Lamprey gender ratio study based on delayed modeling of resource availability changes

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Abstract. This study explores the application of two cutting-edge modeling approaches, the continuous-time staged structural model and the resource availability-driven change-delay model, to reveal the complex dynamics of lamprey populations. Through an exhaustive analysis of relevant literature dealing with lamprey populations, resource availability, sex ratios, and their ecological impacts, the study finds that manipulating lamprey sex ratios can have far-reaching effects on the broader ecosystem. Such alterations can affect resource availability, predator-prey dynamics, and overall ecosystem stability. While sex ratio imbalance may disrupt population structure, the presence of variable sex ratios in lamprey populations may provide an advantage to other organisms (especially parasitoids) by increasing host availability. Combining modeling approaches such as continuous time-stage structural models and models of delayed resource availability-driven change can help predict and understand lamprey population dynamics and their ecological impacts. This study emphasizes the urgent need to develop integrated management strategies that take into account the intricate interactions between lampreys, local environments and ecosystems.

Keywords: Lamprey; resource availability; ecosystem stability; Continuous Time Staged Structural Model; Resource availability driven change delay model.

1. Introduction

The sex ratios of lampreys, a group of jawless fish, play a crucial role in shaping their ecological dynamics and population dynamics. Lampreys exhibit a wide range of reproductive strategies, including both sexual reproduction, which can significantly influence the sex ratios within populations. This paper aims to provide a comprehensive review of the sex ratios of lampreys and their effects on the ecology of aquatic ecosystems. It explores the factors influencing sex determination and sex ratios in lampreys and discusses the ecological consequences of skewed sex ratios on population dynamics, mating systems, and resource utilization. Additionally, the implications of sex ratio imbalances on conservation efforts and management strategies for lamprey populations are also discussed [1].

Studies focusing on lamprey populations, resource availability, sex ratios, and their ecological implications were analyzed. Data from field surveys, experimental studies, and theoretical models, including the Continuous Time Staged Structural Model and the Resource Availability Driven Change Delay Model, were examined to elucidate the effects of lamprey sex ratio alterations on the larger ecosystem and the fishery industry [2].

2. Resource availability driven change delay model

The construction of the model consists of two distinct stages. In the first stage, we focus exclusively on the mathematical relationships governing the population dynamics of lampreys during their various growth stages. Specifically, we develop population dynamics equations that capture the dynamics of each of the three growth stages of lampreys.

Moving on to the second stage, we shift our attention towards the mathematical relationship between lampreys and their surrounding environmental resources. Here, we employ a change delay model that takes into account the availability of resources as the driving force behind population dynamics. Consequently, we construct population dynamics equations alongside resource dynamics equations that elucidate the interplay between lampreys and their environment.

Lastly, we seamlessly integrate the insights gleaned from both stages. To achieve this, we replace the population dynamics equation from the second stage with the population dynamics equation derived from the three growth stages of lampreys in the first stage. Moreover, we modify the equation describing the juvenile stage in the first stage to incorporate the influence of a delay factor, mirroring the treatment method employed in the population dynamics equation of the second stage.

By combining these complex components, our model achieves a comprehensive and sophisticated representation of the dynamics of lamprey populations, facilitating a deeper understanding of their growth patterns and interactions with the environment [3].

2.1. Rate of change in the number of individuals in juvenile years

$$\frac{dN_J(t)}{dt} = bmin(N_M(t), N_f(t))(1 - ((N_{J+}N_F + N_M)(t - \tau(R(t)))/K) - dN_J(t)\frac{1}{R(t)} - gN_J(t) \quad (1)$$

This equation represents that the change in the number of young individuals consists of three parts:

$$\frac{bh}{min(N_M, A_F)} \cdot \left(1 - \frac{N(t-\tau(R(t)))}{K}\right) \quad (2)$$

New juvenile individuals produced by reproduction of adult individuals (depending on the smaller number of adult males and females, while being affected by time delays constrained by resources).

$$-\frac{dN_J}{R} \quad (3)$$

The natural mortality rate of young individuals,

$$-gN_J \quad (4)$$

The transfer rate of individuals from childhood to adulthood.

2.2. The rate of change in individual quantity during male adulthood

$$\frac{dN_M}{dt} = kgN_j - \frac{d \cdot N_M}{R} - hN_M \quad (5)$$

This equation indicates that the change in the number of adult male individuals is influenced by the growth of young individuals into adult individuals (and differentiation into males), the natural mortality rate of adult males, and the mortality rate after participating in reproductive activities.

2.3. Changes in individual quantity during female adulthood

$$\frac{dN_F}{dt} = (1 - k)gN_J - \frac{d \cdot N_f}{R} - hN_F \quad (6)$$

Similarly, this equation describes the changes in the number of adult female individuals, including the impact of juvenile growth and differentiation into females, the natural mortality rate of adult females, and the impact of mortality rate after participating in reproductive activities.

The dynamic equation of resources needs to describe the spontaneous regeneration ability of resources and the impact of population consumption on resources:

$$\frac{dR(t)}{dt} = a \cdot R(t)\left(1 - \frac{R(t)}{R_{max}}\right) - p \cdot N_{\text{total}}(t) \cdot R(t) \quad (7)$$

This equation describes the changes in resource availability, including the spontaneous regeneration ability of resources and the impact of population consumption on resources.

$$\frac{dN_J(t)}{dt} = bmin(N_M(t), N_F(t))(1 - ((N_{J+}N_F + N_M)(t - \tau(R(t)))/k) - dN_J(t)\frac{1}{R(t)} - gN_J(t) \quad (8)$$

$$\frac{dN_M(t)}{dt} = kgN_J(t) - dN_M(t)\frac{1}{R(t)} - hN_M(t) \tag{9}$$

$$\frac{dN_M(t)}{dt} = (1-k)N_J(t) - dN_F(t)\frac{1}{R(t)} - hN_F(t) \tag{10}$$

The situation we simulated based on the formula is in Figures 1 and 2:

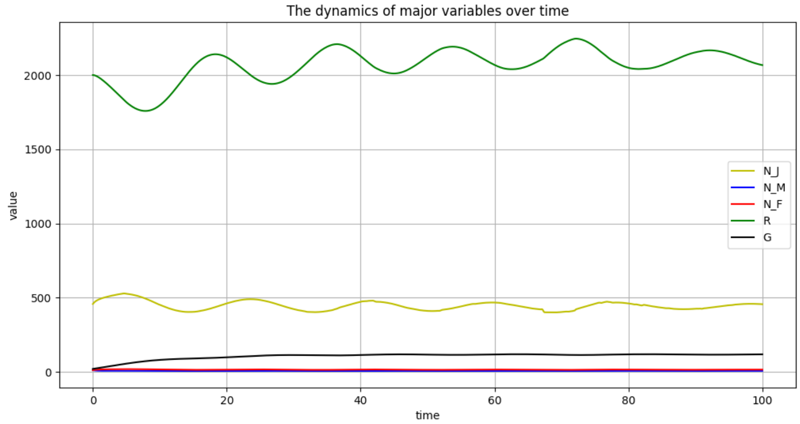

Fig. 1 The dynamics of major variables over time

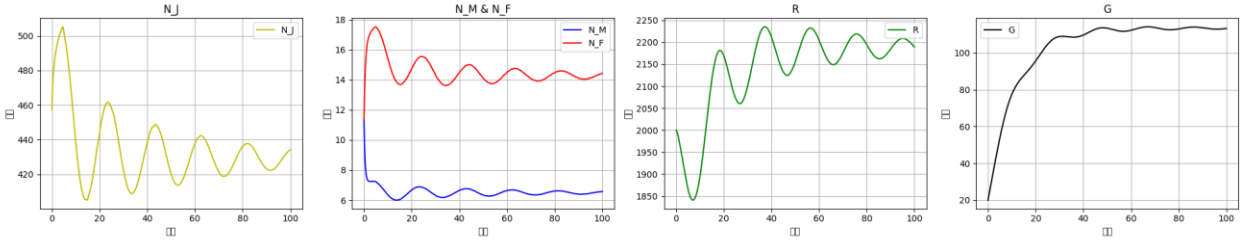

Fig. 2 Dynamics of parameters over time

3. Sensitivity Analysis

3.1. Sensitivity to the Reproductive Rate per Mature Individual

The applications of this model include predicting the dynamic changes of populations under different resource conditions, managing wildlife resources, and understanding the impact of environmental changes (such as seasonal changes, climate change, etc.) on ecosystems. The main challenge of the model lies in accurately defining $\tau(R)$. The functional form requires detailed experimental data and a deep understanding of specific ecosystems. In addition, resource dynamics themselves may be very complex and require additional models to describe. Priorto constructing our model, we consulted the literature and encyclopedic sources to ascertain the characteristics of the lamprey, determining that the reproductive rate for mature lampreys stands at 20; that is, 20 offspring are capable of surviving in a fixed environment. To simulate more general and extensive conclusions, we expanded the range of reproductive rates, resulting in images depicting the total number of lampreys as environmental resources vary.

We observed that this coefficient has a minimal impact on the steady state of the entire ecosystem. Naturally, should the environment deteriorate or become more conducive to lamprey growth, this coefficient might change, potentially affecting the stability of the ecosystem. Hence, more complex models are required to achieve better results when considering unpredictable interference [4].

3.2. Sensitivity to Mortality Rate Post-Parasitism

We have carried out a comprehensive sensitivity analysis on two crucial factors, namely the average reproductive rate (b) and the mortality rate (dh), associated with parasitic species. By examining the temporal dynamics of resource availability (R) in diverse environments, we have made significant advancements in our understanding. Through meticulous observation and analysis, we have uncovered several remarkable findings that shed light on the intricate interplay between these factors.

3.2.1 Average reproduction rate (b)

Based on the visual analysis, we have identified a compelling relationship between the average reproductive rate and the temporal patterns and stability of resource availability within the environment. Notably, our findings indicate that the average reproductive rate primarily influences the periodicity of resource availability while exerting minimal impact on its overall periodic behavior. Here, periodicity refers to the tendency of a variable to oscillate within a defined range or converge towards a specific value.

Upon careful examination of the graphical representations, a distinct trend emerges. Specifically, within the range of 10-20, we observe that a lower average reproductive rate corresponds to a diminished periodicity in resource availability, with a convergence towards larger values. Conversely, a higher average reproductive rate exhibits a heightened periodicity in resource availability, accompanied by an accelerated divergence rate.

These findings offer profound insights into the intricate dynamics between the average reproductive rate and the temporal stability of resource availability. Through this empirical analysis, we enhance our understanding of the underlying mechanisms governing ecological systems, contributing to the broader scientific discourse in this field. An intriguing avenue of inquiry arises from the desire to identify a critical threshold that demarcates the presence or absence of periodicity. Drawing upon the visual observations gleaned from the graphical depictions, we postulate that such a critical value manifests at b=16. Remarkably, our refined sensitivity analysis substantiates this speculation, confirming the proximity of the critical value to b=16.

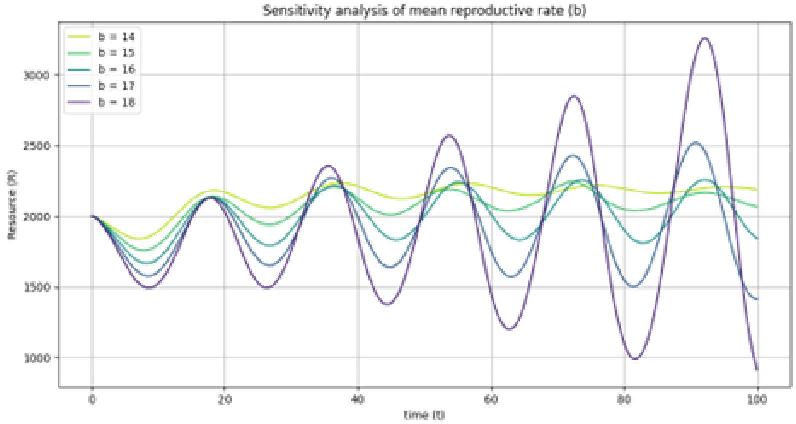

Fig. 3 Sensitivity analysis of mean reproductive rate (b)

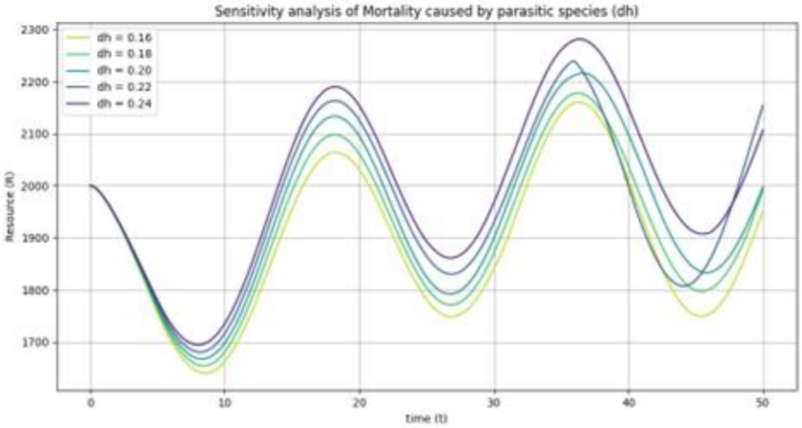

Fig. 4 Sensitivity analysis of Mortality caused by parasitic species (dh)

As shown in Figures 3 and 4, this discerning revelation not only underscores the robustness of our findings but also accentuates the significance of meticulous sensitivity analysis in elucidating the intricate dynamics of ecological systems. By pinpointing this critical threshold, we advance our comprehension of the underlying mechanisms governing the temporal stability and oscillatory patterns of resource availability. Such empirical insights contribute significantly to the scholarly discourse, enriching our understanding of the delicate interplay between predator-prey dynamics and the ecological balance within diverse ecosystems [5].

3.2.2 Death rate caused by parasitic species (dh)

The visual analysis of the Figure 5 reveals a notable relationship between the mortality rate induced by parasitic species and the average available resources. Specifically, higher mortality rates correspond to increased levels of average resource availability. Furthermore, intriguing patterns emerge after the second cycle, suggesting that the mortality rate caused by parasitic species may influence the duration of a cycle.

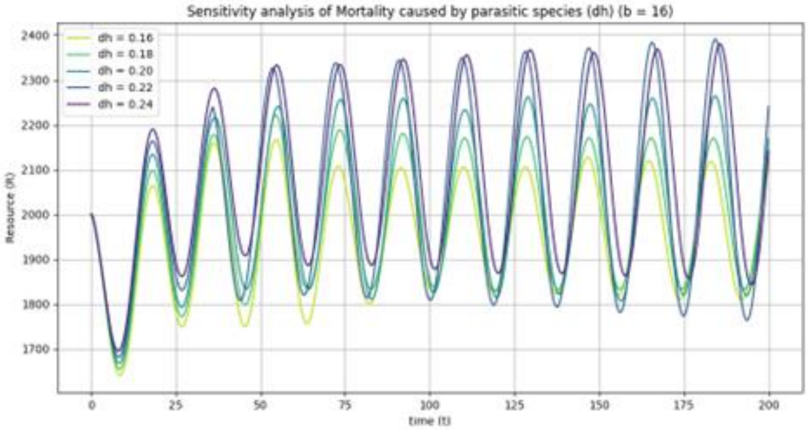

Fig. 5 Sensitivity analysis of Mortality caused by parasitic species (dh) (b=16)

Motivated by these intriguing observations, we embarked on an in-depth investigation to ascertain the potential impact of the mortality rate induced by parasitic species on cycle duration. Employing additional simulations, we rigorously examined the intricate dynamics at play.

This meticulous examination allowed us to delve deeper into the nuanced interplay between the mortality rate and the temporal characteristics of cyclic behavior. By elucidating the potential influence of the mortality rate on cycle duration, our findings contribute to the expanding body of knowledge in the field of ecological dynamics.

Such scholarly endeavors are instrumental in unraveling the intricate relationships within ecological systems, shedding light on the mechanisms that govern the interdependence between parasitic species and resource availability. Through this empirical analysis, we advance our understanding of the fundamental principles that underpin the stability and temporal dynamics of ecological systems.

When we simulate situations for a longer period of time, the duration of a cycle does not seem to be affected by the mortality rate caused by parasitic species. However, when we change the average reproductive rate, another phenomenon arises.

When we changed the average reproductive rate from b=16 to b=18, there was a significant differentiation in the length of the curve’s cycles. According to the Figure 6, the higher the mortality rate caused by parasitic species, the longer the duration of one cycle. The cause of this phenomenon is not yet clear.

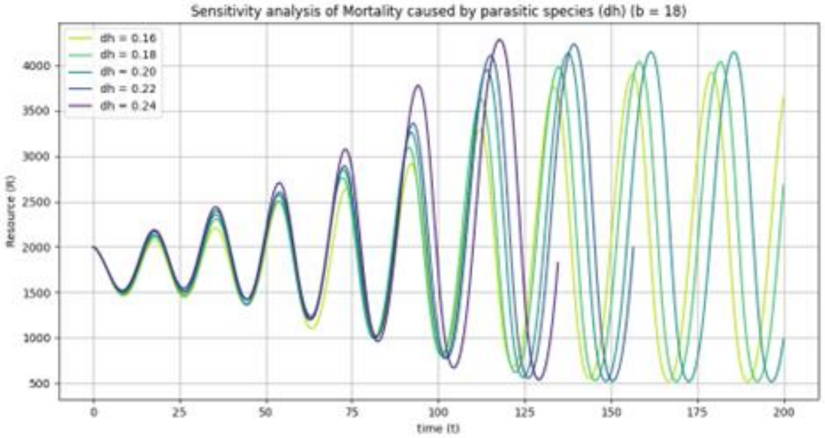

Fig. 6 Sensitivity analysis of Mortality caused by parasitic species (dh) (b=18)

4. Summary

The findings of this study reveal that alterations in lamprey sex ratios have profound impacts on the larger ecological system. Changes in sex ratios can affect the availability of resources, predator-prey dynamics, and the overall stability of the ecosystem. The advantages and disadvantages of such alterations depend on various factors, including the specific ecological context and the interactions between lampreys and other species. While skewed sex ratios may lead to imbalances in the population structure and potentially disrupt the stability of the ecosystem, variable sex ratios in the lamprey population can also offer advantages to other organisms, particularly parasites, by providing increased host availability. The application of modeling approaches, such as the Continuous Time Staged Structural Model and the Resource Availability Driven Change Delay Model, helps in predicting and understanding the dynamics of lamprey populations and their ecological implications.

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