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Study on Sex Ratio and Resource Utilization Based on Logistic Dynamic Population Model

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Abstract: *Based on the Logistic dynamic population model, this paper studies the effect of sex ratio change on ecosystem. Taking sea lampreys as the research object, the population dynamic model, sex ratio model and food chain model were constructed. The results showed that the change of sex ratio would affect the population fluctuation, food chain structure, niche utilization and ecosystem stability of sea lampreys. The advantages and disadvantages of sex ratio change on Lampreys population were analyzed by AHP. The results show that sea lampreys have good environmental adaptability, can control parasites and adapt to predator threats, but there is adaptability to fishery behavior and sensitivity to environmental resource changes. This study provides an important reference for understanding the complex effects of biological sex ratio changes on ecosystems.*

Keywords: *Logistic dynamic population model, sex ratio, food chain model, ecosystem stability*

1. Introduction

Adaptive changes in sex ratio is a characteristic of many animal species, and the result of adaptive changes in sex ratio in real life by multiple factors. Natural selection, genetic factors, environmental factors, species dynamics and other factors may have an impact on the sex ratio. Understanding these influencing factors may help us better understand biodiversity and ecosystem stability, as well as address gender issues in human societies[1]. Although the sex ratios of most species are usually close to 1:1, some species' sex ratios change due to some other factors, e. g., American crocodile sex ratios are affected by nest temperature during hatching. This phenomenon is also common in sea lamp fish, with environmental conditions.

Lampreys play multiple roles in different environments. For certain lake ecosystems, especially in Scandinavia, the Baltic Sea and the Pacific Northwest of North America, lampreys are not only an important species with a significant impact on ecological balance, but also part of the traditional diet of local residents.

In the case of lamprey, the growth rate of the larval stage is a key factor in determining its final sex. It is pointed out that the abundance of food supply directly affects the growth rate of larvae. In food-poor environments, slow-growing larvae are more likely to eventually become males, with male proportions rising up to 78%[2,3]. Instead, in food-rich environments, male drops to about 56%.

Our study focuses on this variation in lamprey sex ratio and its dependence on equine local environmental conditions. Understanding how these marine and lake organisms adapt in their habitats and how they influence sex ratios during retroactive spawning will be of great value for revealing sex dynamics and their ecological adaptive significance.

This article mainly addresses the following issues:

(1) Effects of sex ratio change on ecosystem: By constructing a dynamic population model, we studied the effects of sex ratio change on the ecosystem of sea lampreys, including population fluctuation, food chain structure, niche use and ecosystem stability.

(2) Advantages and disadvantages of changing sex ratio: Using analytic hierarchy process, the advantages and disadvantages of sea lampreys population under changing sex ratio were analyzed.

(3) The impact of sex ratio changes on ecosystem stability: Study whether sex ratio fluctuations lead to ecosystem instability or may form a new ecological balance.

(4) Effects of changing sex ratios on other species: To explore whether changing sex ratios in sea lampreys may have positive effects on other species in the ecosystem.

This paper establishes a model to analyze the impact of sex ratio change on ecosystem and species, which provides a theoretical basis for biodiversity conservation and ecological balance maintenance.

2. Dynamic population model

2.1 Solution idea

When the lamprey population sex ratio change, will have a series of effects on the ecosystem, such as sex ratio change may make the population fluctuations, indirectly change the structure of the food chain and food web, affect the way of survival and reproductive ability, and the change of sex ratio will affect the birth rate, mortality and other indicators, and affect the stability of the whole ecosystem[4]. If the sex ratio change in the lamprey population changes, then the reproductive rate and population growth rate will change accordingly, and a higher male ratio may indicate a slower population growth, as males generally do not or reproduce little. Instead, higher females may accelerate population growth because females can reproduce more offspring, allowing population dynamics and interactions with other organisms to understand the effects of sex ratio variation on the food chain, habitat use, fertility success, ecological balance, and ecosystem stability. Based on the Logistic model, the population dynamic model, sex ratio model, food chain model, to observe the proportion of male lamprey. Under conditions considering changes in sex ratio in lamprey, the Logistic model was used to describe how food availability affects the rate of development in the larval stage and thus the sex ratio in lamprey[5].

2.2 Dynamic population model based on the Logistic mode

Logistic Model, also known as block growth model, is practical for classification problems, or to estimate the possibility of an event, and can also analyze the influencing factors of a problem, mainly used to describe the growth law of the number of species in the case of limited environmental resources. Based on this model, we build a population dynamic model, and the analytical expressions are as follows:

$$\frac{dN}{dt} = \alpha \cdot N \cdot \left(1 - \frac{N}{K}\right) \quad (1)$$

The relationship of the population growth rate with sex ratio is described.

Considering the effect of food resources on sex ratio. Describe food supply as affecting sex ratio by influencing the rate of development at larval stages. The formula is as follows:

$$P(t) = \frac{1}{1 + e^{-\alpha(t - t_0)}} \quad (2)$$

Food chain models were constructed to describe the effect of sex ratio changes in lamprey populations on their lower or epistatic species. The extent of the effect of the predator or the predator on the prey model was used to explore the effect of sex ratio on the food chain. After consulting the relevant information, we analyzed the fertility mode of the lamprey population, and its larvae would occupy other areas to grow. Therefore, we considered that the sex ratio change will affect the reproductive behavior of the population and then affect the reproductive success rate, and constructed a model of sex ratio and reproductive success rate. In place of the effect of larvae on the reproductive area. The effect of sex ratios on habitat use was examined. Combine the above models to build a dynamic population model to analyze the impact of sex ratio change on larger ecosystems.

2.3 Results

When the ideal curve when considering only a single species is as follows, it can be seen that the population growth increases with an S-shaped curve(Figure 1). In the initial stage, the population number is small and the growth rate is relatively slow, gradually accelerating with the increase of the population

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number. The growth rate is maximized when populations reach half the maximum carrying capacity of the environment. After exceeding the maximum capacity of the environment, the growth rate gradually slows down, and eventually the population number reaches the maximum capacity of the environment, when the population growth stops.

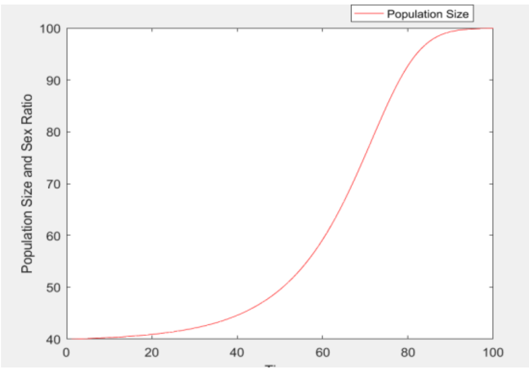

Figure 1: Logistic model

The logistic model is used to simulate the sex ratio change of lamprey, assuming that the initial male ratio is 78% and 56%. In the case of insufficient initial food supply, the population is small, the population growth rate is relatively slow, the food begins to rise naturally, and the male ratio gradually decreases; under the initial sufficient food supply, the population is large, the population expansion rate is fast, the food begins to gradually consume, and the male ratio is gradually increased (Figure 2).

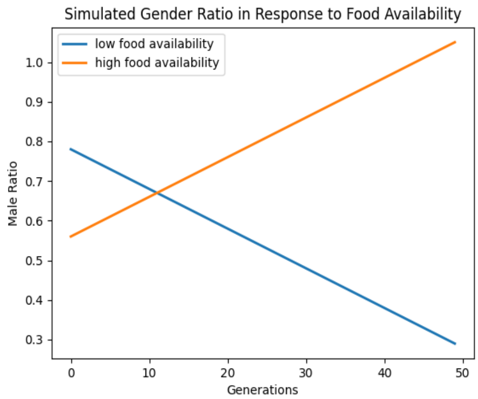

Figure 2: Changes in sex ratio and physical supply over time for sea lamprey

Considering the effect of the sex ratio on food resources, the effect of the male ratio on food supply was obtained by changing the sex ratio from all-female to all-male. According to the images, the initial sex ratio is assumed to be 0.9, and the initial number of food resources is taken as 1000 units. As the proportion of male lampreys increased, the food resources began to decrease (Figure 3).

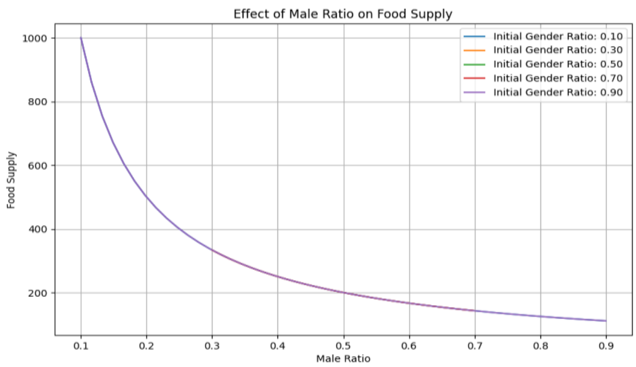

Figure 3: Effect of change in sex ratio on food resources

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Consider the effect of sex ratio on the food chain: we modeled the effect of sex ratio changes on the number of predators to reflect their effect on the food chain. Figure 4 in the left shows the lamprey sex ratio, the same as figure 2, the right shows the number of predators change with the sex ratio image, through the model, in the early condition of sufficient food, food supply with time gradually decrease, the number of lamprey population gradually decreased, predators cannot get enough food, the number will also with its decrease. Conversely, when food is available, the number of sea lamprey will gradually increase, resulting in the number of predators.

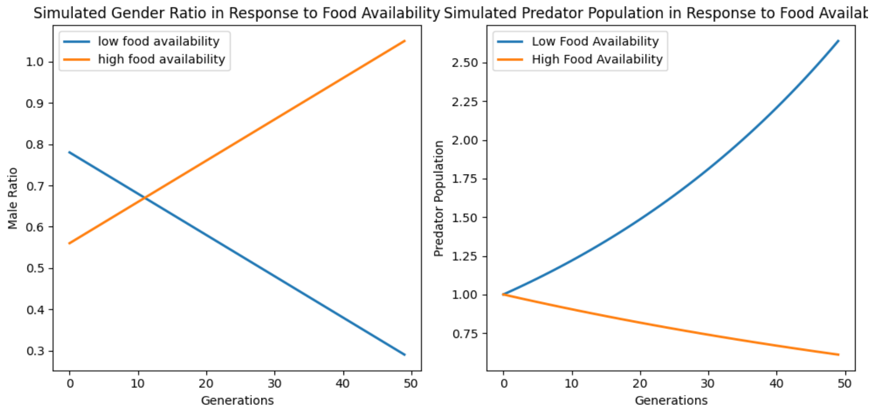

Figure 4: Effect of sex ratio changes on predators

Considering the effect of sex ratio change on reproductive success: the dashed red line represents the maximum reproductive success of the population, reaching the maximum reproductive success of the population only once within the specified time interval. In general, the effect of the sex ratio change on the reproductive success rate is constantly changing and shows a fluctuating trend (Figure 5).

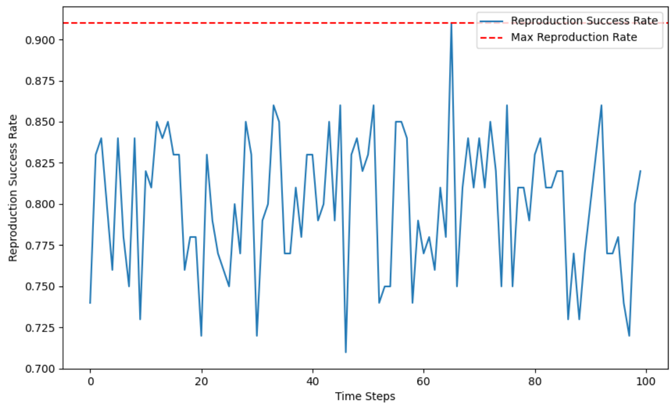

Figure 5: Effect of sex ratio change on reproductive rate

Considering the influence of sex ratio change on habitat utilization: we think reflected in two types of occupancy, mating behavior for the area of the habitat and larval growth for breeding area and resource occupancy, therefore, we establish the initial female ratio of 0.5, simulated breeding 100 generations of sex ratio change and habitat area occupancy model, as shown in Figure 6, Figure 7. Where the red curve represents the maximum habitat capacity, as the number of iterations decreases in habitat utilization, showing a downward trend. According to Figure 7, as the number of iterations increases, there is a decreasing trend overall.

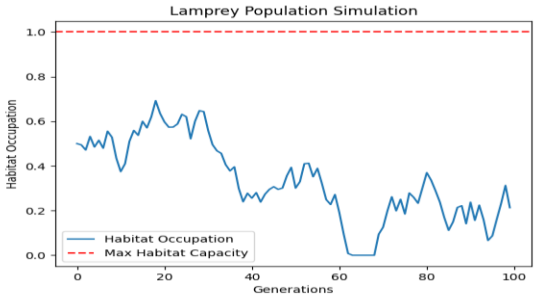

Figure 6: Effect of sex ratio changes (male and female mating) on habitat utilization

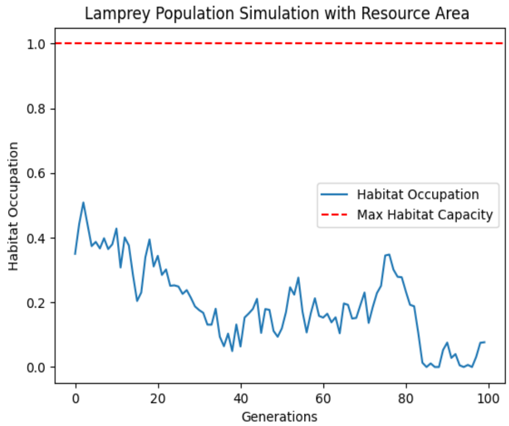

Figure 7: Effect of sex ratio changes (larval growth)

Comprehensive analysis of dynamic population model: Through the influence of sex ratio change on other factors, we established a dynamic population model, taking into account the effects on predator population, reproductive success, and food resources. The proportion of males increases and the reproductive rate of the population decreases, the reproductive success rate at a relatively high level, the reproductive rate will decrease over time. In the case of food adequacy, when the lamprey population increases, the food resources will decline, the male and female ratio imbalance, the lamprey population decreases, which will lead to the gradual increase of food resources. As shown in Figure 8. Top left: Lamprey sex ratio and physical supply over time. Top right: the effect of sex ratio change on the reproductive rate. Bottom left: the sex ratio of lamprey and physical supply over time. Lower right: the supply of food resources to food.

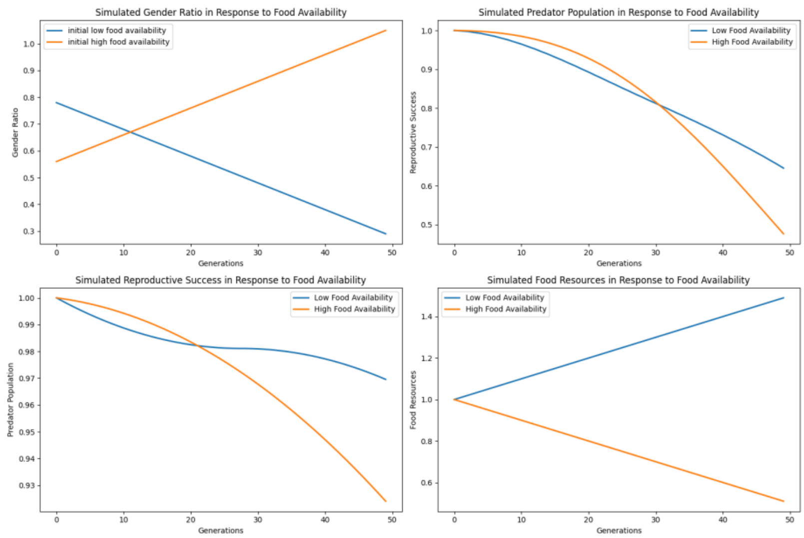

Figure 8: Comprehensive analysis of the effects of changes in sex ratio

Combining the above influence model of sex ratio change in lamprey, we constructed a rating model of comprehensive indicators, as shown in Figure 9. It is found that when the sex ratio is equal, the effect on the environment is slightly reduced with time, but not too large, and it is relatively stable. When the proportion of males is dominant, the degree of environmental impact is greater than that of the proportion of female is dominant, but the population is relatively stable with time, and the impact of both is obviously reduced.

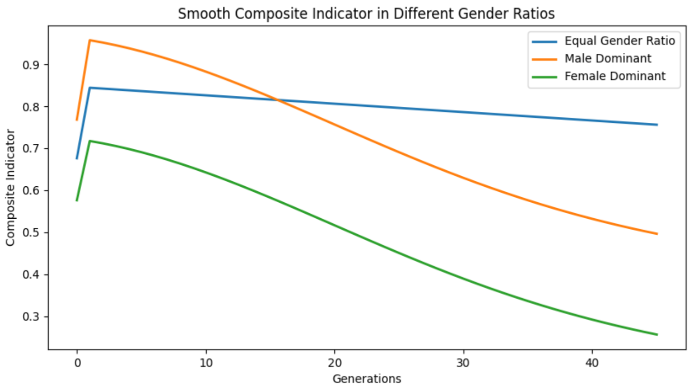

Figure 9: Comprehensive indicator assessment of the change in sex ratio

3. Dynamic ecosystem model

3.1 Dynamic ecosystem model based on dynamic population model and AHP model

Based on the dynamic population model, we used the hierarchical analysis to analyze the sex ratio, reproductive success, predator number, and the influence degree of food resources on the dynamic population model, and obtain the respective influence factors. Construct an ideal sea lamprey population [6].

Hierarchical analysis is suitable for subjective and uncertain situations, and logically uses experience, intuition and insight, which is very suitable for our goals.

We considered the effects of four factors: sex ratio, reproductive success, number of predators, and food resources [7]. By pairing the comparison of the various influencing factors, the following judgment matrix can be obtained according to the importance level.

$$\begin{pmatrix} 1 & \frac{1}{3} & 2 & 5 \\ 3 & 1 & 4 & 6 \\ \frac{1}{2} & \frac{1}{4} & 1 & 2 \\ \frac{1}{5} & \frac{1}{6} & \frac{1}{2} & 1 \end{pmatrix} \tag{3}$$

We need to check for the consistency of the judgment matrix. With the consistency ratio (Consistency Ratio, CR) for the evaluation. The CR can be calculated by Equation (4).

$$CR = \frac{CI}{RI} \tag{4}$$

Where CI is the consistency index and RI is the random index. The CI is calculated from Equation (4).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{5}$$

Where λ max is the maximum eigenvalue of the judgment matrix. The correspondence between n and RI can be obtained by looking up the table.

Calculated λ max = 4.07, CR = 0.027 <0.1. The consistency check was passed. The weight of each factor is shown in Figure 10.

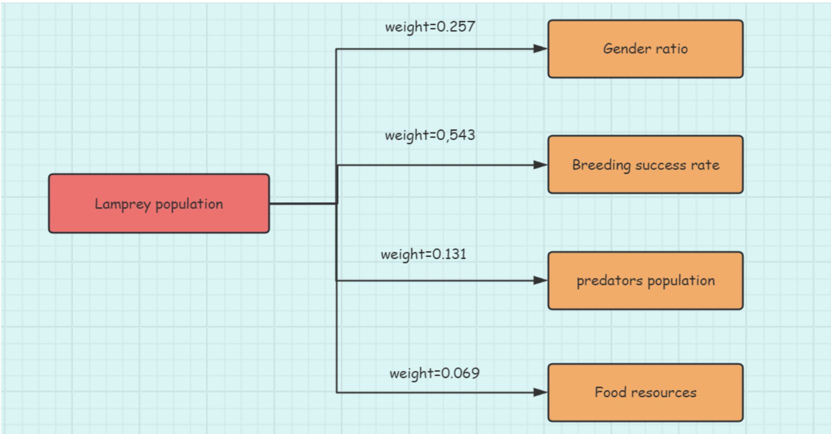

Figure 10: Impact factor weights for the sea lamprey populations

After consulting data, lamprey, as an invasive species of the Great Lakes, has a predator advantage over five Lakes trout, and humans have conducted a lot of fishing control in order to control its population. The Great Lakes provide an excellent living environment for sea lamprey and the influence of other environmental factors on its population. After analyzing all factors by hierarchical analysis method, the following evaluation indicators are obtained. Control of predators, an important role in the food chain, providers of the ecosystem, adaptability to the environment, environmental stress, overfishing, reproductive threats, and predation threats [8]. The species was weighted to evaluate the lamprey population to build a dynamic ecosystem model. To represent the effect of various factors in the ecosystem on the change in the sex ratio of the lamprey population. Then, the advantages and bad factors of lamprey population under the sex ratio change were analyzed.

3.2 Result

To eliminate the perturbation error caused by the random number in the model, we conducted 20 simulations to record the influence of environmental factors when the lamprey sex ratio was fixed and when the lamprey sex ratio changed. We also recorded different conditions for populations with high sex ratios and populations with low male proportions (Figures 11 and 12).

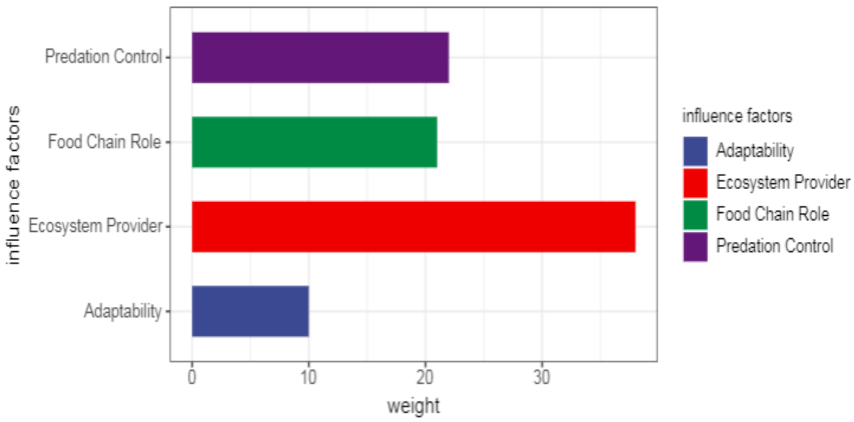

Figure 11: Predominance of the sea lamprey population

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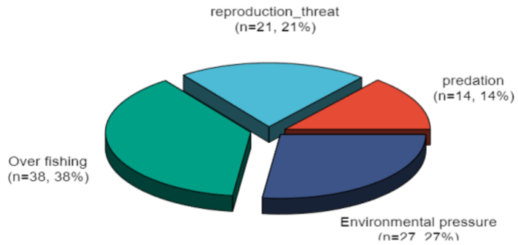

Figure 12: Disadvantage of lamprey populations at fixed proportions

Effect of environment on lamprey populations during sex changes (Figures 13 and 14):

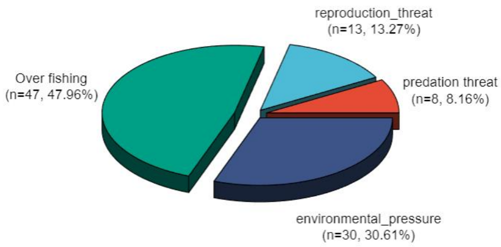

Figure 13: Disadvantage of lower males vs lower lamprey populations

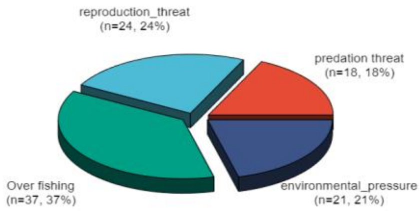

Figure 14: Disadvantage of high male versus lower lamprey populations

We found that the sex adaptability of lamprey population, makes its advantages are: it is the ecosystem supplier, has important contribution to the ecosystem, with parasite control effect, it is better for prey threat adaptability, lamprey population for breeding threatened adaptability, disadvantage are: human fishing adaptability is poor, probably because the species is belong to the ecological environment, ecological environment lack of its predator, breeding, local economic fish death, the local government through human fishing restrictions, lead to its huge impact. And we also found that the population is better adapted to environmental stress when males are large, but it is less adaptable to environmental stress when males are small. This may be because the influence of males on the environment is greater than that of females. With the high proportion of males, the ecological environment can be adjusted timely to improve the environmental resources of lamprey population. On the contrary, with the high proportion of females, the sea lamprey already lives in a suitable environment, and the regulation effect of the ecological environment is relatively slow.

4. Conclusions

In this paper, a dynamic population model was established to study the effects of sex ratio changes on the ecosystem of Lampreys. It is found that the change of sex ratio will affect the population fluctuation, food chain structure and niche utilization, and then affect the stability of the ecosystem. The

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analytic hierarchy process (AHP) analysis showed that sea lampreys had the advantages of strong environmental adaptability, parasite control and predator adaptation, but also had the disadvantages of being sensitive to fishery behavior adaptability and environmental resource changes. These studies provide important insights into the ecological adaptation of biological sex ratio changes, and provide theoretical basis for biodiversity conservation and ecological balance maintenance.

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