Ecological effects of sex ratio in seven gill eels based on logistic regression modeling

Zhaoyang Wu, Bowen Bai, Yu Zhao *

Faculty of Science, Jiamusi University, Jiamusi, China, 154007

* Corresponding Author Email: hjyshuxue@163.com

Abstract. Numerous studies have shown that adaptive changes in the sex ratio of marine sevengill eel species may lead to unforeseen ecological impacts. For this reason, this study aimed to investigate the impacts of changes in the sex ratio of sevengill eels on the ecosystem and to reveal their ecological significance. In this study, a species growth model and a species development model based on logistic regression model were constructed and combined with an integrated prediction model to construct an integrated ecosystem prediction model. The effects of sex ratio on ecosystem stability and function were analyzed by simulating and predicting the dynamic food chain structure of the seven-gill eel population and changes in food resources under different sex ratios. It was found that sex ratio affects the ecosystem in many ways. First, changes in the sex ratio directly affect the reproductive success of the seven-gill eel, which in turn affects the food chain and energy flow. Secondly, sex ratio is also closely related to food resources, and the abundance of food resources affects the change of sex ratio, which in turn affects the stability of the ecosystem. In addition, changes in sex ratios can affect the survival and reproduction of other species.

Keywords: Sevengill Eels, Sex Ratio, Logistic Regression Model, Integrated Forecasting Model.

1. Introduction

The marine seven-gill eel is an ancient organism that is considered a “living fossil”, condensing the evolutionary history of vertebrates, and is therefore of great scientific importance. The species inhabits various ecosystems, mainly lakes and oceans [1]. It is worth noting that the mechanism of its sex ratio change has been a hot spot in ecological research. Studies have shown that the sex ratio of the seven-gill eel is adaptively adjusted according to environmental conditions. For example, the proportion of males will increase when food resources are scarce. The effects of this sex ratio on the ecosystem are manifold, for example, it affects the flow of energy in the food chain structure and the diversity of species.

However, there are relatively few quantitative studies on the ecosystem impacts of changing sex ratios in seven gill eels. The aim of this study is to investigate the effects of changes in the sex ratio of the seven-gill eel on the ecosystem and to reveal its biological significance. An ecosystem model based on logistic regression and integrated prediction model will be constructed. We will analyze the effects of sex ratio on ecosystem stability and function by simulating and predicting the structure of the dynamic food chain and changes in food resources of seven gill eel populations under different sex ratios [2-3]. In addition, we will also explore the effects of changes in sex ratio on other species. For example, the population dynamics of parasites.

The innovation of this paper: This study is the first to explore the impacts of changing sex ratios on the ecosystem of marine seven gill eels, and comprehensively analyzed the impacts of sex ratios on ecosystem stability and functioning through the construction of a growth model and a developmental model, as well as a comprehensive prediction model. It was found that sex ratio changes affected the reproductive success, food chain structure and food resources of seven-gill eels, which in turn affected ecosystem stability, as well as the survival and reproduction of other species. This study provides new perspectives and in-depth understanding of the effects of sex ratio changes on ecosystems, and is of great significance to the field of ecology.

2. Materials and methods

2.1. Data acquisition and pre-processing

In this paper, population data for adult sea sevengill sampled in natural streams in Lake Ontario and Quebec during the spawning year, net catch and adult sea sevengill during the spawning migration were collected from the open-source website. Estimated index detection records for sevengill eels, and relative abundance data for lake trout in Lake Ontario. We filtered and processed the primary data as shown in Figure 1and 2.

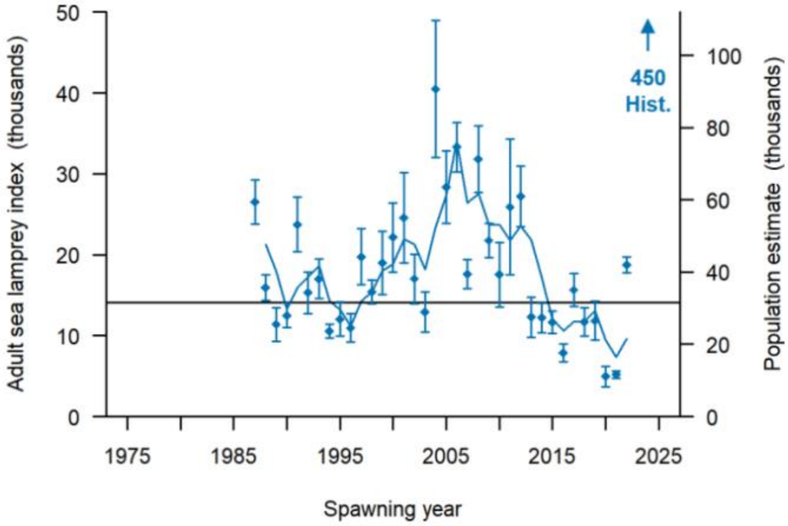

Figure 1. Graph of the number of adult seven gill eel spawning years

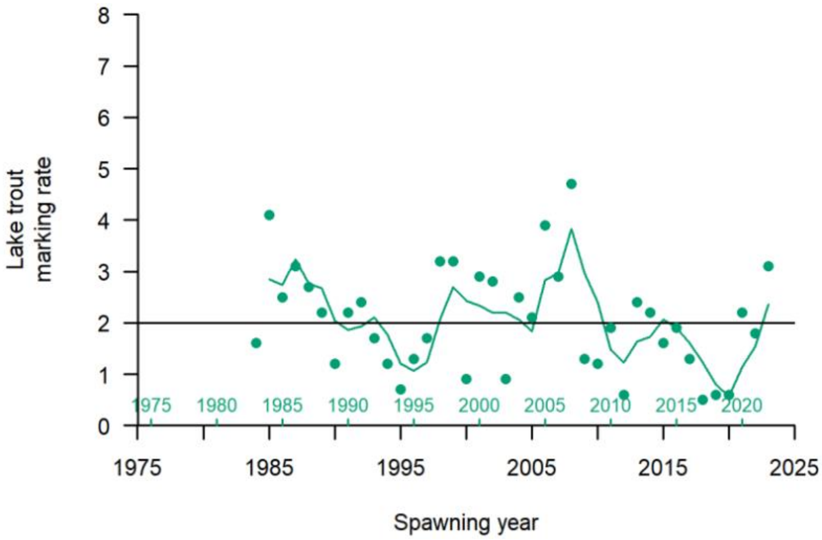

Figure 2. Lake trout abundance maps for seven gill eel spawning years

2.2. Introduction to the methodology

Logistic regression is a statistical model used to solve binary classification problems. The principle converts linear outputs to probability values by means of a linear combination and a nonlinear logistic function, usually a sigmoid function. The hypothesis function needs to be set up in advance, and the hypothesis function should contain the predicted probability values, as well as the parameter vectors, and feature vectors of the model. In order to fit the training data, it is also necessary to define a loss function to measure the difference between the predicted and actual values. The goal of minimizing the loss function is achieved by adjusting the parameters so that the predicted values are as close as possible to the actual values. In order to find the optimal parameters, optimization algorithms such as gradient descent are often used to minimize the loss function. Gradient descent algorithms update the parameter values by calculating the partial derivatives of the loss function with respect to the parameters until convergence conditions are met. The principle of logistic regression modeling is based on the idea of probability and maximum likelihood estimation, which predicts the class of a new sample by fitting the training data. It is simple and effective and widely used in various classification problems [4].

3. Modeling and solving

3.1. Species growth modeling based on logistic modeling

In ecological research focusing on species growth, a refined species growth model can be developed using a logistic framework. This model portrays the dynamics of species growth in an idealized context, where limited environmental resources are treated as the dependent variable, and changes in a single population's abundance serve as the independent variable. This relationship is characterized by its non-linear complexity rather than a straightforward linear correlation. Logistic models underscore the intricate non-linear interplay between environmental resources and population sizes. The logistic equation, representing the ideal growth pattern of a single species, is delineated in Equation (1) [5].

$$N(t) = rN(1-\frac{N}{K}) \tag{1}$$

In this context, r represents the natural growth rate of the species, N denotes the population size, t signifies the time variable, and $1-\frac{N}{K}$ reflects the carrying capacity, indicating the maximum population size that a finite environment can sustain. By solving Equation (1), one can derive Equation (2), which further elucidates the species' population dynamics within these parameters.

$$N(t) = \frac{KN_0e^{rKt}}{K+N_0(e^{rKt}-1)} \tag{2}$$

The population size at the initial moment t=0 is denoted by N_0. This implies that the population growth rate of marine seven-gill eels initially accelerates rapidly and then gradually decelerates as the initial population size increases. This pattern indicates that, in the context of limited resources, species growth is not boundless. As N approaches the carrying capacity K, growth progression tends to a plateau, effectively causing the growth rate to approach zero. This phenomenon underscores the finite nature of resources and their pivotal role in regulating population dynamics.

3.2. Species development modeling based on logistic modeling

The sex ratio of marine seven-gill eels is intrinsically linked to the growth rate during their juvenile stages, with this growth rate being influenced by the availability of food. In this context, it is posited that the variation in food quantity serves as the dependent variable, while the development of the single species acts as the independent variable. This relationship between the dependent and independent variables is characterized by its non-linear nature. Consequently, the equation that encapsulates the shifts in the sex ratio of ideal species development, as dictated by food quantity and based on the Logistic model, is represented in Equation 3.

$$U(t) = \frac{1}{1+e^{-r(t-t_0)}} \tag{3}$$

Where $U(t)$ is the probability that a marine sevengill eel develops into a female, r is the natural rate of growth of the species, and t_0 is the time at which a marine sevengill eel larva begins to undergo a sex change due to food quantity.

4. Results

4.1. Impact of sex ratio on food chains

To mitigate the possibility of random errors in our experimental approach, we explored the influence of sex ratio on the food chain through MATLAB. This involved conducting iterative calculations over 50 generations for the seven-gill eel. For a comprehensive analysis, we established control groups under conditions of both food abundance and scarcity. The outcomes of these simulations are depicted in Figure 3. Where each bar is divided into two parts, the lower half of each bar represents the sex ratio of the sevengill eel and the upper half represents the predator population [6].

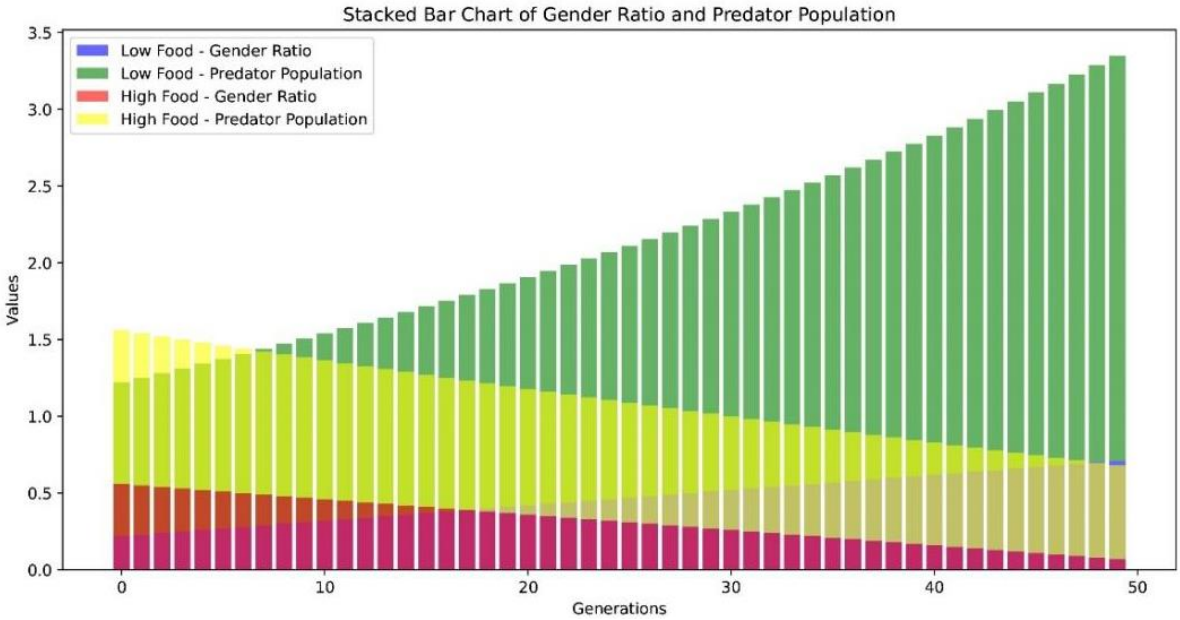

Figure 3. Impact of sex ratio on food chains

As can be seen in Figure 3, food availability directly affects the male-to-female ratio of species in the ecosystem and further affects the number of top predators through the food chain. This dynamic state of equilibrium reveals the vulnerability of the ecosystem and its inherent complexity, while also demonstrating the sensitivity of species to environmental change.

4.2. Impact of sex ratio on species growth

To minimize the potential for random experimental errors, we utilized MATLAB to iteratively calculate the reproductive rate of the seven-gill eel across 100 generations. In addition, to more clearly illustrate how sex ratios affect species growth and the resulting impacts on ecosystems, we mapped the distribution of species growth, as shown in Figure 4.

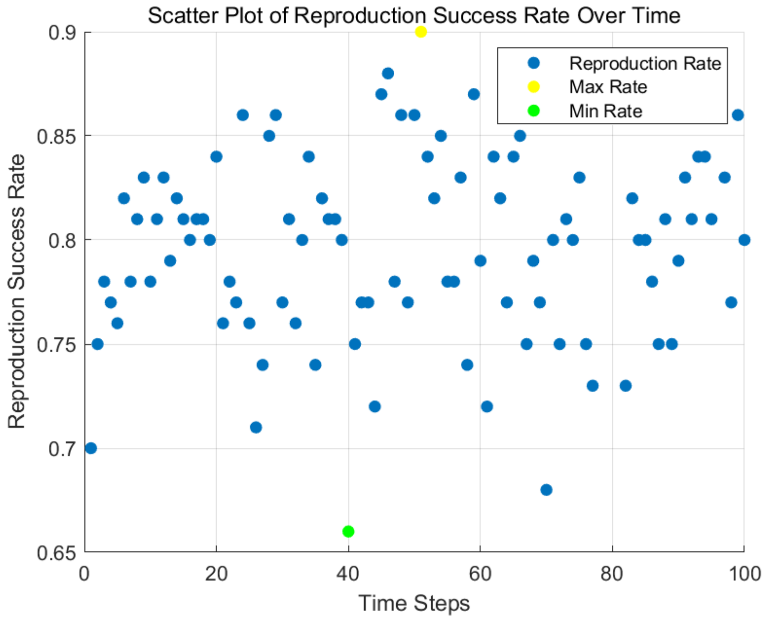

Figure 4. Seven-gill eel species growth distribution map

From Figure 4, it is evident that the reproductive rate exhibits a gradual rise followed by a gradual decline, resembling a cyclic fluctuation akin to waves. This pattern suggests that an optimal sex ratio contributes to heightened reproductive success, leading to a rapid upsurge in population size. Simultaneously, this growth consumes limited resources, eventually reaching or surpassing the environmental carrying capacity. Exceeding this capacity can lead to resource depletion, diminished individual health and survival, and ultimately, population decline. Consequently, a cascade of reactions may ensue, potentially disrupting the ecosystem's equilibrium [7-8].

Additionally, to more lucidly illustrate how the sex ratio influences species growth and, by extension, the ecosystem, we have developed flow charts, encapsulated in Figure 5.

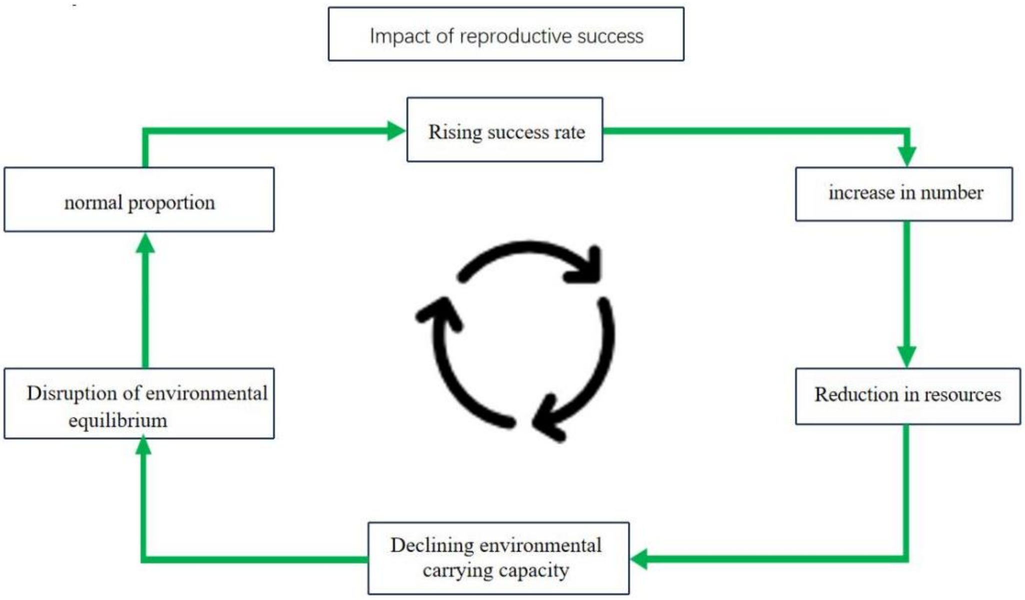

Figure 5. Effects of reproductive success

4.3. Impact of sex ratio on food resources

The iterative calculation of the relationship between sex ratio and food resources was conducted using MATLAB, and the results are presented in Figure 6. In this figure, each spoke's length represents the level of food availability in a particular scenario. Longer spokes indicate higher food availability, while shorter spokes signify lower food availability. By comparing the lengths of these spokes, one can visually assess the variations in food supply across different scenarios [9].

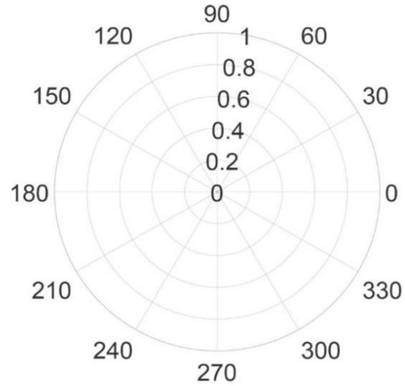

Figure 6. Relationship between sex ratio and food quantity

As depicted in Figure 6, the sex ratio undergoes a shift when the population consists entirely of males, and there is a gradual increase in food resources as the proportion of females in the population rises.

4.4. Synthesized assessment

Following an extensive examination of sex ratios and their repercussions on ecosystems, we have ascertained that sex ratios constitute a pivotal factor influencing numerous facets of ecosystems. To thoroughly gauge the ramifications of sex ratio variations on ecosystems, we amalgamated sex ratios with other elements that impinge upon ecosystems and executed an all-encompassing analysis [10]. Through this integrated approach, we formulated a comprehensive ecosystem evaluation model, aimed at portraying with greater precision the repercussions of sex ratio alterations on the entire ecosystem when entwined with multiple other factors. The effect of sex ratio on the ecosystem was meticulously computed iteratively via MATLAB, as illustrated in Figure 7.

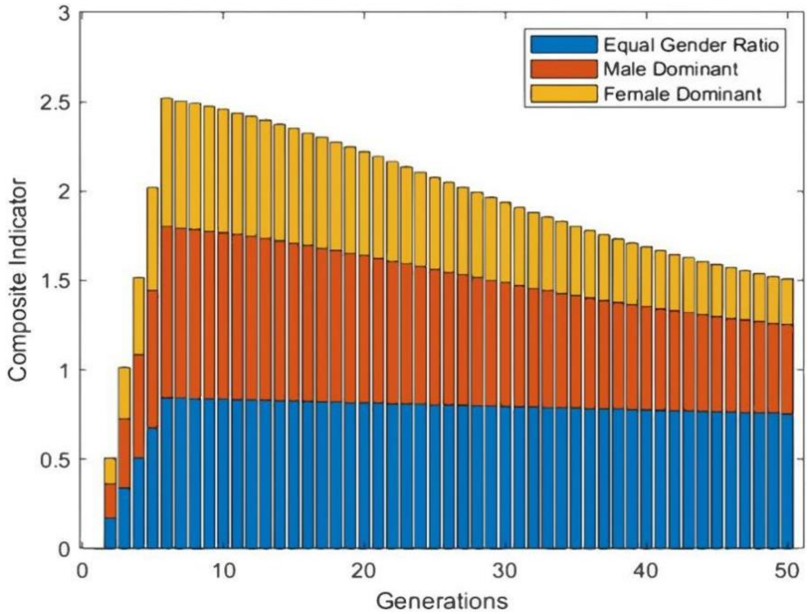

Figure 7. Correlation of different sex ratios with ecosystem change

From Figure 7, it is evident that the influence exerted by females on the ecosystem is comparatively less pronounced than that of males, with the most substantial impact occurring when the sex ratio is balanced at 1:1.

Upon scrutinizing the factors affecting ecosystems in response to variations in sex ratios, it was discerned that the developed model carries some degree of error. The model stems from an intricate analysis of the interplays among diverse ecosystem components, considering how various ecological factors intertwine with one another and the role that sex ratio changes assume within them. Alterations in sex ratios directly impact reproductive success, subsequently shaping the food chain's structure and energy flow, ultimately affecting the ecosystem's overall functionality. While the model is reasonable, accurate, and to some extent, capable of depicting the wider ecosystem impacts induced by sex ratio changes, it serves as a valuable reference for investigating ecosystem interactions resulting from sex ratio shifts.

5. Conclusion

In this paper, an integrated ecosystem model was constructed by combining the species growth and development model based on logistic regression model with an integrated prediction model. It also analyzed the effects of the sex ratio of the seven-gill eel on the stability and function of the ecosystem and revealed its ecological significance by simulating and predicting the dynamic food chain structure of the seven-gill eel population and changes in food resources under different sex ratios.

Future studies need to collect more real data as support to ensure that the data input to the model are more accurate and reliable, especially about the population dynamics and food chain structure of the seven-gill eel. We will also consider introducing more factors that may affect the population dynamics and food chain structure of the seven-gill eel, such as climate change and human activities, in order to construct a more comprehensive ecosystem model that better reflects the complexity of the real ecosystem. For the constructed species growth and development model and the parameters of the integrated prediction model, the prediction accuracy and stability of the model will be improved in the future through finer tuning and model training. The comprehensive ecosystem model will more accurately assess the impact of the sex ratio of seven-gill eels on the ecosystem and provide a more reliable scientific basis for ecological protection and management.

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