The Influence of Competition Trait-Mediated Effects on Intra-Guild Predation System

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Research Article

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Posted Date: August 31st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-799016/v1

The influence of competition trait-mediated effects on intra-guild predation system

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[Abstract] Parasitism can affect the population dynamics in many ways, and its indirect effect is easy to be ignored, that is, it can weaken the host's behavior, physiology and psychology to affect the whole population. In this paper, we build a differential equation model by adding four parameters to study the influence of multiple competitive relationships on the predator-prey system, It includes the enhancement effect g of intraspecific competition and the enhancement effect h of interspecific competition between susceptible population and infected population, the weakening effect m of intraspecific competition and the weakening effect n of interspecific competition between susceptible population and infected population. Through the analysis, it can be concluded that a single g or m can promote the symbiosis of predator and prey, a single h has little effect on the population dynamics, and a single n is not conducive to the symbiosis; The fusion of g and h promotes coexistence, but the fusion of m and n is on the contrary; Interestingly, the combination of multiple regulatory parameters has a chemical effect on the survival of species, but the combination of g, m and h can inhibit coexistence, while the combination of g, m and n can promote coexistence. The reason is that the combination of parameters is not a simple addition of effects, but a prerequisite for mutual influence. To sum up, the research content provides a reference for considering the role of multiple factors, and provides theoretical guidance for explaining ecological phenomena and proving ecological conclusions.

[Key words] Competition function; Multiple factors; Chemical reaction;

1 Introduction

Parasitism plays an important role in the development of ecology and plays a regulatory role in some ecological phenomena. The biological invasion of many aquatic and terrestrial species is inseparable from the influence of parasitism [1,2]. When a new species begins to invade, the virus carried in its body may have a fatal impact on the local native species with the same niche, thus the invasion is successful, For example, the invasion of North American grey squirrels in the United Kingdom and Ireland led to a sharp decline in the number of local red squirrels. Biological invasion was accompanied by parasitic invasion, which would change the traits of local species [3,4]. The existence of many ecosystems also has the influence of parasitism, such as the predator-prey system in the group [4,5]. One of the reasons that this system can widely exist in nature is that it is directly or indirectly regulated by parasitism. For example, density regulation, intraspecific or interspecific predation regulation. Previous studies have shown that the change of single trait has an impact on the coexistence results of predator-prey system in a group [6]. However, parasitic infection affects all the traits of the host, not just a single trait [7-9]. Just as the survival of organisms in nature is not only affected by predators or prey, but also by most organisms in the whole living environment. Therefore, it is more practical to study the fusion effect of multiple feature changes.

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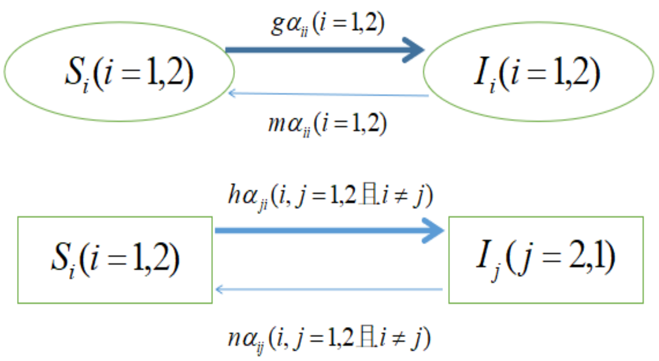
In this paper, four parameters are introduced to establish a new model, and the indirect effect of parasitic competition on the predator-prey system is studied. The sketch is as follows:



Model parameter sketch. The arrow indicates the direction of competition and the bold indicates the enhancement effect of competition($g,h>1$) ,The smaller one indicates the weakening effect of competition $(m,n<1)$,$\alpha_{ij}(i,j=1,2)$ indicates the intraspecific or interspecific competition parameters of species j to species i. The subscript 1 denotes the prey population and the subscript 2 denotes the predator.

2 Model and simulation

In order to study the influence of the variety of competition traits of parasitic regulation, a new model was established by adding corresponding parameters in Hatcher et al. [6]:

$$\frac{dS_1}{dt}=r_1[N_1-(\alpha_{11}S_1^2+g\alpha_{11}I_1S_1+m\alpha_{11}S_1I_1+\alpha_{11}I_1^2)-(\alpha_{12}S_1S_2+h\alpha_{12}I_1S_2+n\alpha_{12}S_1I_2+\alpha_{12}I_1I_2)]$$

$$-\mathrm{k}S_1N_1+ekN_1^2-\gamma_{12}S_1N_2+e\gamma_{21}N_2N_1-\beta_{11}S_1I_1-\beta_{12}S_1I_2$$

$$\frac{dI_1}{dt} = \beta_{11}S_1I_1 + \beta_{12}S_1I_2 - \mathrm{k}I_1N_1 - \gamma_{12}I_1N_2 - \Omega_1I_1$$

$$\frac{dS_2}{dt} = r_2[N_2 - (\alpha_{22}S_2^2 + g\alpha_{22}I_2S_2 + m\alpha_{22}S_2I_2 + \alpha_{22}I_2^2) - (\alpha_{21}S_2S_1 + h\alpha_{21}I_2S_1 + n\alpha_{21}S_2I_1 + \alpha_{21}I_2I_1)]$$

$$-\mathrm{k}S_2N_2 + ekN_2^2 - \gamma_{21}S_2N_1 + e\gamma_{12}N_1N_2 - \beta_{22}S_2I_2 - \beta_{21}S_2I_1$$

$$\frac{dI_2}{dt} = \beta_{22}S_2I_2 + \beta_{21}S_2I_1 - \mathrm{k}I_2N_2 - \gamma_{21}I_2N_1 - \Omega_2I_2$$

In the above model, the parameters of intraspecific or interspecific competition, intraspecific or interspecific infection and intraspecific or interspecific predation of species j to species i are expressed $\alpha_{ij}, \beta_{ij}, \gamma_{ij} (i, j = 1,2)$ respectively; $S_i, I_i, N_i, r_i, \Omega_i (i = 1,2)$ are the susceptible, the infected, the population density, the intrinsic growth rate and the disease mortality rate of species i; The parameters of intraspecific predation and the conversion coefficient are expressed k, e respectively. Then the mathematical software MATLAB is used to simulate and analyze the model. The values of each parameter are shown in the table below:

r_1	r_2	α_{11}	α_{22}	α_{12}	α_{21}	e	γ_{12}
1	1	0.005	0.005	0.0005	0.0005	0.3	0.015
γ_{21}	k	Ω_1	Ω_2	β_{11}	β_{22}	β_{12}	β_{21}
0.01	0.01	0	0	0.05	0.05	0.005	0.005

3 Result

3.1 The effect of the fusion of the g and h on the temporal dynamics of the population

By analyzing the three graphs in Fig. 1, we can draw the following conclusions: (1) in Fig. A, under the premise of no characteristic adjustment, the predator density increases rapidly with the passage of time, then increases slowly, and finally tends to be stable at about 83; The prey first increases to about 30, then decreases rapidly, and finally tends to extinction. The time is about 50, which is mainly due to the predator. (2)In Figure B, after considering the enhancement effect of intraspecific and interspecific competition between susceptible individuals and infected individuals, the general change pattern of predator and prey is very similar to that in figure A, but the most obvious difference is that the prey can coexist with predator; Although the density of the prey in equilibrium is very low, about 8, it is the existence of this part of the prey that leads to the decrease of the density of the predator in equilibrium, about 74. The main reason is that the competition between the susceptible predator and the prey against the infected predator increases, which makes the density of the infected predator decrease, and the overall density of the predator also decreases, which is not enough to make the prey completely extinct, resulting in the difficult survival of the prey at a lower density. The competition between the susceptible predator and the prey makes the infected prey almost extinct, and almost all the surviving prey are susceptible to infection and have strong survival ability. (3) With the increasing intraspecific and interspecific competition between susceptible individuals and infected individuals, the overall density of predators decreased, while the density of prey increased. In a word, the fusion of g and h is beneficial to the survival of the prey, but disadvantageous to the survival of the predator.

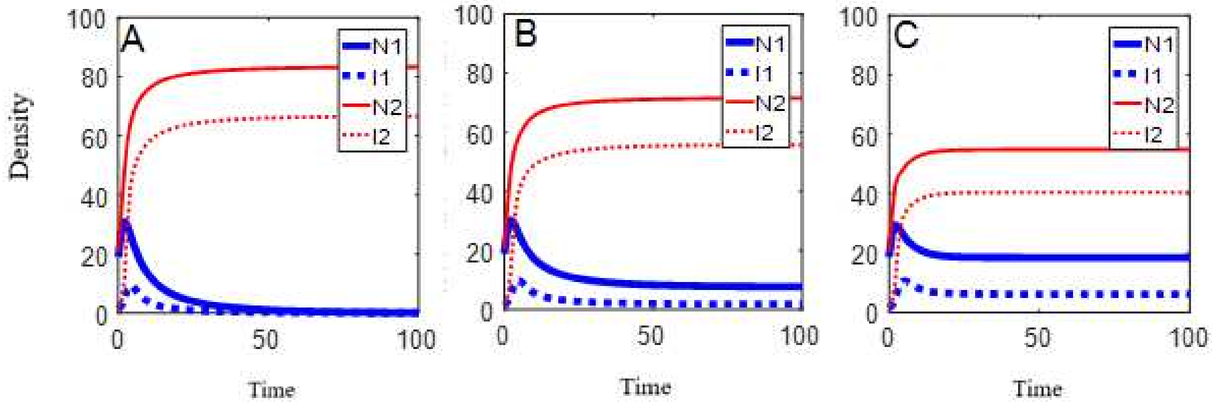


Fig. 1 The competitive traits of two kinds of susceptible to infection and the influence of regulatory parameters on the population. (A) The influence of g and h is not considered ($g = h = 1$) ; (B) Consider the influence of g and h。 ($g = h = 2.5$) ; (C) The effect of g and h was further enhanced ($g = h = 5$)。 Parameter : $m = n = 1$. The values of other parameters are shown in the table above.

3.2 The effect of the fusion of the m and n on the temporal dynamics of the population

By analyzing the three graphs in Fig. 2, it can be concluded that with the increasing intraspecific and interspecific competition between the infected and the susceptible, the overall density of predators is increasing, and the densities of both the susceptible and the infected predators are increasing, which indicates that the fusion of m and n is beneficial to the survival of predators. However, on the contrary, the extinction time of the prey is advancing, which indicates that the fusion of m and n is not conducive to the survival of the prey. In a word, the fusion effect of m and n is opposite to that of g and h。

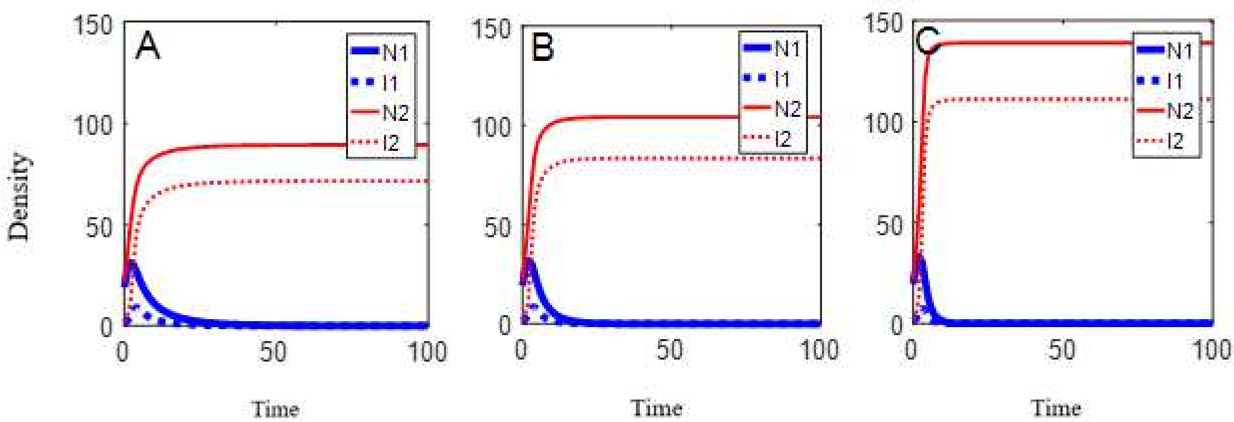
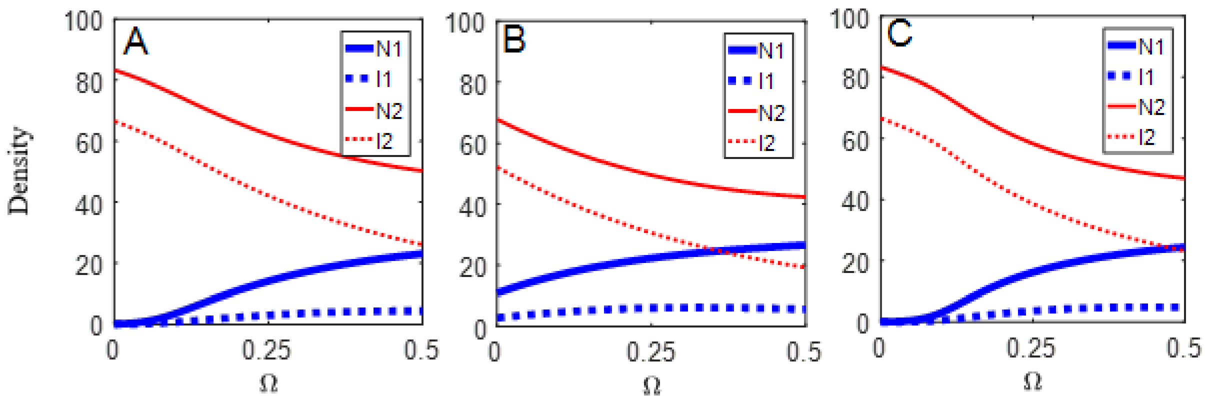


Fig. 2 Competitive traits of two infected individuals against susceptible individuals and the influence of regulatory

parameters on population。(A) The influence of m and n is not considered ($m = n = 0$) ; (B) Consider the influence of m and n ($m = n = -2$) ;(C) The effect of m and n was further enhanced ($m = n = -5$)。Parameter : $g = h = 1$. The values of other parameters are shown in the table above.

3.3 Effects of single characteristic adjustment parameter and extra lethal rate on population density

The host will die after infection because of toxicity. Some of them have low toxicity and will not die immediately after infection; some of them are highly toxic and have a high mortality rate after infection; Therefore, it is necessary to study the effect of the fusion of different lethality and trait regulation on the dynamic relationship between predator and prey. It is assumed that the lethality of parasite to predator and prey is the same, $\Omega_1 = \Omega_2 = \Omega$, $0 \ll \Omega \ll 0.5$。It can be seen from Fig. 3A that when there is no trait-mediated effect, the predator density gradually decreases with the increase of lethality, and the prey transits from extinction to coexistence with predators. Within a certain range, the stronger the parasitic toxicity is, the better the survival of the prey is. From 3B and F, it can be concluded that the prey can survive in the whole definition of Ω, which indicates that the characteristic adjustment parameters g and n are conducive to the harmonious coexistence of predator and prey, and the effect of g is slightly stronger than that of n. It can be concluded from Fig. 3C, D that the parameter h has little effect on the relationship between predator and prey. When h = 10, the change graph of the two species is almost the same as that in Fig. 3A, which indicates that the species relationship is not sensitive to the change of interspecific competition intensity between the susceptible and the infected. Even when h = 50, there is only a weak effect of the short-term drastic change of predator and prey density. Combined with the conclusion in Figure 1, we can see that g plays a decisive role in promoting the fusion of g and h. The obvious conclusion in Fig. 3E is that m is not conducive to the survival of the prey, even when Ω = 0.5, there is no shadow of the prey. m has a strong inhibitory effect on coexistence, and even can counteract the effect of n on coexistence.



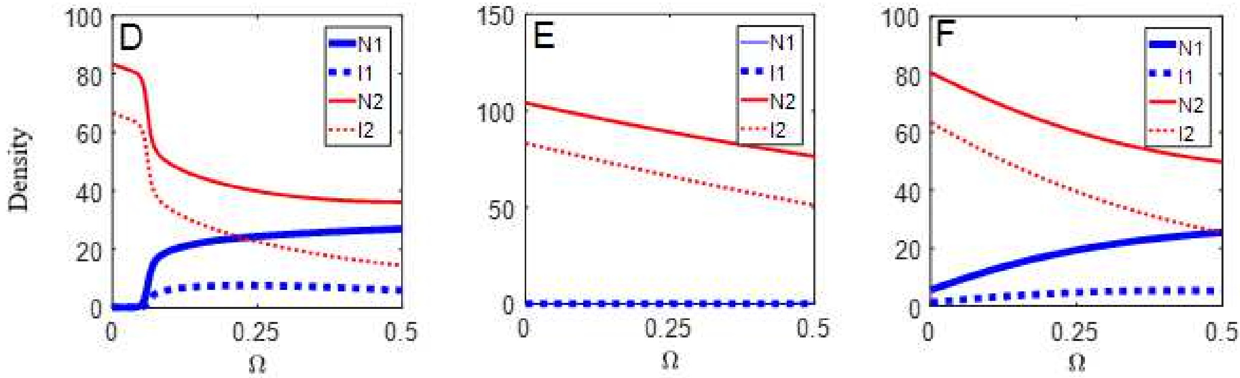


Fig. 3 The effect of the additional lethal rate on the population density by fusing a single trait-mediated parameter。(A) Without trait-mediated effect ($g = h = m = n = 1$) ; (B) With trait-mediated effect of g ($g = 3, h = m = n = 1$) ; (C) With trait-mediated effect of h ($h = 10, g = m = n = 1$) ; (D) With trait-mediated effect of larger h ($h = 50, g = m = n = 1$) ;(E) With trait-mediated effect of m($m = -2, g = h = n = 1$) ;(F) With trait-mediated effect of n ($n = -2, g = h = m = 1$)。 The values of other parameters are shown in the table above。

3.4 The coexistence region is affected by the fusion of multiple trait-mediated effects

Intrinsic growth rate can directly affect the species density, so it can have an important impact on the survival of species, the relationship between populations, community structure, ecological relations and so on. Next, we study the mechanism of species coexistence in the intrinsic growth rate parameter space of predator and prey changing with the fusion effect of characteristic adjustment parameters. The range of the two is $0.5 \ll r_1 \ll 1.5, 0 \ll r_2 \ll 1$ through the six figures in Figure 4, we can get the general change trend: with the increase of r_1 The survival dynamics of predator and prey are as follows: predator wins transition to coexistence state, and then transition to prey wins; With r_2 However, with the increase of 2, the change is completely opposite. Comparing with Fig. 4A and F, it can be seen that the fusion of g, h and m is not conducive to the coexistence of species. The main reason is that the susceptible predators and prey exclude the infected number and increase the susceptible number through intraspecific competition, which eventually leads to the positive conflict between predators and prey. It is obvious that predators have the advantage. However, through the previous analysis, we can see that g and m can promote coexistence, and h has little effect on the dynamic image of predator and prey, which indicates that the effect of the fusion between parameters on the population dynamics is not a simple addition of 1 + 1 = 2, but a more complex chemical reaction. Similarly, by comparing Fig. 4C, D, E and F, it can be concluded that the fusion of h, m and n, the fusion of g, m and n, and the fusion of g, h, m and n can inhibit the coexistence of species to a certain extent; Compared with Fig. 4B and F, the fusion of g, h and n is favorable for coexistence.

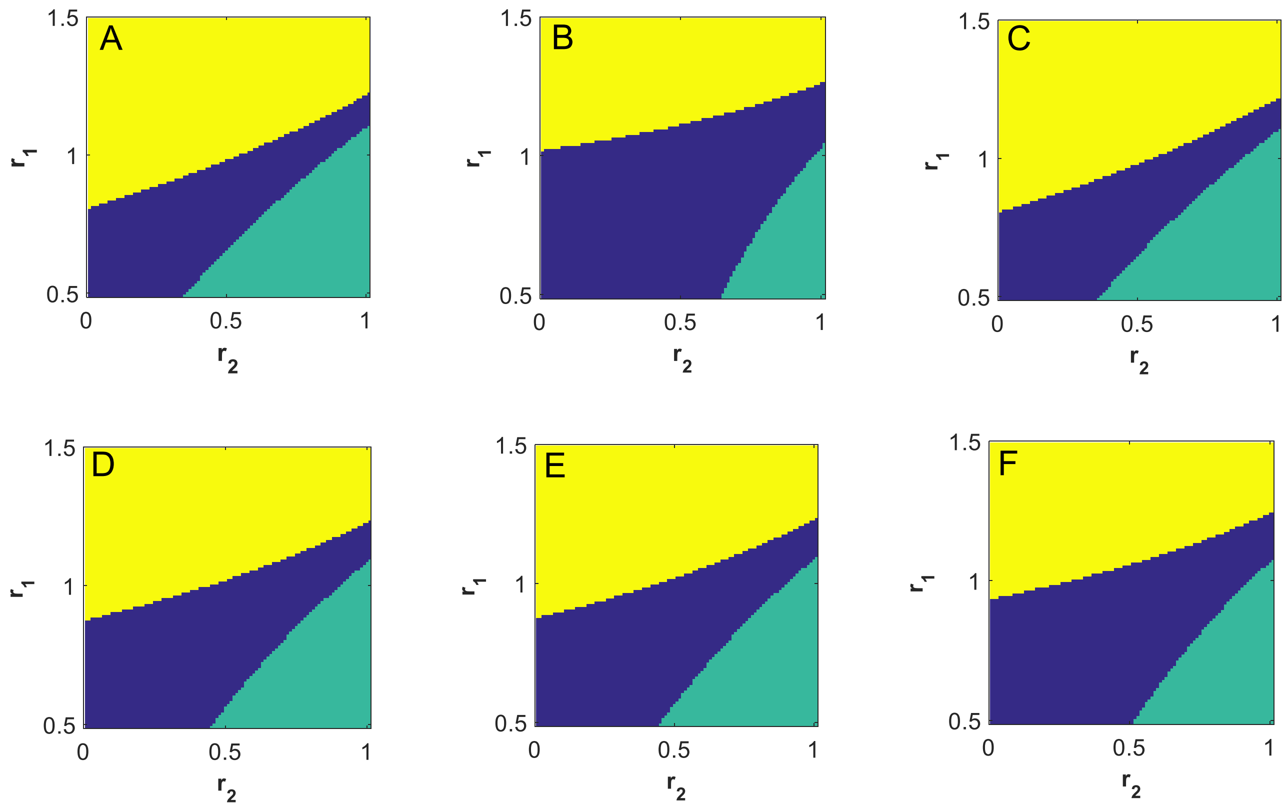


Fig. 4 Influence of adjusting parameters by fusing multiple features。(A) Consider the influence of g、h、m ($g = h = 2, m = -2, n = 1$); (B) Consider the influence of g、h、n ($g = h = 2, m = 1, n = -2$); (C) Consider the influence of h、m、n ($g = 1, h = 2, m = n = -2$); (D Consider the influence of g、m、n ($g = 2, h = 1, m = n = -2$); (E) Consider the influence of g、h、m、n ($g = h = 2, m = n = -2$); (F) Without trait-mediated effect ($g = h = m = n = 1$)。

Yellow and green indicate that prey and predator exist separately, while blue indicates coexistence. The values of other parameters are shown in the table above。

4 Discuss

In this paper, Hatcher et al. [6] model is used to study the influence of the combination of different species and species characteristics on the relationship between predators and prey, and the coexistence of different disease mortality and intrinsic growth rate is considered. Through the simulation analysis of the model, it can be found that the enhanced effect of intra-species competition between susceptible and infected persons and the intra-species competition weakening effect of infected person m can promote the coexistence between predators and bait, among which g promotes coexistence better than m. The competition enhancement effect h of susceptible to infection has little influence on the relationship between them. But the weakening effect of competition between infected and susceptible n can inhibit the coexistence of the two. This inhibition is strong, even can offset the promotion of m, which leads to the inhibition of m and n fusion. However, the combination of three parameters shows chemical reaction phenomenon. The combination of three parameters, which promote coexistence, is the inhibition of coexistence, such as g, h, m. Instead, replacing m in g, h and m with n can promote the coexistence between predators and bait. The content of the study enriches the mechanism of species coexistence, and also puts forward a new challenge direction. Some factors that can not work alone will have unexpected effects when they are put into the group factors. Therefore, it is necessary to fully study the influence of different combinations of different factors.

The research content of this paper enriches the influence content of parasitism regulation characteristics, which is of great significance to guide ecological construction and enrich biological species. However, the impact of habitat is not considered in the model, but in nature, not all environments are suitable for biological growth, and the suitable habitat is not a whole, and there are also quality differences between habitats. Habitat heterogeneity has important influence on biological survival, species dynamics, community function, etc. [10-17]. Therefore, it is of practical significance to study habitat heterogeneity. Single feature regulation can affect the result of invasion in the process of biological invasion, and it is more practical to consider the fusion of multiple feature regulation parameters. Therefore, it is necessary to study the mechanism of the influence of multiple feature regulation on biological invasion. In addition, the high-order interaction plays a significant role in regulating the dynamics of multi species systems [18-23], especially considering the influence of higher-order interaction in competition model can effectively explain the stability of high-dimensional systems [18,19], and can provide a simple prediction of population dynamics [21]. Therefore, the influence of higher order interaction can be further considered on the basis of the model in this paper.

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Date of receipt:

[Fund project] key natural science research project of Anhui Universities in 2020 (Project No.: KJ2020A1088);

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