

Understanding the Effects of Sex Ratio Variations on Ecosystem Sustainability and Environmental Quality

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Abstract. Ecosystem sustainability and environmental quality, essential for life, are influenced by various factors, including the critical but often overlooked aspect of the population sex ratio. This study offers an in-depth analysis of how sex ratio variations in lamprey populations affect ecosystem health, using a logistic model to simulate changes under different conditions. By integrating key factors such as food supply and reproduction rates into a sex ratio model, we demonstrate the substantial impact of sex dominance shifts on environmental indicators and ecosystem well-being. Our research highlights the cascading effects of altered ecological balances and food chains on reproductive success and habitat utilization, ultimately affecting ecosystem stability. The findings reveal the intricate relationship between sex ratio changes and ecosystem health, indicating that imbalanced sex ratios can amplify ecological vulnerabilities, reduce biodiversity, and weaken habitat resilience.

Keywords: Sex ratio, Lamprey population, Adaptive gender ratio variation, Logistic model.

1. Introduction

Ecosystem sustainability and environmental quality are foundational pillars for the survival and prosperity of all living organisms [1, 2]. These components are influenced by a myriad of factors, among which the population sex ratio stands out as a critical yet often overlooked element [3]. Recent research has increasingly pointed towards the significant impact that variations in sex ratios can have on the dynamics of natural populations and, subsequently, on the ecosystems they inhabit [4].

Sex ratio fluctuations, the balance of males to females in a population, can significantly impact reproductive behaviors, social dynamics, and resource distribution, thereby influencing ecosystem health and function [5]. An imbalance may reduce biodiversity, alter competitive and predatory interactions, and affect ecosystem stability. Additionally, the interaction between sex ratios and environmental conditions like food availability and habitat quality can create feedback loops, influencing conservation and resource management efforts. Understanding these effects is vital for sustainable ecosystem management [6].

In this work, we focus on lampreys, examining first how changes in their sex ratios alter ecological balance and food chain dynamics. We then assess the impacts on reproductive success and habitat utilization shifts, ultimately demonstrating how these interconnected factors collectively influence ecosystem stability and environmental quality. This analysis underscores the broad effects of lamprey sex ratio variations, from affecting predator-prey relationships to modifying reproductive outcomes and habitat preferences, and highlights their significance for the overall health and sustainability of ecosystems.

2. Constructing Sex Ratio Model for Lampreys

The logistic model [7] is a common model used to describe population dynamics, which is based on the influence of environmental capacity on population growth rate and is suitable for describing population growth in situations with limited resources. In this question, the habitat of lampreys has limited environmental capacity, and we can use a logistic model to measure the rate of population change. The equation of the logistic model is:

$$\frac{dL}{dt} = rL(1 - \frac{L}{K}) \quad (1)$$

Where N is the Population size of lampreys. T is the time corresponding to the population size of lampreys. R is the inherent growth rate of the lamprey population. K is the environmental carrying capacity of the habitat of the lamprey population.

The analytical solution of the model is:

$$L(t) = \frac{K}{1 + (\frac{K - N_0}{N_0} e^{-rt})} \quad (2)$$

Where N_0 is the initial population quantity (quantity at $t=0$).

In the context of considering the changes in the sex ratio of lampreys, it can be inferred from the information provided in the question that the sex ratio of sea lampreys varies depending on the external environment, and the development speed during the larval stage determines their male and female sex. According to this, we start to use the Gender Ratio Model [8]. The growth rate of these larvae is also influenced by the food supply. In environments with insufficient food supply, the growth rate will be lower, with males accounting for about 78% of the total. However, in environments where food is more easily available, it has been observed that males account for approximately 56% of the total. The following figure 1 show the gender ratio changes under high and low food supply, respectively.

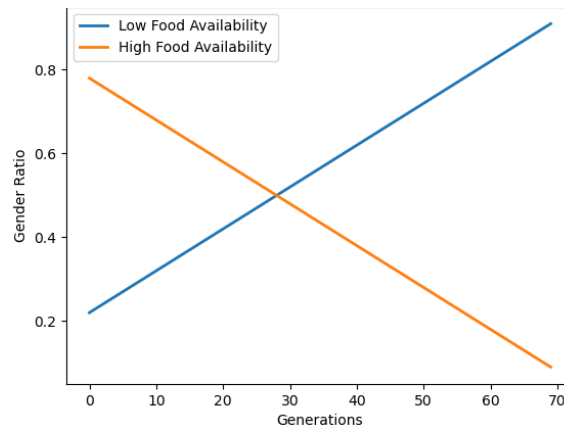


Figure 1. Gender ratio changes with food supply

Then, the Logistic model can be used to describe how food supply affects the developmental rate of lampreys in their juvenile stage, thereby affecting gender ratios. This model is commonly used to describe the variation of a specific feature in a population, and its equation is as follows:

$$P(t) = \frac{1}{1 + e^{-r(t-t_0)}} \quad (3)$$

Where $P(t)$ is the Probability of developing into a female (gender ratio), $t > 8$ weeks. R is the Growth rate. T_0 is the time when the gender ratio began to change (Starting time of gender ratio occurrence: the eighth week) [9].

The gonadal biopsy experiment on sea lampreys found that in some cases, sex may be unstable before the larvae reach 140mm and can change within 8-16 weeks, but it is still unclear whether there is a gender change in larvae larger than 90mm in natural populations. Once from the larval stage to the hemolytic parasitic stage, sex seems to be fixed in adulthood.

However, the sex determination model applicable to lampreys may need to consider more complexity, such as the impact of environmental temperature on the development rate, and so on. Therefore, the model can be further extended to an equation that considers environmental factors,

where the environmental temperature T can be used as a regulating parameter, and its equation is as follows:

$$P(t) = \frac{1}{1 + e^{-r(T)(t-t_0)}} \quad (4)$$

Where $r(t)$ is the influence of temperature on development rate.

3. Effects on ecological systems

The ecosystem is a unified whole formed by the interaction between biological communities and their inorganic environment. The food web is an important structure that organically combines various species in the biosphere. In this study, the population of lampreys is naturally also a part of the food web.

As consumers, it exists in the food chain and can accelerate the material cycle of the ecosystem, However, due to the extremely complex impact of changes in gender ratio on larger ecosystems, this study will divide it into the following seven parts for rational analysis in detail.

3.1. Sex Ratio Affects Food Resources and the Food Chain

Based on the known conditions given in the background of the question, it can be concluded that the growth rate of lampreys during their juvenile period is influenced by food supply. In an environment with insufficient food supply, the growth rate will be lower, and the proportion of males can reach about 78% of the total. In environments where food is more readily available, it has been observed that males account for approximately 56% of the total. The following figure 2 fully illustrates the changes in food supply from all females to all males.

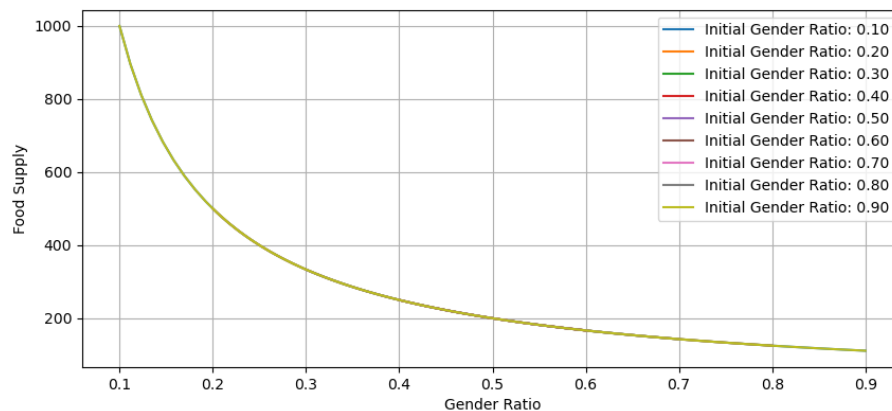


Figure 2. The impact of gender ratio changes on food supply conditions

According to Figure 2, under ideal conditions, when all the lampreys in the environment are females, the food supply conditions are the best. Conversely, when all the lampreys in the environment become males, the food supply conditions are the worst. As the number of females decreases and the number of males increases, the food supply also shows a corresponding decreasing trend.

The lamprey often plays the role of a consumer in the food chain, serving as a predator to capture other prey and also as prey. However, in general, lampreys often appear as predators. So, if there is a change in the sex ratio of lampreys, it will have an impact on the food chain, which is also an important influencing factor. Below, we will study it separately into two situations: high food availability and low food availability [10].

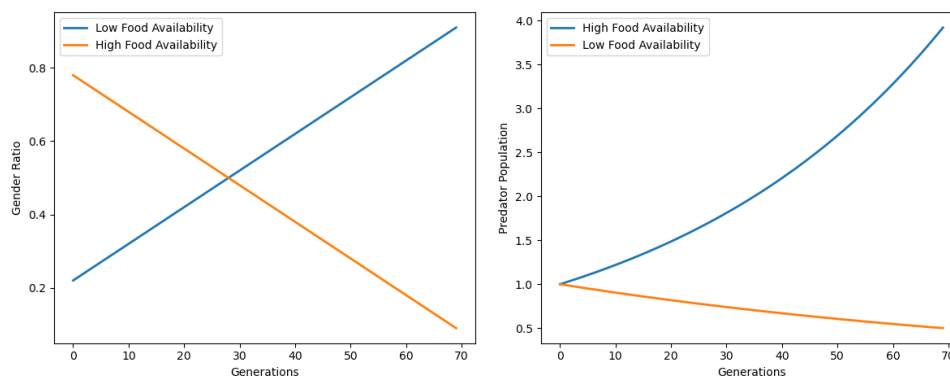


Figure 3. The impact of gender ratio on changes in predator numbers

Figure 3 illustrates that predator numbers increase with abundant food due to more female lampreys boosting reproduction, as shown by the blue line. Conversely, with scarce food and more males, who don't reproduce, the lamprey population declines, as the orange line indicates.

3.2. Sex Ratio Affects Reproductive Rate

In the vast biosphere, there are various and countless species, but reproduction and offspring are carried out by every species, and of course, the lamprey is no exception. But how these countless species reproduce their offspring is different, and the reproduction rate naturally varies. Figure 4 shows the impact of gender ratio changes on the reproductive rate of lampreys.

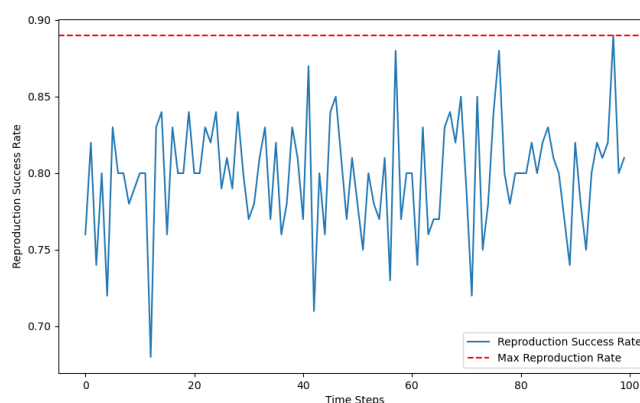


Figure 4. The impact of changes in gender ratio on reproductive rate

3.3. Sex Ratio Affects Habitat and Breeding Area Utilization

The background of the question emphasizes the dependence of gender ratio on local conditions. Through reviewing various literature, we have learned that lampreys live in lake or marine habitats. To obtain the impact of changes in the sex ratio of lampreys on their habitat utilization, we have drawn an area occupation percentage chart.

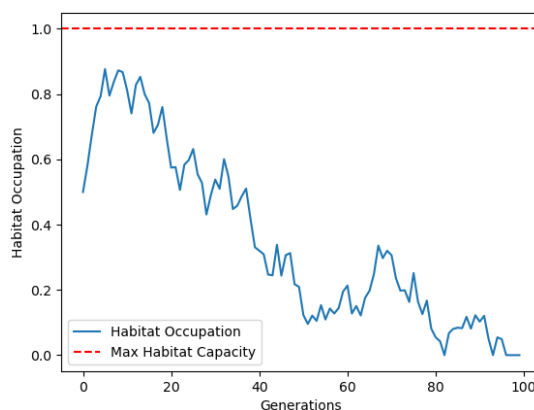


Figure 5. The impact of gender ratio on habitat utilization efficiency

From the results of Figure 5, it can be inferred that the more males there are in the lamprey, the lower the occupancy rate of its habitat area. When the number of males is greater than the number of females, the reproductive rate decreases, and the number of the next generation will correspondingly decrease, leading to a decrease in the population of lampreys and a natural decrease in their utilization of the habitat.

According to the results obtained from Figure 5, it can be seen that when the number of males in the lamprey is greater than that of females, the population will show a downward trend. At this time, not only will the number of females be relatively small, but also the number of males will be relatively small. The reproductive rate naturally shows a downward trend, and the area occupied by the breeding area will also be smaller and smaller.

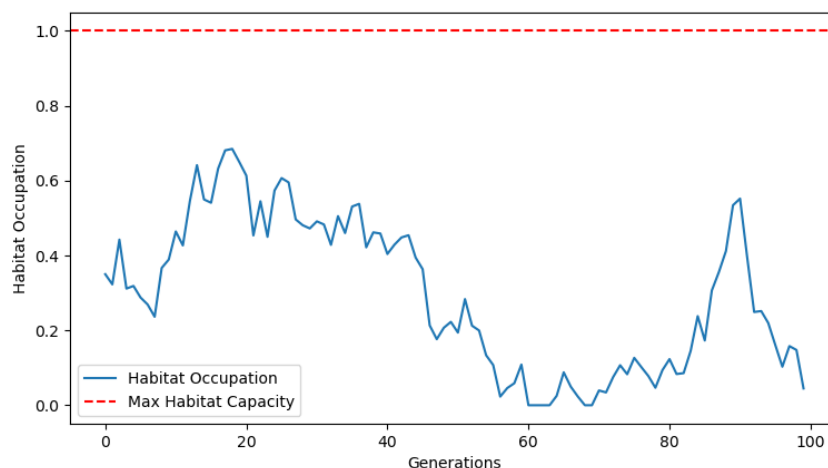


Figure 6. The impact of gender ratio on the utilization rate of habitat breeding areas

3.4. Comprehensive Analysis of the Overall Environment

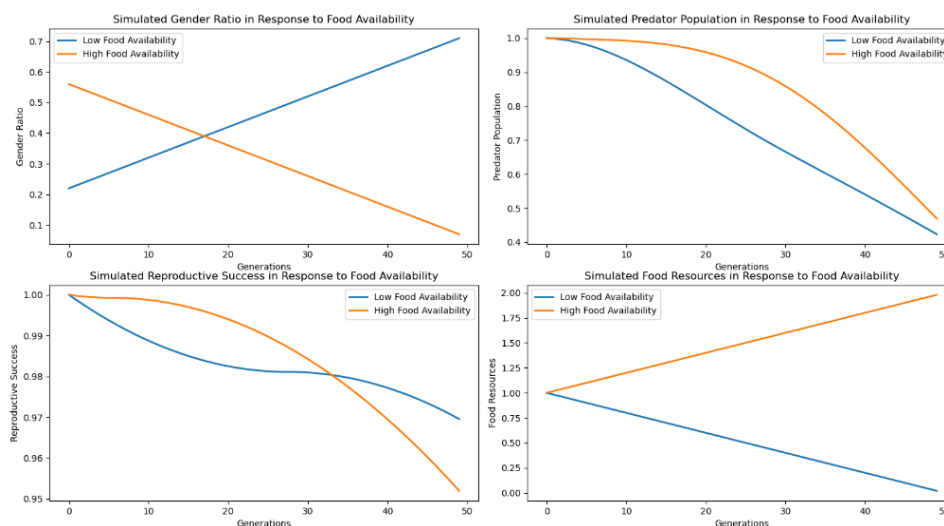


Figure 7. Comprehensive analysis

As shown in figure 7, based on the comprehensive analysis of the five influencing factors mentioned above, it can be concluded that changes in the sex ratio of the lamprey population do indeed affect food supply, food chain, reproduction rate, and habitat utilization. The analysis process needs to separate high food supply from low food supply. Numerous charts demonstrate that as the number of females decreases and the number of males increases, the food supply also shows a corresponding decreasing trend; When there is sufficient food supply, the population will increase; When the number of females is greater than that of males, the reproductive rate increases, the population size increases, and the proportion of habitat occupation and breeding area also increases.

The increase or decrease in the population of lampreys will ultimately have varying impacts on other species (such as parasites), as they participate in the food chain as predators or prey. Numerous food chains form a food web, leading to chain reactions that gradually expand into larger ecosystems.

Next, let's take a look at the simulation of the impact on the environment when females and males respectively dominate and have the same proportion of females and males.

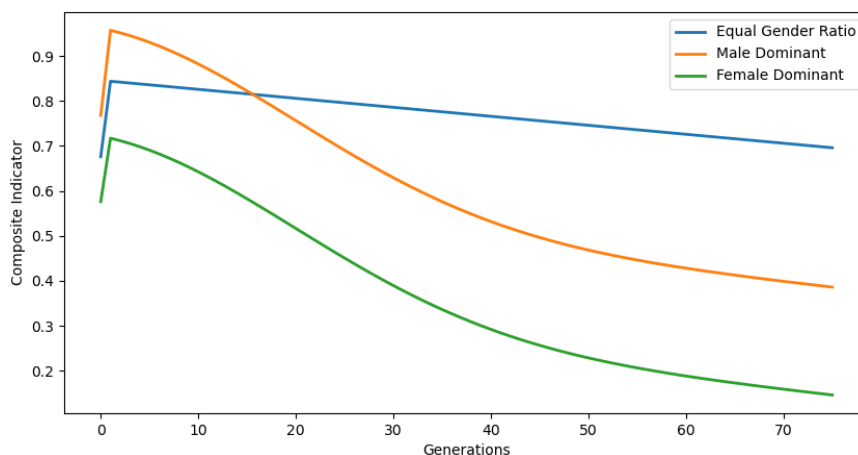


Figure 8. The impact of gender ratios under different weights on the overall environment

From Figure 8, it can be seen that when female lampreys dominate, the reproductive rate of the population is higher, leading to a continuous increase in the population and relatively low comprehensive indicators, which have a significant impact on the overall environment. When male lampreys dominate, the reproductive rate of the population is very low, but due to their significantly poorer comprehensive indicators, the impact of this population on the overall environment is more significant.

Although both male and female dominance has a significant impact on the environment, compared to females, the impact of male dominance on the environment is much greater. The reason for this phenomenon is that when females dominate, that is, when the number of females is significantly larger than males, the overall indicators are relatively better (such as sufficient food supply). So even if the number of offspring produced by females is large, leading to population growth, the environment will not be affected as much as males.

However, when the gender ratio is relatively balanced, the comprehensive indicators are relatively good and have a relatively small impact on the overall environment. Even if there is a corresponding trend of decline, the impact is much smaller than when females and males dominate. So, whether it is dominated by females or males, it will lead to a decrease in comprehensive indicators and cause serious damage to larger ecosystems.

4. Conclusion

This study reveals the nuanced interplay between sex ratio variations in lamprey populations and their significant impacts on ecosystem health and quality. Through logistic and sex ratio modeling, we show how shifts in sex dominance can drastically alter environmental metrics, affecting larger ecosystems. Our findings spotlight sex ratio balance as a key factor in ecological resilience, indicating that skewed ratios can amplify vulnerabilities, diminish biodiversity, and weaken habitat strength.

Additionally, the research underlines the importance of considering sex ratio variations in conservation and ecosystem management strategies. It provides essential insights for fostering sustainable ecological practices, highlighting the need for incorporating sex ratio dynamics to enhance ecosystem health and biodiversity. This dual focus enriches our understanding of ecological interdependencies and advocates for more nuanced approaches to environmental stewardship.

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