ingegneria sismica
International Journal of Earthquake Engineering
Anno XLIII - Num. 3 - 2026

A Study on the Effects of Adaptive Sex Ratio Shifts in Seven-gill Eels on Ecosystem Dynamic Stability and Interspecific Relationships

He Sun[1,*]

[1] School of Electronic Information and Control Engineering, Guangzhou University of Software, Guangzhou, China, 510990

SUMMARY: *As a unique species, the growth rate of seven-gill eels during their larval stage is influenced by environmental food availability, which in turn determines the dynamic adjustment of their sex ratio. This study focuses on the profound impact of this mechanism on complex ecosystems. The research first established a differential equation model reflecting the relationship between sex ratio and population size. Simulations revealed that when food scarcity causes the male proportion to rise significantly to 78%, the population's demand for resources changes accordingly. Subsequently, a population competition model was used to analyze the survival competitive advantages of seven-gill eels under different resource conditions. Furthermore, the Lotka-Volterra model was employed to quantitatively examine how population fluctuations caused by shifts in sex ratios affect the balance of predator-prey relationships within the food chain. The study further expanded its perspective to include mutualistic and parasitic relationships between species, simulating how changes in population size under the regulation of the seven-gill eel's sex ratio provide survival and nutritional advantages to other participants in the ecosystem. Finally, sensitivity analysis was used to verify the critical role of survival parameters in the competitive model for system evolution. This study demonstrates that by regulating sex ratios, the seven-gill eel not only optimizes its own survival and reproduction in resource-limited environments but also profoundly alters the steady state of the entire ecosystem through complex interspecific interactions.*

KEYWORDS: *Differential Equation Models; Lotka-Volterra Models; Ecological Equilibrium*

1 Introduction

While most species in nature exhibit balanced sex ratios, the seven-gill eel displays unique adaptive variations in sex ratio, with its sex orientation during the larval stage influenced by growth rates determined by environmental food availability. When food scarcity leads to slow growth, the proportion of males in the population increases significantly, whereas it shifts toward females when food is abundant. This unique biological trait has significant implications for lake and marine ecosystems, as the seven-gill eel plays dual roles as both a predator and a parasite within them. While previous studies have primarily focused on individual biological characteristics of the seven-gill eel, this research proposes and establishes a comprehensive mathematical framework aimed at addressing the scientific question of how sex ratio shifts, through fluctuations in population size, further impact large-scale ecosystems. The innovation of this study lies in introducing an environment-driven sex ratio factor into classical differential equation modeling, and systematically quantifying this biological feedback mechanism from

---

*sunhe18319897377@163.com

https://doi.org/10.65102/is20261281

multiple dimensions, including biological competition, predation within food chains, mutualistic symbiosis, and parasitism. The general research plan for this section is as follows: first, construct differential evolution equations for sex ratios and population dynamics; then, simulate competitive equilibrium points under different environmental conditions by adjusting model parameters; use the Lotka-Volterra model to analyze the stability boundaries of the ecosystem under population surges; and finally, explore the indirect benefits to other biological populations[1-3].

2 Differential Equation Modeling of Lamprey Sex Ratio and Population Size, and Ecosystem Impact Analysis

We know that the sex ratio of lampreys is influenced by the external environment, the growth rate of sea lampreys in the larval stage determines whether they are males or females, and their growth rate is influenced by food supply. The growth rate is slow and the proportion of males can reach 78% in the case of insufficient food supply, while the proportion of males is 56% in the environment of abundant food supply. Based on the above information, this paper will model the differential equations for the change of sex ratio and population size in the population and analyze the effect on the ecosystem[4-6].

Analysis of sex ratio and population size variation in lamprey populations:

When lampreys can change their sex ratio, they can affect the ecosystem in several ways:

Changes in the ecological balance of the ecosystem
Changes in food chain predation relationships
Changes in the population of lamprey
Changes in food chain competition
Impacts on ecosystem stability

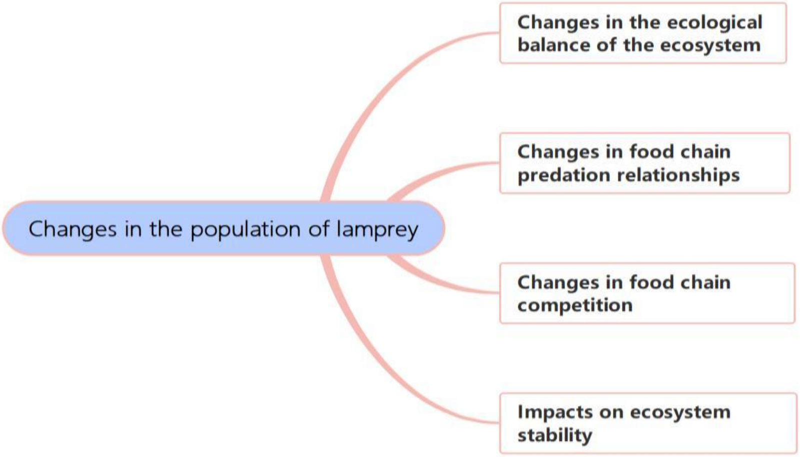


Figure 1: Impacts on the ecosystem when lamprey can change its sex ratio

Impacts on the ecosystem when lamprey can change its sex ratio is shown in Figure 1.

2.1 Differential equation modeling of changes in sex ratio and population size

The relationship between the sex ratio of lamprey and the change in population size can be obtained by setting up a differential equation[7].

2.1.1 Model Assumption

No human intervention

No maritime disaster impact

Good water quality, suitable for living organisms

No impact of marine disasters.

Lamprey can migrate up rivers for normal reproduction.

2.1.2 Model Building

Since the availability of food determines the sex ratio, the relationship between food and sex can be expressed as:

$$X(t) = f(Food(t)) = \begin{cases} 78\% \\ 56\% \end{cases} \tag{1}$$

where, $X(t)$ refers to the proportion of males, $Food(t)$ refers to the food availability function; when food availability is low, $X(t) = 78\%$, when food availability is high, $X(t) = 56\%$.

With the above relationships, we can build the model:

$$\frac{dN}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right) - D(N(t)) \tag{2}$$

So the sex ratio as a function of population size can be expressed as:

$$\frac{dM}{dt} = rM(t)(X(t)) \tag{3}$$

$$\frac{dF}{dt} = rF(t)(1 - X(t)) \tag{4}$$

where $X(t)$ is varied by the availability of food. Above we can get the change in sex ratio due to change in availability of food[8, 9].

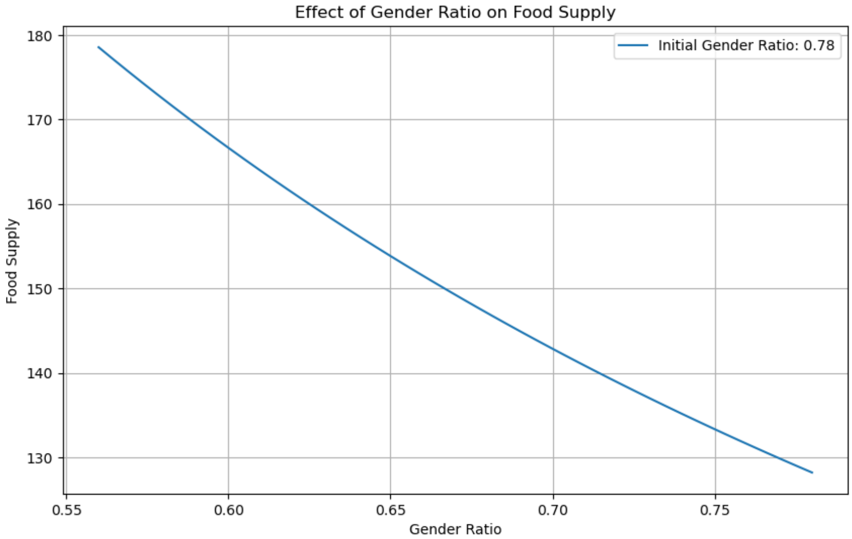


Figure 2: Changes in the sex ratio of lampreys due to changes in food availability

Changes in the sex ratio of lampreys due to changes in food availability is shown in Figure 2.

Assuming an initial food supply of 100, the lamprey sex ratio peaked at 0.78, implying that the proportion of males reached a maximum value, and as the proportion of males decreased, the lamprey population's demand for food supply and demand gradually increased, and when the sex ratio was 0.56, the food supply reached a maximum[10-12].

2.1.3 Model Solution

Lamprey growth slows down when food availability is low, at 78% males and 22% females. We can obtain a visual simulation of the final total population and the number of male females when we assume a natural growth rate of 1, an environmental carrying capacity of 200, a natural mortality rate of 0.1, and an initial population of 10, as follow:

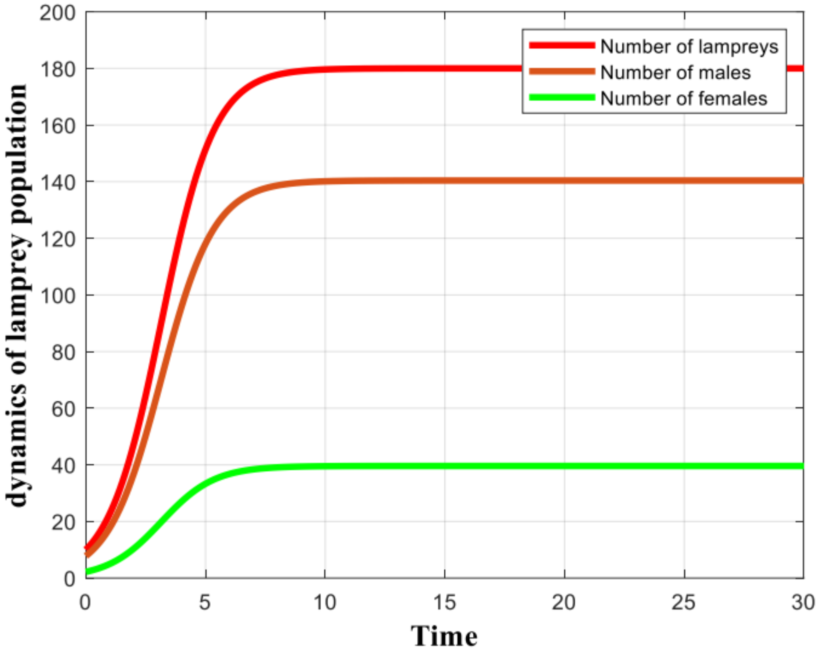


Figure 3: Changes in the total number of lampreys and changes in the number of males and females when food supply is low

Changes in the total number of lampreys and changes in the number of males and females when food supply is low is shown in Figure 3.

When food supply is sufficient and the proportion of males is 56% and the proportion of females is 44%, we assume a natural growth rate of 1, an environmental carrying capacity of 200, a natural mortality rate of 0.1, and an initial population of 10[13-15]. The final visualization simulation of the total number of lampreys, the number of male lampreys, and the number of female lampreys is shown below:

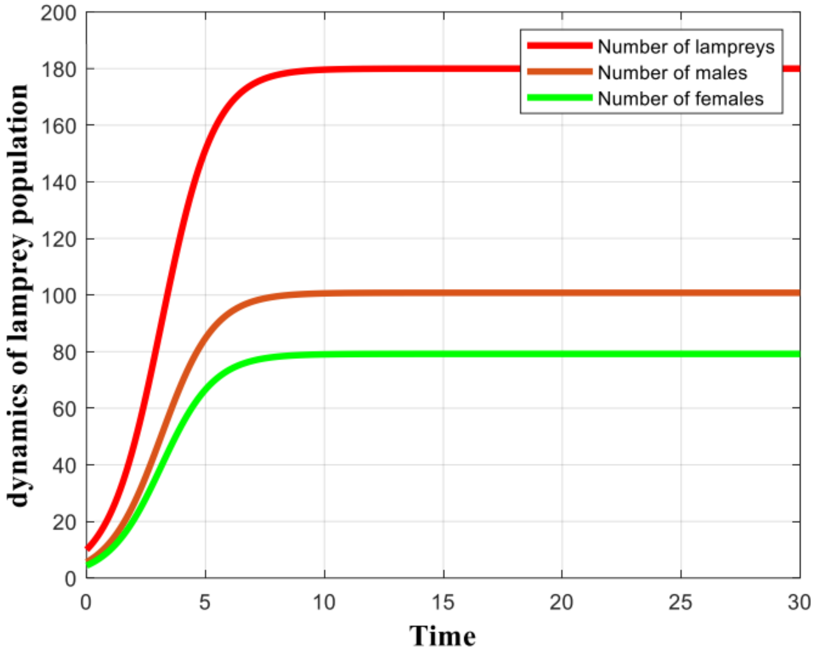


Figure 4: Changes in total number of lampreys with adequate food supply, changes in number of males, females

Changes in total number of lampreys with adequate food supply, changes in number of males, females is shown in Figure 4.

When a population of lampreys changes its sex ratio, it causes a change in the size of the lamprey population[16-18].

2.2 Impact on Ecosystems

2.2.1 Biocompetitive Relationships

When food is plentiful and there are no natural predators in that marine river area, the proportion of female lampreys rises, which in turn results in higher natural growth rates of lampreys and higher mortality rates or lower competitiveness of other species of organisms, resulting in a much reduced survival until extinction of weak competitiveness[19, 20]. We model population competition as follows:

Model assumption:

We assume comparable population densities.

We assume that the individuals of the population are all healthy.

We assume no exposure to natural disasters.

We hypothesized that both populations of lamprey and other populations obeyed a logistic law in terms of population changes when they survived alone.

Model building:

$$\frac{dx}{dt} = r_1 x\left(1 - \frac{x}{N_1}\right) \tag{5}$$

$$\frac{dy}{dt} = r_1 y\left(1 - \frac{y}{N_1}\right) \tag{6}$$

In equations (5) (6), x is the population of lamprey, y is the population of other organisms, r is the intrinsic growth rate, and N is the environmental maximum holding capacity. When their two populations survive together, the lamprey causes a stunting effect on the growth of the other organism's population, while the other organism's population is unable to cause a stunting effect on the lamprey.

$$\frac{dx}{dt} = r_1 x\left(1 - \frac{x}{n_1} - S_1\frac{y}{n_2}\right) \tag{7}$$

$$\frac{dy}{dt} = r_2 y\left(1 - \frac{y}{n_2} - S_2\frac{x}{n_1}\right) \tag{8}$$

In equations (7) (8), x is the number of lamprey populations, y is the number of other populations, r_1 and r_2 are their intrinsic rates of increase, and n_1 and n_2 are their maximum capacities. S_2 indicates that for resources feeding other stocks, the consumption (relative n_1) per unit number of lampreys is S_2 times the consumption per unit number of other stocks. And vice versa for S_1.

Therefore, we set the intrinsic growth rate of lamprey and other populations to be 1, the maximum capacity of both to be 200, the initial population of lamprey to be 20, and the initial population of other populations to be 10, S_1 to be 0.5, and S_2 to be 1 for the simulation. As shown in the figure below:

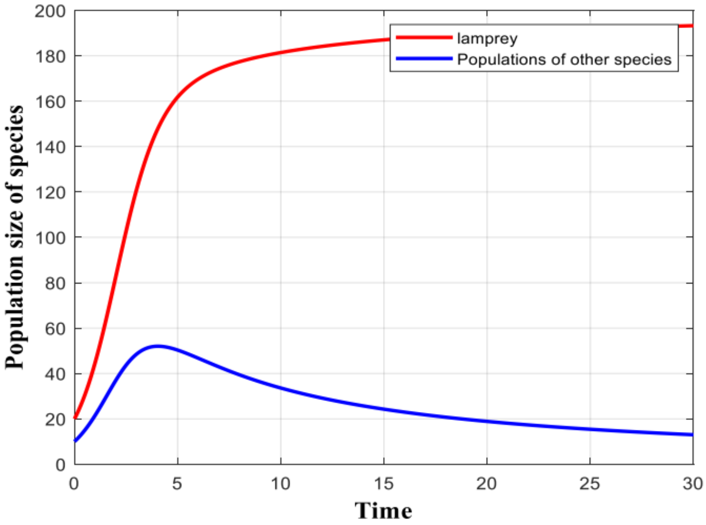


Figure 5: Competitive relationships between lamprey and competing populations

Competitive relationships between lamprey and competing populations is shown in Figure 5.

2.2.2 Predation Relationships in Food Chains

In order to consider the ecosystem impacts of changes in lamprey sex ratios, we want to develop a model of prey and predators. When lamprey populations increase or decrease, this affects the number of their predators and their prey, which in turn causes impacts on the food chain and the ecosystem. We can build the Lotka-Volterra predator-prey model to observe this.

Model assumption:

We assume a sustainable increase in the number of prey.

We have assumed that there are no uncontrollable factors (natural disasters) affecting.

We assume that resources are abundant, the environment is suitable, and the number of rats grows exponentially when they survive on their own.

Model building:

$$\begin{cases} \dfrac{dU}{dt} = \alpha U - \beta UV \\ \dfrac{dV}{dt} = \zeta UV - rV \end{cases} \tag{9}$$

where (9) is the prey growth rate equation and (10) is the predator growth rate equation.

Model solution:

We set the intrinsic growth rate of prey to 1, the proportion of prey captured by predators per unit of time to 0.1, the rate of increase of predators due to predation to 0.02, the mortality rate of predators to 0.5, and the number of prey in the initialization condition to 40 and the number of predators to 18. Visual simulation of the relationship between prey numbers and predator numbers:

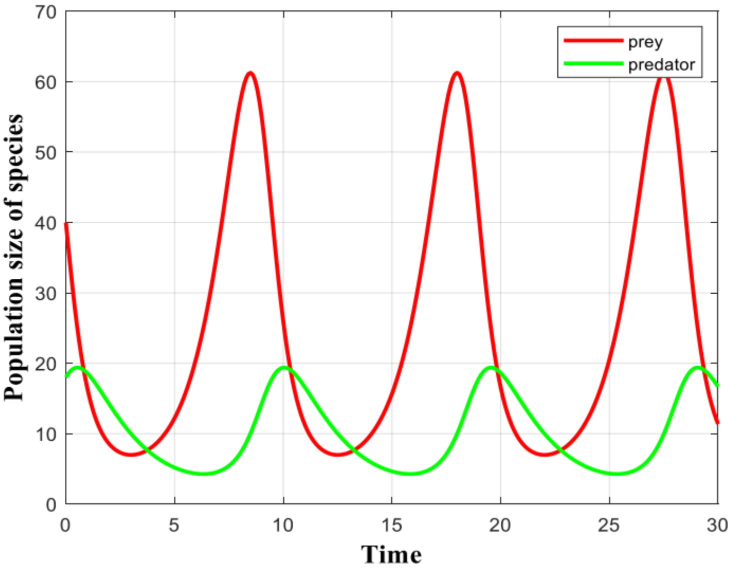


Figure 6: Plot of changing quantitative relationships between prey and predator

Plot of changing quantitative relationships between prey and predator is shown in Figure 6.

3 Analysis of Strengths and Weaknesses of Lamprey Populations Based on Variable Sex Ratios

3.1 Strengths and Weaknesses of the Lamprey Stock

To understand the strengths and weaknesses of lamprey populations, it is important to understand the role that lampreys play in the ecosystem and to clarify their parasitic, predator-prey relationships. These are important to our understanding of the ecological implications of changes in lamprey sex ratios. Lampreys feed primarily on blood, and their adults usually parasitize large fish. Adult lampreys attach themselves to their host fish through their toothed sucker mouths and feed on the host's blood.

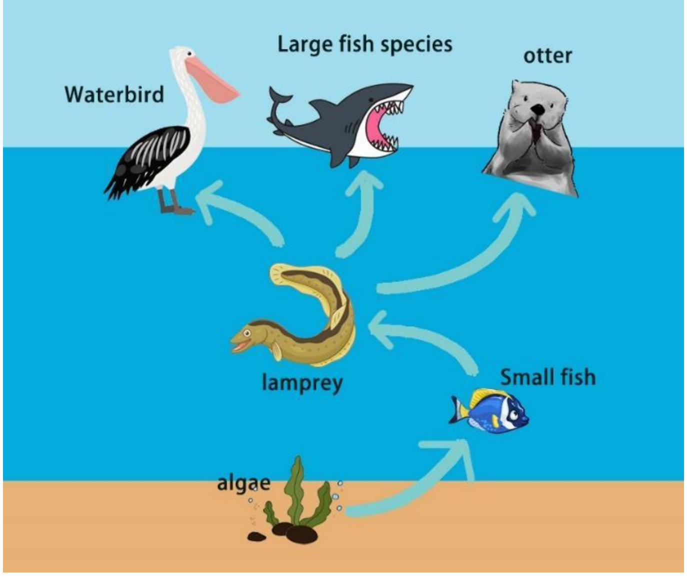


Figure 7: The food chain of the lamprey

The food chain of the lamprey is shown in Figure 7.

Table 1: Predation, predation and parasitism of lamprey

Relationship	Type	Reason
The prey of lampreys	freshwater fish	Salmon and red eye trout are the main sources of food for lampreys when they live in freshwater
	Sea fish	When lampreys live in the ocean, they parasitize on various marine fish
The predator of lampreys	birds	Some birds prey on the juvenile or adult stages of lampreys
	fish	Some large fish prey on lampreys
	human	Some humans treat lampreys as a delicious delicacy
Parasitism of lampreys	Health damage	Continuous blood loss and wounds may weaken the host's health
	population dynamics	Parasitic behavior may affect the quantity and structure of host fish

Predation, predation and parasitism of lamprey is shown in Table 1.

After considering the predation, prey and parasitism relationships of lampreys above, we then go on to consider the effects that changes in the sex ratio of lampreys have on their ecosystem.

The following occurs when there is an insufficient supply of food and when there is an adequate supply of food:

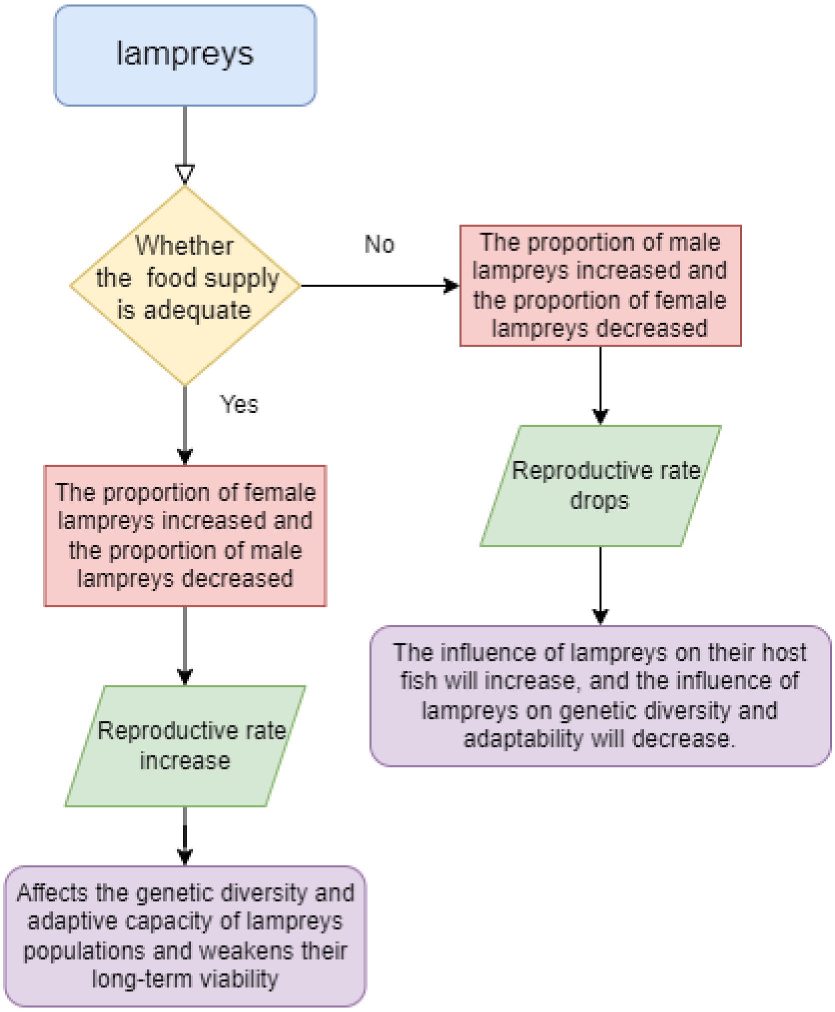


Figure 8: Effects of food availability on lamprey populations and food chains

Effects of food availability on lamprey populations and food chains is shown in Figure 8.

Through the above figure, we can learn that the population of lamprey should be controlled at a certain number, too much or too little will affect our ecosystem. When competition or predation between two populations reaches an equilibrium that implies mutual coexistence in order not to cause extinction. When competition or predation between two populations reaches an equilibrium that implies mutual coexistence in order not to cause extinction.

3.2 Population Competition Model for Simulation Solution

We solved the simulation using the population competition model developed in the first question.

When two populations compete with each other for the same food source and living space, what are the various conditions that allow them to achieve mutual coexistence.

3.2.1 Model Building

$$\frac{dx}{dt} = r_1 x\left(1 - \frac{x}{n_1} - S_1 \frac{y}{n_2}\right) \tag{11}$$

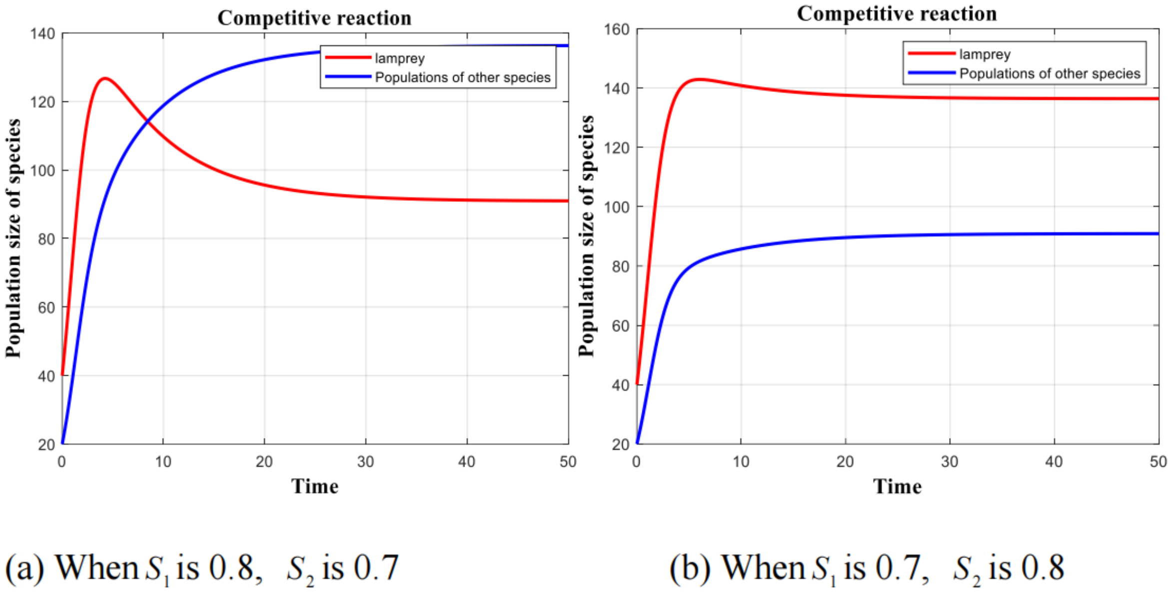
$$\frac{dy}{dt} = r_2 y\left(1 - \frac{y}{n_2} - S_2\frac{x}{n_1}\right) \qquad (12)$$

where x and y are the numbers of lamprey and other populations, respectively, r_1 and r_2 are their intrinsic growth rates, and n_1 and n_2 are their maximum capacities. S_1 and S_2 represent the survivability of the two species, the lower the value the higher the survivability.

3.2.2 Model Solution

1. Seek when lampreys outnumber other species:

2. We arrived at a set number of adjustments to set the number of lamprey twice the number of the rest of the species, with a maximum environmental capacity of 200, simulated in time intervals from 0 to 50 steps of 0.1, with the same natural growth rate of the two species, and an equilibrium reached by changing the values of S_1 and S_2 viability in order not to cause extinction.



(a) When S_1 is 0.8, S_2 is 0.7 (b) When S_1 is 0.7, S_2 is 0.8

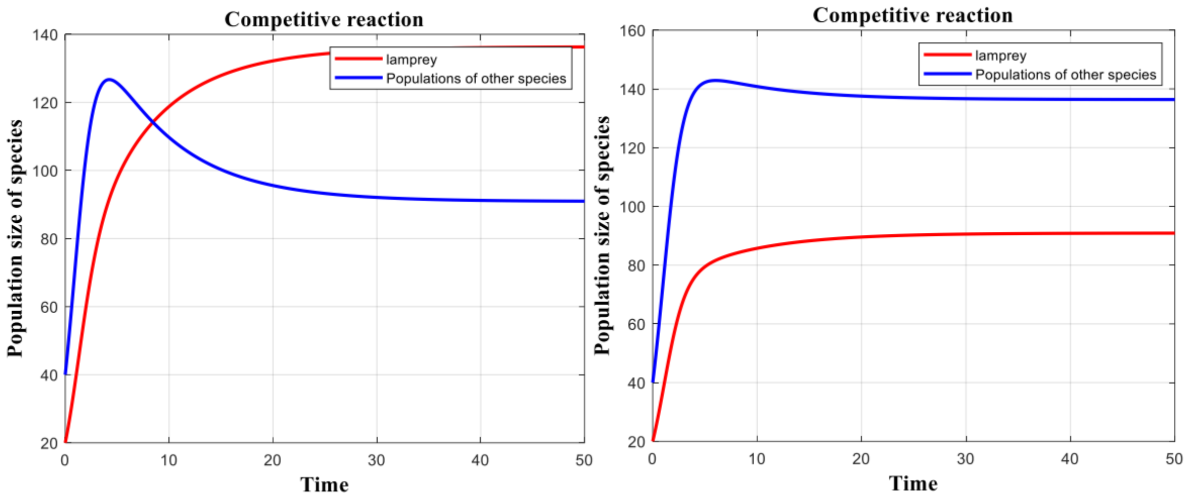
Figure 9: Competition with competing populations when lampreys outnumber other species

Competition with competing populations when lampreys outnumber other species is shown in Figure 9.

We can tell that when both S_1 and S_2 are less than 1 and the difference between S_1 and S_2 is not large, the two species will eventually stabilize at some stable value and eventually reach equilibrium coexistence, and that the size of S_1 and S_2 determines the size of the population when which population eventually stabilizes in competition.

3. When lampreys are less abundant than other species:

4. The results of the simulation when we changed the initial population of the rest of the population to be twice the number of lampreys and kept the rest of the settings unchanged are as follows:

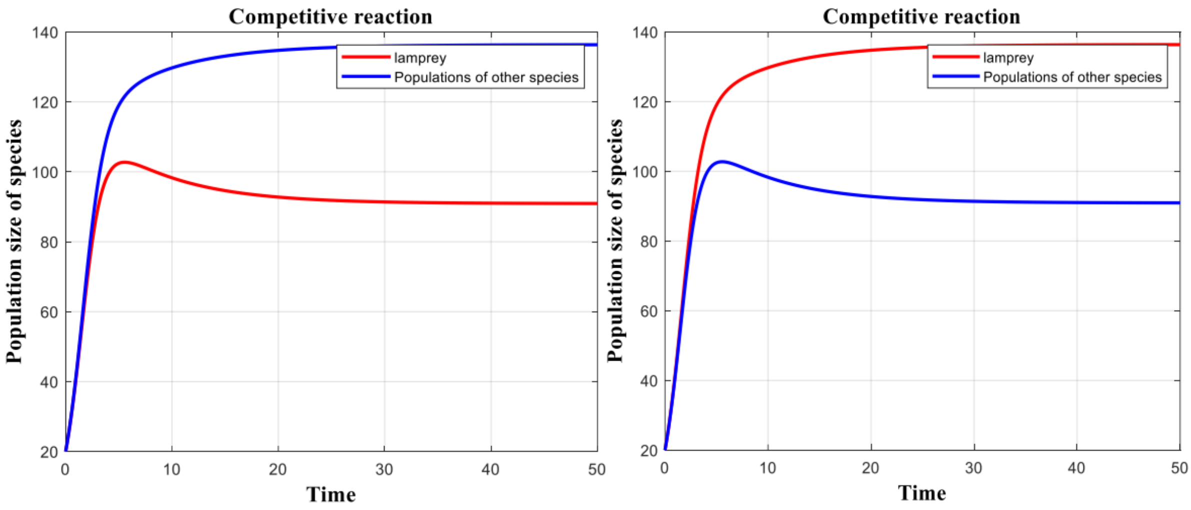


(a) When S_1 is 0.7, S_2 is 0.8 (b)When S_1 is 0.8, S_2 is 0.7

Figure 10: Competition with competing populations when lampreys are less than other species

Competition with competing populations when lampreys are less than other species is shown in Figure 10.

5. Seek when the number of lampreys is the same as the number of other species:



(a) When S_1 is 0.8, S_2 is 0.7 (b) When S_1 is 0.7, S_2 is 0.8

Figure 11: Competition with competing populations when lamprey populations are equal to those of other species

Competition with competing populations when lamprey populations are equal to those of other species is shown in Figure 11.

It can be concluded from the above graph of the change in the quantitative relationship between species that in population competition, the stability of the competitive relationship between two populations is determined by the ability to survive S_1 and S_2. Only when both are less than 1 and greater than 0 and the difference is not too much, the two species will reach a competitive equilibrium with each other and the two sides will not go extinct.

3.3 Summary of Strengths and Weaknesses of Lamprey

Through the above model, we conclude that the lamprey has the advantage of adjusting the sex ratio of the population under different survival conditions, thus adapting to the survival environment, in the competitive environment when the lamprey is in an advantageous condition, the lamprey will reduce the male ratio and increase the female ratio, thus favoring the reproduction and evolution of the population, and when the lamprey is in a disadvantageous position in competition with other species, the lamprey will increase the male ratio and decrease the female ratio, thus reducing the demand of males for limited resources and allowing more energy to flow to females to reproduce the population. When lampreys are at a competitive disadvantage with other species, they will increase the proportion of males and decrease the proportion of females, thus reducing the demand for limited resources by males and allowing more energy to flow to females to reproduce the population.

Advantage:

(1) Adjusting sex ratios may allow lamprey populations to adapt more efficiently to different environmental conditions, particularly the availability of food resources. In environments where food is scarce, a higher proportion of males may help to reduce the overall demand for limited resources, as females usually require more resources to reproduce.

(2) Changes in adaptive sex ratios may affect the ability of lampreys to provide ecological services as parasites. For example, their ability to control certain pests or maintain ecological balance.

Disadvantage:

(1) Adjustments in sex ratios may lead to changes in reproduction rates, which may affect population size and survival.

(2) Changes in adaptive sex ratios may affect the ecology of other species, thereby altering interrelationships in ecosystems.

4 Effects of Lamprey Sex Ratio on Ecosystem Stability Based on the Lotka–Volterra Model

Changes in the gender of lampreys can have an impact on their population size. Changes in the population size of the lamprey can have an impact on the stability of the ecosystem.

4.1 Impact on Stock Competition

We start by looking at the effects of competitive relationships in the food chain, and again we pull out the population competition model we developed earlier:

$$\frac{\mathrm{dx}}{\mathrm{dt}} = \mathrm{r_1 x}\left(1 - \frac{\mathrm{x}}{\mathrm{n_1}} - \mathrm{S_1}\frac{\mathrm{y}}{\mathrm{n_2}}\right) \tag{13}$$

$$\frac{\mathrm{dy}}{\mathrm{dt}} = \mathrm{r_2 y}\left(1 - \frac{\mathrm{y}}{\mathrm{n_2}} - \mathrm{S_2}\frac{\mathrm{x}}{\mathrm{n_1}}\right) \tag{14}$$

x, y are the populations of lamprey and other species, respectively, r_1, r_2 are their intrinsic growth rates, n_1, n_2 are their maximum capacities. S_1 and S_2 represent the viability of the two species, the lower the value the higher the viability.

The initial population of lamprey in the model will become larger when the population of lampreys rises sharply. Because the initial population of lamprey suddenly becomes larger, the balance in the food chain is temporarily broken, and because the waters where the lamprey live rarely encounter natural enemies, no one intervenes, resulting in the survival ability of the population in competition with the lamprey decreases, and the value of the lamprey rises.

We set the initial population size of 200 and 100 respectively, the maximum environmental capacity of 2000, the natural growth rate of 1, the value of 0.6, and the value of 1 to obtain the following visualization through model simulation:

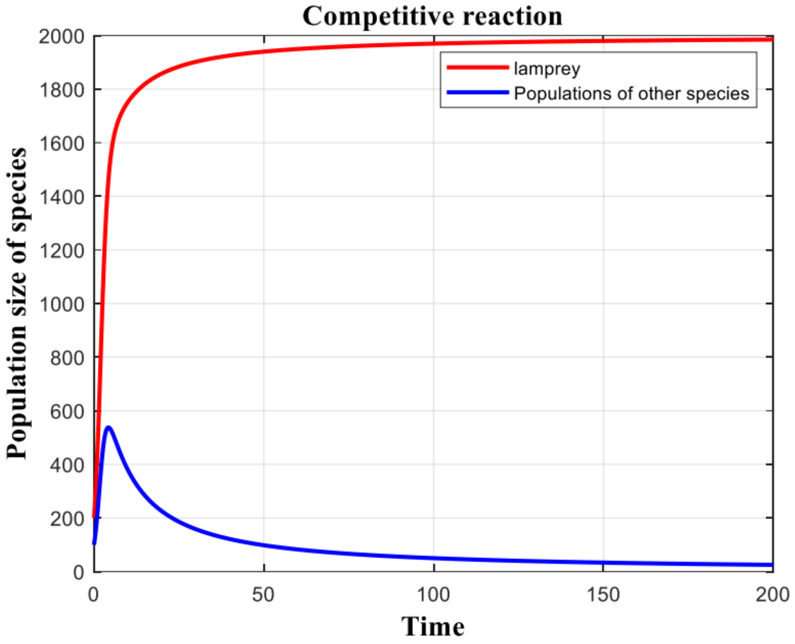


Figure 12: Competitive relationships between lampreys and competing populations

Competitive relationships between lampreys and competing populations is shown in Figure 12.

We can see from the above figure that when the sex ratio of the lamprey changes resulting in a very high population of lampreys will lead to the extinction of other competing populations due to loss of competition, affecting the stability of the ecosystem.

4.2 Implications for Predation Relationships

Let's look again at the predation relationships of species in the food chain, and again we come up with the Lotka-Volterra predator-prey model that we built in our previous problem:

$$\frac{dU}{dt} = \alpha U - \beta UV \tag{15}$$

$$\frac{dV}{dt} = \zeta UV - rV \tag{16}$$

(15) is the growth rate equation for the prey and (16) is the growth rate equation for the predator.

To ensure the stability of the predatory relationship, we can list the following relationships:

$$\frac{dU}{dt} = \frac{dV}{dt} \tag{17}$$

Understood:

$$\mathrm{\alpha U - \beta UV = \zeta UV - rV} \tag{18}$$

Solution:

$$\begin{cases} \mathrm{U_1 = 0} \\ \mathrm{V_1 = 0} \end{cases} \text{or} \begin{cases} \mathrm{U_2 = \dfrac{r}{\zeta}} \\ \mathrm{V_2 = \dfrac{\alpha}{\beta}} \end{cases} \tag{19}$$

We can derive values for the population sizes of and for the two equilibrium points above.

In general, it is impossible to have a moment when the number of both is zero, so we choose the second value of U and V as the equilibrium point, which must also be a stable equilibrium point. Let the deviation of U and V compared to U_2 and V_2 be written as:

$$\mathrm{U(t) - U_2 = \varepsilon(t)} \tag{20}$$

$$\mathrm{V(t) - V_2 = a(t)} \tag{21}$$

From this we can rewrite the Lotka-Volterra equation:

$$\mathrm{\frac{d\varepsilon}{dt} = -\frac{r}{\delta} a} \tag{22}$$

$$\mathrm{\frac{da}{dt} = \delta\, \partial \varepsilon} \tag{23}$$

Substituting (22) into (21) yields:

$$\mathrm{\frac{d^2\varepsilon}{dt^2} + \alpha r \varepsilon = 0} \tag{24}$$

Solving the second order differential equation yields:

$$\mathrm{\varepsilon(t) = A\cos\sqrt{\alpha r t} + B\sin\sqrt{\alpha r t}} \tag{25}$$

A and B are constants established by the initialization state. It follows by the same reasoning that:

$$\mathrm{a(t) = \delta\sqrt{\frac{\alpha}{r}}(A\sin\sqrt{\alpha r t} - B\cos\sqrt{\alpha r t})} \tag{26}$$

The above solution suggests that the deviation between prey U and predator V populations will only oscillate around the equilibrium point over time, showing a cyclical pattern. For example, the first question of the simulation yields a graph of the relationship between prey and predator:

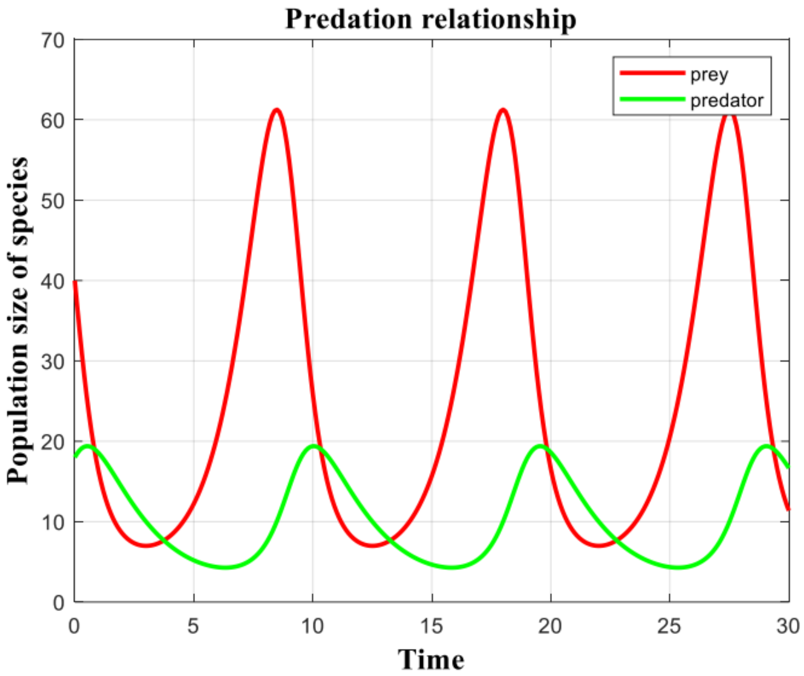


Figure 13: The prey-predator relationship

The prey-predator relationship is shown in Figure 13.

Using the lamprey as a predator, when there is a sudden increase in the number of predators this can lead to an increase in the initial population of the predator and an increase in the proportion of prey caught by the predator per unit of time. This results in extinction of the prey, and it also results in a lower population when the prey is extinct and the predator has no prey to hunt. As shown in the figure below:

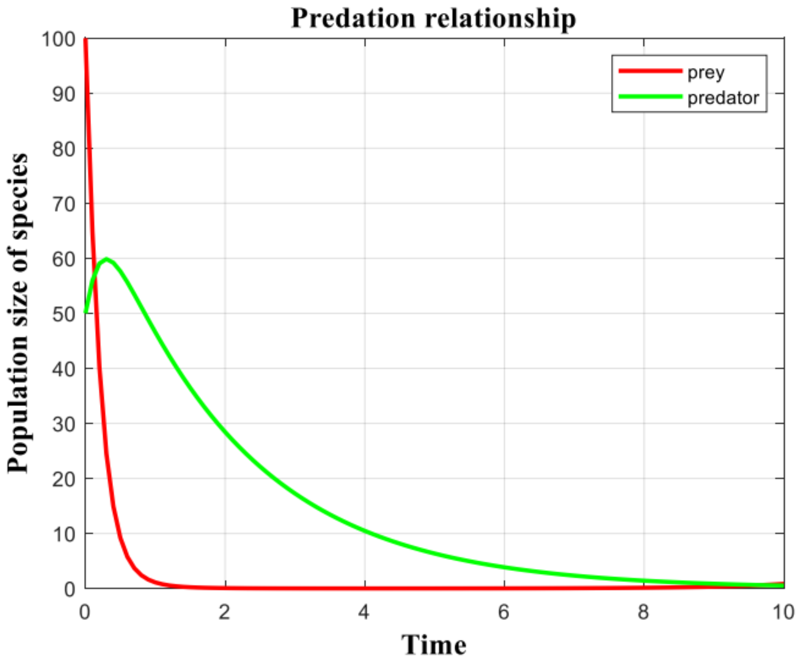


Figure 14: Prey-predator relationships during predator surges

Prey-predator relationships during predator surges is shown in Figure 14.

From the above, we can know that when the sex ratio of lamprey changes resulting in a very high population of lamprey, it will lead to a decrease in the number of populations of organisms below its food chain or even extinction, which will disrupt the food chain, resulting in a rupture of the ecological balance, loss of biodiversity, and a serious impact on the stability of the ecosystem.

5 Modeling the Advantages of Lamprey Sex Ratio Variation for Symbiotic and Parasitic Relationships in the Ecosystem

5.1 Model Building

Our answer to the question of whether lampreys can provide an advantage to other ecosystem participants is yes.

Let's start with the example of the parasite, which has a parasitic relationship with the lamprey. That is, the parasite is the host organism and the lamprey is the host. Parasitism is actually a relationship between two organisms that live together, with one benefiting and the other being victimized, with the latter providing nutrients and a place to live for the former.

The relationship between lampreys and parasites can be categorized as mutually beneficial symbiosis and parasitism. Mutualistic symbiosis is a relationship of mutual interest between a parasitic organism and its host. Parasitism is a relationship between a parasitic organism and a host in which one party is harmful and the other is beneficial.

We can mimic the symbiotic and parasitic relationships between lampreys and parasites by improving the modeling of population size for problem one:

$$\frac{\mathrm{dN}}{\mathrm{dt}} = \mathrm{r_1 N(t)} \left(1 - \frac{\mathrm{N(t)}}{\mathrm{K}}\right) - \mathrm{D_1} \cdot \mathrm{N(t)} \tag{27}$$

$$\frac{\mathrm{dJ}}{\mathrm{dt}} = \mathrm{r_2 J(t)} \left(1 - \frac{\mathrm{J(t)}}{\mathrm{N(t)} * \mathrm{n}}\right) - \mathrm{D_2} \cdot \mathrm{J(t)} \tag{28}$$

$N(t)$ is the number of lamprey, $J(t)$ is the number of parasites, r_1 and r_2 are the natural growth rate of lamprey and parasites, respectively, K is the environmental capacity, n represents the number of parasites per lamprey, D_1 and D_2 are the natural mortality rate of lamprey and parasites, respectively. $N(t) * n$ in the model represents the environmental holding capacity of the parasite as affected by the number of host lampreys.

5.2 Model Solution

When lampreys and parasites are in a mutually beneficial symbiotic relationship:

We set the environmental holding capacity K to 200, the natural growth rates r_1 and r_2 of lamprey and parasites to be the same, the number of parasites c on each lamprey to be 1, and the mortality rate to be the same, and the results of the model simulation when the initial numbers of lampreys and parasites are 10 and 5, respectively, are visualized as follows:

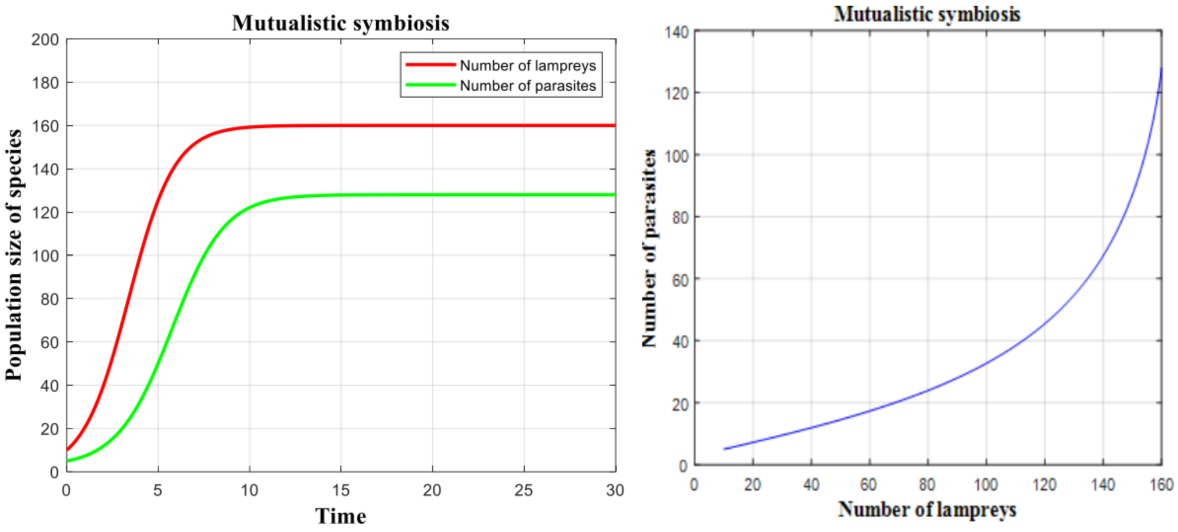


Figure 15: Mutualistic symbiosis when the number of parasites on each lamprey is 1

Mutualistic symbiosis when the number of parasites on each lamprey is 1 is shown in Figure 15.

Through the relationship diagram of mutualistic symbiosis, we know that mutualistic symbiosis not only gives the parasites a good place to live, but also positively affects the host, the lamprey. When the population size of the lamprey population changes because of the sex ratio, the number of parasites will also change. Therefore, lampreys can provide a survival advantage to other ecosystem participants by changing their sex ratio.

When the lamprey and the parasite are in a parasitic relationship:

We set the environmental capacity to 200, the natural growth rate of lampreys and parasites to be the same, the number of parasites on each lamprey to be 2, the mortality rate of lampreys to be increased, and the results of the model simulation when the initial number of lampreys and parasites are 10 and 5, respectively, are visualized as follows:

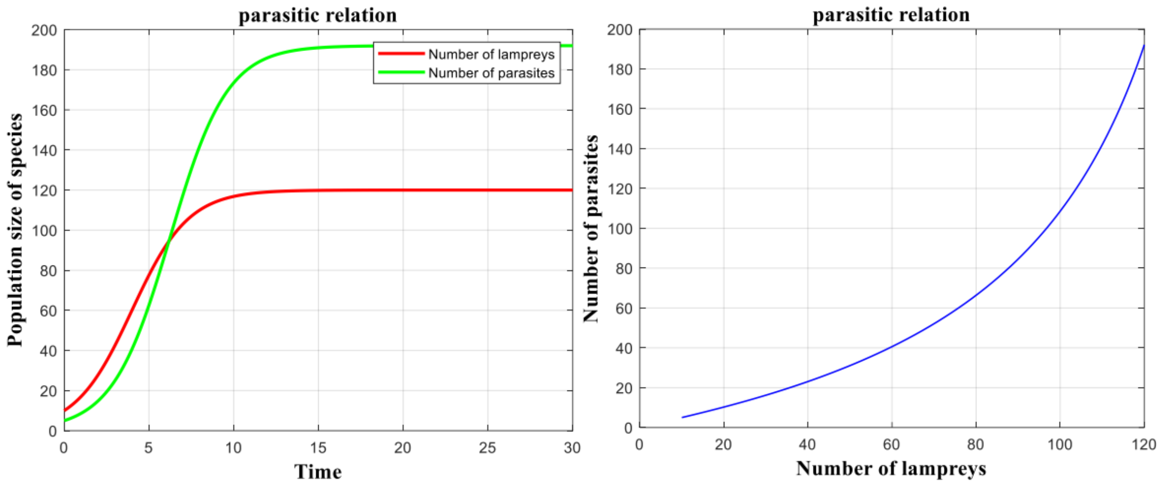


Figure 16: Parasitism when the number of parasites on each lamprey is 2

Parasitism when the number of parasites on each lamprey is 2 is shown in Figure 16.

Through the above figure we can know that when the lamprey and the parasite are in a parasitic relationship, the population size of the host decreases, while the population size of the parasitic organism increases dramatically due to the large amount of nutrients it receives from the host. Therefore, the change in population size due to the change in the sex ratio of the lamprey will provide a survival and nutrient food advantage for the other ecosystem participants, the parasites.

In addition to being parasites, lampreys offer many advantages to other ecosystem participants:

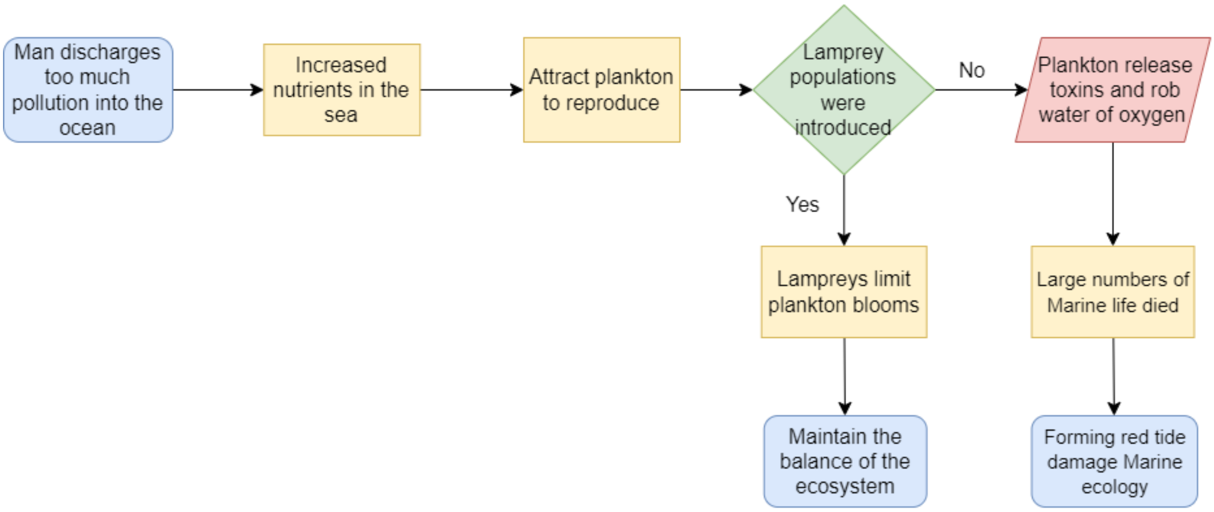


Figure 17: Sea lamprey feeding on plankton

Sea lamprey feeding on plankton is shown in Figure 17.

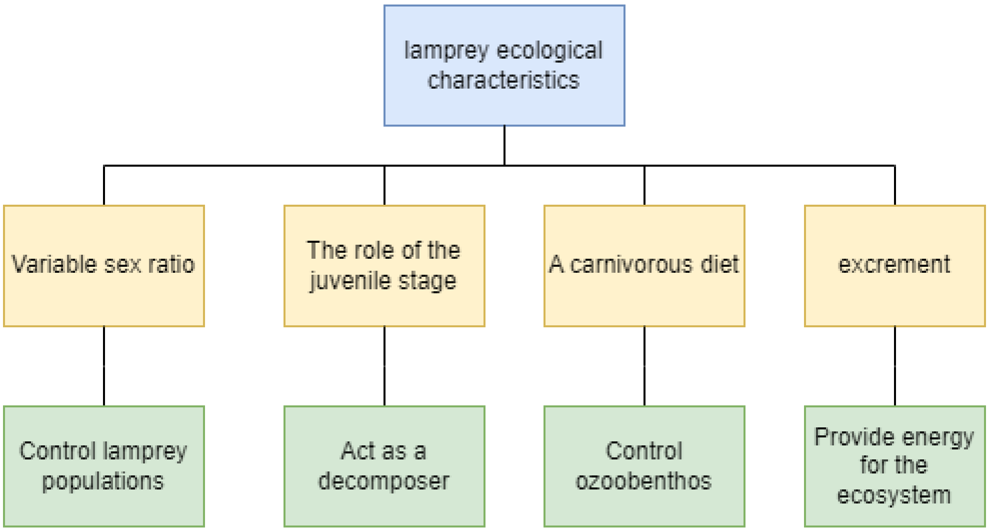


Figure 18: Control of ecosystem balance

Control of ecosystem balance is shown in Figure 18.

6 Sensitivity Analysis

For the model we built above, we analyze the sensitivity of the population competition model of model 2, by adjusting the intrinsic growth rate of the model r_1 and r_2, the maximum capacity of the two species n_1 and n_2, the viability of the two substances S_1 and S_2, in order to observe and understand the sensitivity of each factor to the population competition model.

When we increase the difference between the viability values of S_1 and S_2 and the value of viability is greater than 1, the following situation occurs:

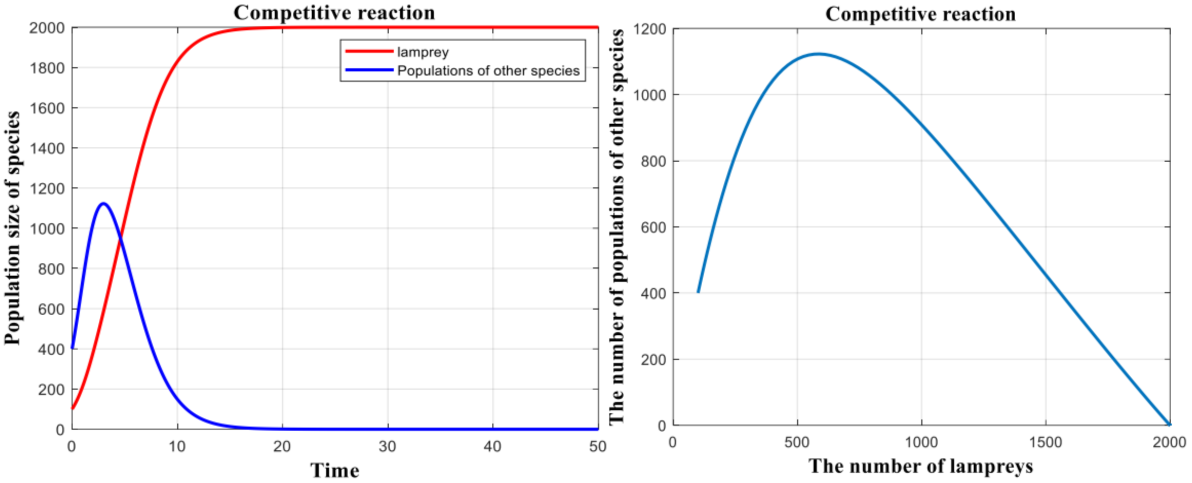


Figure 19: Population changes of lampreys and other populations after changes in S_1 and S_2

Population changes of lampreys and other populations after changes in S_1 and S_2 is shown in Figure 19.

The graph above shows that when we set the intrinsic growth rate to 0.6 and the intrinsic growth rate to 1.5, the final value stabilizes at the point where the lamprey reaches its maximum capacity and the other species go extinct.

Taking our preconditions of 0.6 and 1.5 and changing the rest of the conditions, we get the following scenario when we just change the intrinsic growth rate and the value of 0.3:

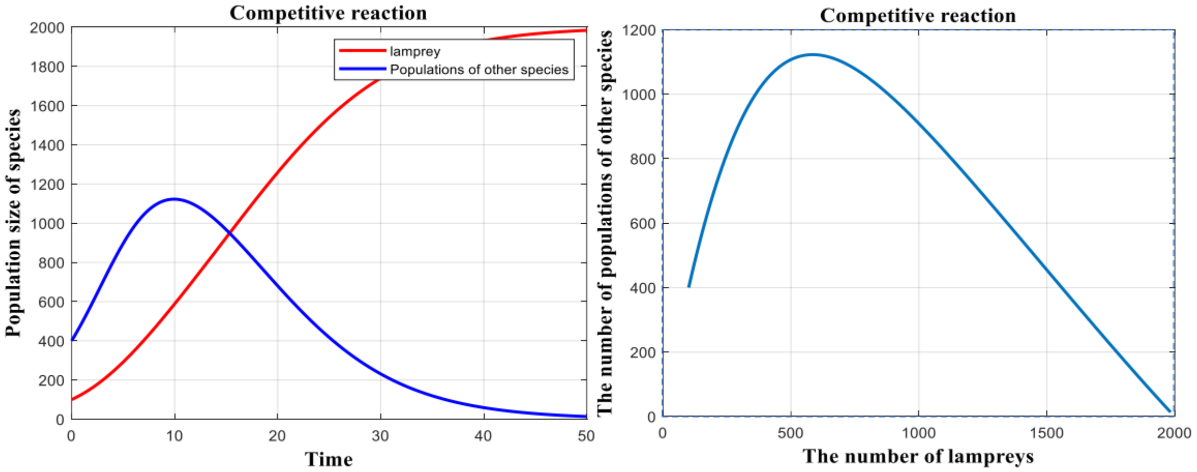


Figure 20: Population changes of lampreys and other populations at a natural growth rate of 0.3

Population changes of lampreys and other populations at a natural growth rate of 0.3 is shown in Figure 20.

We can see that the final result for both species is still that the lamprey reaches its maximum capacity and the other species goes extinct, unlike the original change when the difference between S_1 and S_2 becomes larger and the value of 1 is greater, but the rate of change slows down, which is caused by the fact that their intrinsic growth rates, r_1 and r_2, become smaller. There is not much difference between the changes caused by the original change and the difference between the original change and the extinction of the other species and a value greater than 1.

Taking our preconditions of 0.6 and 1.5 and changing the rest of the conditions, we get the following scenario when we change the difference in the capacity of the two species, $n_1 = 1000$ and $n_2 = 2000$:

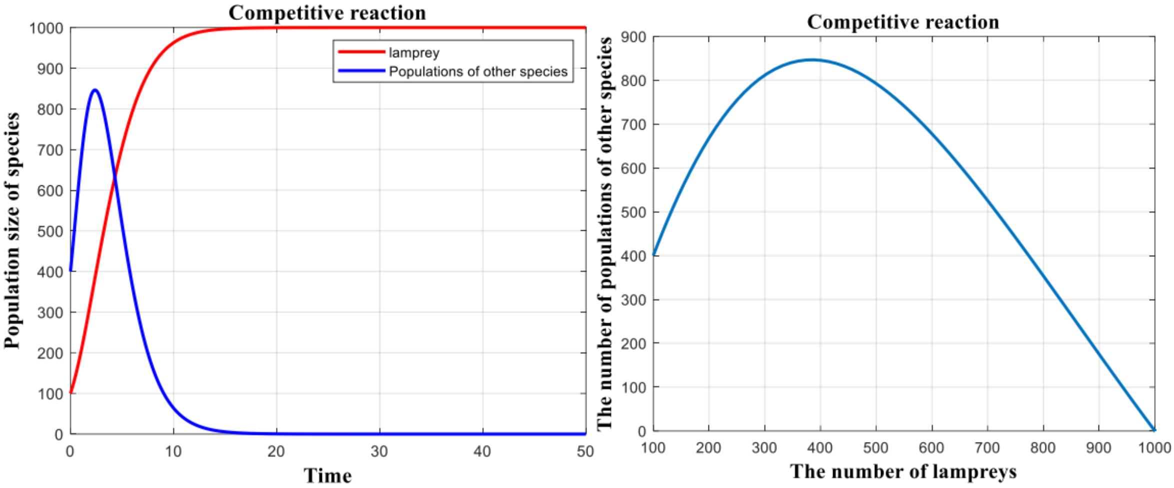


Figure 21: Population changes in lampreys and other populations of different capacities

Population changes in lampreys and other populations of different capacities is shown in Figure 21.

We can see that the two species with a change in the maximum capacity condition come up with the result that the other competing species will still go extinct. Therefore, the change of capacity does not affect who will go extinct in the end.

To summarize, we have to control the value of the viability of the two populations in order to control the healthy balance of population competition, and the value of the viability should be greater than 0 and less than 1, and the difference is not very big. No matter how to change the intrinsic growth rate, the values of initial population size and maximum population capacity can not change the result that one of the species will face extinction. Meanwhile, we can also learn that in the population competition model, the value of viability is highly sensitive to the model, and the values of other conditions are very sensitive to the model.

7 Conclusions

By establishing a series of complementary mathematical models, this study systematically summarizes the mechanisms by which the seven-gill eel adapts to environmental pressures through the regulation of sex ratios, as well as its multidimensional impacts on the ecosystem. The findings reveal that while this adaptive regulation helps seven-gill eels optimize their population structure under resource constraints, it may also disrupt the original competitive balance and predation cycles due to excessive fluctuations in population size, leading to the extinction of other species or ecosystem destabilization. At the same time, the study confirms that this regulatory mechanism can provide nutritional advantages to certain symbiotic organisms. Limitations of this study include the lack of extensive field data to validate the competitive model, and the simplification of environmental temperature and parameter normalization in the Lotka-Volterra model, which limits the precise simulation of real-world complex ecosystems. Future research should focus on collecting higher-frequency field observation data to validate the model and consider incorporating additional dynamic environmental variables, such as human disturbance and water quality fluctuations, to enhance the model's practical applicability and predictive accuracy.

References

[1] Sarasamma S, Li W. CRISPR/Cas in sea lamprey: new tools for functional genomics and genetic control[J]. Reviews in Fish Biology and Fisheries, 2026, 36(1): 41.

[2] Bai X, Guan Y, Dai J, et al. Exploration of Ecosystem Stability by Lampreys' Specific Gender Mechanism[J]. Journal of Physics: Conference Series, 2025, 3158(1): 012012.

[3] Wilkie P M. How the resilient ecophysiology of the sea lamprey allowed them to invade the Laurentian Great Lakes and could protect them from climate change[J]. Frontiers in Fish Science, 2025, 1591515.

[4] Abersons K, Raibarte P, Elferts D, et al. Weak Reproductive Response of European River Lamprey to a Newly Built Fishway—A Case Study From Latvia[J]. River Research and Applications, 2025, 42(1): 284-292.

[5] Priyadi A, Permana A, Nur B, et al. Adaptation and domestication of endangered wild betta fish (Betta channoides) originating from East Kalimantan, Indonesia[J]. Aquaculture, 2026, 742900.

[6] Beauséjour A P, Zielinski S B, Dubuc R. Behavioral, Endocrine, and Neuronal Responses to Odors in Lampreys[J]. Animals, 2025, 15(14): 2012.

[7] Lucas J, Teichert N, Husset C M, et al. Direct evidence of predation on endangered sea lamprey in estuarine tidal area[J]. Journal for Nature Conservation, 2025, 126998.

[8] Liang H, Qiu C, Huang Q, et al. Research on the Impact of Resource Availability: A Case Study of Lamprey[J]. International Journal of Biology and Life Sciences, 2025, 10(3): 7-10.

[9] Frick K, Moser L M, Liedtke T, et al. Performance Comparisons for Artificially Propagated and Wild Pacific Lamprey Juveniles and Larvae[J]. Aquaculture, Fish and Fisheries, 2025, 5(3): e70070.

[10] Tamrakar S, Huerta B, Davidson C W Y, et al. Liver metabolomic profiles of sea lamprey (Petromyzon marinus) are influenced by sex and maturation stages.[J]. Metabolomics : Official journal of the Metabolomic Society, 2025, 21(3): 69.

[11] Griffin R K, Holbrook M C, Zielinski P D, et al. Not all who meander are lost: migrating sea lamprey follow river thalwegs to facilitate safe and efficient passage upstream.[J]. The Journal of experimental biology, 2025.

[12] E. M S, Frank S, Mark G, et al. Reintroduction success of brook lamprey (Lampetra planeri) in a lowland stream in the Netherlands[J]. Knowledge & Management of Aquatic

Ecosystems, 2025, (426): 32.

[13] Nowosad J, Kujawa R, Sherzada S, et al. Histomorphological and Dynamical Changes in Female River Lampreys during Maturation under Controlled Conditions as a Part of Lamprey Restoration Programs[J]. Animals, 2024, 14(17): 2516.

[14] Mao R, Su Z, Ma X, et al. An ecological population study of lampreys in the Lotka-Volterra tertiary trophic level based on sex differences[J]. Ecological Modelling, 2024, 110826.

[15] Moser M, Maine A, Shonat T, et al. Oxygen consumption of sexually mature adult, first-feeding larval, and yearling Pacific Lampreys[J]. North American Journal of Fisheries Management, 2023, 43(6): 1664-1672.

[16] M A S, S N J, J M S, et al. Synergistic behavioral antagonists of a sex pheromone reduce reproduction of invasive sea lamprey.[J]. iScience, 2023, 26(10): 107744.

[17] Maine N A, Moser L M, Jackson D A, et al. Probiotics improve survival and growth of larval Pacific Lamprey in laboratory culture[J]. North American Journal of Fisheries Management, 2023, 43(6): 1648-1663.

[18] Ortega D J, Hahlbeck N, Derrickson C, et al. Thermal refuge use and parasitism: Spatiotemporal variation in anchor worm and lamprey wounds on Klamath redband trout[J]. Ecosphere, 2023, 14(9):

[19] M E W, T K S, Olivia B, et al. Evaluating the utility of effective breeding size estimates for monitoring sea lamprey spawning abundance.[J]. Ecology and evolution, 2023, 13(9): e10519.

[20] Nolwenn D, Romane N, Ahmed S, et al. Sperm competition experiments reveal low prezygotic postmating isolation between parasitic and nonparasitic lamprey ecotypes.[J]. Ecology and evolution, 2023, 13(4): e9970.