Research on the Sex Ratio Variation of Sea Lampreys and Its Ecological Impact Based on the Lotka-Volterra Competition Model

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Abstract. Changes in sex ratio are a common adaptive phenomenon in biodiversity-rich ecosystems, which is reflected in many species, and the adjustment of the sex ratio of sea lampreys reflects its response to resource constraints and is critical for maintaining ecosystem stability. In this study, the population of sea lampreys was taken as an example, and the Lotka-Volterra competition model was used to explore the changes in the sex ratio of sea lampreys with environmental resource conditions. We found that the sex ratio of sea lampreys could reach 78% of the total population in an environment with a low food supply rate. In environments where food is more readily available, males make up about 56% of the population, which means that the population size of sea lampreys can have a significant impact on the changes in the population of competing species, affecting the time of extinction of the species and the population size in the early competition. Finally, we explore the ecological effects of sex ratio and resource availability.

Keywords: Sea lampreys, Lotka-Volterra competition model, Sex ratio, Ecosystem stability.

1. Introduction

In freshwater and Marine ecosystems, lamprey has an important ecological position as a unique aquatic organism. The changing sex ratio of sea lampreys not only reflects the biological mechanism of adaptation to environmental changes, but also has a profound impact on the function and balance of the ecosystem. In recent years, scientists have become increasingly concerned about changes in the sex ratio of sea lampreys and their ecological consequences, in particular how they affect the entire food chain and food web by affecting population size and structure, while also being critical for maintaining ecosystem stability[1].

To study changes in the sex ratio of sea lampreys and their ecological consequences, this study developed a Lotka-Volterra competitive model of population dynamics, sex ratio, and environmental resource interactions in sea lampreys[2]. We adopted the Lotka-Volterra competition model because we had read a large number of biological research models (similar ones include the Effect of high-order Interactions on host-parasite community dynamics by Gao et al in Acta Ecologica Sinica). Diversity begets stability by IAN A. HATTON: Sublinear growth and competitive coexistence across ecosystems), found that the Lotka-Volterra competition model is the most widely used and most suitable for this study.

In this study, the Lotka-Volterra competition model based on the dynamics of sea lampreys population, the interaction of sex ratio, and environmental resources, and predicted and analyzed the population changes of sea lampreys under different conditions and the impact on the ecological environment. We set the relevant parameters around the relevant biological significance in this study. Modeling the sex ratio change of Sea Lampreys is a complex and multi-level task, which needs to consider factors such as reproduction rate, living conditions, population dynamics, resource utilization, and biological interactions. Therefore, we first analyzed the sex ratio of sea lampreys, then analyzed the external conditions, and finally analyzed the ecological significance of the sex ratio adjustment in sea lampreys.

2. Model construction and analysis

2.1. Research idea

In the ecosystem, sea lampreys are a species with adaptive sex ratio variation, and their sex ratio change is closely related to resource availability.When the sex ratio of sea lampreys is changed by external environmental factors, this change may lead to changes in the interspecific relationship, and thus affect the stability of the ecosystem[3].

When the number of sea lampreys can change its sex ratio, the impact on the larger ecosystem is reflected in the number of populations, and the effects of population increase or decrease are transmitted through the food chain and food web in the ecosystem, directly affecting the species that compete with sea lampreys (intraspecific and interspecific competition) and the species that have predation relationships[4]. At the same time, this impact will continue to spread through the food chain and food web, thus affecting the entire ecosystem, and even changing the ecological balance[5].

When the population of sea lampreys can change its sex ratio, that is, interspecific regulation, in which intra-species competition is the main factor and the sex differentiation of sea lampreys is closely related to the development rate, we can conclude that the main factor affecting the sex ratio of sea lampreys population is the adequacy of resources (food). Then consider the classification problem. When the parents are in the larva, the larva population is too large, that is, the resources (food) are insufficient, the intra-species competition is stimulated, and the supply of resources (food) is insufficient. At this time, the larvae that differentiate into females decrease, and the larvae that differentiate into males increase, the ratio of males to females decreases, the number of progeny decreases, and the population of sea lampreys decreases, whereas the number of sea lampreys increases.

2.2. Model building

In biology, the Logistic Growth Model is commonly used to describe the number of biological populations, where N(t) represents the number of populations at time t. N_0 is the initial population number, that is, the number at t=0, r is the inherent growth rate of the population, and k is the environmental capacity[6].

This model describes the process of rapid population growth at first, but as the population approaches the environmental capacity, the growth gradually slows down and eventually stabilizes.

$$N(t) = \frac{K}{1 + \frac{(K - N_0)}{N_0} e^{-rt}} \tag{1}$$

The sex ratio mainly affects the fertility rate of sea lampreys, and the fertility rate refers to the average number of births per year during the reproductive period of sea lampreys[7]. By referring to the data, we know that most sea lampreys are monogamous, and in most cases, the number of females is less than that of males. Through barrel management, we can make the following assumptions, that is, the increase of fertility rate of this species is related to the proportion of females in this species. In conclusion, we assume a fertility influencing factor r_s and we assume that $r_s = 1$ when the ratio of males and females is the largest. We assume that the state at this time is the standard state, and explore the impact of fertility rate on population number by changing the value of r_s. Therefore, the specific result after transforming the formula is shown in Figure 1.

$$N(t) = \frac{K}{1 + \frac{(K - N_0)}{N_0} e^{-r(r_s)t}} \tag{2}$$

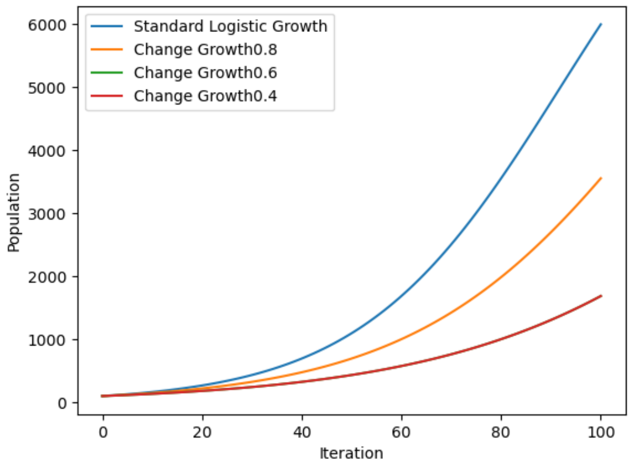

Figure 1 Changes in population size of lower sea lampreys with different fertility rates as a function of reproductive times

3. Model insights into the effects of food supply on competition

3.1. The effect of food on intraspecific competition

The sex ratio of sea lampreys is highly correlated with food availability, and in low food availability environments, the percentage of males can reach about 78% of the total population[8]. The proportion of men in environments where food is more readily available is about 56% of the population. Therefore, we use the Sigmoid function to fit, and the rationality of the model can be verified from the perspective of biology and ecology.

1. Use of Sigmoid function: Sigmoid function is often used to model saturation and hunger responses in biological processes. Here, the sigmoid function can model the non-linear effect of food supply on the sex ratio. As the food supply increases, the sex ratio gradually becomes saturated, which fits the reality of many biological populations.

2. Threshold effect: The threshold parameter 'R0' in the model represents the threshold of the food supply rate, that is, when the food supply rate is higher than this threshold, the proportion of females will increase significantly(R stands for food availability). This reflects the sensitivity of some organisms to environmental changes and may be related to reproductive strategies, adaptation and resource allocation.

3. Male ratio reference line: Added male ratio reference line to indicate the expected male ratio under low and high food supply rates. This helps to more intuitively understand the model's output and provides a quantitative understanding of how male ratios change over different environmental conditions.

4. Reflection of the actual environment: the output of the model is consistent with the actual observed biological behavior. At low food availability, the male ratio is higher, possibly to increase the fitness of the population. At high food availability rates, the population has a relatively low proportion of males, possibly to allocate resources more efficiently.

$$Sigmoid(x) = \frac{1}{1 + e^{-x}} \tag{3}$$

$$female_{ratio} = \frac{1}{1 + e^{-a(R-R_0)}} \tag{4}$$

$$male_{ratio} = 1 - female_{ratio} \tag{5}$$

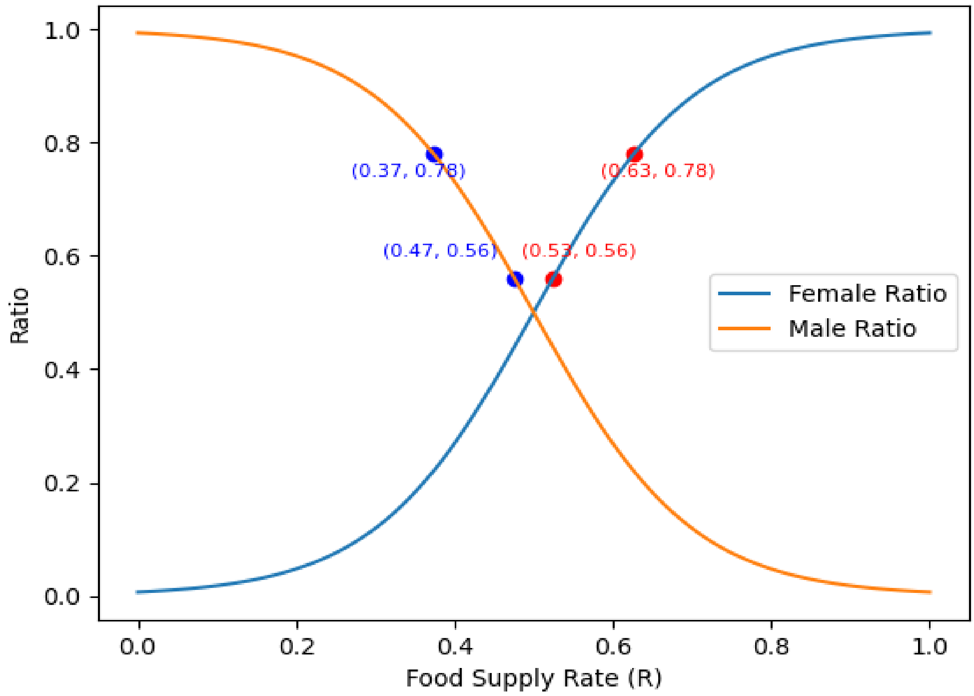

Figure 2: The impact of resources (food) on intraspecific interactions

From the figure 2, can see that the influence of food on the male ratio is negatively correlated, while that on the female ratio is positively correlated. Combined with the 2.3 pre-model, we can conclude that when the population increases or decreases, the intraspecific competition will be intensified or weakened, thus affecting the food supply rate and thus the sex ratio of sea lampreys. Finally, the sex ratio will feed back to regulate the population size[9].

3.2. The effect of interspecific competition on competitors

The phenomenon of interspecific competition when two species use the same resource or space. The more similar the two species are, the more their niches overlap and the more intense the competition. According to the Gauss hypothesis, interspecific competition can be divided into two forms: one is that niche overlap is too high, competition is too intense, and interspecific competition is fierce (see Figure 3(A)). The other is that the niche overlap is small, the competition is relatively moderate, and the interspecific competition shows that both can survive, but the environmental capacity of the party at a disadvantage in the competition will decrease (K value), and the speed of reaching K value will slow down (Figure 3(B)).

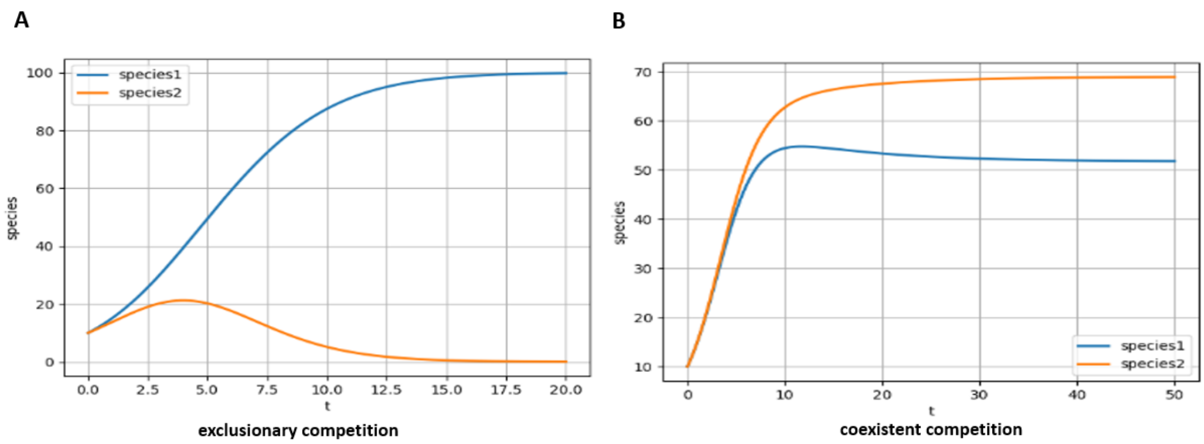

Figure 3 A: exclusionary competition B: coexistent competition

To better express the effect of interspecific competition on the sex ratio, we used the Lotka-Volterra competition model to express interspecific competition

$$\frac{dx}{dt} = r_1 x \left(1 - \frac{x}{K_1}\right) - \alpha_{12} xy \tag{6}$$

$$\frac{dy}{dt} = r_2 x \left(1 - \frac{y}{K_2}\right) - \alpha_{21} yx \tag{7}$$

x and y are the population sizes of species 1 and species 2, respectively.(Size of competing populations)

r_1 and r_2 are intrinsic growth rates for each species.(Intrinsic growth rates of each competing population)

K_1 and K_2 are the environmental capacity (i.e. the maximum carrying capacity of the resource) for each species.

α_{12} and α_{21} are the intensity of competition, indicating the effect of one species on another.

In general, we know from the above that when the number of lampreys can change its sex ratio, the impact on the larger ecosystem is reflected by the number of populations. Therefore, we can change the number of populations of x and y to reflect the intensity of competition, or we can reflect the competition of species by the overlap of ecological niches (changing α_{12} and α_{21}). However, at this time, we take the case of serious overlap of ecological niche as an example to show that we keep α_{12} and α_{21} and change x and y, and the result is shown in Figure 3(A).

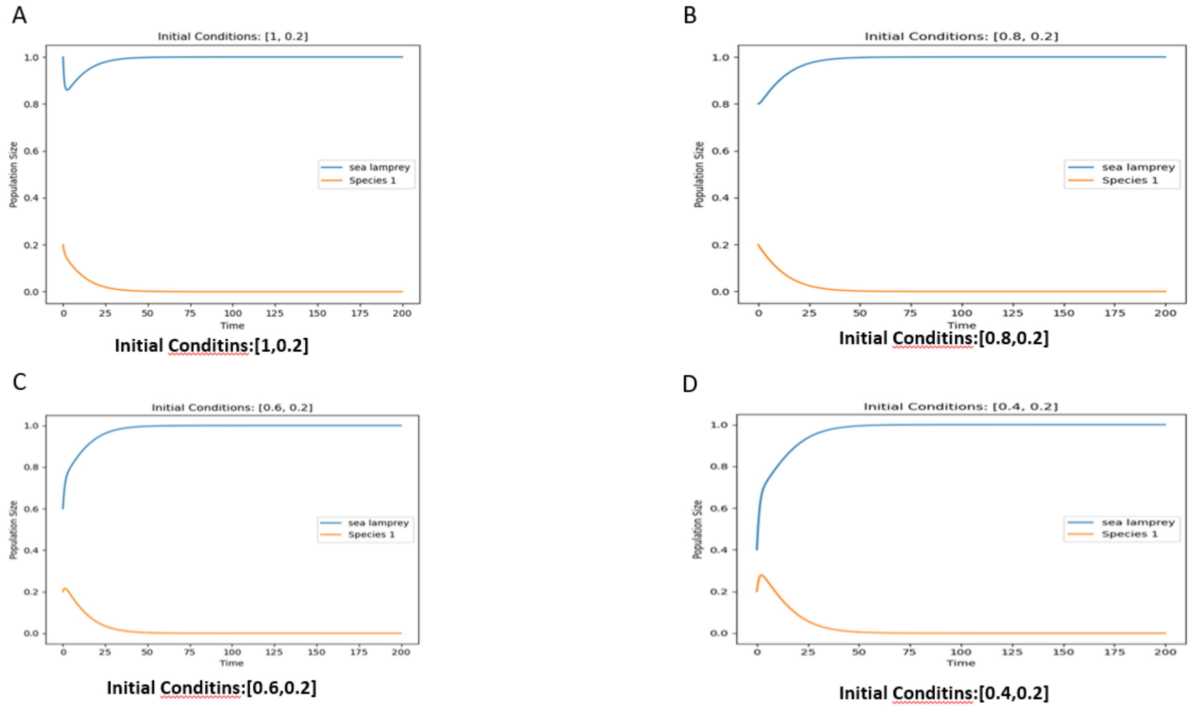

Figure 4 Different initial conditions

3.3. Analysis of simulation results

By comparing the four subgraphs, we can see that when the initial population proportion changes, it will have different impacts on the populations in the competitive relationship[10]. As shown in Figure 4(A), we can intuitively see that the population of Species 1 declines very fast, and the population has no upward trend. In Figure 4(B), although we set down the population of sea lamprey in the initial conditions, it is intuitively the same as Figure 4(A). The population of Species 1 is still declining very fast, and the population of Species 1 does not have an upward growth trend. We continue to decrease the population of sea lamprey and obtain Figure 4(C). It can be observed that the population number of Species 1 is not directly declining, but has some trend of population increase, although not so strong. When we continue to look at the population number of sea lampreys, Figure 4(D) is generated, from which we can easily observe that the population number of Species 1 is not initially declining. There was a very significant increase. Through the comparative analysis of the four subgraphs, we can infer that the population size of sea lampreys will have a significant impact on the population change of the species in the competitive relationship, and will affect the extinction time of this species and the population size in the early competition.

4. Conclusions

After reviewing the literature, we found that reproduction is the most important factor affecting the sex ratio of sea lampreys, and the breeding process is most susceptible to temperature and food resources. Therefore, we established the Lotka-Volterra competitive model of the population dynamics of sea lampreys, the interaction of sex ratio, and environmental resources to predict and analyze the population changes of sea lampreys under different conditions and the impact on the ecological environment. The results showed that the influence of food on the proportion of males was negatively correlated with that of females. At the same time, when the population of sea lampreys increases, the number of competing species will decrease, thus affecting the stability of the ecosystem.

This paper provides a research approach and framework for animal ecological assessment, and finally discusses the ecological effects of sex ratio and resource availability, proving that changes in biological sex ratio can have a great impact on the stability of ecosystems.

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