Ecosystem Impacts of Changes in the Sex Ratio of Lampreys Based on Logistic and TOPSIS Models

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Abstract. This paper has investigated the significant sex ratio changes shown by lampreys under specific environmental conditions, and has analysed the impacts of lampreys on the ecosystem. It has explored the effects of changes in its sex ratio on food resource use, food chain structure, reproduction rate, and habitat use based on an ecosystem model of logistic modelling, thus revealing the major adjustments in ecological balance and impacts on system stability that may result from changes in sex ratio. This paper has further applied the TOPSIS model to parasitoids to analyse the potential advantages that changes in sex ratios bring to other species within the ecosystem, including the effects on food webs, ecological niches, parasitism processes and system health. The results of this study suggest that changes in the sex ratio of lampreys can provide advantages to specific species (especially parasitic species) through a variety of mechanisms.

Keywords: Lampreys, Logistic Model, TOPSIS Model, Change in Sex Ratio.

1. Introduction

Exploring changes in species sex ratios and their ecological impacts is becoming a key topic in ecology [1]. Particularly for species such as the lampreys, which show significant sex ratio changes under specific conditions, studies can reveal the effects of sex ratio changes on ecosystem function and stability. Current research focuses on understanding how these changes affect the internal dynamics of species and their interactions with other components of the ecosystem [2], and the integrated impacts at the level of the whole ecosystem are not well understood, especially in terms of how to accurately quantify the impacts of these changes on ecosystem services and functions [3].

Based on the above background and the current state of research, this paper analyses the impacts of changes in the sex ratio of the lampreys on the larger ecosystem in various ways using an ecosystem model based on a logistic model, while using a TOPSIS model to assess the advantages that changes in the sex ratio provide to other species (e.g., parasitoids). These analyses aim to refine our understanding of the ecological consequences of changes in sex ratios and provide scientific support for related ecological management.

2. An ecosystem model based on the Logistic model

In order to explore the impacts of changes in the sex ratio of the lampreys on the larger ecosystem, this paper established a population dynamics model and a sex ratio model based on a logistic model, and combined these two models to form a final ecosystem model. Using this model, this paper analysed the effects of sex ratio on food resources, food chain, reproduction rate, habitat use (area occupation), and habitat use (breeding area occupation). Finally, this paper comprehensively analysed the effects of changes in sex ratio on the overall environment, and at the same time, gave the corresponding comprehensive indicator ratings.

2.1. The establishment of an ecosystem model

2.1.1. The establishment of a population dynamics model

Population dynamics modelling is a key tool in the study of ecosystem complexity and mechanisms [4]. In this paper, we used a Logistic model to analyse the ecological impacts of changes in the sex ratio of lampreys. The model presupposed that population growth was limited by environmental capacity and provided a mathematical framework for growth stability. Specifically:

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

Among them, N is the population size, t is time, r is the intrinsic growth rate of the population, and K is the environmental holding capacity (the maximum amount of population that can be supported in the environment).

The model solution is:

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

Among them, N_0 is the initial population size (at t =0).

By using a logistic model as a background for population dynamics modelling, this paper analyses the effects of changes in the sex ratio of the lampreys on its food chain position, reproductive rate, habitat efficiency and ecosystem stability and diversity.

2.1.2. The establishment of a sex ratio model

In analysing the complexity of the interactions between population dynamics and sex ratio in ecosystems, understanding changes in sex ratio is essential for predicting population trends and maintaining ecological balance [5]. This paper also employed a logistic-based sex ratio model to explore how resource availability affected the sex ratio of lamprey's larvae, providing a new perspective for understanding sex differentiation under resource constraints and enhancing the overall understanding of population dynamics.

The logistic model used in this paper has the property of describing the development of a specific biometric trait as an S-shaped curve [6]. In this paper, the model has been applied to analyse the probability of a lamprey larva developing into a female, viz:

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

Among them, $P(\mathrm{t})$ is the probability of developing into a female (sex ratio), r is the rate of growth, and t_0 is the time when the sex ratio began to change.

To account for the effect of ambient temperature on sex ratio, the model was extended as follows:

$$P(\mathrm{t},\mathrm{T}) = \frac{1}{1+e^{-r(T)(t-t_0)}} \tag{4}$$

Among them, $\mathrm{r}(T)$ indicates the effect of temperature T on developmental rate.

Through sex ratio modelling, this paper was able to quantitatively describe the dynamics of sex ratios as a function of environmental conditions, and considered the effects of ambient temperature to enhance the applicability and accuracy of the model. This model provided a new way to understand how resource availability affects developmental rates and thus sex ratio, and provided an important tool for exploring the relationship between population dynamics and resources in ecosystems [7].

2.1.3. The establishment of an integrated ecosystem model

Based on the population dynamics model and sex ratio model introduced above, this paper constructed an integrated ecosystem model to explore the combined impacts of resource availability and changes in lampreys sex ratio on the ecosystem. The model key integrated four major aspects: food web analysis, population dynamics, resource availability and ecological niche, and reproductive behaviour, aiming at a comprehensive understanding of the impacts of changes in the sex ratio of the lampreys on the ecosystem through multiple mechanisms, and providing scientific support for ecological conservation and management.

2.2. Model results and analyses

Using the ecosystem model developed, this paper analysed the impact of changes in the sex ratio of lampreys on the larger ecosystem in a number of ways. The results are shown in the fig below:

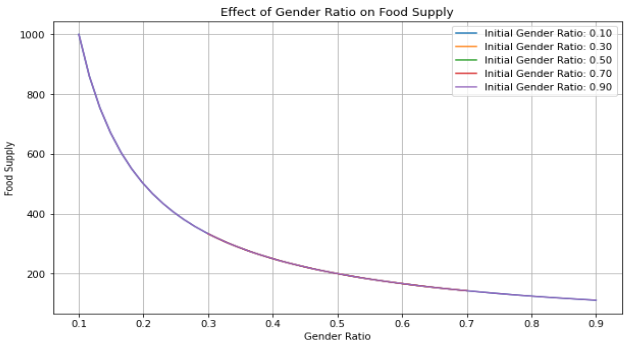

Figure 1. Sex ratio affects food resources

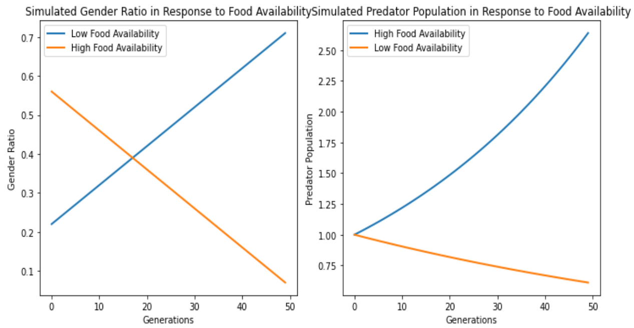

Figure 2. Sex ratio affects food chains

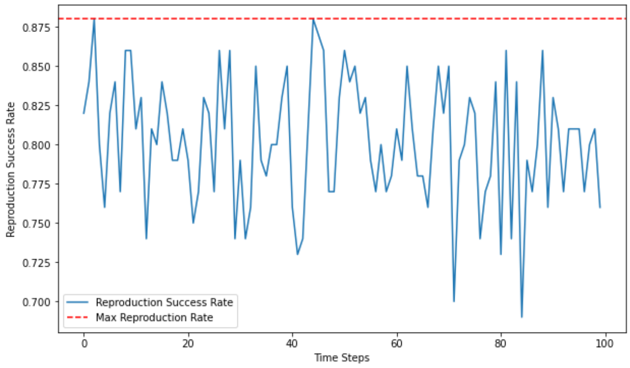

Figure 3. Sex ratio affects reproduction rate

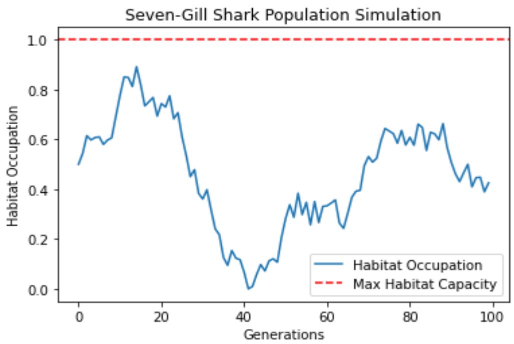

Figure 4. Sex ratio affects habitat use (Area occupied)

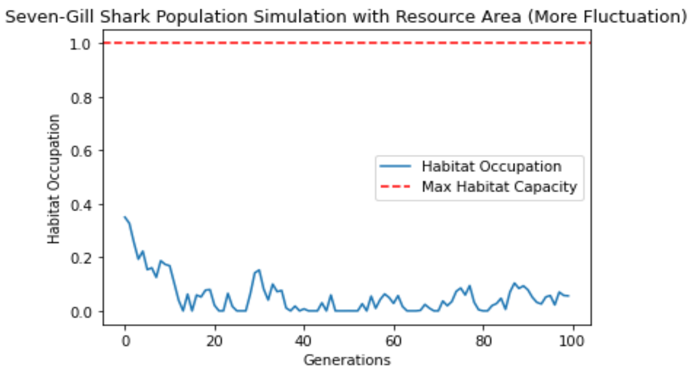

Figure 5. Sex ratio affects habitat use (Breeding area occupancy)

The analyses showed that the increase in male ratio of lampreys was associated with changes in a number of ecological parameters. Fig 1 showed that the increase in male ratio was accompanied by a decrease in food availability, indicating that sex ratio had a significant effect on food resources. Fig 2 revealed that the increase in male ratio led to a decrease in the number of predators feeding on lampreys in times of insufficient food availability, while a decrease in male ratio contributed to an increase in the number of predators in times of sufficient food, thus confirming that sex ratio had a direct effect on the food chain. Fig 3 shows that changes in sex ratio are associated with fluctuations in population reproduction rates, and Fig 4 and Fig 5 further show that an increase in the proportion of males leads to a decrease in habitat size and use of breeding areas, implying that sex ratio plays a key role in habitat use. These findings emphasise the importance of sex ratio regulation for understanding and predicting ecosystem dynamics.

After completing the specific analyses of each aspect, this paper will analyse the impact of the gender ratio on the overall environment in a comprehensive manner, along with a comprehensive indicator rating, the results of which are shown in the figure below:

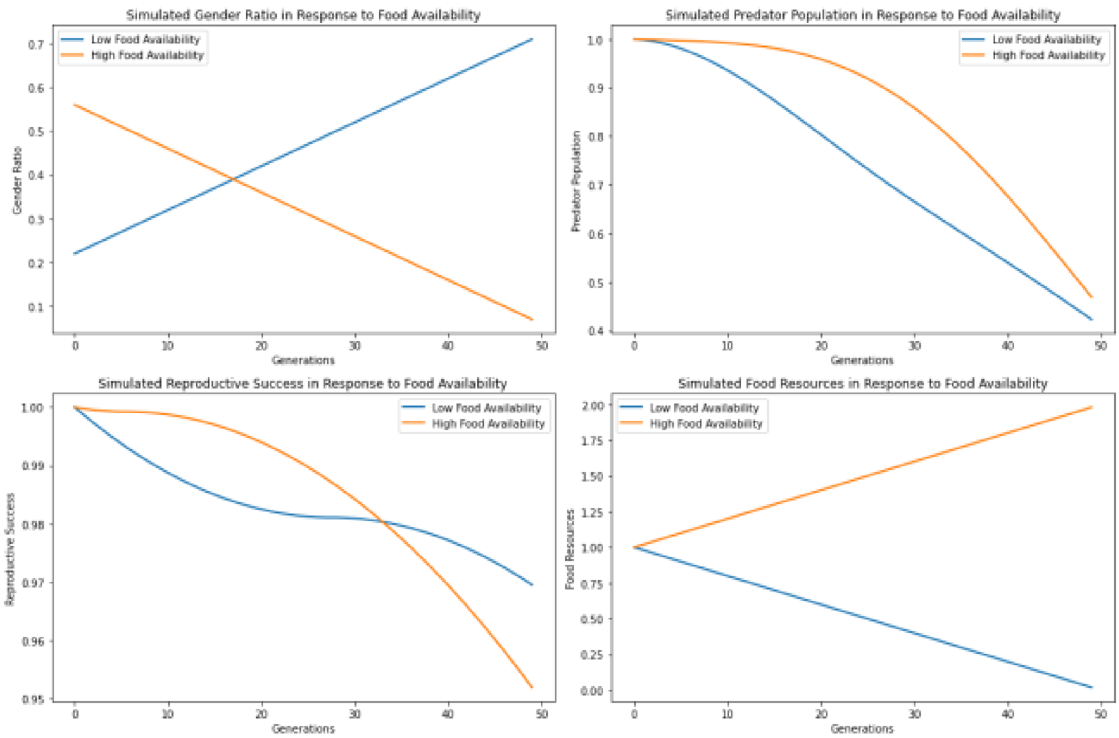

Figure 6. Integrated analysis of impacts on the overall environment

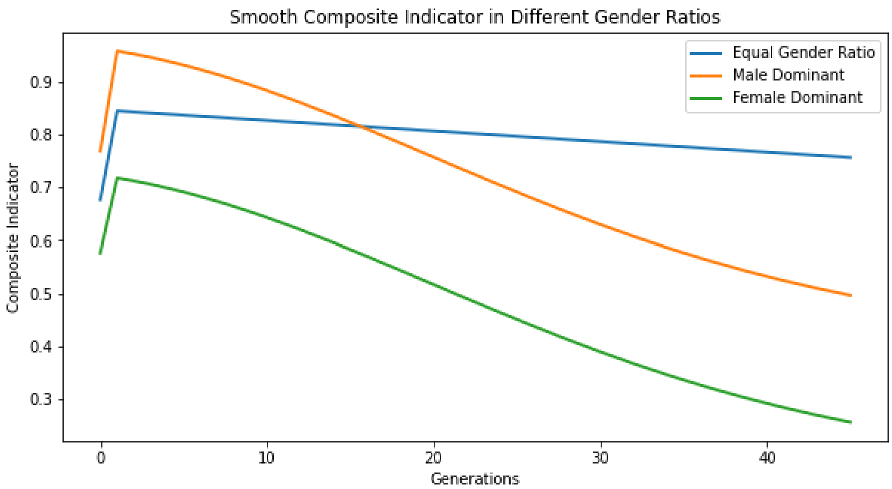

Figure 7. Composite indicator ratings

Taken together Fig 6 and Fig 7, the results of the study clearly demonstrate the effects of the sex ratio of the lampreys on food resources, the food chain, reproduction rates, and habitat use (both total area and breeding area). Together, these graphs reveal that ecological conditions significantly improve when the male ratio decreases (i.e., approaching male-female balance). This finding highlights the critical role of sex ratio balance in maintaining ecosystem health and stability.

2.3. Conclusions of the model

Through the use of ecosystem model, this paper revealed the significant impacts of changes in the sex ratio of lampreys on the ecosystem, and summarized the key conclusions as follows:

(1) Changes in ecological balance

The change in sex ratio of lampreys affected the groups of organisms in the food web, which was crucial for the balance of the ecosystem and the maintenance of biodiversity.

(2) Food chain effects

Sex ratio adjustments affected their role as a food source, which in turn affected predator populations and energy and material flows.

(3) Breeding rate

An imbalance in sex ratio affected reproductive success, which was related to population survival and species interactions within the ecosystem.

(4) Habitat uses

Sex ratio changes affected habitat use patterns, species diversity, and habitat quality.

(5) System stability

Changes in sex ratio might reduce ecosystem resistance, increase vulnerability, and affect sustainability.

These findings emphasised the importance of considering sex ratio changes in ecological management and conservation, and provided insights for biodiversity conservation.

3. The establishment of a TOPSIS model

In order to explore the advantages provided by changes in the sex ratio of the lampreys to other species (e.g., parasitoids), this paper chose parasitoids as the object of study and opted to build a TOPSIS model.Because it is commonly used in multi-attribute decision problems [8], which is exactly the direction of this paper.

3.1. Selection of evaluation indicators

When considering the interrelationships among various organisms in the ecosystem and the effects of changes in the sex ratio of the lampreys on these relationships, the evaluation indicators chosen are critical [9]. After reviewing a large amount of information and expert assessment, the final evaluation indicators were determined as follows:

(1) Impact of food webs

Describe the predation relationship between individual organisms in the ecosystem.

(2) Ecological niche change

Describes the predation relationship between individual organisms in the ecosystem, emphasising the ecological niche change.

(3) Parasite transmission

Parasite loads and sex ratios of male and female lampreys were used to simulate trends in parasite populations.

(4) Ecosystem health

Taking into account the effects of food webs, ecological niche changes and parasite transmission, this paper simplifies them into competitive and cooperative relationships for assessing the overall health of ecosystems.

3.2. The establishment of an index model

Changes in the sex ratio of lampreys may lead to changes in their predatory behaviour, which may affect the abundance and variety of species they prey on. This may have a direct impact on other fish, crustaceans and other organisms in the ecosystem [10].

On the basis of food webs, this paper considered that the ecological niche of the lampreys in the ecosystem might change due to changes in the sex ratio, and used the NetworkX and Matplotlib libraries to create and visualise a food-web diagram with ecological niche changes, which described the predatory relationships among the organisms in the ecosystem, as shown in Fig 8.

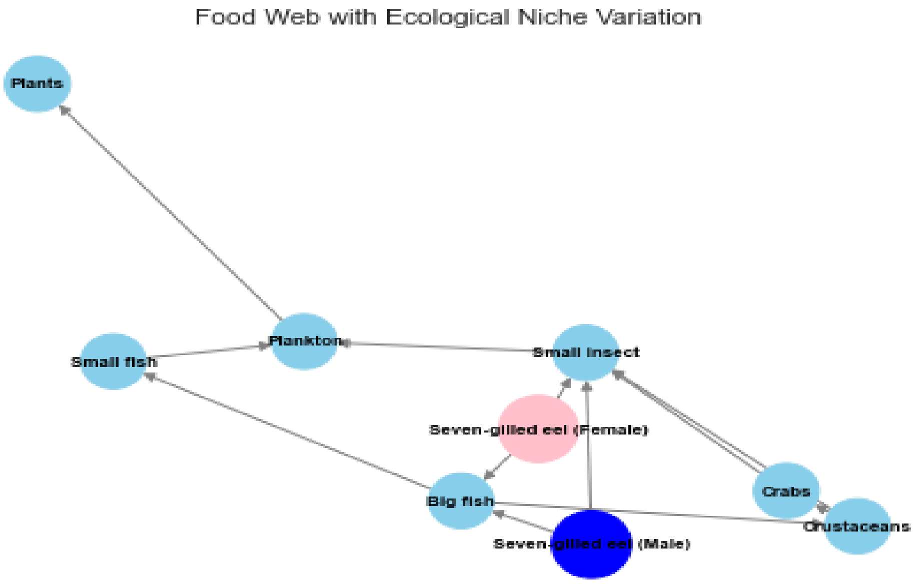

Figure 8. Ecological niche construction

If lampreys are intermediate hosts for certain parasites, changes in sex ratio may affect parasite transmission and life cycle.For parasite transmission, in order to simulate the change in parasite population over time, this paper used the NumPy library to create an array named parasite_population to represent the change in parasite population over time.The dynamics of parasite populations were simulated by setting parasite loads and sex ratios of male and female lampreys, according to which the trends of parasite population changes were investigated to better understand the effects of sex ratios on parasite populations in the ecosystem,as shown in Fig 9.

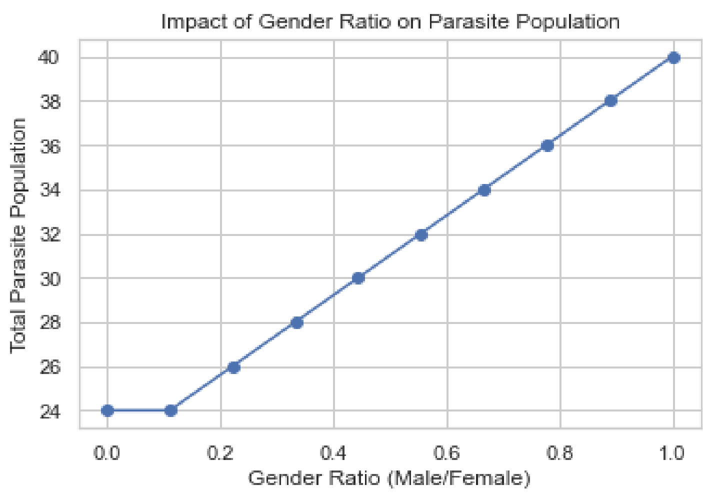

Figure 9. Variation of parasite population with sex ratio

Competitive and co-operative relationships between lampreys and with other species may be affected by changes in sex ratios, which in turn affect the overall health of the ecosystem.This paper used NetworkX and the Matplotlib library to create and visualise a dichotomous diagram to visualise the competitive and cooperative relationships between the lampreys and other organisms,as shown in Fig 10.

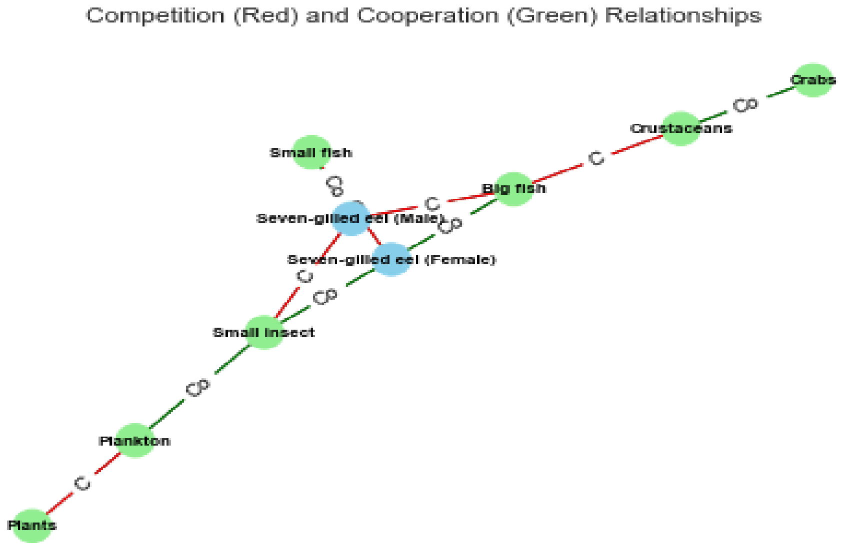

Figure 10. The construction of competitive and cooperative relationships

3.3. Model solution

After obtaining the model for each indicator, expert assessment and literature data are collected to form a decision matrix X containing the values of the four evaluation indicators in different scenarios, which is then solved step by step.

(1) The decision matrix X is normalised to obtain the normalised decision matrix R:

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{5}$$

For the four evaluation indicators, the expert assessment method was used to provide values for each indicator in different scenarios, combined with the existing literature, and the evaluation indicators and the corresponding values were formed into a tabular form for variable extraction.

(2) The standardised decision matrix R was weighted to obtain the weighted normalised decision matrix Y:

$$Y_{ij} = \omega_j \times R_{ij} \tag{6}$$

Among them, ω_j is the weight of the jth attribute.

The extracted independent and dependent variables were standardised to ensure that they were on the same scale to avoid the evaluation being affected by differences in scale.

(3) Calculate the positive ideal solution and the negative ideal solution:

$$A_j^+ = max_i(Y_{ij}) \tag{7}$$

$$A_j^- = \min_i(Y_{ij}) \tag{8}$$

The standardised variables were subjected to the determination of the ideal solution, which was used for the subsequent calculation of the scores for each scenario.

(4) Calculate the Euclidean distance from each solution to the positive and negative ideal solutions:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (Y_{ij} - A_j^+)^2} \tag{9}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (Y_{ij} - A_j^-)^2} \tag{10}$$

(5) Calculate a composite score for each solution:

$$C_i = \frac{D_i}{D_i^+ + D_i^-} \tag{11}$$

The score reflects the composite performance of each scenario relative to the positive and negative ideal solutions, i.e., the composite performance of the effects of changes in the sex ratio of lampreys on parasite populations under each scenario with different weightings for the effects of the physical network, ecological niche alteration, parasite transmission, and ecosystem health,as shown in Table 1.

Table 1. Comprehensive Score& Rank

Target / Num	Gender Ratio Change	Competition Complexity	Parasite Population Change	Food Web Complexity	Score	Rank
0	0.2	0.3	0.1	0.2	0.000000	5
1	0.4	0.5	0.3	0.4	0.244710	4
2	0.6	0.7	0.5	0.6	0.487898	3
3	0.8	0.9	0.7	0.8	0.725602	2
4	1.0	1.0	1.0	1.0	1.0	1

(6) Sorted: Each solution was sorted according to its overall score, and the highest-ranked solution was selected as the best solution,as shown in Fig 11.

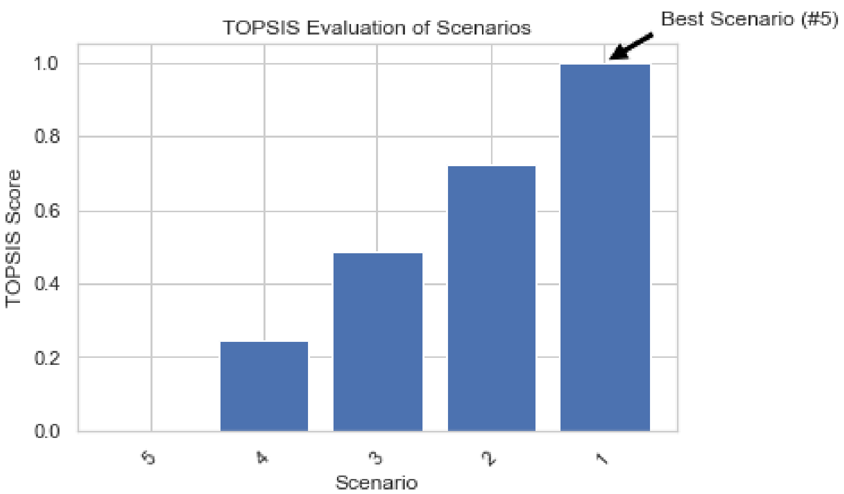

Figure 11. TOPSIS Composite Evaluation Scores

3.4. Analysis of TOPSIS model

The results show that changes in the sex ratio of lampreys can indeed provide advantages to other species (e.g., parasitoids), depending on a number of factors such as the ecological roles of the lampreys, changes in predation and parasitism behaviours, adaptations of the parasitoids, and ecosystem feedbacks. Changes in the sex ratio of lampreys may increase the number of females, facilitating host provisioning for parasites; lampreys of different sexes may exhibit different predation and parasitism behaviours, affecting parasite dispersal and host selection; parasites may exhibit adaptations to changes in the sex ratio of lampreys, thereby increasing their parasitism success; and changes in population dynamics of lampreys may have a cascading effect on other species, thereby affect parasite abundance and distribution.

4. Conclusion

This paper explored the effects of changes in the sex ratio of the lampreys on the balance of the ecosystem as well as the potential impacts on other species, especially parasitoids, through the analyses of an ecosystem model based on the logistic model and the TOPSIS model. It was found that changes in the sex ratio of lampreys had significant impacts on food web structure, energy flow, species interactions, reproductive success and habitat use, which not only concerned the survival and reproduction of a single species, but also affected the stability and biodiversity of the whole ecosystem.TOPSIS model analyses showed that changes in the sex ratio of lampreys provided other species in the ecosystem, especially the parasitoids, with specific advantages that may directly or indirectly affect the life cycle and distribution of parasites by influencing the number of individuals, predation and parasitism behaviours, host selection of parasites, and adaptive changes. In summary, this study highlights the important role of changes in sex ratio of lampreys in maintaining ecosystem function, promoting biodiversity and influencing survival strategies of other species, providing a scientific basis for ecological conservation and resource management.

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