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Dynamical System Model for Plant Communities

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Abstract: *The number of species in a community has a strong influence on its drought adaptation. In this paper, we analyze a discrete competition model for nonlinear dynamical systems of plant communities in Inner Mongolia, based on which we iterate through control variables so as to obtain the minimum number of species required to enable plant communities to benefit from biodiversity, and extend the model to the larger environment.*

Keywords: *plant community, dynamical system, Iteration*

1. Introduction

Studies have shown that when growing under extreme drought conditions for long periods of time, the adaptation of a plant community to the environment is closely related to the number of species in that community. Communities with a higher number of species were more dominant in adapting to drought conditions than the progeny of communities with a lower number of species. These observations have triggered public reflection on the relationship between drought adaptation and number of species.

2. Problem Analysis

We take the plant community of Inner Mongolia grassland as a typical case and establish a system of iterative equations of dynamical systems to study the influence of the number of species in the plant community on the drought adaptability of this community. First, the species in the Inner Mongolian grassland plant community were divided into two major species groups[1], herbaceous and non-herbaceous, taking into account the specificity of species distribution in the Inner Mongolian grassland. Second, considering that data on the number of species are not easy to collect, the land area occupied by species can be used to reflect the number of that species. Again, to simplify the problem, each species in both herbaceous and non-herbaceous plants is considered to be uniformly distributed. Finally, considering the effects of time and weather, iterations can be performed on a monthly cycle, while weather conditions are considered to cycle on an annual basis. The correlation analysis of the collected relevant data is performed, the corresponding parameters are set for representation, and a system of iterative equations modeling the dynamical system with discrete variables is established, and the study is carried out by adjusting the variables and iterating continuously. A combination of MATLAB and Python is used to find the limits to simplify the solution process and to test the sensitivity of the model. The process of the problem analysis is shown in Figure 1.

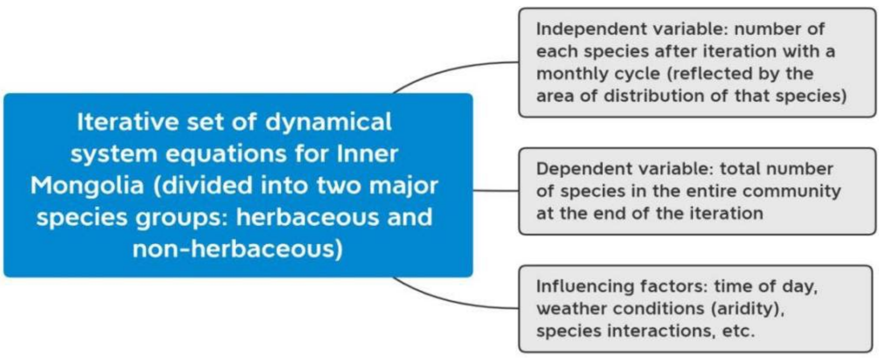

Figure 1: The problem analysis mind map

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3. Model Building

3.1 Model Preparation

(1) Data processing

The total land area of Inner Mongolia is about 1.183 million $m2$, as shown by the information obtained.The approximation is 1.2 million$m2$. Therefore, the distribution area of herbaceous and non-herbaceous vegetation is 900,000 $m2$ and 300,000 $m2$ respectively. The distribution of herbaceous and non-herbaceous vegetation is 900,000 and 300,000 respectively[2].

By analyzing the distribution area of species in Inner Mongolian grasslands in recent years, this data was correlated and parameters characterizing the interactions between species were derived in the context of real-life situations.

Combining the precipitation statistics of Inner Mongolia[3], the weather coefficients can be roughly classified into three classes according to the amount of precipitation: abundant precipitation period, normal weather period, and extreme drought period, and the values of weather coefficients w in these three classes are considered to be 1.1, 1.05, and 0.9, respectively.

(2) Basis of the model

Combining the specific conditions of herbaceous and non-herbaceous plants, relevant parameters were set, the number of species as the independent variable, the time, weather conditions and the interaction between species were taken into account, and a system of iterative equations for the dynamical system with discrete variables was established respectively[4]. The control variables method was applied to find the equilibrium point when the community tends to stabilize. Subsequently, initial values were set for herbaceous and non-herbaceous plants respectively for iteration, while the weather coefficients were made to cycle in annual cycles to simulate the effect of the number of community species on the community over time under different weather conditions. The specific modeling procedure is shown in Figure 2.

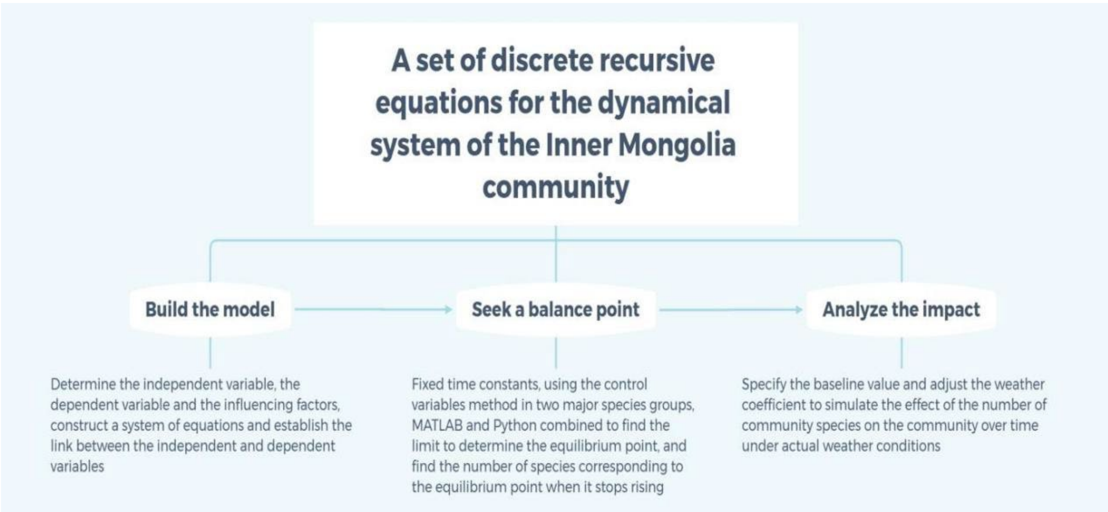

Figure 2: Model construction of problem 1 and the framework of problem solving ideas

3.2 Model building

Establishing relationships: a system of iterative equations for the dynamical system with discrete variables is established for herbaceous and non-herbaceous plants, respectively, and the general form of this system of equations is as follows.

$$\begin{cases} P_n = P_{n-1}((1+a_p) - b_p P_{n-1} - B_p(M-1)p_{n-1} - c_p N R_{n-1})w \\ R_n = R_{n-1}((1+a_R) - b_R R_{n-1} - B_R(N-1)R_{n-1} - c_R M P_{n-1})w \end{cases} \tag{1}$$

Introduction of symbols: is the coverage area of species P after n months. It is the natural growth rate of the species' coverage area.b is the intra-species competition coefficient. B is the coefficient of competition between similar species. c is the coefficient of competition between dissimilar species.

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Considering that the interactions between species may involve: intra-species competition, similar competition, and heterogeneous competition, three competition parameters are established here. Since herbaceous and non-herbaceous plants have different properties, their corresponding parameters will be different. Assuming that each species in each major species group has the same properties in terms of competition, each species in each major species group can be represented by the same equation, so several equations are streamlined into two equations with the same structure. By correlation analysis of the available data on the distribution area of vegetation in Inner Mongolia, we can determine the competition-related parameters in the corresponding equations for herbaceous and non-herbaceous plants as shown in the Table 1[5].

Table 1: Table of model competition-related parameter values

Parameters \ Species group type	Herbaceous plants	Non-herbaceous plants
b	0.05	0.04
B	0.045	0.035
c	0.03	0.025

Considering the effects of time and weather, we let n iterate by month, while the weather condition is represented by the weather coefficient, which can be categorized into three blocks, i.e., periods of abundant precipitation, periods of normal weather, and periods of extreme drought, so that the values of the weather coefficient w under these three blocks are 1.1,1.05,0.9, respectively, and the average value of the weather coefficient is considered to be 1.

Combined with the local situation of Inner Mongolia, the natural growth rate can be made $a_P=a_R \approx 0.1$

Assuming that the species are evenly distributed among the major species groups, and after the above data processing we get that the total area of herbaceous plants is about 900,000 m^2 and the total area of non-herbaceous plants is about 300,000m^2 For example, when we set the initial number of species M for herbaceous plants, the initial value of the formula is calculated as follows.

$$P_0 = 90/M \tag{2}$$

Here we set the initial number of species types for herbaceous and non-herbaceous plants as M=200, N=20, respectively, and for the convenience of analysis, we consider the total area of Inner Mongolia as unit 1 in the calculation.

After setting the initial values, the area of vegetation cover after a few months can be iterated, after which we can follow equation

$$\mathrm{s} = \mathrm{P_n M} \tag{3}$$

The vegetation coverage area of herbaceous plants and non-herbaceous plants were determined separately, and the sum of the two was the total coverage area of the community. The relationship between the number of species in the community and the total vegetation coverage area of the community could be established by substituting the number of species into the above equation.

Finding the equilibrium point: According to biological knowledge, the community will stabilize after several iterations[6]. By iterating we can determine the equilibrium point at each initial value, thus constructing a relationship between the number of species types and the steady-state value of the total area covered by the community, and finding the number of plant species corresponding to the time when the steady-state value stops rising, which is the minimum number of species needed to make the community benefit from endemic biodiversity. Since we divided the species into two main categories, a direct analysis would have two variables, which is very unfavorable for our analysis, so we considered a control variable approach, assuming that the climatic conditions were always consistent with most of the time, taking a weather coefficient of 1. A review of the data showed that the number of species types of herbaceous plants was about 230 species, and for efficiency, assuming that the climatic conditions were always consistent with most of the time Increase the number of non-herbaceous plants from N=1, iterate sequentially, calculate the total area of each species in the community until the total area of species tends to be stable, stop increasing the initial value of non-herbaceous plants after 100 iterations, record and compare the stable value of the total area of the community after each iteration and its corresponding number of non-herbaceous plant species, draw a relationship curve, find the steady-state value when it stops rising The number of species of non-herbaceous plants corresponding to the steady-state value stops rising, and then control the number of species of non-herbaceous plants to keep the same number, and iterate in the same way to find the number of species of herbaceous plants corresponding to the steady-state value stops rising, so that the number of species of herbaceous plants and non-herbaceous plants corresponding to the stability threshold can be determined. A combination of MATLAB and Python is used to solve for the limit to simplify the operation. According to the analysis, it can be seen that before the number of community species reaches the stability threshold, the community is unstable, highly influenced by the environment and has poor environmental adaptability, while after reaching the stability threshold, the community tends to be stable and has strong adaptability. Therefore, the number of species determined by the control variables method is the minimum number of species required to enable the community to benefit from endemic biodiversity[7].

Analysis of impacts: Using the number of species types as the base with 200 herbaceous plants and 20 non-herbaceous plants, we need to vary the weather coefficients considering that the weather conditions are not always ideal in real situations. To study the effect of increasing the number of species, we first kept the number of herbaceous species constant at M=200, and let N increase from 1. We made the weather coefficient change cyclically in a time series with an annual cycle, and stopped the iteration when N=25. Similarly, let the number of non-herbaceous species remain stable at N=20, and let M increase from 200, so that the weather coefficient changes cyclically in a time series with an annual cycle, and stop the iteration when M=280, record the total area occupied by the corresponding community species at the end of the iteration, and draw the relationship curve. By observing and comparing the above curves, we can derive the effects of increasing the number of herbaceous species and non-herbaceous species, respectively.

4. Results and Analysis

(1) Results

Solving for the minimum number of species required to enable communities to benefit from endemic biodiversity through iterative search using the control variables method.The relationship curves between the community coverage area and the number of community species obtained by iteration using the control variable method are shown in Figure 3 and Figure 4.

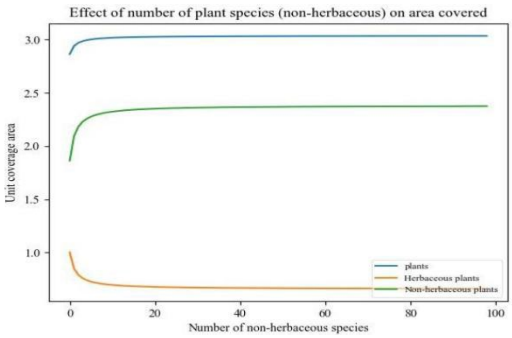

Figure 3: Minimum number of solutions

(M=200, N increasing one by one)

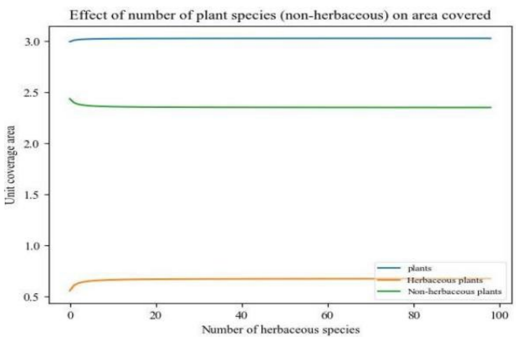

Figure 4: Minimum number of solutions

(N = 20, M increases one by one)

The effect of species population growth on communities at different times and under different weather conditions (equivalent to the sensitivity analysis of the M and N models) is shown in Figure 5 and Figure

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6.

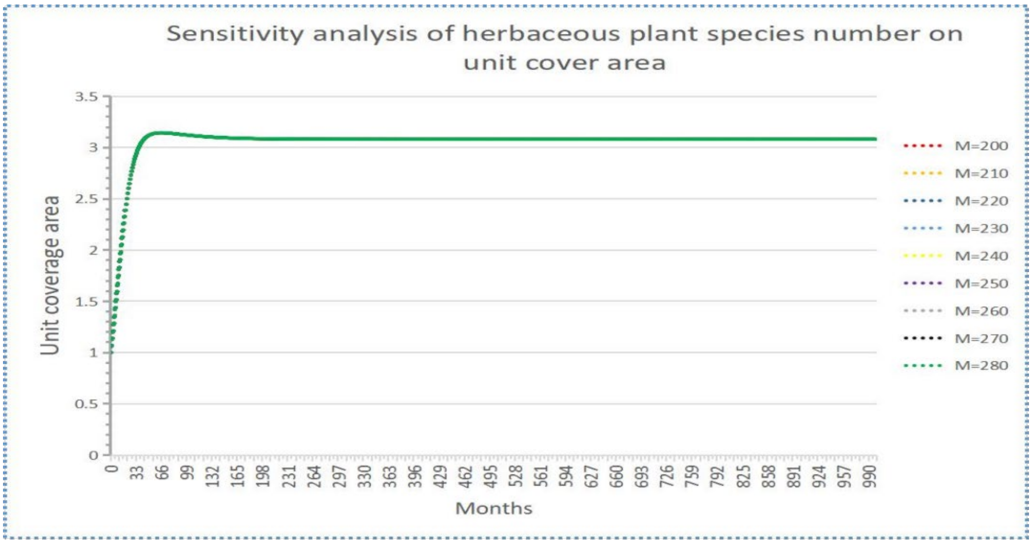

Figure 5: Sensitivity of the total coverage area to the number of herbaceous species types (N=20, M increases from 200 to 280)

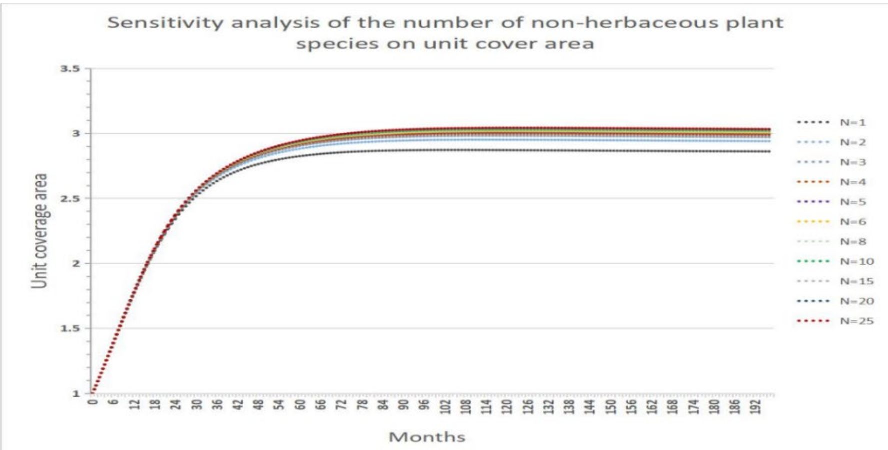

Figure 6: Sensitivity of the total coverage area to the number of herbaceous species types (M=200, N increases from 1 to 25)

(2) Analysis

Looking at Figures 3 and 4 it is clear that the minimum number of species required to be able to benefit the community from endemic biodiversity is approximately M=1 and N=15. By observing the curves we have additional findings: When there is no wide variation in the initial value of herbaceous plants, it does not have a significant effect on the trend of the community. Thus we learn that the results are not sensitive to changes in M, so that this minimum number is not very demanding for the number of herbaceous plants M.

From Figure 5 and Figure 6, it can be seen that both herbaceous and non-herbaceous plants tend to stabilize over time. And the increase in the number of species all increase the total area covered by the community in the same time, then the increase in the number of species is beneficial to the expansion of the community survival range.

5. Extension Model

The model can not only study the Inner Mongolia region, but also put into a large environment to study, for example: the system without dominant species can be seen as a unified structure of the equation, the system where the number of species is influenced by other factors can be adjusted appropriately to the existing parameters or add new parameters corresponding to other influencing factors, and when the environment is complex, the parameters that were originally constants can be expressed by a certain

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functional relationship equation or change the equation The structure of the analysis.

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