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Research on Ecosystem Dynamics Based on Lamprey Population Dynamics Model

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Abstract. Adaptive sex ratio variation is a remarkable phenomenon in the biological world. Lampreys are one of the examples. Some researches have shown that the sex ratio of sea lampreys can vary based on external circumstances, and some scholars believe that. the Great Lakes can improve the eco-environment of fish stocks by changing the sex of lampreys. This paper studied the ability for a species to alter its sex ratio depending on resource availability, and provided the resulting interactions in an ecosystem by modeling.Firstly, the paper chose the population dynamics model based on the Lotka-Volterra equation, combined with the dependence of sex ratio on resource availability. Through adjusting model parameters such as predation intensity, symbiosis facilitation intensity, and dynamic rate of change in sex ratio, the paper investigated how changes in lamprey's sex ratio impact the broader ecosystem. The model results showed that changes in the sex ratio of lampreys induce fluctuations in population dynamics that affect other species that interact with lampreys, thereby altering the structure and stability of the ecosystem.Secondly, we selected the differential equation model of gender differentiation. the paper used partial differential system dynamics equations to describe the dynamic changes in the number of female and male individuals ,used genetic algorithm and genetic models to simulate the evo-lution of genotype frequency and sex ratio, introduced adaptive genes to consider the adaptabil-ity of genotypes in different environments. ,optimized genotype frequency by simulating evolu-tionary process to adapt to changes in external environment by Genetic algorithm, and ana-lyzed the advantages and disadvantages of lampreys' population according to the results.

Keywords: Lotka-Volterra equation,the population dynamics model,ecological network model,differential equation model.

1. Introduction

Adult Marine lampreys die directly by sucking the blood of the host fish, or the host fish dies from infection of the skin wound after being bitten by Marine lampreys (PhilipsGL.Schmid WD.etal.1982). This parasitic predation by lampreys has led to a dramatic decline in native fish populations in the Great Lakes of North America. For lake herring, trout and walleye in particular, the appearance of Marine lampreys was a devastating blow. Before Marine lampreys entered the Great Lakes, annual trout production in the United States and Canada was about 6,804 tons: By the early 1960s, only about 136 tons of trout had been caught.[1]

Lampreys have a very unique way of reproduction. Female lampreys usually release their eggs into the seawater during the breeding season, while male lampreys release sperm for in vitro fertilization. After a period of incubation, the fertilized eggs hatch into larval lampreys. The larval lampreys feed on plankton and gradually migrate to the deep sea as they grow. Researchers from the United States Geological Survey and Michigan State University found that slowing down the growth rate of lampreys during the larval stage can increase the chances of becoming males. The researchers also found that if there was not enough food in the water environment, the proportion of male lampreys would reach a high level of 78% after three years. Conversely, if there was enough food, the proportion of males in the group would drop to 56%. Using this study, the researchers can control the lamprey population.

2. Establishment of population dynamic model

2.1. Dynamic sex ratio model of lampreys

In order to explore the changes of sex ratio of lampreys population under different conditions of resource availability and the relationship between sex ratio and resource availability, a dynamic model of sex ratio of Lampreys population was established. Consider the effect of sex ratio on reproductive rate and mortality. To establish a population dynamic model of lanternfish based on resource availability.

$$R = \alpha + \beta A \tag{1}$$

(2.1)Where R is the male ratio, A is the availability of resources (such as the amount of food), a and β are model parameters that need to be obtained through data fitting.

Consider the dynamic change of sex ratio Rt in time t, which is related to the availability of resources At :

Where f is a function describing the change in sex ratio, which can be set based on actual data or assumptions, for example:

$$f(A_t, R_t) = \gamma(A - A_{threshold}) \tag{2}$$

$A_{threshold}$ is the threshold of resource availability that affects gender transition, and is the regulation coefficient, which indicates the strength of the influence of resource availability on the speed of sex ratio change.

In order to better characterize the effects of different sex ratios, dynamic models were established for male and female lampreys respectively.

$$\frac{dN}{dt} = r_p N(1 - \frac{N}{K(A)}) - b \tag{3}$$

$$N = M + F \tag{4}$$

$$\frac{dM}{dt} = r_m M - d_m M + b_m aPM \tag{5}$$

$$\frac{dF}{dt} = r_f P - d_f F + b_f aPF \tag{6}$$

$$\frac{dP}{dt} = r_p P - aP(M + F) \tag{7}$$

Where M is the population size of male sea lampreys,rm is the reproductive rate of male sea lampreys,dm is the mortality rate of male sea lampreys.bm is the predation efficiency of male sea lampreys (the efficiency of converting food into population growth),F is the population size of female sea lampreys,rf is the reproductive rate of female sea lampreys,df is the mortality rate of female sea lampreys,bf is the predation efficiency of female sea lampreys,N is the population size of sea lampreys.b is the predation rate of sea lampreys,KA is the maximum carrying capacity of resources in the environment,a is the probability of lamprey being preyed on,P is the population size of lampreys,rp is the natural growth rate of lampreys.

In this model, as a predator, lampreys' impact on the ecosystem is mainly reflected in the changes in the number of their own population and the number of their prey populations.

The Lotka-Volterra equation of lampreys as prey is not considered here, because lampreys have basically no natural predators in the natural environment, and are only heavily preyed upon by humans. While humans, as omnivores, eat a wide range of diets, lampreys are only a small part of the diet of a very small number of people. Therefore, placing humans directly into Lotka-Volterra models does not accurately simulate real-world scenarios. Here, the effect of human predation on lampreys populations is characterized as the mortality of lampreys (i. e. , mortality = natural mortality + mortality due to human predation).

This model considers predation and symbiosis between females and males, as well as the effect of sex ratios on the population as a whole. The dynamic change of sex ratio is influenced by external environmental factors. The number and sex ratio of females and males are simulated under different conditions. In the simulation, we studied the effects of changes in the sex ratio of lampreys on the larger ecosystem by adjusting model parameters such as predation intensity, promoting symbiosis intensity, and dynamic rate of change in sex ratio. In particular, to see whether changes in the sex ratio lead to changes in the numbers and distribution of other species, and the impact of such changes on the stability of the entire ecosystem.

2.2. Model Solution

To solve this model, the paper use numerical methods such as Euler's method or Runge-Kutta's method.Here the paper use the odeint function from Python's scipy. integrate library to solve these differential equations.

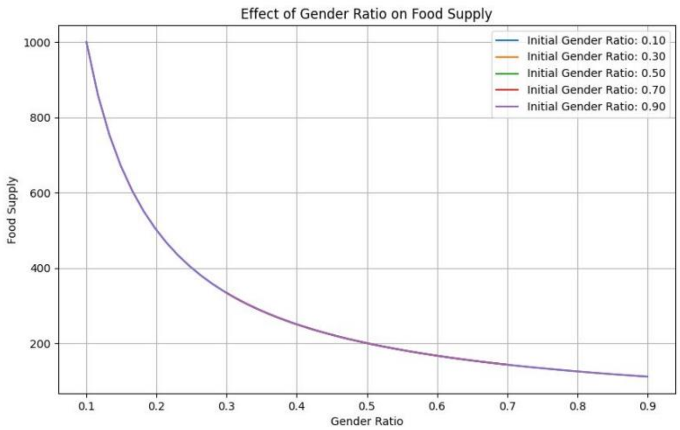

Fig 1: Effect of Gender Ratio on Food Supply

The Fig 1 above shows the changing trend of the sex ratio of lampreys population under different resource availability conditions. Under the condition of insufficient food resources, the male ratio increases.When food resources are sufficient, the male ratio decreases.

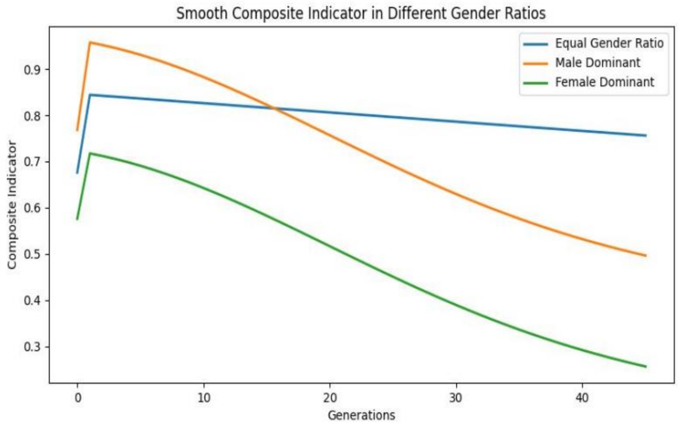

Fig 2: Smooth Composite Indicator in Different Gender Ratios

The Fig 2 above shows the number of offspring produced by a lamprey population with different sex ratios and a smooth composite indicator.

In the drawing section, the paper show the population dynamics of prey and predators respectively, as well as changes in the sex ratio. The simulation results can be observed by adjusting the values of these parameters to better understand the impact of these parameters on the ecosystem.

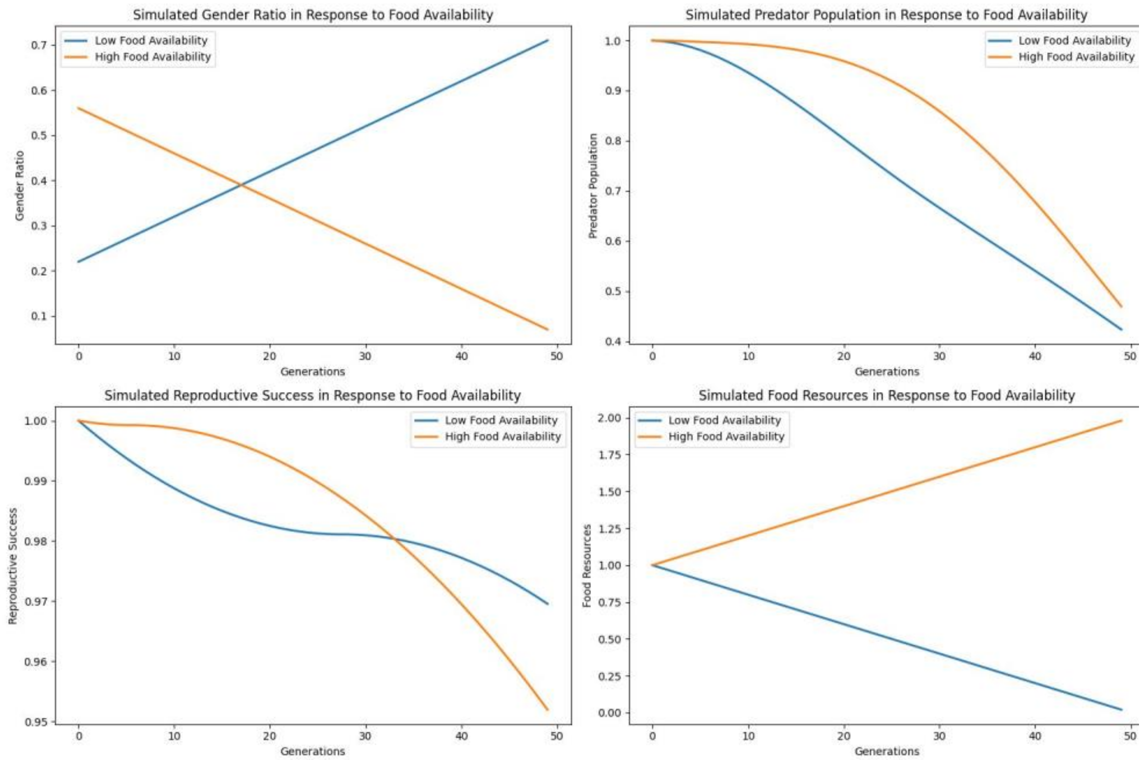

Fig 3: Comprehensive analysis of the impact on the environment

Based on the above Fig 3 observations and conclusions, the effects of changes in the sex ratio of lampreys on the dynamic population fluctuations and ecosystem stability can be more specifically explored, and the changes in the sex ratio between females and males may lead to different behaviors in feeding and being preyed upon. For example, females may exhibit more aggressive behavior when foraging for food and setting up nests, while males may be more focused on territorial defense. This different behavior may directly or indirectly affect other species, altering their ecological roles and distributions.

And there are population fluctuations, and when the proportion of females increases, more reproductive behavior may be observed, leading to population fluctuations in lampreys. The increased proportion of females may have increased the frequency and success of breeding, leading to fluctuations in prey and predator populations. This could have knock-on effects on other species that depend on lampreys, causing their populations to fluctuate. It also affects ecosystem stability, which can be negatively affected by excessive sex ratio fluctuations. If the sex ratio changes too drastically, it can cause instability for multiple populations in an ecosystem, making it difficult for them to maintain equilibrium. This can cause instability at the ecosystem level, with knock-on effects on the interactions of other species, ultimately affecting the stability of the entire ecosystem.

3. Evolutionary game theory

3.1. Model Establishment

The strengths and weaknesses of lampreys ' populations can be considered in terms of their ecology, physiology, and behavior.

The paper build a population genetic model based on energy budget and life history theory to explore the effect of sex ratio on fitness. Using Evolutionary Game Theory to Analyze the stability of Different Sex Ratio strategies and Evolutionarily stable Strategies (ESS).

In order to model the second problem mathematically, we can make an evolutionary game theory model to analyze the advantages and disadvantages of changes in the use of sex ratio for lamprey populations. We will consider the plasticity of sex ratio as a strategy and explore how different sex ratio strategies affect the reproductive success and fitness of populations.

The kinetic equation of the model is as follows:B: The number of successful breeding in time t.H: The number of predators at time t.

Reproduction equation:

$$\frac{dB}{dt} = \rho p_f (1 - p_f) \tag{8}$$

ρis the reproductive success constant, indicating the effect of the number of females on the number of successful breeding F.

p_f is the female ratio, and this equation says that the number of reproductive successes depends on the number of females and their sex ratio. The number of successful breeding is greatest when the ratio of females is 0. 5.

$$\frac{dH}{dt} = \eta P \tag{9}$$

This is the predation equation.

η is the predator attack rate constant, indicating the effect of the population on the number of predators P.

This equation states that the number of predators depends on the population, and that the number of predators increases as the population increases.

The dynamics equations of the overall model:

a .Variation of male number

$$\frac{dM}{dt} = \alpha R - \beta M \tag{10}$$

and represents the growth and mortality of lampreys' males relative to resources and numbers.

b. Changes in female number:

$$\frac{dR}{dt} = \gamma R - \partial M \tag{11}$$

γ and δ represents the growth and mortality of lampreys 'females relative to resources and numbers.

$$\frac{dP}{dt} = \frac{dM}{dt} + \frac{dF}{dt} \tag{12}$$

The above is the expression formula of the total number of lampreys population. The gender ratio is calculated as follows:

$$p_m = \frac{M}{P} \tag{13}$$

$$P_F = \frac{F}{P} \tag{14}$$

3.2. Model Solution

The paper used Python data visualization to analyze lampreys with different sex ratios as shown in Figs 4and 5.

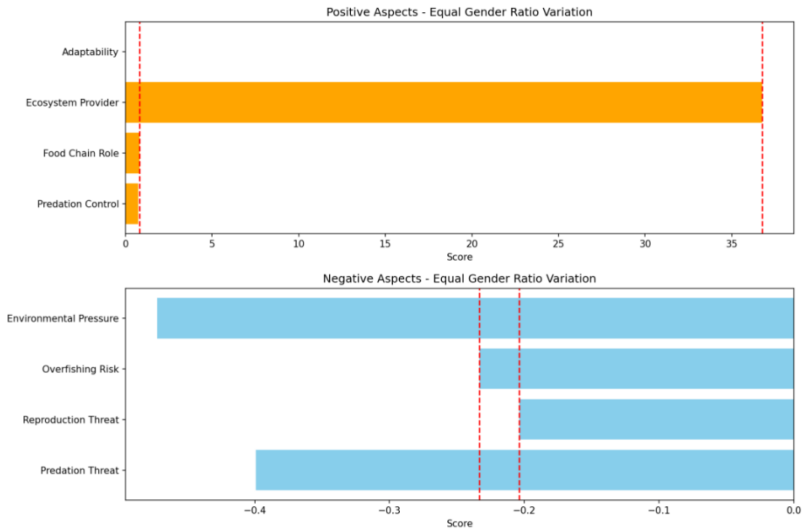

Fig 4: Lamprey population characteristics at different sex ratios

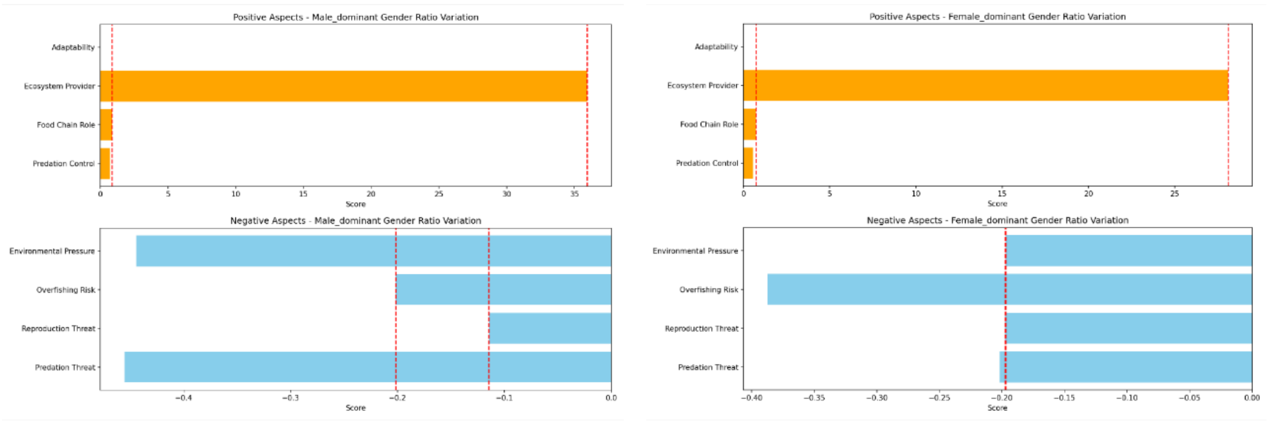

Fig 5: Lamprey population characteristics at different sex ratios

By comparative analysis, the advantages and disadvantages of lampreys ’population were obtained.

Analysis of advantages:

(1). Adaptive advantages:

Lampreys can adapt to different ecological conditions by adjusting the sex ratio to improve the adaptability of survival and reproduction.

This adaptability allows lampreys to adjust their reproductive strategies and maintain relatively high viability in the face of different environmental pressures.

(2). Ecological balance adjustment:

By adjusting population size and sex ratio, lampreys help maintain a relatively stable ecological balance.

Specific implementation: The dynamic adjustment mechanism in the model enables the population to adjust rapidly in the face of external pressure.

Further expansion: This kind of ecological balance adjustment can reduce the impact of external disturbances on the population and improve the stability of the entire ecosystem.

(3). Resource utilization efficiency:

When resources are sufficient, increasing the male ratio can improve reproductive efficiency and encourage populations to use environmental resources more efficiently.

This increase in resource efficiency helps sustain healthier and more prosperous populations, positively impacting the overall health of the ecosystem.

4. Conclusions

Lampreys are aquatic vertebrates native to the Atlantic Ocean that resemble eels ,but differ in that they feed on larger fish. Sea lampreys can survive in the fresh water of the sea Sea lampreys entered the Great Lakes by shipping in the early 20th century, and today are found in all waters of the Great Lakes. The paper model adaptive sex ratio variation in lampreys and explore the multiple implications for ecosystem stability and other species. This helps to understand the reproductive strategies and adaptations of species under different environmental conditions. By establishing the model, we can study the influence of different environmental factors on the sex ratio of lampreys, so as to provide scientific basis for the protection and management of this species. In addition, such models can also help predict the possible effects of future environmental changes on the population structure and reproductive success of lampreys. Therefore, it is of great significance for the study of ecology and conservation biology.

References

[1] ZHANG R. Synthesis of cholic acid derivatives from sex pheromone of Lampreys sea [D]. Jiangxi Agricultural University,2019.

[2] Jiménez-Rodriguez, Fsteban, etal. "ALyapunev-like characterization of predefined-time stability. " IEEEIransactions on Automatic Control 65 11,2020:4922-4927.

[3] Wang D F. Fishery conservation in the Great Lakes of North America: Invasion and control of sea lampreys in the Great Lakes of North America [J]. China Fisheries,2012, (10):34-36.

[4] Jin Huanhuan. A few kinds of biological population model dynamic behavior analysis [D]. Southwest university, 2023. The DOI: 10.27684 /, dc nki. GXNDX. 2022.000673.

[5] Zhang Guangyue. Yellow sea bohai sea moon jellyfish population dynamics simulation and analysis [D]. Tianjin university, 2022. The DOI: 10.27356 /, dc nki. Gtjdu. 2019.004762. [6] Poul Scheel Larsen and Hans Ulrik Riisgárd. Size-specific growth of filter-feedingmarine invertebrates. Journal of Marine Science and Engineering, 2022.

[6] Z Zhenliang, W. Runxin, L. Liyun, and Y. Xiangqin, "The influence of fear effeto the lotka-volterra predator-prey system with predator has other food resource ADVANCES IN DIFFERENCE EOUATIONS, vol. 2020, 2020.

[7] S.Xue”Study on the population control and eyolutionusing sex-and stage-struc-tured mathematical models," Ph.D. dissertation, Donghua University, 2023

[8] Great Lakes Fishery Commission, Sea lamprey - an ancient invader, http://wwwglfc.org /sea-lamprey.php, Accessed: February 5,2024,2023

[9] .J.V. Adams and M.L. Jones, "Estimation of lake-scale stock-recruitment modelsfor great lakes sea lampreys," Ecological Modelling, vol. 467, p.109916, 2022, ISSN:0304-3800.Dol: https://doi.org/10.1016/j.ecolmodel.2022.109916.[Online].Available:https://www.sciencedirect .com/ science/article/pii/s0304380022000394