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Effects of sex ratio changes in Lampreys on ecosystem based on modeling techniques

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Abstract. In this paper, a number of mathematical models were established to study the effects of sex ratio changes in lampreys on this ecosystem. Logistic and Verhulst models were established to describe the population dynamics of Lampreys. Then a food web model and a niche model were construct-ed to describe the food relationships and interactions between different species. The effects of sex ratio of lampreys on ecosystem stability and species interaction were analyzed. Finally, TOPSIS evaluation model was used to evaluate the contribution of sex ratio changes in lampreys to other species. The results show that the change of sex ratio of lampreys will affect their growth rate, and then affect the balance of the whole ecosystem. The model established in this paper provides an important reference for revealing the ecological adaptation significance of the sex ratio change in lampreys.

Keywords: Lampreys; Logistic model; Food web model; Niche model; TOPSIS evaluation.

1. Introduction

Some species will deviate from the sex ratio of 1: 1 at birth, and the sex ratio of lamprey will also change adaptively [1, 2]. Studies show that the growth rate of its larval stage is the key factor to determine sex, and food supply will affect the growth rate. In the case of insufficient food, the proportion of men accounts for about 78% of the population; When it is sufficient, it accounts for 56%.

Based on this background, we study the relationship between sex ratio and local environment, especially lamprey. We need to evaluate how species adjust sex ratio to adapt to resources, build a model to deeply understand the interaction in the ecosystem, and provide valuable suggestions for revealing gender dynamics and its ecological adaptation significance.

This article addresses the following issues:

(1) Mathematical models were developed to describe the effects of lampreys on the ecosystem, including Logistic model, Verhulst model, food web model and niche model, which were used to describe the population dynamics of lampreys and the food relationships and interactions between different species.

(2) To evaluate the effects of adaptation strategies of lampreys on population dominance through sex ratio changes, TOPSIS evaluation model was used to analyze the contribution of sex ratio changes of Lampreys to other species.

(3) The interaction of sex ratio changes in lampreys with different species was analyzed, and the effects of parasite control, food chain adjustment and ecosystem service provision were considered.

(4) To evaluate the sensitivity of lamprey's populations to changes in food resource supply, and to evaluate the robustness and reliability of the model by changing key parameters for sensitivity analysis.

2. Assessment of the effect of sex ratio changes on population dominance in lampreys

2.1. Population dynamics model

2.1.1. Establishment of Logistic model.

Logistic model is a common model to describe population dynamics [3]. This model is because the population growth rate is affected by the environmental capacity, and it is suitable for describing the population growth under the condition of limited resources.

The equation of Logistic model is:

$$\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right) \tag{1}$$

Among them:

•T is time.

•α is the inherent growth rate of population.

•K is the environmental carrying capacity (the maximum number that a population can support in the environment)

The analytical solution of the model is:

$$N(t)=\frac{K}{1+\left(\frac{K-N_0}{N_0}\right)}e^{-rt} \tag{2}$$

Where: N_0 is the initial population number (the number when t=0)

2.1.2. Verhulst model with limited resources

Verhulst model is a special case of Logistic model, which is suitable for considering the limited resources [4]. Wan Cheng of Verhulst model is:

$$\frac{dN}{dt}=rN\left(1-\frac{N}{K}\right)-\alpha N^2 \tag{3}$$

Among them:

•N is the population size.

•T is time

•R is the inherent growth rate of the population

•K is the environmental capacity.

•α is the saturation parameter of population growth.

2.2. Sex ratio model

Under the background of considering the change of sex ratio of lamprey, Logistic model can be used to describe how food supply affects the development speed of larvae, thus affecting the sex ratio. Logistic model is usually used to describe the growth of population or the change of a specific feature [5], and its equation form is as follows:

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

Among them:

•P (t) is the probability of developing into a female (sex ratio)

•R is the growth rate.

•t_0 is the time when the sex ratio begins to change.

This model is based on logistic function, which has S-shaped curve, and is often used to describe the development or change of a feature in biological population. Here, we can interpret P(t) as the probability that the larvae will develop into females. Parameter r indicates the rate of development and t_0 is the time when the sex ratio begins to change.

The sex determination model suitable for lamprey may need to consider more complexity, such as the influence of environmental temperature on the development rate. Therefore, the model can be further extended to consider environmental factors, in which the environmental temperature t can be used as the adjustment parameter:

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

Among them:

R (t) indicates the influence of temperature t on the growth rate.

2.3. Ecosystem model

2.3.1. Food web model:

The food web model describes the food relationship and interaction between different species [6]. In this model, we can consider lamprey as a part of the main food chain.

Population dynamics:

Lamprey population: Use population dynamic equation (such as Logistic or Verhulst model) to describe the change of lamprey population.

Other species: including food sources and predators of lamprey.

Food chain relationship:

Describe the predation and predation behavior of lamprey and their contribution to the food chain.

The effect of simulating the reproductive behavior of lamprey on the next level in the food chain.

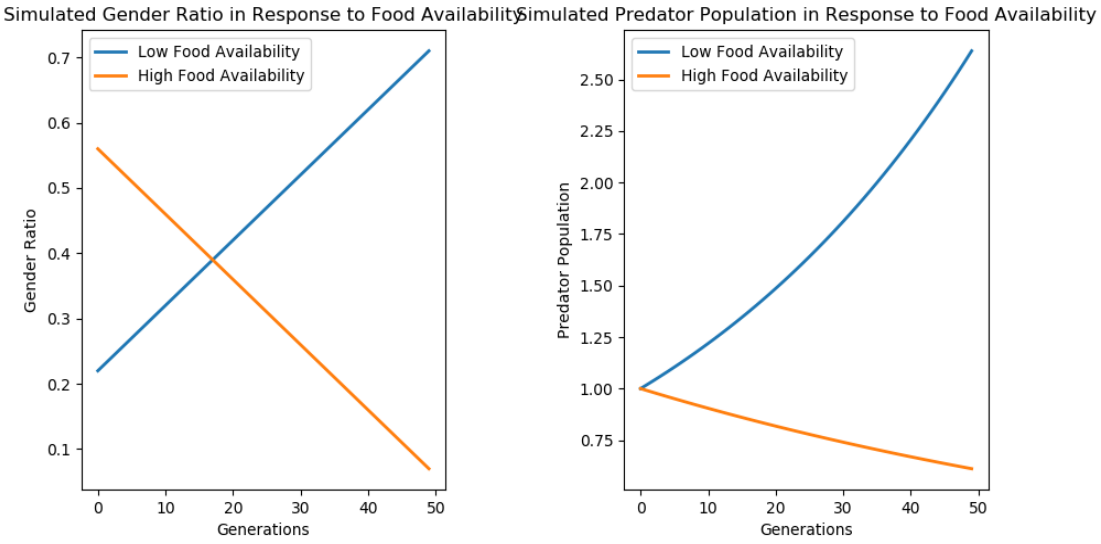

Figure 1. Changes of sex ratio under different levels of food supply

Based on the assumption that the initial male ratio is 22% and the initial male ratio is 56%, the change of male ratio is simulated. According to the high and low food availability, with the increase of algebra, the predator population decreases when the food availability is high, and vice versa (Figure 1).

2.3.2. Niche model:

Niche model describes the role of different species in the ecosystem and the way of resource utilization. In this model, we can consider the niche of lamprey and its changes.

Population dynamics:

The population dynamic equation is used to describe the change of lamprey population, including the change of sex ratio.

Resource utilization:

Describe how lamprey uses different resources, especially the food chain and resources related to the change of its sex ratio, and simulate the competitive relationship between resource utilization and other species in the ecosystem.

The following are the results of simulated gender ratio in the case of limited resources (Figures 2 and 3).

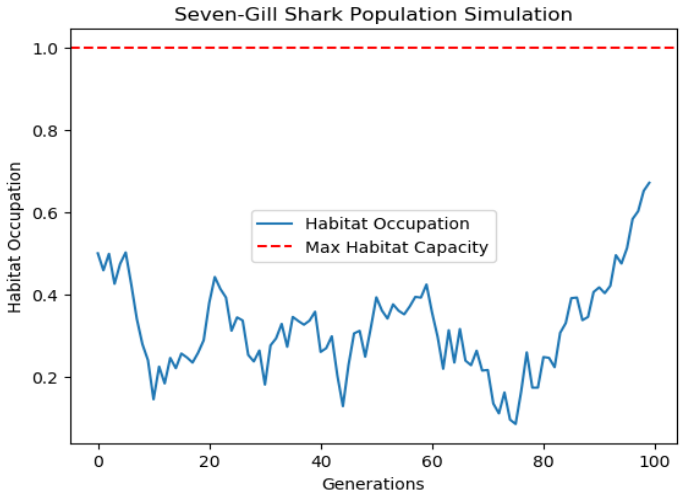

Figure 2. Habitat occupation changes with time.

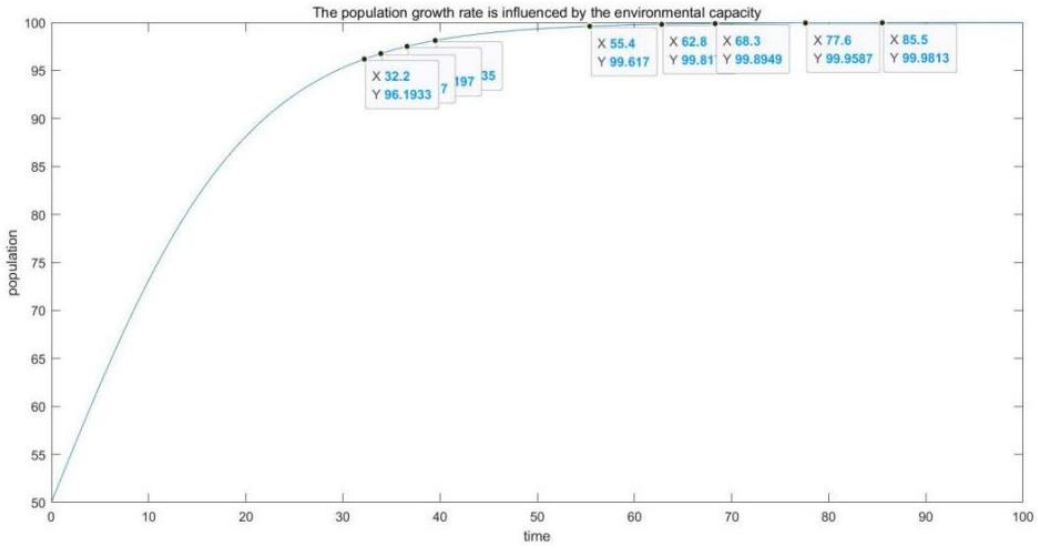

Figure 3. Population growth rate is affected by environmental capacity.

Reproductive behavior:

Consider the influence of sex ratio change on the reproductive behavior of lamprey and how this affects the reproduction and niche of other species. The following figure 4 is a simulation diagram of the results of the next generation gender ratio and resource area occupation ratio updated according to the current gender ratio and resource area occupation ratio in the ecosystem.

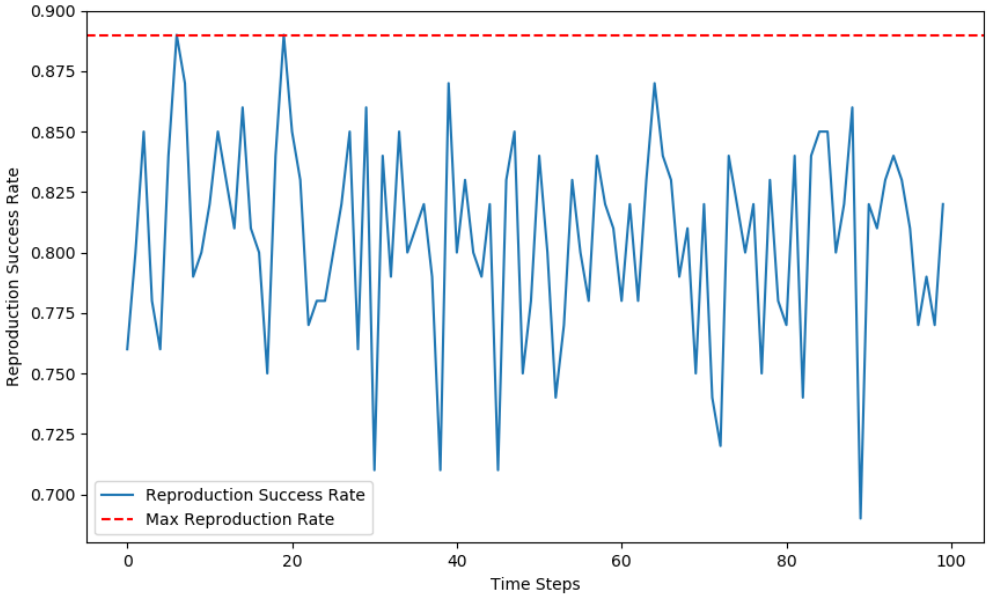

Figure 4. Variation of reproductive success rate with time.

3. Modeling analysis of sex ratio change and species interaction in Lampreys

3.1. Comprehensive evaluation principle

Stability: A dominant population should be able to maintain a relatively stable comprehensive index under different environmental conditions and not easily affected by external pressure.

Adaptability: the dominant population should be able to adapt to different environmental conditions and maintain a relatively high reproductive success rate and an appropriate gender ratio.

Ecological role: As a part of the ecosystem, lamprey population should be able to have a positive impact on the whole ecological chain, such as maintaining ecological balance by controlling the number of predators (Figure 5).

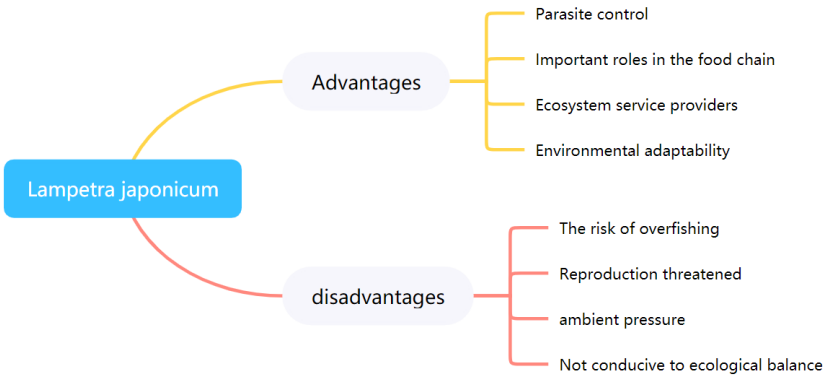

Figure 5. Comparison of advantages and disadvantages of lamprey population

3.2. Advantages and disadvantages

When the ratio of men to women is equal, the results of the ratio of advantages and disadvantages are shown in Figure 6.

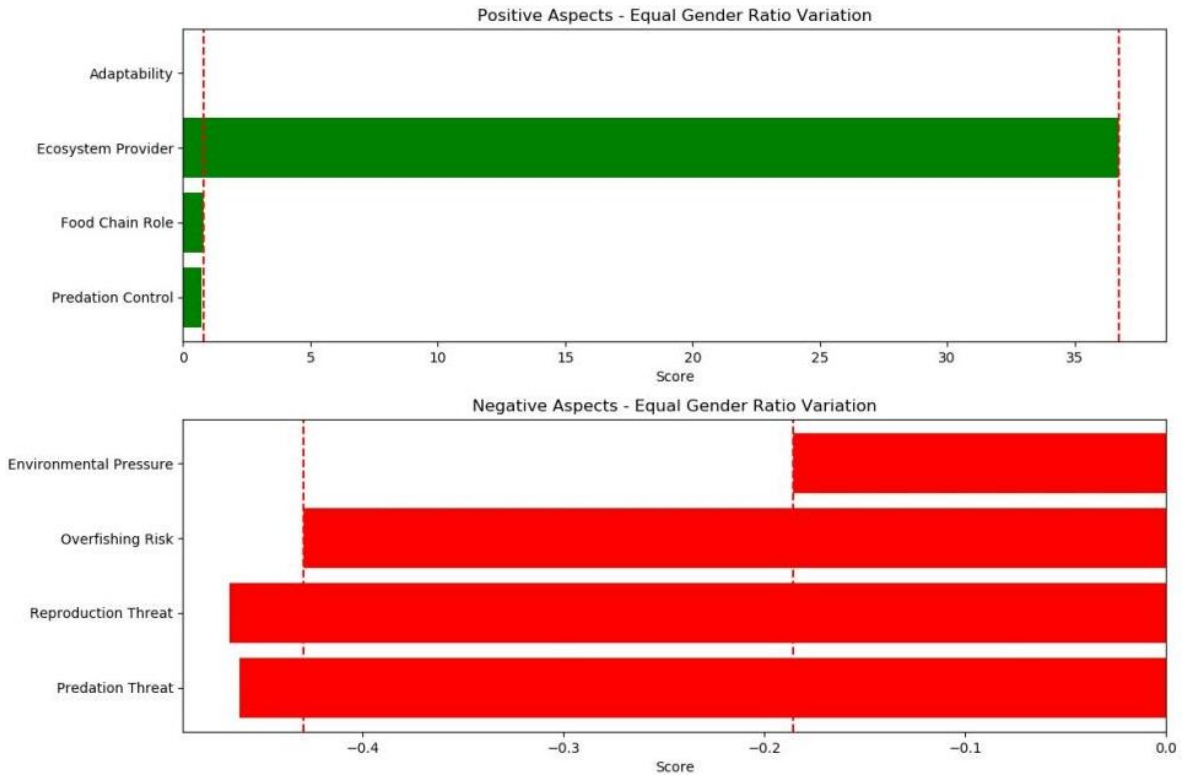

Figure 6. When the ratio of male to female is equal, the ratio of advantages and disadvantages.

4. Sensitivity assessment of lamprey populations to food resource availability

4.1. Control of parasites

Parasite control: If lamprey has a great influence on parasites during predation, the change of sex ratio may lead to the fluctuation of parasite number, which will affect the health of other aquatic organisms (Figure 7).

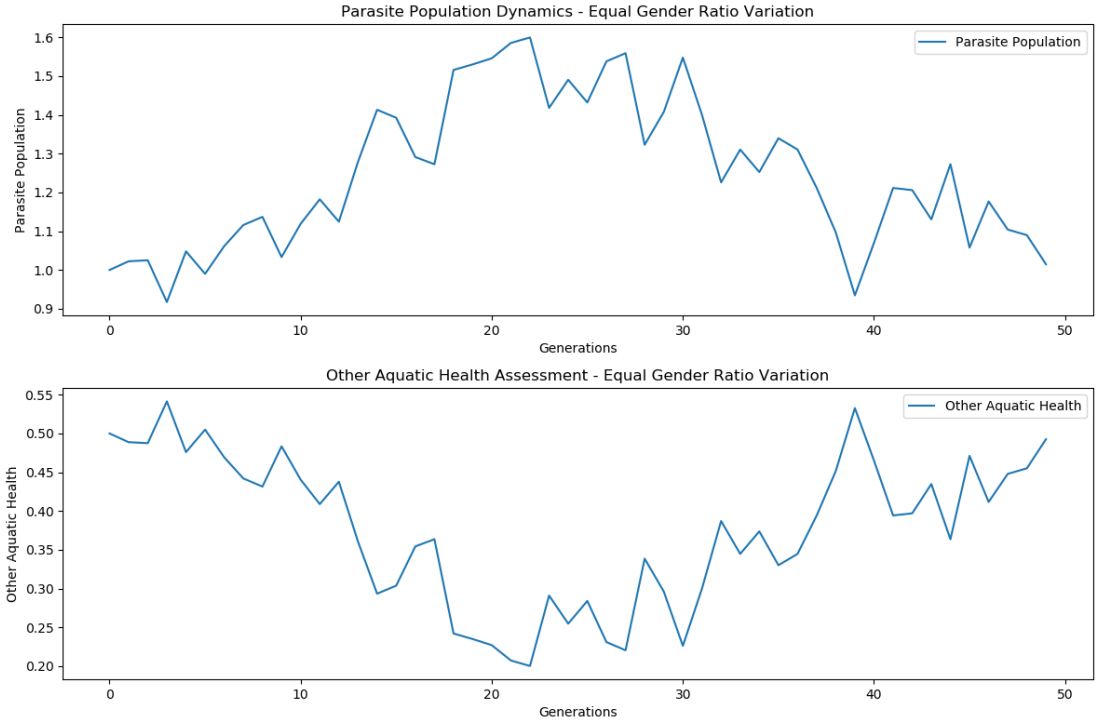

Figure 7. The population dynamics of parasites and the changes of health assessment of other aquatic organisms with time under the condition of equal proportion change.

4.2. Adjustment of food chain

Adjustment in the food chain: lamprey may occupy an important position in the food chain, and the change of sex ratio may cause the adjustment of the whole food chain, including the number and behavior of other predators and prey [7-10] (Figure 8).

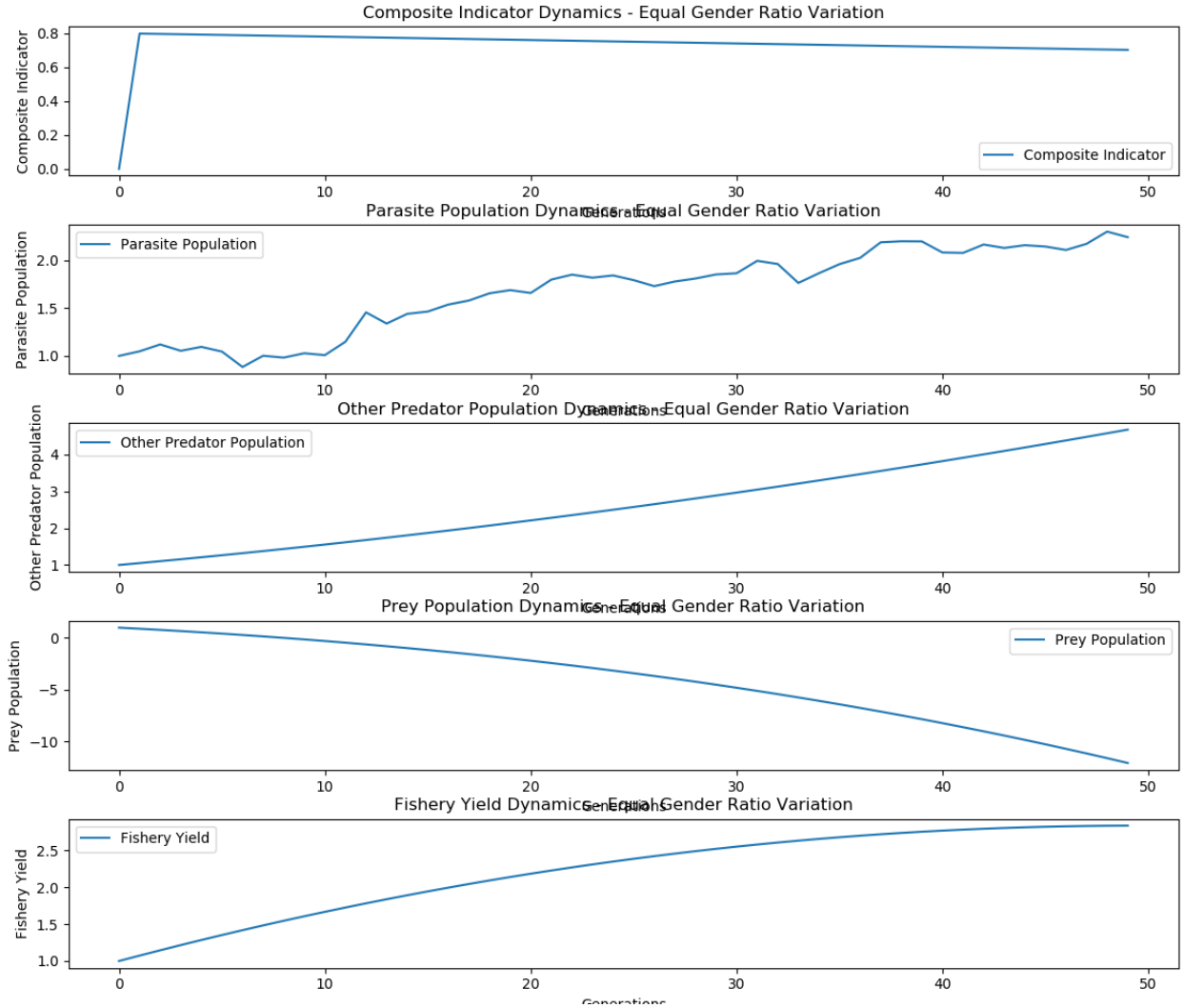

Figure 8. Changes of sex ratio of each population

4.3. Ecosystem service provider

Ecosystem service providers: If lamprey is the food source of local human community, the change of sex ratio may affect local economy and food security (Figure 9).

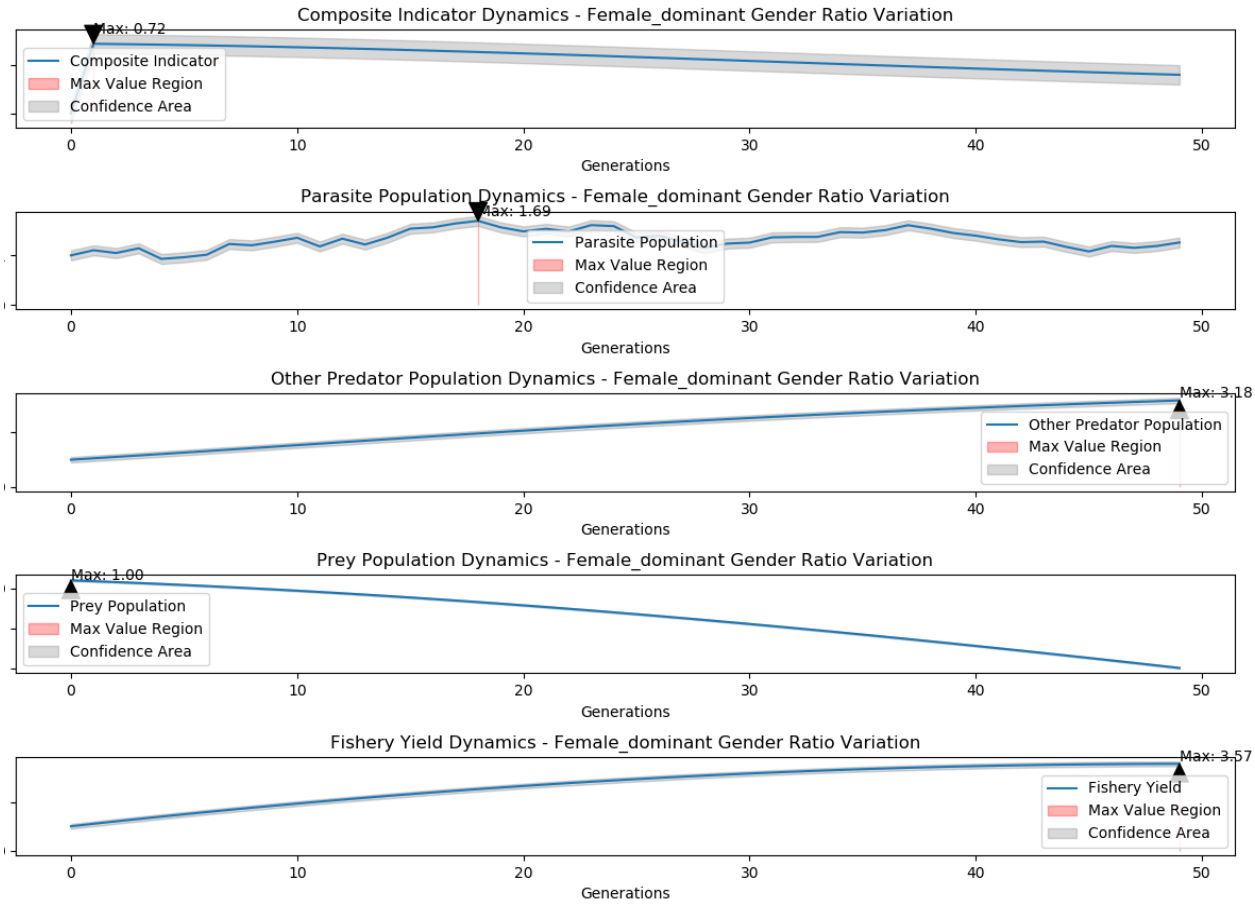

Figure 9. Changes of sex ratio of female-dominated populations

According to the results of the model, the key factors affecting the stability of the ecosystem are put forward.

Formulate management strategies to maintain or enhance the stability of the ecosystem (Figure 10).

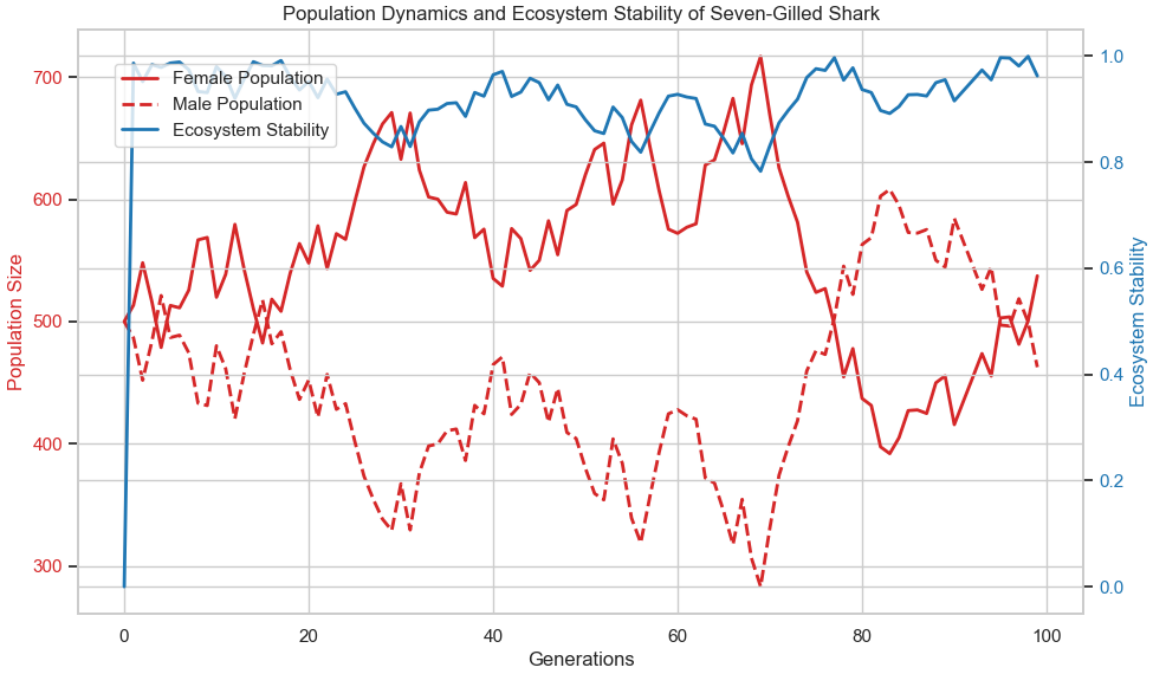

Figure 10. Population dynamics (male and female) and ecosystem stability

5. Conclusion

In this paper, a mathematical model was established to study the effects of sex ratio changes on lamprey's ecosystem. The results show that the change of sex ratio can affect the growth rate of lampreys, which in turn affects the balance of the whole ecosystem. The model established in this paper provides an important reference for revealing the ecological adaptation significance of the sex ratio change in lampreys. Future studies could further consider the influence of other environmental factors to bring the model closer to reality. The study of this paper also has certain reference value for the protection and management of lampreys.

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