

Relationship Between Sex Ratio and Ecosystem in Lampreys Based on Logistic Model

Yujun Gao^{1, *, †}, Bin Zhang^{2, †}

¹ Leicester International Institute, Dalian University of Technology, Panjin, China, 115004

² School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China, 215123

* Corresponding Author Email: yizhixiaobenlang@163.com

† These authors contributed equally.

Abstract. In order to clarify the ecological ramifications of adaptive sex ratio fluctuation in lampreys, this study explores the dynamics of the population and its sex ratio using a logistic model. With the use of simulation methods and observational data, the study builds a comprehensive model to evaluate how changes in the sex ratio affect the ecosystem. With skill, the logistic model is used to forecast changes in the population of lampreys, accounting for the impact of food supply on the larval stage and subsequent determination of sex. Using MATLAB for data processing and visualization, the study further combines agent-based modeling (ABM) to replicate lamprey behaviors and their environmental interactions. Through an analysis of how sex ratio affects resource competition, predation, and population dynamics, the study sheds light on the ecological implications of changes in sex ratio in lampreys. The consideration of the ecosystem's stability in light of changes in the sex ratio and the possible advantages for parasitic ecosystems in the paper's conclusion lays the groundwork for further ecological and conservation research.

Keywords: Logistic Models; Verhulst Model; An agent-based (ABM) Model.

1. Introduction

The sex ratio of lampreys has been a topic of interest in the study of ecosystem dynamics. Research has shown that sea lamprey sex ratios can shift significantly following the initiation of sea lamprey control measures, with ratios changing from predominantly male to predominantly female populations [1]. Research has shown that sea lamprey sex ratios can shift significantly following the initiation of sea lamprey control measures, with ratios changing from predominantly male to predominantly female populations. These changes in sex ratios have been found to have impacts on the population dynamics of other organisms within the ecosystem [2-5]. A study on seven-gill eels has provided insights into the ecological impacts of changing sex ratios in lampreys, emphasizing the importance of understanding the implications of these changes for the overall ecosystem [6]. Commercial fishery data in the Great Lakes has also been utilized to analyze sea lamprey sex ratios and their implications for juvenile sea lamprey ecology [7]. The study suggest that changes in the sex ratio of lampreys can provide advantages to specific species (especially parasitic species) through a variety of mechanisms [8]. Additionally, research has shown that the growth rates of sea lampreys can influence the male-to-female ratio of larval populations, highlighting the complex interactions at play in lamprey ecosystems [9]. A research provided field evidence suggesting that larval growth rate directly influences sex determination in sea lampreys, which could have implications for the sex ratio and ecosystem dynamics [10]. The literature on lampreys' sex ratio and its ecosystem impacts highlights the interconnected nature of species dynamics within aquatic environments and the importance of considering these factors in conservation and management efforts.

Overall, Our primary goal is to analyse the correlation between the sex ratio of the sevengill eel population and the ecosystem. Article will employ the logistic model and Verhulst model to establish this relationship. Both models are used because they take into account environmental carrying capacity, i.e. the maximum population size that the environment can support. Changes in sex ratios

may affect how populations utilize limited resources. Additionally, article will utilise the Agent-Based Modelling (ABM) technique to gather essential data and subsequently explain the eel population's impact on the ecosystem through the obtained icons.

2. The basic fundamental of research

2.1. The formulas of logistic model

Logistic models are frequently employed for the purpose of categorization and prediction analysis. Given that the results are expressed as probabilities, the dependent variable is constrained to the range of 0 to 1. Logistic regression involves applying a logistic transformation on the probability, which is the ratio of the probability of success to the probability of failure. This is commonly known as the log odds or the natural logarithm of the odds. The logistic function is shown in Figure 1.

$$P(t) = \frac{1}{1 + e^{-r(t-t_0)}} \quad (1)$$

The fundamental concept of the grey Verhulst model is that the population size of organisms experiences exponential expansion, but this development is gradually constrained by environmental restrictions, leading to a deceleration in the growth rate and eventual stabilization at a steady state. The model is primarily employed to elucidate processes characterized by a condition of saturation. And this is a specific instance of the logistic model in Figure 2.

$$\frac{dT}{dt} = rT \left(1 - \frac{T}{K}\right) - \alpha T^2 \quad (2)$$

2.2. The Framework of ABM

Agent-based models (ABMs) are computational models that replicate the behaviors and interactions of autonomous subjects, such as individuals or collective entities like organizations or groups. These models are used to evaluate the overall impact of these subjects on the system.

3. Results

3.1. The establishment of simulation model

Since this is an ecological investigation, it is suitable to utilize a logistic model for making predictions regarding the sex ratio of the lampreys. This will facilitate the development of a mathematical model that precisely represents the relationship between the availability of food and the rate of growth during the larval stage, and subsequently, the ensuing proportion of males to females. Logistic models are commonly used to represent changes in population size or fluctuations in a certain characteristic.

Simultaneously, given that the abundance of food might influence the sex ratio of the lamprey population, and taking the scenario where resources are restricted, Verhulst model can be carried out using.

By utilizing these two models and replacing the data, this article derive the outcomes for the sex ratio of the lamprey population, as presented below:

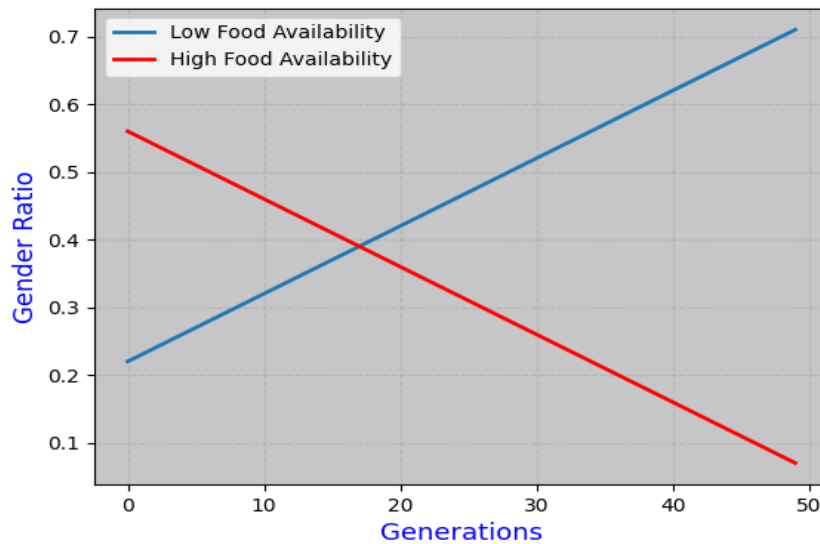


Figure 1. Effects of sex ratio on lampreys generations

3.2. Impact of sex ratio on ecosystems

A lamprey agent-based model (ABM) was employed to simulate the behaviour of lampreys and their interactions with the environment and other agents. The objective was to investigate the ecological consequences of the sex ratio of these fish. The following is the final output produced by modeling the ABM with Matlab:

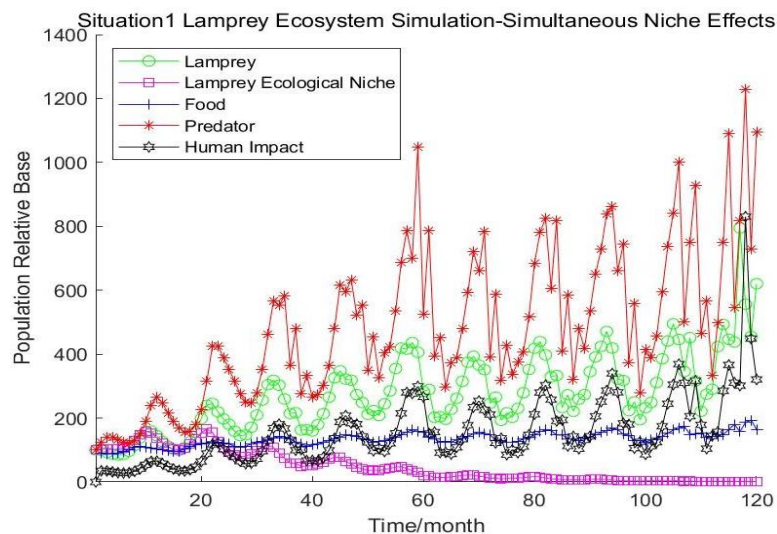


Figure 2. Effects of sex ratio on ecosystems

The graph depicting the number of lampreys clearly exhibits a cyclical fluctuation. When there is a sufficient food supply, the population of lampreys increases rapidly because of a balanced sex ratio, resulting in a bigger population than the typical species with a balanced sex ratio. On the other hand, when there is a relatively low amount of food available, the population of eels decreases more significantly. Moreover, the entire population undergoes periodic fluctuations in numbers that are linked to the reproductive cycle, resulting in an overall rising trajectory.

As the lamprey population grew, the stabilisation of the sex ratio led to an increase in reproduction rate. However, this rise in reproduction rate seemed to cause a decrease in the cohort's ability to find food. As a result, the population continued to decline and remained within a specific range. The Lamprey Ecological Niche, which depicts the species count in the lamprey cohort, exhibited an initially consistent and gradual rising trend.

When there is an adequate food supply, the quantity of food remains relatively constant due to its stability and smaller amplitude.

The Predator represents the population of predators, characterised by a larger magnitude and a comparable pattern to the blue line. This suggests a direct relationship between the populations of lampreys and predators, where the number of predators increases when there is enough food available.

When there is a sufficient abundance of food, the Human Impact, symbolising human predation, remains at a consistently low level, suggesting that the impact of people on lampreys and other predators is quite minimal.

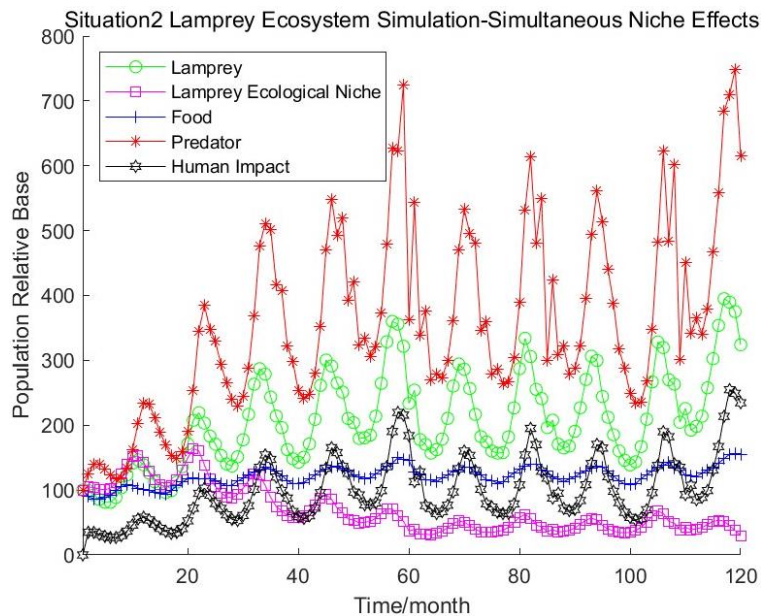


Figure 3. Effects of sex ratio on ecosystems

According to the information in Figure 3. The population of seven-gill eels is highly responsive to quick fluctuations in numbers, mostly caused by variations in the sex ratio. This sensitivity makes them more susceptible to changes in food availability compared to other species with a consistent sex ratio. However, there is no clear pattern of increase or decrease in their population over time. The Lamprey, which represents the population of seven-gill eels, exhibits regular fluctuations, suggesting that the number of seven-gill eels increases swiftly when there is an ample food supply and declines rapidly when there is a scarcity of food, assuming a stable food source.

The number of species within the lamprey's ecological niche, as indicated by the Lamprey Ecological Niche, initially exhibited a consistent and stable cycle. Nevertheless, the growing lamprey population experienced a decline and eventual extinction due to the inability of the species in the same ecological niche to acquire enough food, caused by the population's stable sex ratio resulting in an increased reproduction rate.

The Food represents the quantity of food, which is currently little but shows some fluctuations that could suggest a more closely balanced relationship between supply and demand.

The Predator pattern of variation, like that of the lamprey, does not exhibit any noticeable upward or downward trend in predator numbers.

The low level of the Human Impact depicting human predation suggests that there was no significant rise in human predation as a response to changes in the food supply.

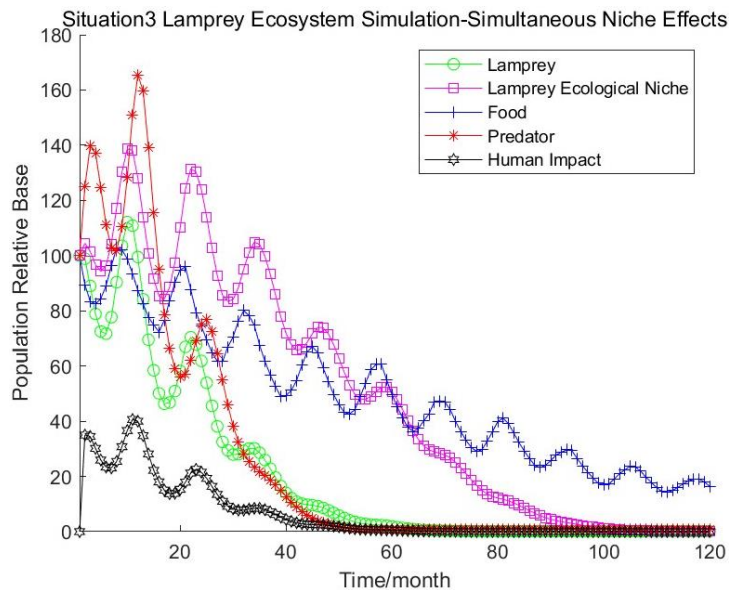


Figure 4. Effects of sex ratio on ecosystems

According to the information in Figure 4. The population of seven-gill eels, indicated by the Lamprey, starts with a sex ratio close to one and exhibits quicker reproduction due to the relatively high food availability, which has not yet experienced a severe reduction. Over time, there is a substantial fall in the population of eels and a steady decrease in the availability of food, resulting in a corresponding decrease in the number of eels. Ultimately, the population declines as a result of insufficient food and the resulting imbalance in the sex ratio of seven-gill eels, which leads to an increased mortality rate among them. This phenomenon is caused by an unequal distribution of males and females, resulting in increased death rates and reduced ability to reproduce due to insufficient food.

The population's skewed sex ratio leads to a decrease in reproduction rate as the eel population decreases, hence enhancing the ability of coexisting species to obtain their own sustenance. The Lamprey Ecological Niche depicts the quantity of coexisting species of eels. As a result, animals occupying the same ecological niche can endure diminishing food resources for a longer duration before facing extinction, albeit ultimately they are unable to survive.

The Food, which represents the quantity of food, steadily diminishes, in accordance with the drop in the number of seven-gill eels. This is presumably a result of over consumption of food resources and the challenge of returning them to their original level.

The Predator, symbolizing the overall predator population, similarly shows a decreasing pattern, indicating that a scarcity of food leads to a decrease in the number of predators.

Initially, the Human Impact depicting human predation and the number of predators were indistinguishable. Over time, the frequency of human predation declined at a faster rate, possibly due to a decrease in the availability of lampreys and other predators that people were able to capture in response to food scarcity.

4. Conclusion

By combining logistic modeling and agent-based simulations, this study has conducted a detailed investigation into the impact of changes in the sex ratio of lampreys on the entire ecosystem. The results highlight the crucial significance of maintaining a balanced distribution of males and females in order to ensure ecological stability. They also emphasize the possible negative consequences of human interventions on this equilibrium. The study not only predicts the changes in population size of lampreys based on different sex ratios, but also emphasizes the importance of taking these changes into account when developing conservation measures to preserve the long-term well-being of the ecosystem.

References

- [1] Yasmin T, Grayson P, Docker M F, et al. Pervasive male-biased expression throughout the germline-specific regions of the sea lamprey genome supports key roles in sex differentiation and spermatogenesis [J]. *Communications Biology*, 2022, 5 (1): 434.
- [2] Liang Z, Li X, He G. Ecosystem Impacts of Changing Sex Ratios in Lampreys Based on Multi-Model Analysis [J]. *Highlights in Science, Engineering and Technology*, 2024, 99: 395-407.
- [3] Wei Y, Fang Y, Cheng J, et al. Study on the Gender Change of the Lamprey in Ecosystem Based on Verhulst and Logistic Models [J]. *Academic Journal of Science and Technology*, 2024, 10 (2): 196-200.
- [4] Ji Z, Chen J, Wang Z. A Study on Lamprey's Population Based on Sex-Ratio-Related Growth-Balance Model [J]. *Transactions on Computational and Applied Mathematics*, 2024, 4 (1): 48-55.
- [5] Ying B, Xiao Z, Zhou M. Sex Ratio of Seven Gill Eels Based on Lotka-Volterra Modelling and AHP Approach [J]. *Academic Journal of Agriculture & Life Sciences*, 2024, 5 (1): 44-51.
- [6] Zhang Y, Yao S. Sex Ratio of Seven Gill Eels Based on System Dynamics and Dynamic Generalisation Models [J]. *Highlights in Science, Engineering and Technology*, 2024, 93: 109-119.
- [7] Hume J B, Bravener G A, Flinn S, et al. What can commercial fishery data in the Great Lakes reveal about juvenile sea lamprey (*Petromyzon marinus*) ecology and management? [J]. *Journal of Great Lakes Research*, 2021, 47: S590-S603.
- [8] Li R, He M, Zhao S. Ecosystem Impacts of Changes in the Sex Ratio of Lampreys Based on Logistic and TOPSIS Models [J]. *Highlights in Science, Engineering and Technology*, 2024, 99: 326-334.
- [9] Yasmin T. Analysis of sea lamprey gonadal transcriptomes to investigate the genetic basis of sex determination, differentiation, and sexual maturation [J]. 2023.
- [10] Johnson N S, Swink W D, Brenden T O. Field study suggests that sex determination in sea lamprey is directly influenced by larval growth rate [J]. *Proceedings of the Royal Society B: Biological Sciences*, 2017, 284 (1851): 20170262.