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Research on the Future Stability of Lamprey Based on Balanced Ecosystems

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Abstract. Lamprey is an ancient jawless fish known for its parasitic lifestyle. It has a unique ability to adjust gender ratios according to the environment and has had a profound impact on aquatic ecosystems. This interesting behavior, an adaptive and survival dance, invites us to delve deeper into the lives of these ancient creatures. The method used in this article simulates various aquatic habitats during a hypothetical period, including complex food chain interactions, availability of natural resources, population growth rate, and gender ratio of lamprey populations, among other key variables. This design allows for intricate interactions between ecosystem components and the sex ratio of lamprey populations. In order to evaluate how changes in the sex ratio of lampreys affect ecological dynamics, this study combines differential equation modeling with agent based modeling (ABM). By studying the interaction between the population, environmental resources, and reproductive rate of lampreys, this paper constructs a complex ecosystem simulation model and a comprehensive indicator to measure the ecological impact of different gender ratios.

Keywords: Adaptive Sex Ratio Variation, Lampreys, Ecological Dynamics, Ecosystem Simulation Models.

1. Introduction

Aquatic ecosystems are facing increasing pressure from human and environmental forces. In this article, the adaptive sex ratio adjustment of the lamprey plays a crucial role in understanding these dynamics. This species uniquely adjusts its reproductive strategy to cope with environmental changes, especially food supply. This is a crucial strategy for survival and has a significant impact on the entire ecosystem. The ability of species to adjust gender ratios based on environmental signals poses obstacles and prospects for maintaining ecological balance and biodiversity. Therefore, a deep understanding and modeling of these changes is crucial for effective ecosystem management and protection[1].The study of sex ratio variation in aquatic species, particularly in lampreys[2], has garnered increasing attention in recent ecological research. Several studies have highlighted the significance of environmental factors, such as food availability, in influencing sex ratio dynamics[3]. These changes are known to impact not only the population structure of the species but also the broader ecosystem interactions[4]. Research on lamprey biology has shown that variable sex ratios can have profound implications for population dynamics and species interactions[5]. Furthermore, ecological modeling studies have provided insights into how these variations can affect ecosystem stability, highlighting the need for comprehensive models to understand these complex dynamics[6].The adaptive nature of sex ratios in response to environmental conditions, as seen in lampreys, presents both challenges and opportunities for ecological conservation and management. This body of research forms the foundation for our study, emphasizing the importance of an integrated approach to understanding and managing these complex ecological relationships.

2. The ecological significance of the elasticity of gender ratio in the Lampley population

2.1. Predator prey model with gender ratio adjustment

On the basis of the basic principles of ecological modeling, this article extends the classic Lotka Volterra predator-prey equation to include the adaptive sex ratio changes of lamprey populations affected by environmental factors such as food supply[7]. This adjustment aims to reflect the observed phenomenon where the sex ratio in lampreys shifts in response to ecological pressures, affecting their population dynamics and interaction with predators. The differential equation used is derived from the initial conditions and parameters specific to the growth rate and predation rate of lampreys, as well as the critical threshold for adjusting the gender ratio under environmental pressure. The model is defined as follows:

$$\begin{cases} \dfrac{dN_m}{dt} = \alpha_{m_{adjusted}} N_m - \beta_m N_m P \\ \dfrac{dN_f}{dt} = \alpha_{m_{adjusted}} N_f - \beta_f N_f P \\ \dfrac{dP}{dt} = \delta\left(N_m + N_f\right)P - \gamma P \end{cases} \tag{1}$$

Nm and Nf represent male and female populations of lampreys, respectively. P represents the predator population that preys on the lampreys. α is the adjusted growth rate of males and females, regulated by the environmental capacity factor k and the total population $N=N_m+N_f$. β_m and β_f represents the predation rates of males and females, respectively. δ A function of the growth rate of predators and the abundance of lampreys, and γ Indicates the natural mortality rate of predators.

Parameters such as α, β_m, β_f, δ, γ, and k, along with the threshold for total population (totalN_threshold), are empirically determined based on observed data and ecological studies Initial conditions for N_m, N_f, and P are set based on current population estimates.

Fig 1 shows the periodic interaction between lampreys and their predators influenced by gender dynamics. The initial surge in male lampreys populations is believed to be a strategic biological response to predation pressure, possibly attributed to the physical characteristics of males that help them more effectively avoid predation. This fluctuation leads to a recalibration of the response of the lampreys population to predation, demonstrating the role of gender ratio in maintaining ecological balance.

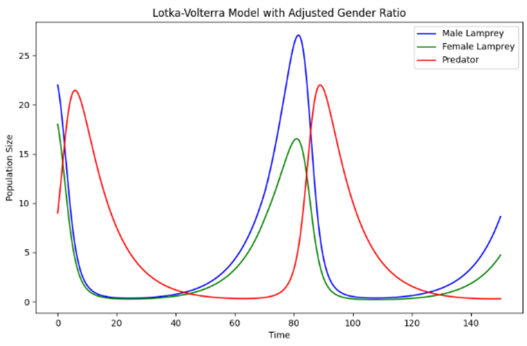

Fig 1: Enemy and lamprey

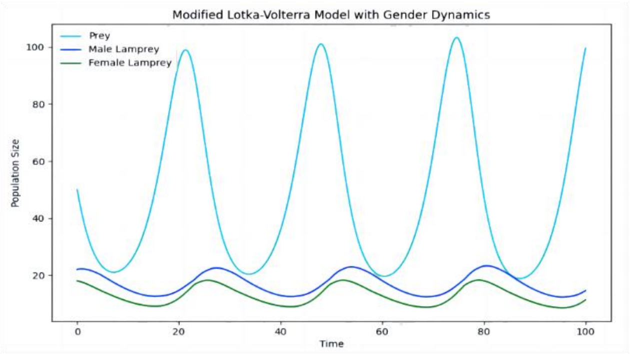

Fig 2: Prey and lamprey

In the ongoing study of this article, the interaction between the sex ratio dynamics of lampreys in ecosystems and their prey populations is investigated. The extended analysis of this article is visualized in the provided graphical data, using an improved Lotka Volterra model to combine gender dynamics with traditional predator-prey relationships[8]. The extended differential equation system now includes a subtle representation of prey reproduction dynamics, which is influenced by the sex specific predation rate of the lampreys. Therefore, the model is represented as:

$$\begin{cases} \dfrac{dP}{dt} = \gamma_p P\left(1 - \dfrac{P}{K_P}\right) - \beta_m N_m P - \beta_{fp} N_f P \\ \dfrac{dN_m}{dt} = \gamma_m N_m\left(1 - \dfrac{N_m}{K_m}\right) - \alpha_{mp} N_m P \\ \dfrac{dN_f}{dt} = \gamma_f N_f\left(1 - \dfrac{N_f}{K_f}\right) - \alpha_{fp} N_f P \end{cases} \tag{2}$$

P represents the prey population. r_P. r_m and r_f are the intrinsic growth rates of prey, male and female lampreys, respectively. K_p, K_m, and K_f are the carrying abilities of prey, male and female lampreys.

Fig 2 shows how the number of prey affects the sex ratio of lampreys. As prey increases, females grow faster, which may be because juvenile fish benefit from a better food supply. However, males still maintain a numerical advantage in the population. After the number of prey reaches its peak, the number of lampreys will decrease, which may be due to the hunting habits of adult males, leading to a sharp decrease in the number of prey and lampreys.

2.2. Interactions with Competitors and Sex Ratio Dynamics

In addition to predatory pressure, the population of lampreys often faces resource competition from other species. In order to understand the impact of these competitors on the dynamic sex ratio of lampreys, the paper further extended our model to include the interactions between lampreys and competing species[9]. This extension captures the observed changes in gender ratio due to the presence of competitors, reflecting the adaptability of the lamprey population. The augmented system of differential equations includes terms representing the growth dynamics of the lampreys population and its interactions with competing species, as follows:

$$\begin{cases} \dfrac{dN_m}{dt} = \gamma_m N_m\left(1 - \dfrac{N_m}{K_m} - \alpha_{mc}\dfrac{C}{K_c}\right) \\ \dfrac{dN_m}{dt} = \gamma_f N_f\left(1 - \dfrac{N_f}{K_f} - \alpha_{fc}\dfrac{C}{K_c}\right) \\ \dfrac{dC}{dt} = \gamma_c C\left(1 - \dfrac{C}{K_c} - \alpha_{cm}\dfrac{N_m}{K_m} - \alpha_{cf}\dfrac{N_f}{K_f}\right) \end{cases} \tag{3}$$

N_m and N_f represent the populations of male and female lampreys, while C represents the population of competing species, and r_m, r_f, and r_c represent the intrinsic growth rates of male lamprey, female lampreys, and competitors, respectively. K_m, K_f, and K_c are the carrying capacities of male and female lampreys, as well as their competitors. α_{mc} α_{fc} and α_{cm} α_{cf} is the competition coefficient between male and female lampreys and their competitors[10].

The competition coefficient and carrying capacity are estimated based on empirical observations and existing ecological data[11]. Our numerical simulation shows that an increase in competitors will lead to a significant change in the gender ratio of lampreys, and the male population will also increase significantly. This change is attributed to differences in resource demands and reproductive strategies between the sexes.

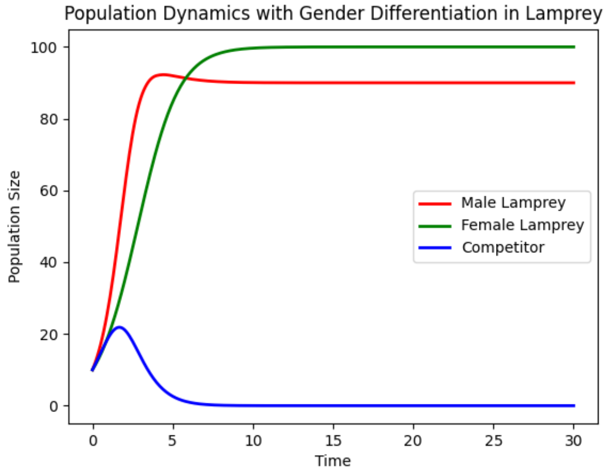

Fig 3: Oscillatory interactions between competitor and lamprey populations

Fig 3 shows the adaptive gender ratio changes of lampreys to competition. As the number of participants decreases, the lamprey will readjust to a more adaptable gender ratio, indicating their flexibility and strategic adaptability in different ecological environments.

2.3. The Relationship between the Gender Ratio of Lampreys and Natural Resource Factors

The adaptability of the lampreys population, especially in terms of gender ratio dynamics, highlights their high population resilience and ability to utilize environmental resources. In our simulation, conducted in a controlled ecosystem similar to an aquarium, we mainly focus on how the gender ratio of the introduced lampreys population responds to natural factors[12]. This interest largely stems from the inherent differences in attributes between females and males, which is crucial for understanding the adaptability of populations.

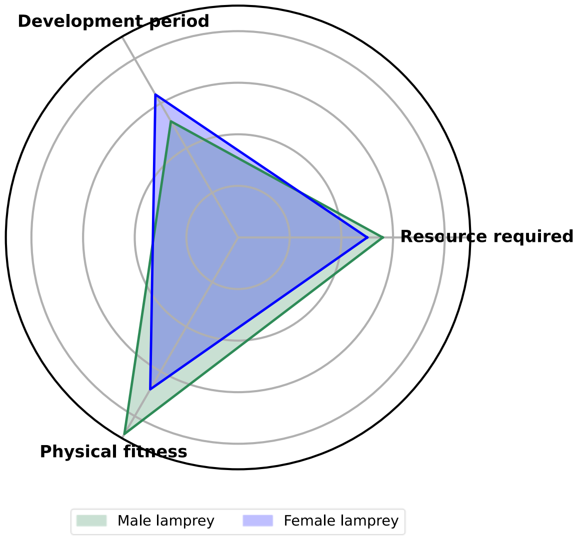

Fig 4: Comparison of differences in attributes between male and female lampreys

To quantitatively capture the dynamics of gender ratio, this article defines the proportion of male P_m (t) and female P_f (t) in the population at any given time t as:

$$P_m(t)=\frac{N_m(t)}{N(t)}, P_f(t)=\frac{N_f(t)}{N(t)} \tag{4}$$

Among them, N_m (t) and N_f (t) represent the number of male and female lampreys at time t, and N (t) represents the total population size.

According to the logistic growth model, we have considered the impact of limited resources on these proportions[13]. The gender ratio is modeled as changing with changes in environmental carrying capacity K, and a decrease in resources leads to an increase in the male ratio, as shown in the following function:

$$P_m(t)=\frac{1}{1+e^{-r(t-t_0)}} \tag{5}$$

Here, r is the rate of change in sex ratio, and t_0 is the inflection point corresponding to the time at which the male proportion is 50%.

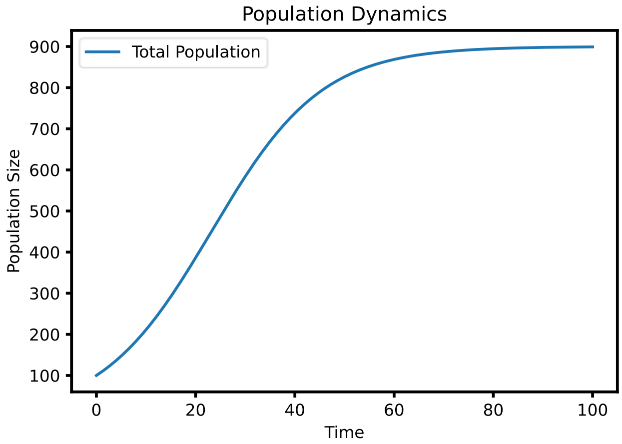

Fig 5: Trend of changes in the lampreys population

The simulation in this article starts with a gender ratio of 56% to 44%, showing a population surge until reaching environmental constraints, as shown in Fig 5, where the initial sharp rise in the growth curve is followed by a steady period.

The sex ratio undergoes a three-phase evolution as shown in Fig 6. At first, resource richness temporarily skews the ratio towards females, a trend that becomes evident after a 20-unit period, which corresponds to the time needed for sex differentiation.

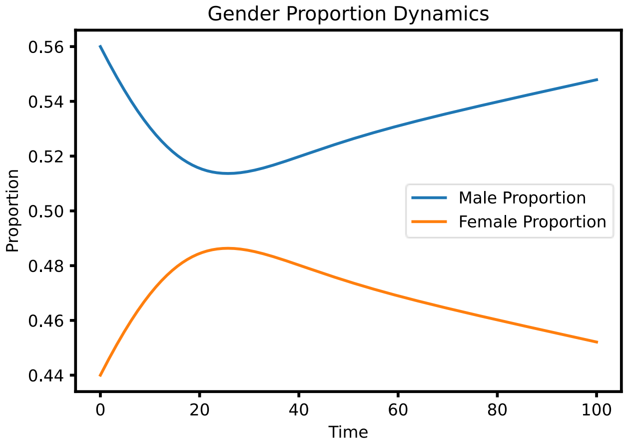

Fig 6: Fluctuations in the proportion of males and females in the population of lamprey

As shown in the environmental condition curve, with the gradual consumption of resources, the gender ratio tends to lean towards males. This observation links the decrease in food supply with an increase in the proportion of males, which may reach as high as 78%. This phenomenon highlights that young lampreys tend to develop into males when faced with relatively scarce resources.

Beyond the threshold of 20 units, as resources decrease to half of their original level, this article observes a significant increase in the proportion of males and a corresponding decrease in the proportion of females. As the simulation draws conclusions, there is a clear male dominated proportion, reaffirming the population's adaptation mechanism to resource scarcity. This adjustment reflects a natural evolutionary strategy of optimizing survival and reproductive success under limited resource conditions.

At moment 0, this article suddenly introduces a whole group of mature lampreys into a simulated closed ecosystem. As shown in Fig 7, the initial sharp decline in resource availability is directly due to the sudden introduction of mature populations into the ecosystem. This introduction has led to direct and significant consumption of resources, in stark contrast to the more gradual resource consumption typically observed by naturally expanding populations over time. This difference emphasizes the direct pressure that mature populations impose on ecosystem resources.

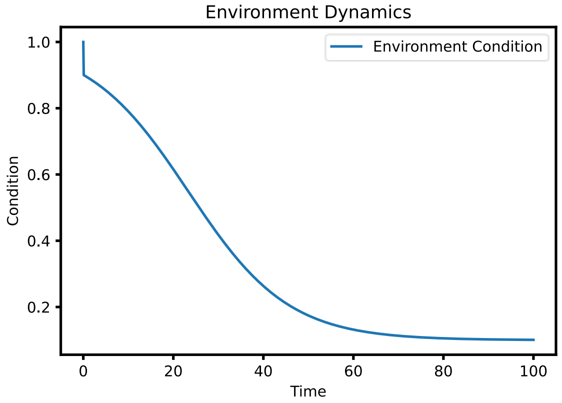

Fig 7: Research on the Environmental Conditions of the Growing lampreys

When comparing these scenarios, the significant impact of introducing a large number of mature populations into a limited environment is evident, highlighting the unsustainability of resource utilization compared to naturally expanding populations. This analysis emphasizes the importance of population dynamics in ecosystem management and reminds people to pay attention to the consequences of disrupting natural growth processes.

The adaptive sex ratio changes in lamprey populations emphasize key evolutionary strategies for coping with environmental variations. The analysis in this article emphasizes that the shift towards male or female dominance is a strategic adaptation to resource availability, affecting reproductive success and reconsidering ecosystem health. This adaptation-beneficial for female to grow and enhance reproduction in resource rich situations, and beneficial for male to have an advantage in resource scarce situations to protect resources - affects the dynamics of ecosystem resources.

2.4. Relationship between Gender Ratio and Breeding Rate of Lampreys

Agent based modeling (ABM) is a computational method that allows for the simulation of complex systems through the interaction of autonomous agents, each with different characteristics and behaviors[14]. In ecological research, modeling the behavior of individual organisms and their interactions in ecosystems is particularly useful. In this study, ABM was used to simulate the dynamics of sex ratio and its impact on the reproductive rate of lamprey populations over a period of time.

In the ABM framework, the state of each individual represents a lampreys, defined by a set of variables such as gender (S_i), age (A_i), and reproductive ability (R_i). The changes in these states over time can be modeled through a set of rules or equations. For example, the probability of an agent reproducing within a given time step can be expressed as:

$$R_i(t+1)=R_i(t)\cdot f(S_i,A_i,E(t)) \tag{6}$$

where f is a function representing the reproductive fitness of an agent, dependent on its sex and age, as well as the environmental condition E(t) at time t.

To explore the impact of gender ratio disturbance on reproductive rate, we used ABM analysis to examine two scenarios over 30 years. The first scenario starts with a gender ratio of 20% females to 80% males (2:8), and the second scenario starts with an equal gender ratio of 50% females to 50% males (5:5). The results of these simulations are shown in Figs 8 and 9.

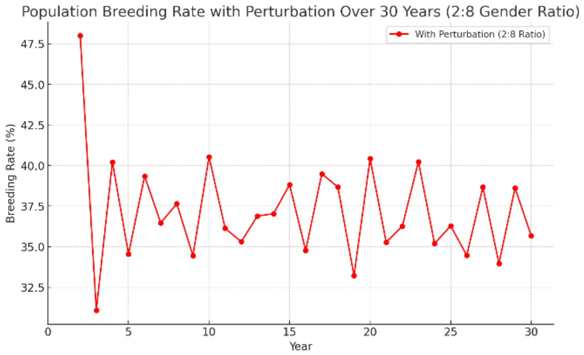

Fig 8: Reproductive rate with a sex ratio of 2:8

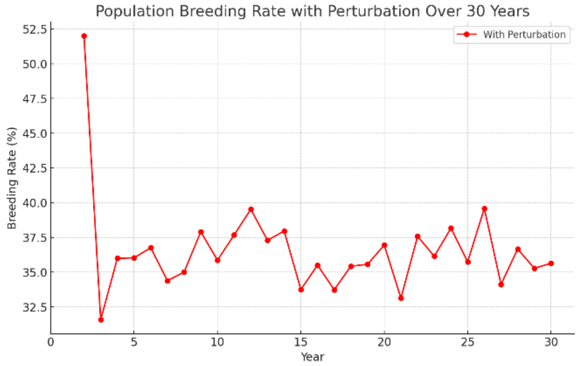

Fig 9: Reproductive rate with a sex ratio of 5:5

The fluctuation of the reproductive rate shown in Fig 8 indicates that over time, a gender ratio initially biased towards males may lead to higher variability in reproductive success rate. This can be attributed to the competitive nature of mating in populations with scarce females, leading to periods of high reproductive success rates, followed by a decline in male populations competing for limited mating opportunities.

On the contrary, Fig 9 shows a more stable reproductive rate under the same sex ratio, which may reflect less competition and more consistent mating opportunities. This stability highlights the importance of maintaining gender balance for ecological sustainability in terms of the long-term survival ability of the population.

These findings indicate that managing gender ratios is crucial for controlling lampreys. By carefully adjusting the ratio of males to females, the paper can significantly affect their reproductive ability and population growth rate, providing innovative strategies for ecological protection and invasive species control.

2.5. Generation dynamics and habitat occupation of lampreys

The paper simulation explores lampreys' (Petromyzon marinus)[15] generational dynamics and habitat occupation, revealing a nonlinear growth pattern in their expansion across available habitats (Fig 10). Initially, lampreys rapidly colonize new habitat units, showcasing their strong colonization capabilities. Yet, this growth stabilizes over time as habitat availability plateaus, indicating an equilibrium state constrained by environmental carrying capacities.

The relationship between generational growth and habitat occupation is modeled as:

$$H_n = \frac{H_{\max}}{1+e^{-k(n-n_0)}} \tag{7}$$

Here, H_n is the number of habitats occupied in the nth generation, $H_{\max}$ is the maximum capacity, k is the growth rate, and n_0 marks the turning point from growth to balance. This model emphasizes the balance between population expansion and environmental constraints.

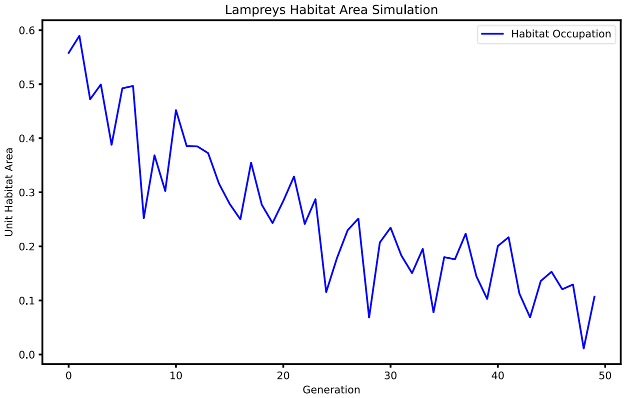

Fig 10: Generation dynamics and habitat occupation of lampreys

This generation analysis helps us understand the spatial ecology of lampreys, emphasizing the importance of habitat availability and its impact on population dynamics. As can be seen from this article, regulating habitat areas is crucial for maintaining sustainable populations of lampreys and ensuring the ecological integrity of aquatic ecosystems.

3. Conclusions

This article reveals the complex dynamics in aquatic ecosystems through simulation synthesis in four different scenarios, each of which manipulates the gender ratio of the lamprey population. Through these carefully constructed models, there is a stark contrast between ecosystems that bear the static gender ratio burden and ecosystems that benefit from natural dynamic adjustments of these ratios. When the gender ratio is artificially fixed, whether it is male dominated, female dominated, or an equal balance between the two, the ecological consequences are negative. Each situation will inevitably bring pressure to the ecosystem, manifested as resource depletion, reduced prey count, and overall ecological decline. These results emphasize the adverse effects of inflexible gender ratios on ecosystem health and stability.

On the contrary, simulations that allow for dynamic gender ratio adjustments - similar to natural conditions-showed significantly different results. This scene reveals the crucial importance of adaptive sex ratio regulation in maintaining ecological balance in lampreys. The ability of the lampreys population to respond to environmental cues and adjust its gender ratio accordingly has brought about resilience and stability that has never been seen in fixed proportion scenarios so far. The ecosystem not only maintains a dynamic balance among various species but also puts its natural resource base in a healthier state.

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