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The change of sex ratio in Lamprey based on predator and Logistic model

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Abstract. This paper studies the sex ratio and resource availability of lamprey population, through the predator model and Logistic model of lamprey population dynamic simulation. Differential equations were used to dynamically describe the dynamic changes within lampreys population, and then the effects of changes in sex ratio on the food chain, population reproduction rate, habitat occupation and resource availability were analyzed. Optimize and analyze the population dynamic change model to simulate the impact of changing sex ratio on the population. Based on the competition and mutualism between lampreys and parasites, combined with the food chain in which they are located, the ecological model of multi-species interaction is re-established on the basis of the original model to solve the problem, and the sensitivity analysis of the final result is carried out.We found that changes in the sex ratio of lampreys populations can provide an advantage to other species.

Keywords: Predator model, Logistic model, Sex ratio model, The sex-ratio regulation function.

1. Introduction

1.1. Background

In the 1950s, lampreys invaded the Great Lakes of North America, which once brought devastating damage to the populations of lake trout, lake pinhead salmon, white salmon and other economic fish, and became one of the major risks to subvert the ecosystem of local waters[1]. They live a parasitic life, using their funnel-shaped round mouths to their advantage. They use the teeth of their tongues to file through the bodies of large fish. They have glands in their mouths that secrete mucus, This mucus can prevent the blood of big fish from coagulating, so as to facilitate the lampreys to absorb the host's blood, which may eventually lead to the death of the host[2]. The existence of lampreys has caused devastating damage to the fish in the environment, affected the diversity of the ecosystem, and had an important impact on the development of human aquaculture. The flood of lampreys has seriously affected the local aquaculture industry and caused economic losses in aquaculture and fisheries, so it is particularly important to study how to regulate and affect their sex to reduce the number of offspring they reproduce.

1.2. Main work

Adaptive sex ratio change is a strategy that can adapt to the environment and resource allocation in the animal kingdom. Such changes affect the reproductive rate of individuals as well as the genetic diversity and homeostasis of populations. A model was established to study the sex ratio in lampreys population. Explore the effects on the larger ecosystem when a population of lampreys changes its sex ratio. Ecosystem stability is associated with changes in the sex ratio of lampreys populations. To explore whether changes in the sex ratio of lampreys populations can affect other

species in the ecosystem, such as parasites, to their advantage.

2. Preliminary

2.1. Assumption

1.It is assumed that the growth and reproductive capacity of lampreys are affected by the availability of environmental resources.

2.Assuming that no other species invade during the experiment, the ecosystem is in a stable state.

3.The lampreys have the same genetic material during the experiment.

2.2. Analysis of the data

In nature, living things have a natural desire to reproduce and tend to grow rapidly, but the growth rate of food and resource supplies is relatively limited, and it is difficult to keep up with the growth rate of living things[3]. When the environmental capacity of the ecosystem reaches its maximum, the resource supply cannot meet the rapid growth of organisms, and death will occur, thus reducing the number of organisms. Restore the balance between resources and living things, as shown in Figure 1.

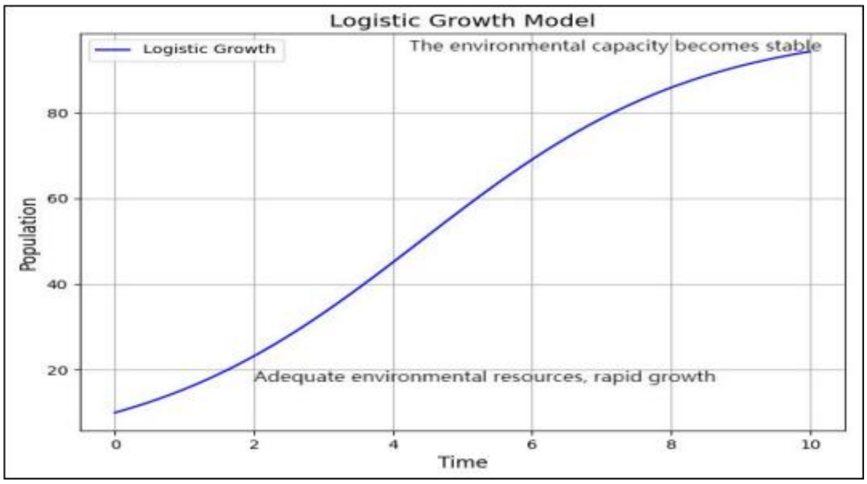

Figure 1. Logistc growth model

The results showed that when exposed to abundant water, lampreys were larger, matured earlier, and were almost exclusively female. Lampreys, which live in waters where food is scarce, are not only small, they are almost always male. Research by the United States Geological Survey (USGS) and Michigan State University found that the sex of lampreys is determined by their growth rate[4]. And the survival rate of lampreys was not affected by the number of fish in their environment.

Based on the relationship between the growth rate of lampreys larvae and the resource availability in their environment, a model of the dynamic change of lampreys population was established.

Analysis of the effects on the larger ecosystem when a population of lampreys changes its sex ratio. Explore the effects on ecosystems when a population of lampreys can change its sex ratio. The food web structure of lampreys in the water area was analyzed. According to the development history of lampreys, the larva of lampreys had no obvious external sex characteristics, so this stage was defined as the genderless stage for the convenience of future solution.

Assuming that the ratio of males to females in the initial lampreys population in this water area was 56:42, the relationship between the growth rate of lampreys and the availability of resources in the environmental water area was explored. The high availability of resources represented the high content of nutrients such as plankton in the water area.

Starting from the role of lampreys in the ecosystem, through the corresponding relationship in the food chain, the advantages and disadvantages of lampreys population are comprehensively analyzed from many aspects.

The original basic model was optimized, the differential equation was established, the environmental tolerance and other factors were introduced, and the evolutionary game theory model was used to analyze the effects of the plasticity of sex ratio on the adaptability and reproductive success of lampreys population. Define fitness functions and search for evolutionarily stable strategies (ESS)[5], identify the optimal sex ratios that may occur under different environmental conditions, and analyze the effects of these ratios on population dominance and inferiority.

Although lampreys can cause serious damage to the ecosystem and biodiversity of their environment, their native medicinal value cannot be ignored. Lampreys are unusually rich in nutrients. The fish body can also be used as medicine. The medicinal taste is sweet and warm, and has the effect of nourishing and strengthening the body[6]. It has the effect of treating mouth and eye skewness, night blindness, corneal dryness, etc. So it can increase economic benefit by formulating reasonable control plan.

2.3. Notations

The symbols used in the paper are listed in Table 1.

Table 1 Notations

Symbol	Definition
N	Total population of lampreys
F	Number of females in the population
M	The number of males in the population
u	Birth rate of lampreys
d	Mortality of lampreys
b	The feeding rate of lampreys
O	The size of the prey population
a	The probability of prey being preyed upon
$G(p)$	Regulating function of sex ratio of lampreys
Q	Number of parasites
L	Number of competitors

3. The Model of sex ratio

The sex ratio of lamprey is affected by the growth rate of larvae, and the change of the environment will cause the growth rate of juvenile lamprey to be different[7]. The relationship between sex ratio and the food supply of the environmental waters in which the model is established. At this point, the problem is transformed into an ecosystem-related problem, and the predator model is used to simulate the dynamics of lamprey population changes to establish a differential equation, as follows.

Regardless of the variation of the population within the lamprey by the external environment, the population variation is inferred according to the birth rate and death rate in the population.

Then, when the lamprey sex ratio changes, the Logistic model is used to describe the development speed of the larval stage and thus affect the sex ratio, and the following sex ratio model is obtained[8]. Adult lamprey will live on other fish, so the analysis of the capture rate of lamprey, the ecosystem, the prey efficiency of lamprey and the natural growth rate of prey can be obtained.

A game-theoretical model was used to analyze the advantages and disadvantages of sex ratio changes on lamprey populations. Considering the plasticity of the sex ratio, we find out the different sex ratio strategies affecting the reproductive success and adaptability of the population. Assuming that the population of lamprey sex ratio are fixed at 1:1 and 3:7, the changes of the ecosystem stability is analyzed.

The dynamic simulation of lamprey can output the adjusted values of different sex ratios in different environments according to the number of prey species. At this time, it changes between 0 and 1. When it approaches 0, the lamprey population sex approaches to females, and when it approaches 1, the lamprey population sex approaches to males.

When the sex ratio is fixed at 1:1, the reproductive rate of lampreys population is evenly divided between the two sexes, and the optimized model can be obtained. When the sex ratio is fixed at 3:7,the reproductive rate of the lamprey population is allocated to three females and seven males.

Explore the effects of the sex ratio change in lamprey populations on other members of the ecosystem, and establish an ecological model of multi-species interactions by integrating the food chain relationships of the ecosystem.

3.1. Solutions of sex ratio changes in lamprey populations

Assuming that the initial ratio of males to females in the lampreys population is 56:42, the simulation changes the resource availability and observes the change of the sex ratio in the population, as shown in Figure 2 below.

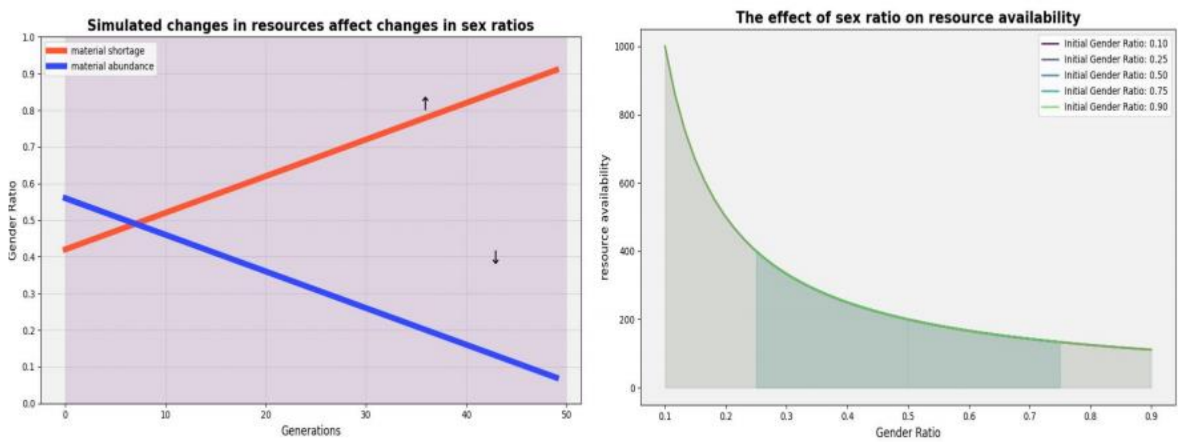

Figure 2. Gender impact of resource changes

According to the trend of the curve of the image, in the area with abundant resources, the ratio of males to females will decrease, while in the area with abundant resources, the ratio of males to females will increase. Then the relationship between sex ratio and reproductive rate of lampreys population was studied.

Assuming that the sex ratio is proportional to the reproductive rate, the simulation changes the sex ratio and observes the effects of different sex ratios and resource availability on the reproductive success rate, as shown in Figure 3 below.

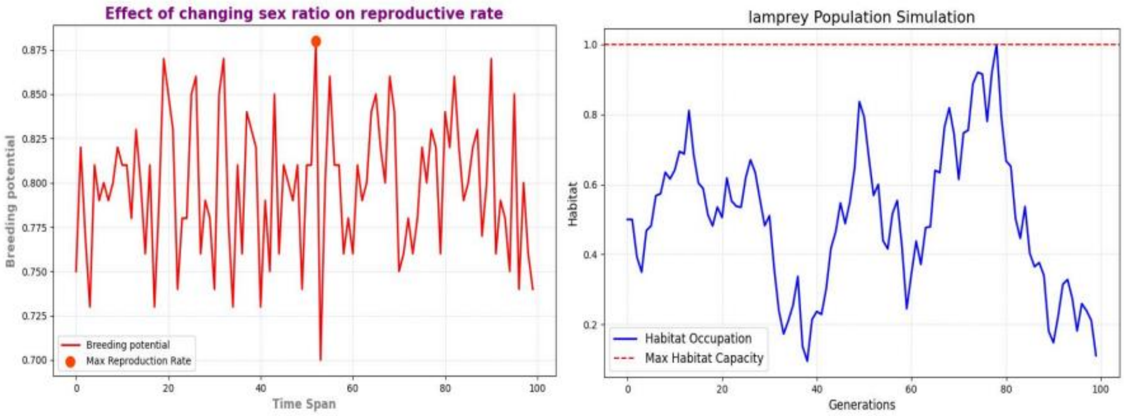

Figure 3. Effect of sex ratio change on reproductive rate

Changes in the sex ratio of lampreys population led to changes in the reproductive rate of the population, which ultimately affected the changes in the number of predators feeding on lampreys in this ecosystem. For the simulation of predators feeding on lampreys, since the sex ratio of lampreys depends on the growth rate of juveniles, two conditions were assigned to simulate the changes of predators and sex ratios.

It is concluded that when the sex of lampreys population can be changed, the reproductive rate within the population will first be affected and the dynamic change of its population will be affected[9]. Due to the food chain relationship in the ecosystem, the diversity of the ecosystem will be changed. Moreover, due to the restriction of environmental tolerance and availability, the habitat area of various organisms in the ecosystem will be changed and the sex ratio will be changed Changes will lead to changes in the number of lampreys population, which in turn will affect the number of predators, resulting in changes in the food chain structure of the ecosystem, and considering the competitive relationship among them, adult lampreys will parasite on soft-bodied organisms, causing the death of soft-bodied organisms, affecting the richness and stability of the ecosystem.

3.2. Solutions of other models

Through the dynamic change model of lampreys population, the sex change was simulated, and the reproductive rate of lampreys population, the degree of threats received in the reproductive process, the change of food resources, the dynamic change of predators, human intervention, fishing and other changes were compared, as shown in Figure 4 and Figure 5 below.

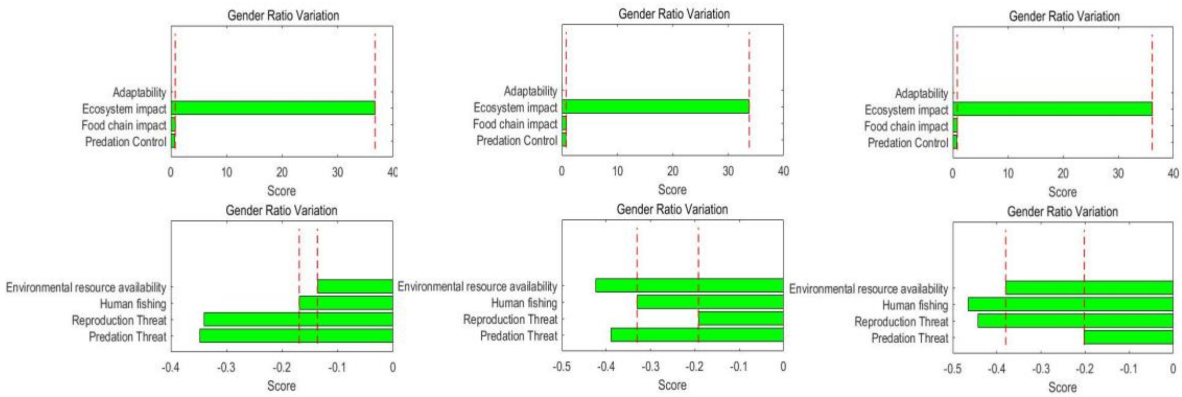

Figure 4. Effects of different sex ratios on lampreys populations

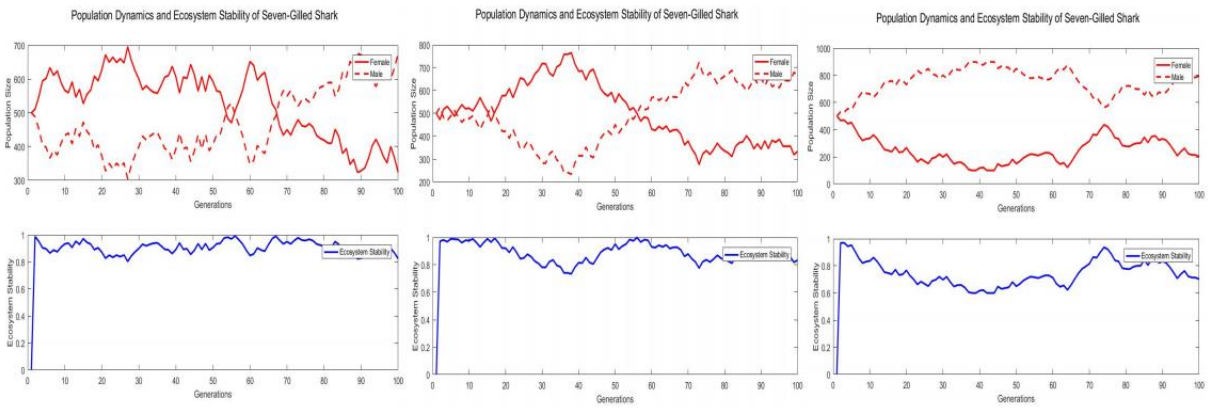

Figure 5. Effects of changing sex ratio on ecosystem stability

Observing the trend of the curve in the simulated image, when the sex ratio in the population approaches 1:1, the stability of the ecosystem is the most stable, and with the change of the sex ratio, the stability of the ecosystem also changes

The greater the proportion of males in a lamprey population, the less stable the ecosystem in which it lives. Therefore, it is necessary to regulate the sex ratio of lampreys population to reduce the influence of ecosystem stability.

Lampreys can be adsorbed on mollusks, which is also equivalent to a parasitic relationship, and there is the possibility that the object of parasitism is the same organism, so there is a competitive relationship between lampreys and parasites[10]. In addition, the unique body structure of lampreys means that organisms adsorbed by lampreys will increase the probability of being parasitized by parasites. Therefore, there is a mutually beneficial symbiotic relationship between lampreys and parasites.

The effect of changing the sex ratio of lampreys population on parasite transmission is simulated, as shown in Figure 6 below.

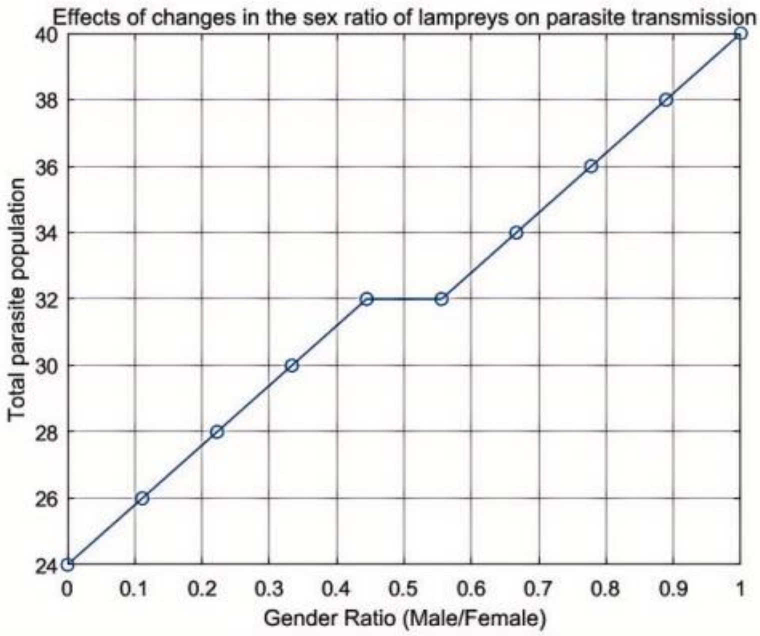

Figure 6. Effects of sex ratio on parasite transmission in lamprey populations

As can be seen from the curve trend of the image, the number of parasites will gradually increase with the increase of the proportion of males in Lampreys population. Since lampreys enter the breeding period, the adults will die after laying eggs, and the parasites will live on the residues for a period of time, the changes of the parasite population tend to be stable at this stage, and when the fertilized eggs mature and hatch into larva, the parasites will start a new round of parasitizing. Based on dynamic scale models of lampreys populations, a change in the sex ratio may result in an increase in the number of hosts required by the parasite, or provide more resources for survival, which the parasite may benefit from. In this case, the changing sex ratio gives the parasite an advantage for survival and reproduction.

However, in the case of excessive parasite populations, the limited availability of environmental resources leads to increased competition in the ecosystem, affects the food chain of the ecosystem, and affects the population size and reproduction of lampreys and other aquatic animals, and the change in the sex ratio of lampreys does not provide favorable conditions for its own population and other organisms. In conclusion, the change of sex ratio of lampreys population may have an impact on parasites as well as other aquatic organisms, and reasonable artificial intervention of lampreys population can improve the stability and economic benefits of the ecosystem.

4. Analysis

The Logistic model can be used to better predict the sex ratio of lampreys population, and the change of sex ratio of lampreys population can be simulated by adjusting parameters, so as to predict the impact on the ecosystem. The established predator model can take into account the interactions between predators and prey, so as to better simulate the dynamics of lampreys populations. The established model comprehensively considered the effect of sex ratio on the birth rate and death rate of lampreys population, which improved the accuracy of prediction. The model is fully combined with the reality, making the model simple and easy to understand. Considering many important factors, a reasonable model can be obtained, such as food supply, temperature influence, parasite control, etc., so that the obtained model fits the reality and has high application value.

The model has some limitations. It is weak in dealing with nonlinear problems and sensitive to outliers in the ecosystem. When the model was built, the mating situation of lampreys was not taken into account. During the breeding season of lampreys, male lampreys would seek multiple females for mating, forming a polygamous breeding pattern, which would change the reproductive rate of lampreys population and may affect the accuracy of the model. For the occurrence of ecosystem outliers, data can first be cleaned, and possible outliers can be found out by checking the data, and then processed accordingly. Robust Statistics algorithm is adopted, which is a statistical theory and method that can minimize the influence of outliers and improve the accuracy of prediction to a greater extent. According to the simulation data in the model solution, the most beneficial governance scheme for the local environment is found.

5. Conclusion

This paper studies the sex ratio and resource availability of lamprey population, through the predator model and Logistic model of lamprey population dynamic simulation, using the mechanism of lamprey population, through the dynamic simulation change lamprey population sex ratio on the stability of the ecosystem.Based on the conclusions, strategies to maintain the stability and diversity of the ecosystem are formulated, and reasonable solutions are proposed to prevent and control the proliferation of this species. The model established in this paper can be extended to the field of ecology. Understanding the quantity and change trend of the studied population is conducive to the formulation of appropriate conservation and management strategies, and can also be applied to fishery management, pest prevention and control, disease prediction and control, and ecosystem restoration.

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