

Effects of changes in lamprey sex ratios on ecosystem stability: a Lotka-Volterra model-based study

Hanlu Yan^{*,#}, Shanghao Zhou[#]

Jinan University-University of Birmingham Joint Institute, Jinan University, Guangzhou, China, 511436

*Corresponding author: yhl9450706@163.com

#These authors contributed equally.

Abstract. The aim of this study was to investigate the effects of external environmental factors on the sex ratio of lampreys and the possible changes in population size and structure as a result of such effects. We simulated the population dynamics of male and female lampreys separately by modeling the population dynamics of lampreys based on the Lotka-Volterra model, and considered the effects of human predation on the lamprey population. By adjusting model parameters, such as predation intensity, initial sex ratio and rate of change in sex ratio dynamics, we simulated changes in the sex ratio of lampreys under different conditions and observed the effects of such changes on the ecosystem. The results suggest that changes in the sex ratio of lampreys may lead to changes in the abundance and distribution of other species, which in turn may affect the stability of the ecosystem. In addition, we analyzed the model results and presented graphs showing changes in predator and prey population dynamics and changes in lamprey sex ratios, further illustrating the effects of changes in sex ratios on ecosystem dynamics, population size and stability.

Keywords: Sex ratio, population dynamics, ecological balance, Lotka-Volterra modeling.

1. Introduction

The sex ratio of biological populations plays an important role in ecosystems, reflecting dynamic changes in population structure and ecological balance. In recent years, studies on how external environmental factors affect sex ratio have attracted increasing attention. In this context, changes in the sex ratio of the sevendill eel (lamprey), an important ecosystem member, may have important implications for ecosystem stability and species diversity[1-2].

Seven-gill lampreys are primitive jawless fishes, and their sex ratio may be affected by many factors, including temperature, water quality, and human activities. Once the sex ratio changes, it will directly affect the number and composition of the seven-gill eel population[3], which in turn will have far-reaching effects on the food chain and ecological balance in which it is located. Therefore, an in-depth study on the changes in the sex ratio of the sevendill eel and its impact on the ecosystem is of great scientific significance and practical value.

The aim of this study is to investigate the mechanism of external environmental factors on the sex ratio of the sevendill eel, as well as the effects of sex ratio changes on ecosystem dynamics, population size and species interactions, through the establishment of mathematical models and simulation experiments. With the help of the classical predator-prey model (Lotka-Volterra model), we will combine the sex-adaptive variation characteristics of the sevendill eel population, and carry out modeling and parameter adjustment to simulate the trend of the sevendill eel population under different environmental conditions[4-5]. Through this study, we aim to reveal the biological mechanisms behind the changes in sex ratio and provide scientific basis for ecosystem management and conservation.

2. The Establishment of Model

In response to this question, if the sex ratio of lampreys is affected by external environmental factors, then this may lead to changes in population size and structure. We can study population

dynamics and other biological interactions to understand the impact of sex ratio changes on the food chain and ecological balance[6].

The Lotka-Volterra model is a classical predator-prey model for describing interactions between two species. The model is suitable for describing the dynamics of populations where one population is the predator, and one is the prey. Considering that the lamprey is a parasite, and in a parasitic relationship, the host (parasite, parasitic plant, etc.) obtains nutrients from the host and influences the survival and reproduction of the host, this relationship can also be analogized to the predator-prey relationship in the predator-prey model. However, lampreys are populations with sex-adapted variation. We need to make some modifications to the Lotka-Volterra model to reflect this.

However, we did not consider the Lotka-Volterra model of lampreys as prey here because natural predators of lampreys are almost non-existent in nature, and they are only preyed upon by humans in some areas, so we only added the mortality of lampreys due to human predation to the mortality rate of lampreys. And to simplify and better characterize the effects of different sex ratios, we modeled the dynamics of male and female lampreys separately.

Modeling male population dynamics: If the sex ratio of lampreys is influenced by external environmental factors, this could result in significant changes in population size and structure. Understanding these dynamics is crucial for assessing the impact on the food chain and ecological balance. The Lotka-Volterra model, a classical tool for analyzing predator-prey interactions, can be adapted to study lamprey populations.

Since lampreys exhibit sex-adapted variations, modifications are necessary to integrate this complexity into the model. Unlike traditional prey species, lampreys face limited natural predation, primarily from humans in certain regions. Therefore, incorporating mortality due to human predation becomes a critical factor in lamprey population dynamics.

To accurately capture the effects of different sex ratios, we model the dynamics of male and female lampreys separately. This approach allows us to examine how changes in sex ratio influence population growth, survival rates, and ultimately, the ecological equilibrium of lamprey populations:

$$\frac{dM}{dt} = r_M M - d_M M + b_M a P M \quad (1)$$

Modeling female population dynamics:

$$\frac{dF}{dt} = r_F F - d_F F + b_F a P F \quad (2)$$

And modeled the population dynamics of the prey:

$$\frac{dP}{dt} = r_P P - a P (M + F) \quad (3)$$

where M is the population size of male lampreys, r_M is the production rate of male sea lampreys, d_M is the mortality of male lampreys, b_M is predation efficiency of female lampreys, F is the population size of female lampreys, r_F is the production rate of female sea lampreys, d_F is predation efficiency of female lampreys, a is probability of prey being taken, P is prey population size, natural growth rate of prey.

This model considers the fact that the dynamics of sex ratio is affected by external environmental factors and simulates the changes in sex ratio under different conditions. It is possible to study the effects of changes in the sex ratio of the lampreys on the larger ecosystem by adjusting model parameters such as predation intensity, initial sex ratio, and the rate of change in the dynamics of the sex ratio. It was observed whether changes in sex ratio would lead to changes in the abundance and distribution of other species, and whether changes in the abundance of other species would lead to changes in the sex ratio of the lampreys, as well as the effects of such changes on the stability of the ecosystem.

3. The Analysis of Result

By solving the model and creating visual graphs, we arrive at our results. Figure 1 illustrates the dynamic changes in the population dynamics of both predators and prey, providing a visual representation of how these populations interact over time. On the other hand, Figure 2 focuses specifically on the changes in the sex ratio of predators, shedding light on the intricate relationship between sex ratios and population dynamics within the ecosystem.

Through simulation exercises, we can manipulate the values of the parameters in the equations (1), (2), and (3) to observe the effects on the ecosystem. This allows us to gain a deeper understanding of the role played by these parameters in shaping the dynamics of predator-prey interactions and the overall ecological balance.

For example, adjusting the reproductive rates or mortality rates of predators and prey in the model equations can simulate scenarios of environmental changes or species introductions. By studying how these changes affect population sizes, sex ratios, and ultimately, the stability of the ecosystem, we can draw valuable insights into the resilience and vulnerability of ecosystems to various disturbances.

Furthermore, visualizing the simulation results through graphical representations not only enhances our comprehension of complex ecological processes but also facilitates the communication of findings to stakeholders and policymakers. This enables informed decision-making and the implementation of effective conservation and management strategies to sustainably preserve ecosystems and biodiversity..

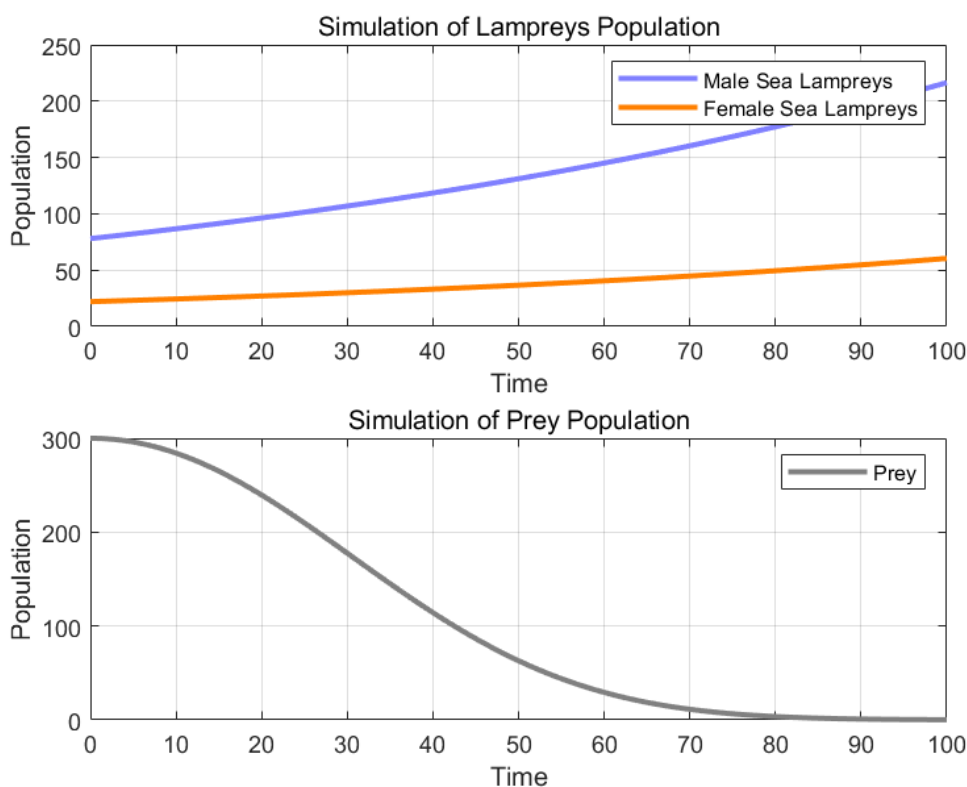


Figure 1: Simulations of population

Based on the observations and conclusions of Figures 1, the effects of changes in the sex ratio of lampreys on ecosystem dynamics, population size, and ecosystem stability can be discussed more specifically and the changes in the sex ratio may lead to different behaviors in terms of predation and prey, such as in Figure 2 where the sex ratio keeps decreasing and the number of females keeps increasing under high food supply, thus increasing the reproduction rate of the population, and under low food Under low food availability, the sex ratio keeps climbing and the number of males keeps increasing, and male lampreys can increase their survival rate by parasitizing on other fish for food.

This can have a knock-on effect on other lamprey-dependent species, causing fluctuations in their populations and affecting the ecosystem[7-8].

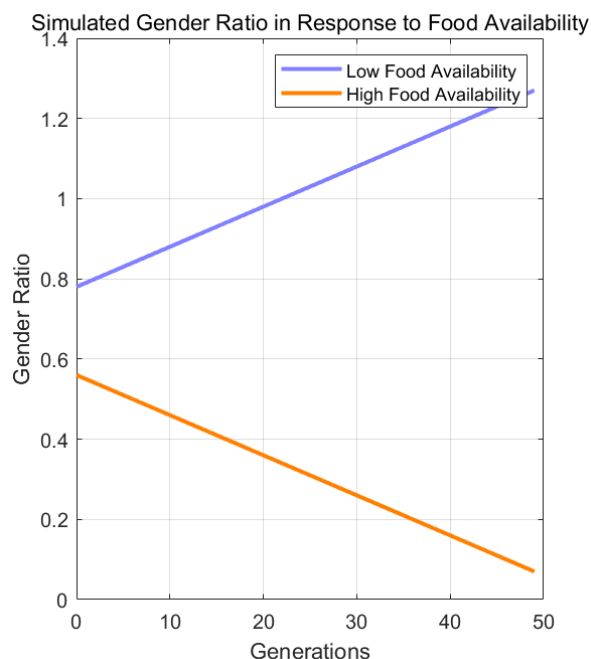


Figure 2 Simulated gender ratio with different food availability

In this model, the lamprey acts as a predator, and its impact on the ecosystem is mainly reflected in the change in the size of its own population and the change in the size of its prey population. If the sex ratio fluctuates too drastically, it may lead to instability of multiple populations in the ecosystem, which may affect the whole ecosystem.

Considering the effect of natural enemies of the lamprey, we can observe Figure 3, which illustrates that when food resources are scarce, the sex ratio changes, leading to an increase in the number of natural enemies. Conversely, when there is an abundance of food, the sex ratio stabilizes, resulting in a decrease in the number of natural enemies, specifically the seven-gill eel population. This fluctuation in the number of natural enemies due to changes in the sex ratio highlights the potential instability in the natural enemy population caused by these fluctuations.

These dynamics emphasize the interconnectedness of species within an ecosystem and the cascading effects that changes in one population, such as the lamprey's sex ratio, can have on other populations, including both prey and predators. Understanding these complex interactions is essential for managing and maintaining ecological balance in such ecosystems.

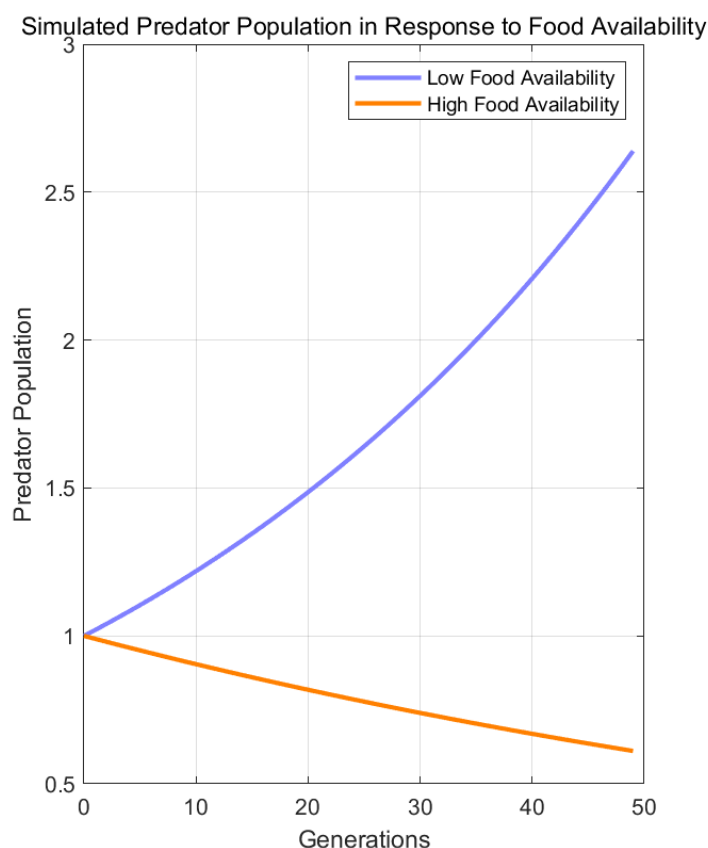


Figure 3. Predator population with different food availability

In this problem, parameters mentioned above need a lot of experimental analysis to obtain. And we use numerical methods to simulate the experimental phenomena this time, so we selected the suitable parameters as the initial values by consulting relevant information[9-10].

4. Conclusions

In this study, we thoroughly explored the effects of external environmental factors on the sex ratio of the sevengill eel (lamprey) and the mechanism of its impact on the ecosystem through the establishment of mathematical models and simulation experiments. First, we took the sevengill eel (lamprey) as the research object and explored its population dynamics and ecological interactions, with a special focus on the potential impacts of sex ratio changes on the food chain and ecological balance.

In the process of modeling, we adopted the classical predator-prey model (Lotka-Volterra model), but made appropriate modifications and parameter adjustments to the model to address the sex-adaptive variation characteristic of sevengill eel populations. We divided the sevengill eels into two groups, males and females, and established population dynamic equations to simulate them respectively. Through the simulation experiments, we observed the effects of changes in sex ratio on the population size, species richness and ecosystem stability of the sevengill eel under different environmental conditions.

In the analysis of the simulation results, we found that changes in sex ratio may lead to fluctuations in the population size of the sevengill eel, which in turn affects the food chain and ecological network in which it is embedded. In particular, under high food availability, an increase in the number of females may accelerate the reproduction rate of the population, while under low food availability, an increase in the number of males may increase its survival rate by parasitizing other fish for food.

These changes not only affect the sevengill eel population itself, but may also trigger instability in multiple populations, affecting the balance and stability of the entire ecosystem.

In addition, we also explored the effects of natural enemies of sevengill eels on their population dynamics and found that changes in sex ratio may indirectly affect the population size of natural enemies, further affecting the stability of the ecosystem. Therefore, studying the effects of sex ratio changes on the ecosystem not only helps to understand the mechanism of the population dynamics of the sevengill eel, but also provides an important reference for ecosystem management and conservation.

In summary, this study not only expands the understanding of the ecological characteristics of the sevengill eel, but also provides a new theoretical and empirical basis for exploring the effects of sex ratio changes on the ecosystem. We hope that these research results will provide scientific support and decision-making suggestions for biodiversity conservation and sustainable ecosystem development.

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