of sea lampreys, and the reproductive success rate of sea lampreys q was determined by the sex ratio of males and females. The closer the sex ratio of males and females was to 1, the higher the reproductive success rate was. The number of male and female sea lampreys is affected by many factors. We can set up the equation of the number of male sea lampreys and the number of female sea lampreys. At the same time, we can also set up an equation for the prey population. Using this model, we can obtain the changes in the number of females, the number of males, and the number of prey populations over time.

We set the sex driving function a *g(M,F)*, which represents the proportion of males in newborn lampreys. For the convenience of calculation, we simplified the values as follows.

$$g(M,F)=\frac{M^{'}}{M^{'}+F^{'}} \tag{1}$$

$$\omega=\frac{P}{M\beta_1+F\beta_2} \tag{2}$$

$$g(M,F)=\begin{cases}0.78, \omega \prec \lambda_1\\ 0.56, \omega \succ \lambda_2\\ 0.78-\dfrac{\omega-\lambda_1}{\lambda_2-\lambda_1}, \lambda_1 \prec \omega \prec \lambda_2\end{cases} \tag{3}$$

M and *F* are the populations of male and female lampreys. *P* are the populations of prey. *M'* and *F'* are the populations of newborn males and females. β_1 and β_2 are the food resources required by males and females.

If there is an adaptive change in the sex ratio of sea lampreys, we can set up the following equation.

$$\frac{dM}{dt}=(r_M(1-\frac{M}{K_M})Mg(M,F)*q+r_F F(1-\frac{F}{K_F})g(M,F)*q)*\frac{p}{1000}-d_M M+b_M aPM \tag{4}$$

$$\frac{dF}{dt}=(r_F F(1-\frac{F}{K_F})[1-g(M,F)]*q+r_M(1-\frac{M}{K_M})M[1-g(M,F)]*q)*\frac{P}{1000}-d_F+b_F aPF \tag{5}$$

$$\frac{dP}{dt}=r_P P-aP(M+F) \tag{6}$$

$$q=\begin{cases}1-|\frac{M}{M+F}-0.5|-|\frac{F}{F+M}-0.5|, \text{otherwise}\\ 0, M=0 \cap F=0\end{cases} \tag{7}$$

f represents the resource consumption rate of lampreys. *r* is the reproductive rate of lampreys. *d* is the mortality rate of lamprey. *b* is the predation efficiency. *K* is the environmental capacity. The subscripts of *M*, *F*, and *P* represent male, female, and prey respectively. *a* is the probability of prey being preyed upon. *t* is the time, and *q* is the reproductive success rate.

From this equation, we can get the following series of results over time.

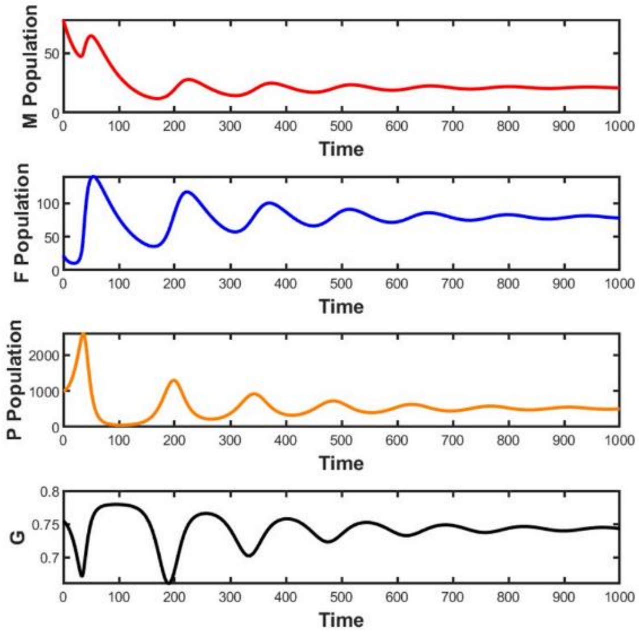

Figure 1. Under specific initial conditions, when considering the sex adaptive change ability, the graph illustrates the changes over time in the number of male lampreys, female lampreys, prey lampreys, and the sex ratio of newborn sea lampreys, from top to bottom respectively.

Then, we assumed that sea lampreys cannot adapt to changes in sex ratio, and set up an equation for this.

$$\frac{dM}{dt} = r_M M(1-\frac{M}{K_M})*P*f_F - d_M M + b_M aPM \tag{8}$$

$$\frac{dF}{dt} = r_F F(1-\frac{F}{K_F})*P*f_F - d_F F + b_F aPF \tag{9}$$

$$\frac{dP}{dt} = r_P P - aP(M+F) \tag{10}$$

$$r_M = r_F \tag{11}$$

The time-dependent results obtained from this equation are as shown in Figure 2.

As shown in figure 1, we can find that the female population, the male population, and the prey population will change as the number of each other changes. Therefore, on the whole, the three will show an approximate periodic change, which can also indicate that the adaptive sex changeability of lampreys can maintain the lamprey population and its prey population at a stable value, and enhance the adaptability of lampreys to environmental changes. This ability has a positive effect on maintaining the balance and stability of the greater ecological environment. By comparing the two, we can find that, without considering the influence of some external factors, the population number and sex ratio of lampreys can be maintained at a relatively stable level and will not fluctuate in a large range, which is conducive to the survival of the lamprey population. If lamprey populations do not have this ability, there is a risk of population extinction. But this ability to change the sex ratio has also limited the expansion and growth of lampreys to some extent.

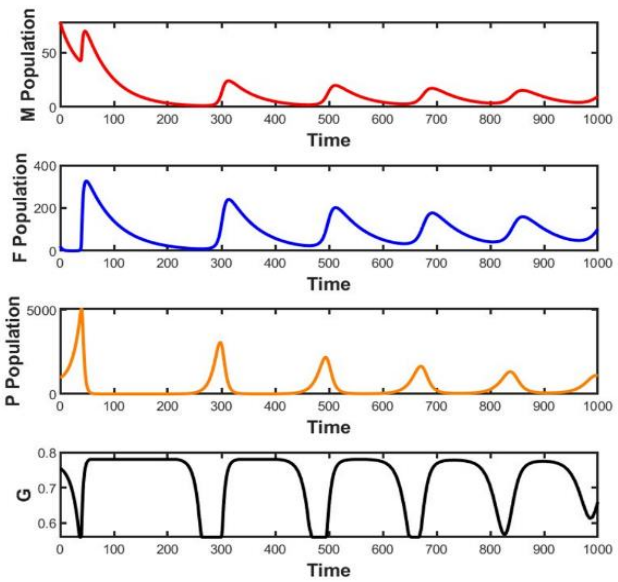

Figure 2. Under specific initial conditions, when not considering the sex adaptive change ability, the graph illustrates the changes over time in the number of male lampreys(red), female lampreys(blue), prey lampreys(yellow), and the sex ratio of newborn sea lampreys(black), from top to bottom respectively.

3. Effects on the lamprey population

3.1. The model

We take the model established above that considers gender change and the model that does not consider gender change.

To explore the advantages and disadvantages of adaptive changes in sex ratios for lamprey populations, we modified the male and female ratios and the amount of food in the two established models respectively. In this way, we can quantitatively explore the differences in the responses to the gender imbalance caused by the harsh environment and special reasons.

The follow figures show the changes in the number of male and female sea lampreys, the prey number of sea lampreys, and the sex ratio of newborn sea lampreys over time under different conditions.

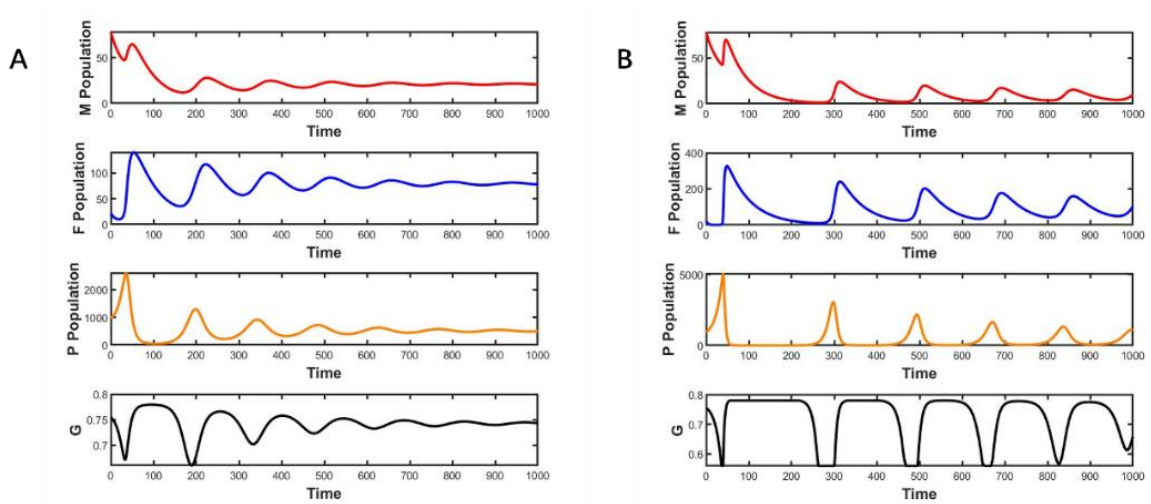

Figure 3. The changes of the number of male sea lampreys, the female sea lampreys, the prey and the sex ratio of newborn sea lampreys under the initial conditions of an initial male - female ratio of 78:22 and an initial prey population of 1000 sea lampreys(A) Considering the capability of gender adaptation. (B)Not considering the capability of gender adaptation.

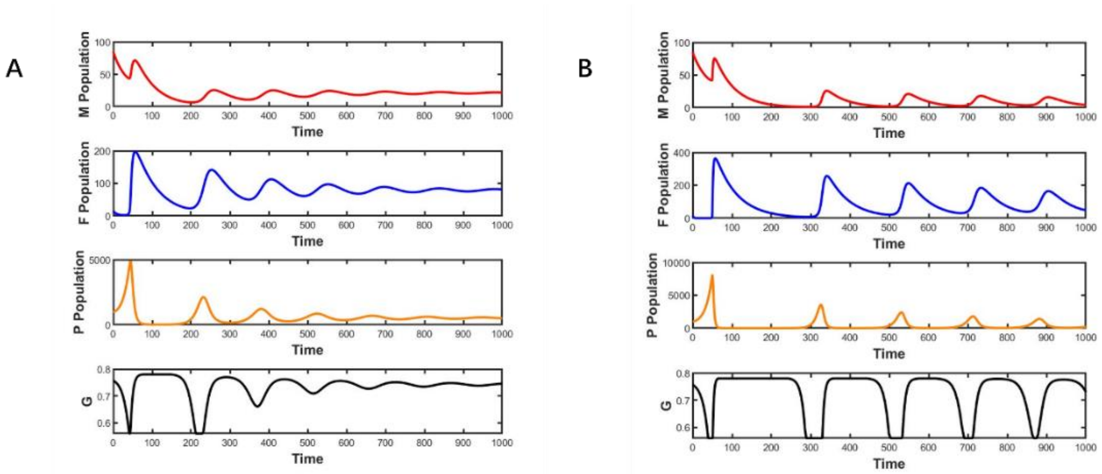

Figure 4. The changes of the number of male sea lampreys, the female sea lampreys, the prey and the sex ratio of newborn sea lampreys under the initial conditions of an initial male-female ratio of 15:85 and an initial prey population of 1000 sea lampreys(A) Considering the capability of gender adaptation. (B)Not considering the capability of gender adaptation.

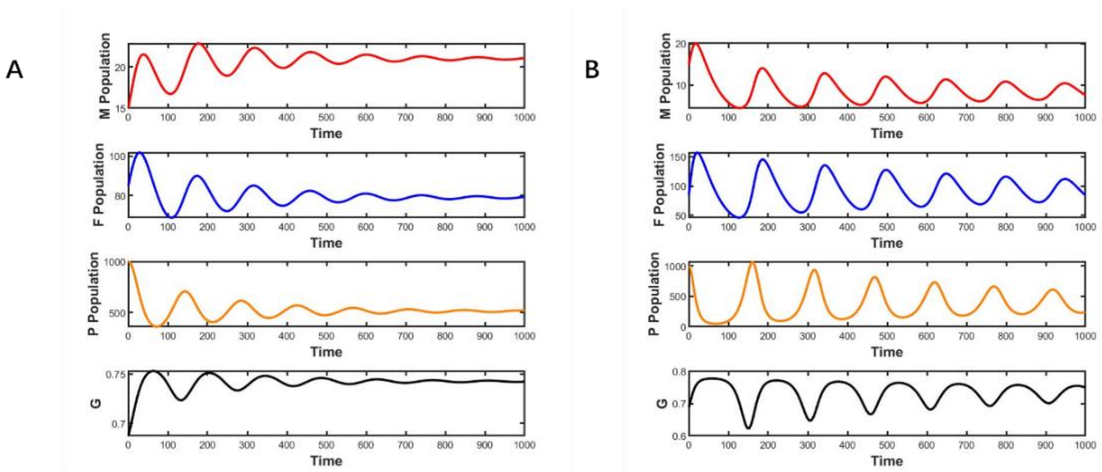

Figure 5. The changes of the number of male sea lampreys, the female sea lampreys, the prey and the sex ratio of newborn sea lampreys under the initial conditions of an initial male - female ratio of 85:15 and an initial prey population of 1000 sea lampreys (A) Considering the capability of gender adaptation. (B) Not considering the capability of gender adaptation.

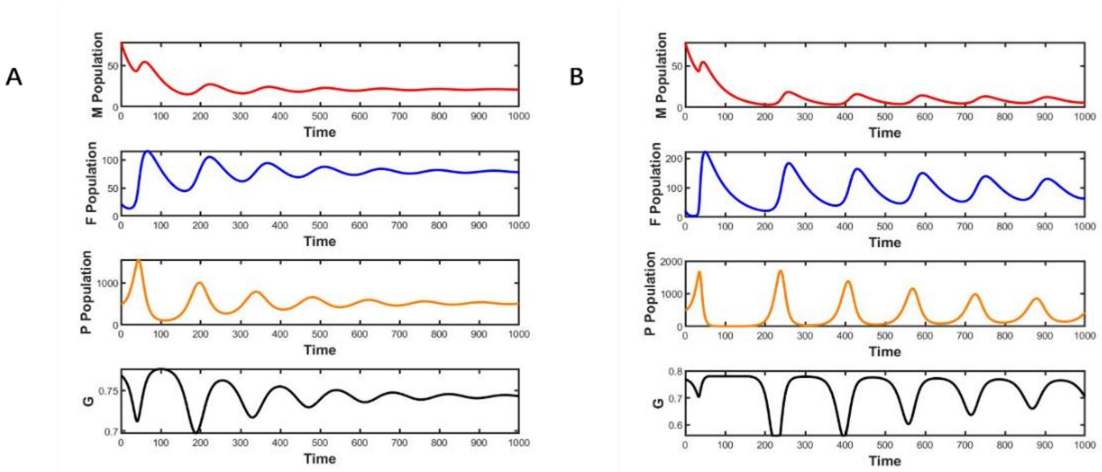

Figure 6. The changes of the number of male sea lampreys, the female sea lampreys, the prey and the sex ratio of newborn sea lampreys under the initial conditions of an initial male-female ratio of 78:22 and an initial prey population of 500 sea lampreys(A) Considering the capability of gender adaptation. (B)Not considering the capability of gender adaptation.

The Figure 4 and Figure 5 showed that the sea lampreys with the capability of gender adaptation are more adaptable to gender imbalance environment than those without this capability. The Figure 6 explained that the sea lampreys with the capability of gender adaptation are more likely to survive the lack of nutrition than those without this capability.

The analysis showed that compared with female lampreys, male lampreys have the stronger foraging ability and survival ability under harsh environmental conditions. In addition, too low a male and female ratio will lead to a lower reproductive success rate, decrease the number of newborn lampreys, reduce the demand for food, housing, and other resources of the lamprey population, and be more conducive to the survival of the lamprey population. This increases the resilience of lamprey populations to harsh environments. However, the ability to change genders also has certain drawbacks. When the environment is harsh to a certain extent, the newborn offspring are male, and the reproductive success rate is zero, in which case the risk of population extinction will be greatly increased.

3.2. Stability test of the model

We utilize the first method of Lyapunov to test the stability of the model. First, we set $\frac{dM}{dt}=\frac{dP}{dt}=\frac{dF}{dt}=0$ and solve for the values of $Mi_0, Fi_0, Pi_0 (i=1,2,3,...)$. Then, we take the partial derivatives of formulas (9) ~ (11) *F*, *M* concerning, and *P*, substitute in the corresponding values of Mi_0, Fi_0, Pi_0, and form a series of 3×3 matrices with the results. Next, we solve for the eigenvalues of these matrices. When all the real parts of the eigenvalues are less than zero, the point is a stable equilibrium. When there is any eigenvalue, whose real part is greater than zero, the point is an unstable equilibrium.

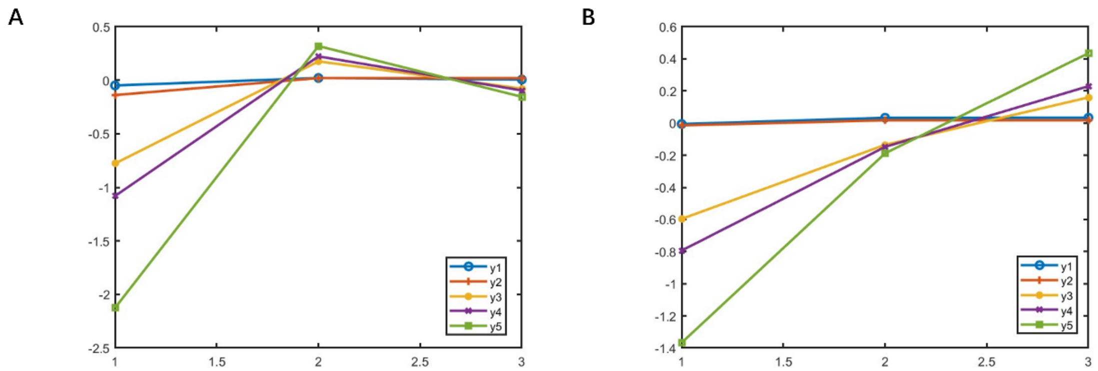

Figure 7. The changes in the real parts of the eigenvalues obtained using the first method of Lyapunov under two scenarios: one with the capability of gender adaptation and the other without.(A) Considering the capability of gender adaptation.(B)Not considering the capability of gender adaptation.

By observing the fluctuations of the five groups of eigenvalues taken in the two cases in Figure 7, we can find that the real part of the eigenvalues constantly fluctuates around 0, so we can conclude that the points we obtained are all unstable equilibrium points. This suggests that the model we constructed will experience fluctuations, consistent with the results obtained from our model. Furthermore, when the population of species reaches an equilibrium point, its number still changes significantly over time. The model only stabilizes when the population of the lamprey and its prey both reach the environmental carrying capacity, at which point disturbances at the equilibrium point will return to equilibrium. This method allows us to conclude that the model we have established is reasonable.

4. Conclusions

In this study, the Lotka - Volterra model was utilized to establish a model that did not account for the gender adaptive ability of lampreys and to set up the change equation of the male and female populations of lampreys as well as the prey populations of lampreys. The results are presented in Figure 1, followed by an analysis of how the images of the three populations changed over time. Subsequently, in consideration of the sex adaptive ability of lampreys, the sex regulation function G(g(F, M)) was introduced to modify the model, and the revised results were displayed in Figure 2. Upon comparing the two scenarios, it was discovered that gender adaptive changeability could better maintain the stability of the ecological environment. These models were then applied to study the lampreys themselves, altering the environmental conditions and comparing the outcomes. It was found that the sex-adaptive ability of lampreys aids in maintaining the stability of the lamprey population, although this ability also has the potential to inhibit the expansion of the lamprey population to a certain extent. Lastly, the established model was tested and the stability of the model was verified.

This paper provides a research idea and framework for the study of the impact of species on the environment in the field of ecology. This study tested the stability of the model we used and proved the feasibility of this method.

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