

Study on the Impact of Lamprey Sex Ratio Variations on Ecosystem Dynamics from a Food Web Perspective

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Abstract. This study explores the impact of variations in the sex ratio of lampreys on ecosystem dynamics within a food web context. Using the Volterra predation and prey model, the research analyzes the natural growth and decline rates of populations, predator-prey relationships, and competition. The paper examines how changes in the sex ratio of lampreys affect the populations of herbivores, omnivores, and carnivores, as well as the survival of indigenous people. The analysis utilizes biological data from juvenile sea lampreys and employs Matlab for data fitting, establishing a relationship between the sex ratio of lampreys and the availability of food in the ecosystem. The findings highlight the interconnectedness of species within the food web and the significant role of sex ratio variations in lampreys on the larger ecosystem.

Keywords: Lamprey, Sex ratio, Ecosystem dynamics, Food web.

1. Introduction

The complexity of ecosystem dynamics has long been a subject of interest in ecological research^[1, 2]. Within aquatic ecosystems, lampreys are a pivotal species, influencing the structure and function of the food web^[3]. Their role as both predators and prey makes them integral to the ecological balance^[4, 5]. However, the sex ratio of lampreys, like in many other species, is subject to variations due to environmental factors, which can lead to shifts in population dynamics^[6]. Understanding these changes is crucial for comprehending the broader impacts on the ecosystem, including the effects on other species and the overall biodiversity^[7]. This background forms the foundation for investigating the relationship between the sex ratio of lampreys and the dynamics of the larger ecosystem.

This study begins by constructing a food web using the Volterra predation and prey model to analyze ecosystem dynamics. It then examines the natural growth and decline rates of populations, along with predator-prey interactions and competition among species. The research focuses on the impact of lamprey sex ratio variations on the populations within the food web and the survival of indigenous people. Finally, the study employs biological data and Matlab for data fitting to establish a relationship between the sex ratio of lampreys and food availability in the ecosystem.

2. Population Dynamics and Predation Relationship Models in the Food Web

To analyze what happens to the larger ecosystem when the sex ratio of lampreys changes, we first need to artificially specify the chain of relationships between animals and plants in the food web, the food web. In a food web, the following relationships exist:

(1) Natural growth and decline rate of a population: when a population can replenish its energy with resources, the population has a natural growth rate; On the contrary, the population has a natural decrease rate. For example, there will be a natural rate of increase for herbivores, a natural rate of decrease for carnivores, and a natural rate of increase for both herbivores and carnivores.

(2) Predator-prey relationship: Higher-ranking species can prey on lower-ranking species. Through this process, the number of individuals in the prey population decreases and the number of individuals in the predator population increases, and these numbers are determined by the original number of individuals in the two populations and a proportional factor.

(3) Competition: When two populations (here it can be the same population) share a common prey or need a common resource, the two populations compete. Competition can occur at more than the same level, that is, it can be implemented across levels. After a competitive process, the number of individuals in both populations will decrease, and these numbers will also be determined by the original number of individuals in both populations and a proportional factor. When the two populations are different, the competition is interspecific. When the two populations are the same, the competition becomes an intraspecific competition.

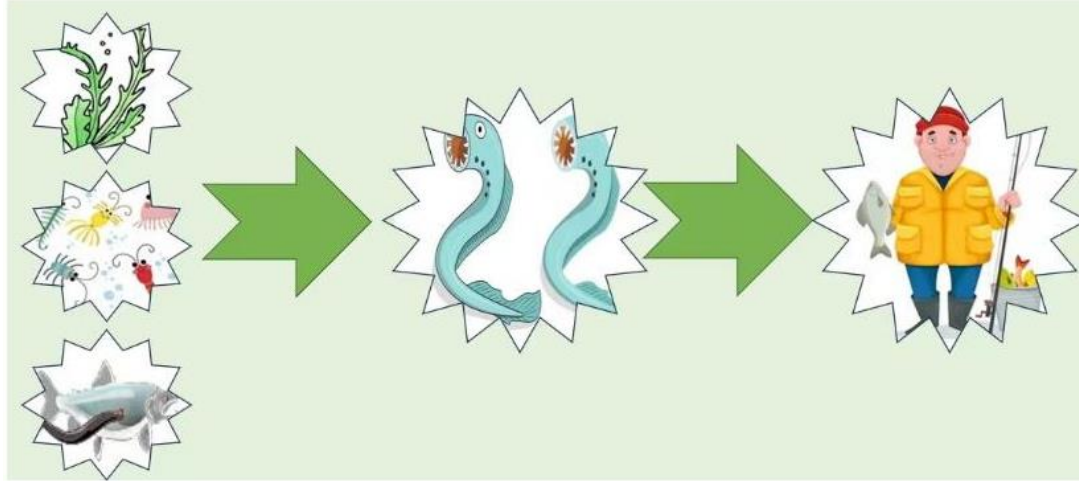


Figure 1 Food web topology

As shown in figure 1 and the above statement, the variation of the quantity of a population P in the "food web" (set as O) (set as p) satisfies the following equation:

$$\frac{dp}{dt} = ap + A(p, O) - B(p, O) \quad (1)$$

Where t is the time, a is the natural growth or decline rate of population P , $A(p, O)$ is the increase or decrease of population P in the food web O due to predation (increase is positive, decrease is negative), and $B(p, O)$ is the decrease of population individuals due to competition (positive).

The Italian mathematician Volterra proposed the Volterra model in the 1920s^[8]:

$$\begin{cases} \frac{dx}{dt} = rx - axy \\ \frac{dy}{dt} = -dy + bxy \end{cases} \quad (2)$$

Where r represents the natural growth rate of population x , and a represents the reduction rate of predation of x by y . d represents the natural reduction rate of y , and b represents the growth rate of y after preying on x . The model has some limitations, that is, it cannot analyze more complex succession relationships between species, and it cannot be simply applied to the analysis of food webs.

In the Volterra model of predation and prey, more species and food web relationships are introduced, which can reflect the food chain structure of more than three levels of reaction. The biological system is shown in Figure 2.

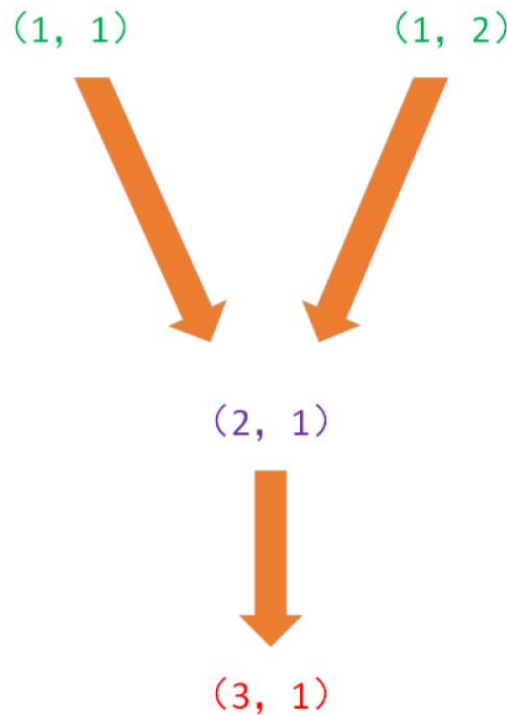


Figure 2 Food web relationship schematic

(1) (1,1) and (1,2) represent the two populations of level 1 (herbivorous fish and zooplankton), (2,1) represents the population of level 2 (lampreys), and (3,1) represents the population of level 3 (indigenous people).

(2) The arrow shows the predator-prey relationship, from the prey to the predator.

(3) Populations (1,1), (1,2) are herbivores, populations (2,1) are omnivores, and populations (3,1) are carnivores, which means that populations (1,1), (1,2), and (2,1) have natural growth rates, while populations (3,1) have natural decline rates.

(4) There is competition between herbivores, between herbivores and omnivores because of their need for resources (plants), and between animals that share prey. In particular, there is intra-competition.

Based on the Volterra predation and prey model, the following predation and prey model is established^[9]:

$$\left\{ \begin{array}{l} \frac{du}{dt} = u_1 u - u_2 u w - u_3 u - u_4 v - u_5 w \\ \frac{dv}{dt} = v_1 v - v_2 v w - v_3 v - v_4 u - v_5 w \\ \frac{dw}{dt} = w_1 w + w_2 u w + w_3 v w - w_4 k w - w_5 w - w_6 u - w_7 v - w_8 k \\ \frac{dk}{dt} = -k_1 k + k_2 w k - k_3 w \end{array} \right. \quad (3)$$

Where u is the group (1,1) (herbivorous fish), v is the group (1,2) (zooplankton), w is the group (2,1) (lampreys), and k is the group (3,1) (indigenous people). u_1 v_1 w_1 k_1 represents the natural rate of increase or decrease by race; u_2 v_2 w_2 w_3 w_4 k_2 is the rate of decline in predation by species; The remaining variables represent the rate of reduction after racial struggle with other races or with one's race.

3. Impact of Lamprey Sex Ratio Variations on the Ecosystem

The sex ratio of lampreys varies according to the external environment. Lampreys grow at a lower rate and the proportion of males increases (males consume less food than females) when there is less food available^[10]. In environments where food is more readily available, the proportion of males decreases. Thus, the male ratio can be assumed to be a one-dimensional function of the amount of food.

$$H = \alpha - \beta A \quad (4)$$

Among them, H —the male percentage of lampreys, A —the food amount of lampreys, and the coefficient of α and β can be obtained by data fitting.

Based on biological data from juvenile sea lampreys sampled from natural streams in Michigan and Quebec, Canada, and sea lampreys tested by the U.S. Geological Survey's Hammond Bay Biological Station. Using Matlab for data fitting, the following fitting formula and fitting curve are shown in Figure 3:

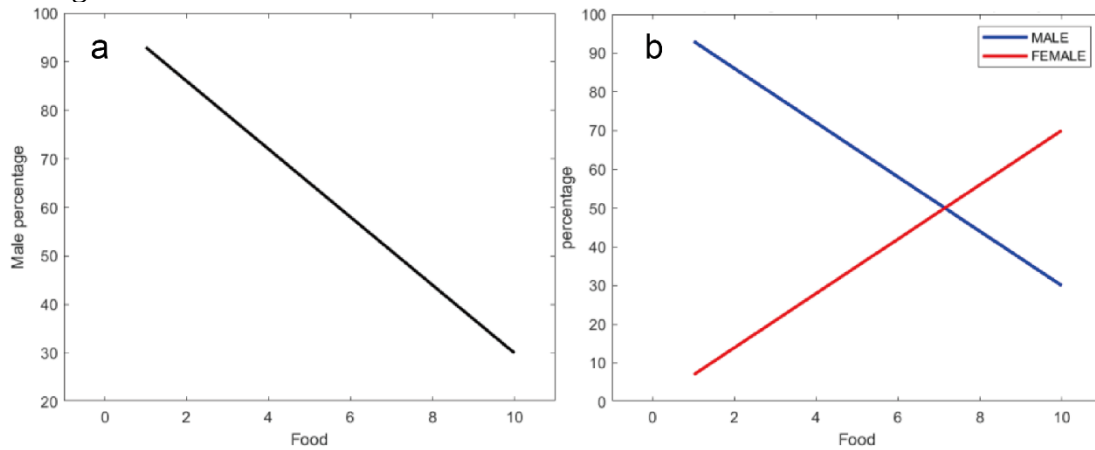


Figure 3 Sex ratio (percentage) Function of food quantity: (a) male percentage; (b) Percentage of males and females

$$H = 100 - 7A \quad (5)$$

The unit of H is %.

The sex ratio of lampreys is affected by the ecosystem: when the amount of food in the ecosystem increases, the percentage of males in lampreys increases and the population of lampreys decreases; The amount of food in the ecosystem decreases, the percentage of females in the lampreys goes up, and the lampreys population goes up.

Similarly, changes in the population of lampreys will also affect the ecosystem: as a predator of plankton and herbivores, changes in the population of lampreys will directly affect the population of plankton and herbivores; Lampreys are the food of indigenous people, and changes in their numbers will also affect the survival of indigenous people.

Therefore, here are three scenarios to study the effects on the ecosystem when a population of lampreys can change its sex ratio.

(1) The male/female ratio of lampreys is 1:1.05 (male/female ratio is equal)

The initial population size is set to $u_0=23$ $v_0=24$ $w_0=15$ $k_0=5$.

As can be seen from the figure, when the ratio of male and female lampreys is equal, the population is moderate.

(2) The male-to-female ratio of lampreys is 1:1.6 (more males than females).

The initial population size is set to $u_0=25$ $v_0=24$ $w_0=10$ $k_0=5$

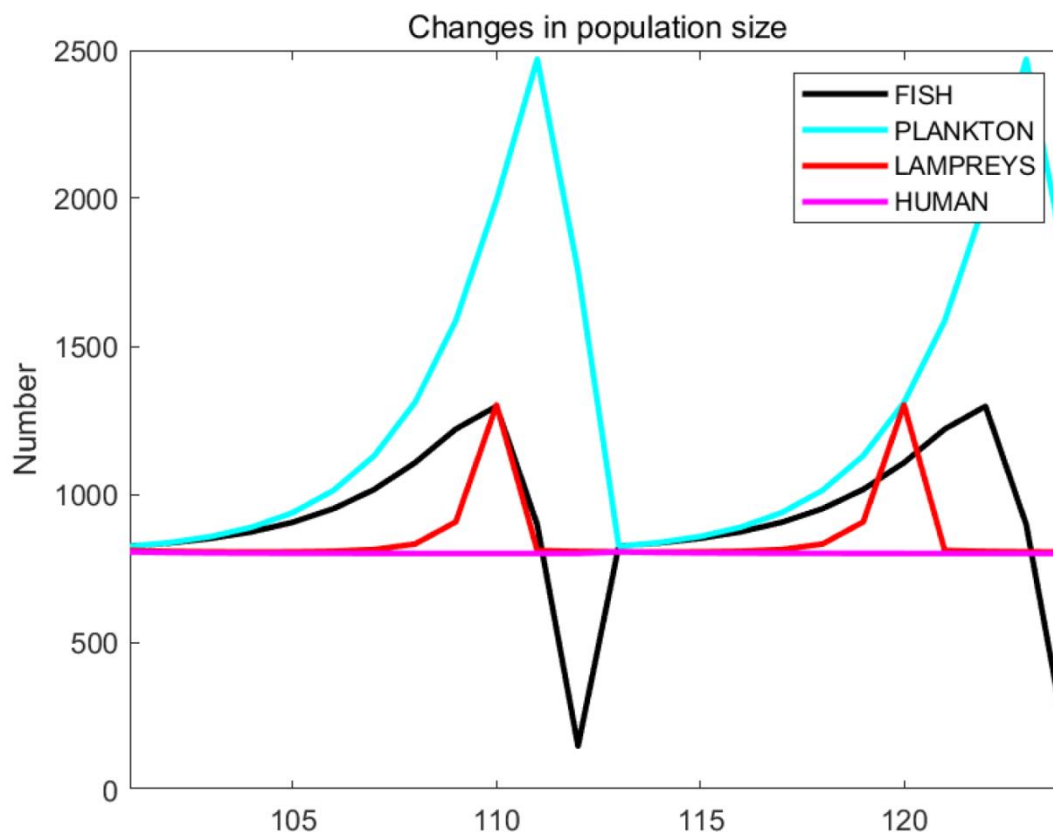


Figure 4 more males than females

As can be seen from figure 4, when the ratio of male and female lampreys is equal, the population is smaller

(3) The male-to-female ratio of lampreys is 1.7:1 (more females than males)

The initial population size is set to $u_0=25$ $v_0=24$ $w_0=10$ $k_0=5$

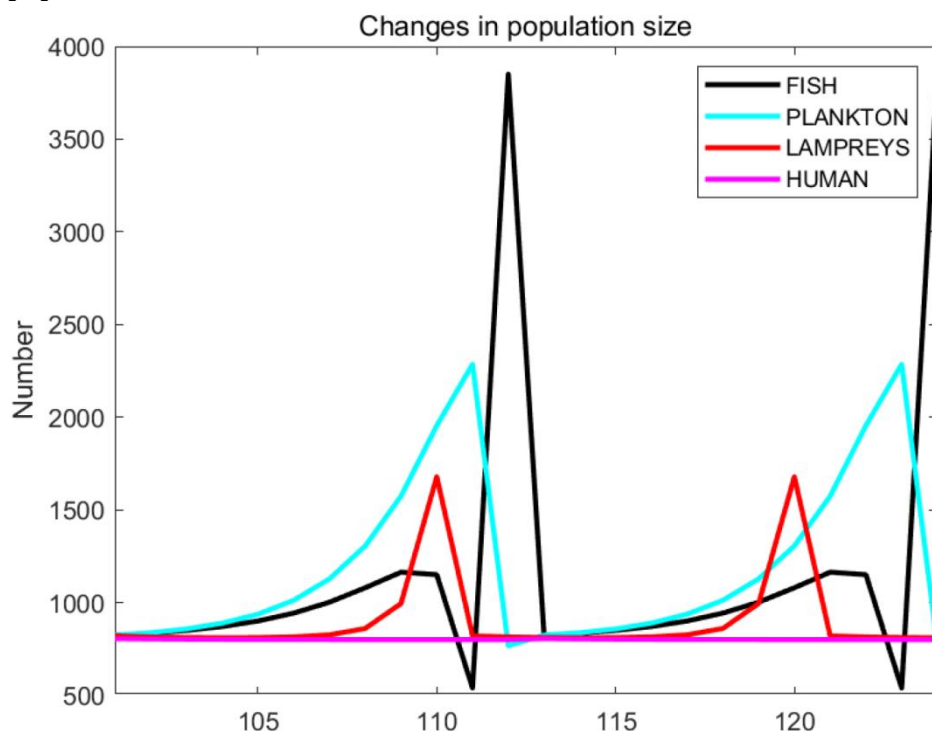


Figure 5 more females than males

As can be seen from figure 5, when the ratio of male and female lampreys is equal, the population is larger.

4. Conclusion

This study delves into the impact of changes in the sex ratio of lampreys on ecosystem dynamics, particularly within the context of a food web. By employing the Volterra predation-prey model, combined with experimental data and Matlab fitting, this paper analyzes the natural growth and decline rates of communities, predator-prey relationships, and interspecific competition. The findings indicate that variations in the sex ratio of lampreys significantly influence the population sizes of herbivores, omnivores, and carnivores in the food web, as well as the survival of indigenous people. When the sex ratio of lampreys shifts towards males, their population decreases, thereby reducing predation pressure on plankton and herbivores, which in turn affects the structure and function of the entire food web. Conversely, an increase in the female ratio leads to a rise in the lamprey population, increasing predation on lower trophic levels and impacting ecosystem balance. Additionally, as a food source for indigenous people, changes in the lamprey population directly influence their livelihood and culture.

This research underscores the importance of considering species' sex ratio variations in ecosystem management and conservation. Future studies could further explore the effects of different environmental factors on the sex ratio of lampreys and how these changes propagate through the food web to affect the overall health and stability of the ecosystem. Moreover, research could be expanded to other species and ecosystems to comprehensively understand the role of sex ratio variations in ecological dynamics.

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