Research of Grassland Ecosystems and Communities Based on A Cyclical Model

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Abstract. In grassland ecosystems, different plants rely on and interact with each other, as well as with their geographic space, so that an inseparable and interdependent plant community is formed. To figure out the evolution of plant communities and the interactions between different plant species under dry conditions, a cyclical plant community model is established from two aspects that vary with time. One part of the cyclical model is a model of plant environmental adaptability based on the TOPSIS method and the Radial Basis Function Neural Network Algorithm. To quantify the adaptation of plants to the environment, the Plant Life-Form Adaptation Index (PLFAI) is introduced and the growth of different species is calculated in the model. The other part of the model introduces a model of plant species diversity and ecological niche to analyze the ecological niche width and spatial distribution characteristics of different plants over time, which is based on the Simpson diversity indices and Shannon-Wiener indexes. The niche concept emphasizes the spatial and temporal changes of species and is more concerned about how environmental factors affect the niche and how species adapt and respond to these changes. Also, small influences of human activities are incorporated into the model's scope by giving samples of White Gaussian Noise. Those contributory factors are negligible but necessary. These parts summarize the plant ecological environment impact model, which can be used to study the long-term survival of plant communities. By studying and using the models above, it is easy to conclude the evolution of grassland plant communities and the interactions among plants under drought conditions.

Keywords: Cyclical model, TOPSIS method, Radial Basis Function Neural Network Algorithm, Simpson diversity indices, Shannon-Wiener indexes.

1. Introduction

Plants have unique life forms, which record the evolutionary history of life on Earth, like stars in the Milky Way. As the main producers in ecosystems, plants play an important role in maintaining ecological balance. During the growth process, plants often encounter many adverse environmental conditions, which we call stress or adversity. Due to global climate change, frequent droughts have become a huge challenge for grassland ecosystems in recent years. In the environment, different plants use mechanisms such as competition, cooperation, and complementarity to match their resources with the environment, achieving ecological balance.

Research has been conducted over several years about the grassland ecosystem [1]. Also, all kinds of related models have been made to predict the diversity and the exact situation of vegetation cover. However, those models have two main disadvantages: Data quality issues: They require high-quality data to maximize its utility. If the data is incorrect or missing, it may lead to inaccurate prediction results. Limited scope of model application: They don't consider large-scale human activities as serious natural disasters, which may limit the actual scope of the model's application. So the main idea of the paper is to solve these issues.

The relationship between forest health and global change is determined by various influential factors. So, the model of plant community is necessary to investigate and predict how the grassland ecosystem develops [2]. Finding the adaptability of different kinds of plants needs several statistical methods, which include the TOPSIS method and the Radial Basis Function Neural Network Algorithm [3][4][5]. Except for those external factors, the complex interaction of plants can be quantified by giving exact data to calculate Simpson diversity indices [6]. The heterogeneity of communities is considered and can be counted by calculating Shannon-Wiener indexes [7][8]. The influences caused by human beings are taken into consideration. White Gaussian Noise is used to estimate and substitute these deviations in the model [9]. The entire model can be used to study the long-term survival of plant communities [10].

2. Model of The Grassland Ecosystem

2.1. Model of Plant Environmental Adaptability

To quantify the adaptation of plants to the environment, we introduce the Plant Life-Form Adaptation Index (PLFAI). The main influencing factors are introduced in Figure 1.

The PLFAI is introduced to quantify plant adaptation to the environment. It is based on the relationship between plant life forms (herbs, shrubs, and trees) and local environmental factors. By calculating the adaptability index of different life forms in a given region, the adaptability of vegetation to the environment can be evaluated. Understanding the growth and adaptation characteristics of different plants in different environmental conditions within an ecosystem can guide vegetation restoration and protection, as well as ecosystem management.

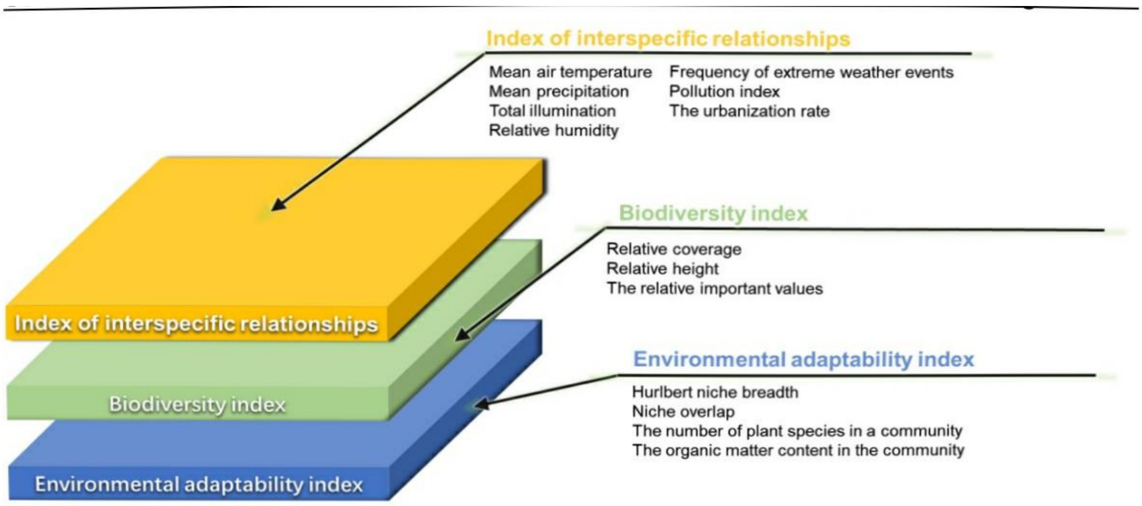

Figure 1. The framework of environmental factors

Using the TOPSIS method, we analyzed three common types of plant communities in arid areas, and selected temperature, humidity, water demand, and required illumination time as the resource indicators needed for their survival. These correspond to the average temperature T, average humidity Pr, average precipitation Rh, and illumination time I in the environmental factors, and are used to construct the original matrix.

$$M_i = [\,Pr_i \quad T_i \quad I_1 \quad Rh_i\,] \tag{1}$$

Among them, the average temperature, humidity, and sunshine hours are interval-type indicators, while the average precipitation is a middle-type indicator. After positive normalization, the relative mechanism of the plant community to the average precipitation Pr, average temperature T, sunshine hours I, relative humidity Ph, urbanization rate percentage HA, extreme weather frequency ENF, and pollution PL in the environmental factors can be obtained. Using the PLFAI index to evaluate, the size of the value reflects the adaptability of the plant community in the ecosystem.

$$PLFAI = \sum_{i=1}^{n} \frac{Z_{ij} - Z_{i\min}}{Z_{i\max} - Z_{i\min}} \tag{2}$$

In the formula, Z_{ij} represents the ideal solution for the j-th plant community for the i-environmental factor, and Z_{imin} represents the worst condition for the i-th environmental factor in the environment, Z_{imax} represents the best condition for the i-th environmental factor in the environment.

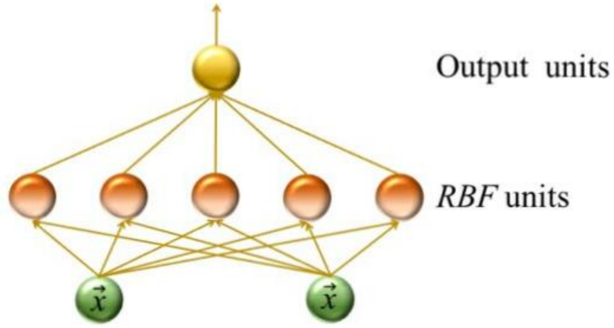

Figure 2. The model of the Radial Basis Function Neural Network Algorithm

Considering the strong periodicity and complex nonlinearity associated with time, a kernel function is used to map the data to a high-dimensional space for better classification performance. We use a radial basis function neural network to map the data to an infinite-dimensional space in Figure 2, allowing for better processing of the nonlinear features of periodic data.

2.2. Model of Plant Species Diversity and Ecological Niche

The Simpson index is one of the indicators used to measure species diversity in an ecosystem. It describes the probability that two individuals randomly selected from a sample belong to different species. The formula for calculating the Simpson index is as follows:

$$D = 1 - \sum_{i=1}^{n} P_i \tag{3}$$

where n is the total number of species in the surveyed plot, and $p_1$is the relative importance value of the i-th species.

According to the formula of the Simpson index, it can be concluded that there is a negative correlation between plant species diversity and the value of the Simpson index. The model selected 5 common tree species, 5 shrub species, and 5 herbaceous plant species as examples to determine their dominance in dry and wet seasons based on whether they form the Simpson index. Specifically, during the dry season from 2018 to 2022, the dominance of shrubs was higher than that of trees, while the dominance of trees was higher than that of herbs. In contrast, during the same period of the wet season, the dominance of herbs was higher than that of trees, while the dominance of trees was higher than that of shrubs. The model is consistent with the plant environmental adaptation model, therefore the fitted plant dominance is universal and can predict the diversity of common plants in representative areas.

We introduce the concept of ecological niche, which reflects the role and position of a species in the ecosystem. It describes the characteristics of how a species utilizes resources, interacts with other species, and adapts to the environment. Ecological niche can also reflect the importance of a species in the ecosystem and its contribution to the entire ecosystem. Therefore, we use Hurlbert's niche width to describe the occupation of all resources by different species:

$$B_a = \frac{B_i - 1}{r - 1} \tag{4}$$

where B_i is the Levins' niche width, and its calculation formula is:

$$B_i = -\sum_{j=1}^{r} P_{ij} \log P_{ij} \tag{5}$$

In the formula, P_{ij} represents the frequency of the species' occupation of resource j relative to its occupation of all resources, and r represents the resource level.

To accurately analyze the competition and cooperation among species, we introduce the concept of ecological niche overlap, which refers to the degree of overlap between the similar parts occupied by two or more species in the ecological niche. The degree of ecological niche overlap determines the degree of interaction and competition among species. If two species have a small ecological niche overlap, their competitive relationship will be small, and they are more likely to coexist in the same ecosystem. On the contrary, if their ecological niche overlap is large, their competitive relationship will be more intense, and the possibility of coexistence will be reduced. By calculating the ecological niche overlap between different species, we can better understand their interactions and adaptation strategies, and predict the stability and evolutionary process of the ecosystem. We provide the calculation method for ecological niche overlap:

$$NO_{ik} = \frac{\sum_{j=1}^{r} n_{ij} * n_{kj}^{2}}{\sqrt{\sum_{j=1}^{r} n_{kj}^{2} \sum_{j=1}^{r} n_{ij}}} \tag{6}$$

where n_{ij}, n_{kj} is the importance value of species i and k on resources.

3. Results

3.1. The establishment of model

The large data prediction model for the development of the grassland ecosystem is implemented in the Matlab software.

3.2. Predicting the changes in the community

Using the plant environmental adaptability model and the results shown in Figure 3, it was found that in one year, shrubs grew better than trees during the dry season, and trees grew better than herbaceous plants; during the wet season, herbaceous plants grew better than trees, and trees grew better than shrubs. At the same time, using the relative interaction model of Plant Species Diversity and Ecological Niche, it was inferred that over a longer period, herbaceous plants grew better than trees, and trees grew better than shrubs.

We apply M. Gordon's contribution law to analyze the stability of the community. Taking into account the carbon fixation ability of plants in the community, using the model to run the experiment and making a comparison in Figure 4, we found that as the number of species increases, the number of producers in the community increases, and the carbon fixation ability of plants also increases accordingly, leading to a faster growth rate of organic matter content. When the number of species gradually approaches a stable value, the growth rate of organic matter content will remain constant. Therefore, we can conclude that the benefit of the community will continue to increase with the increase of the number of species and remain relatively stable after the number of species approaches stability.

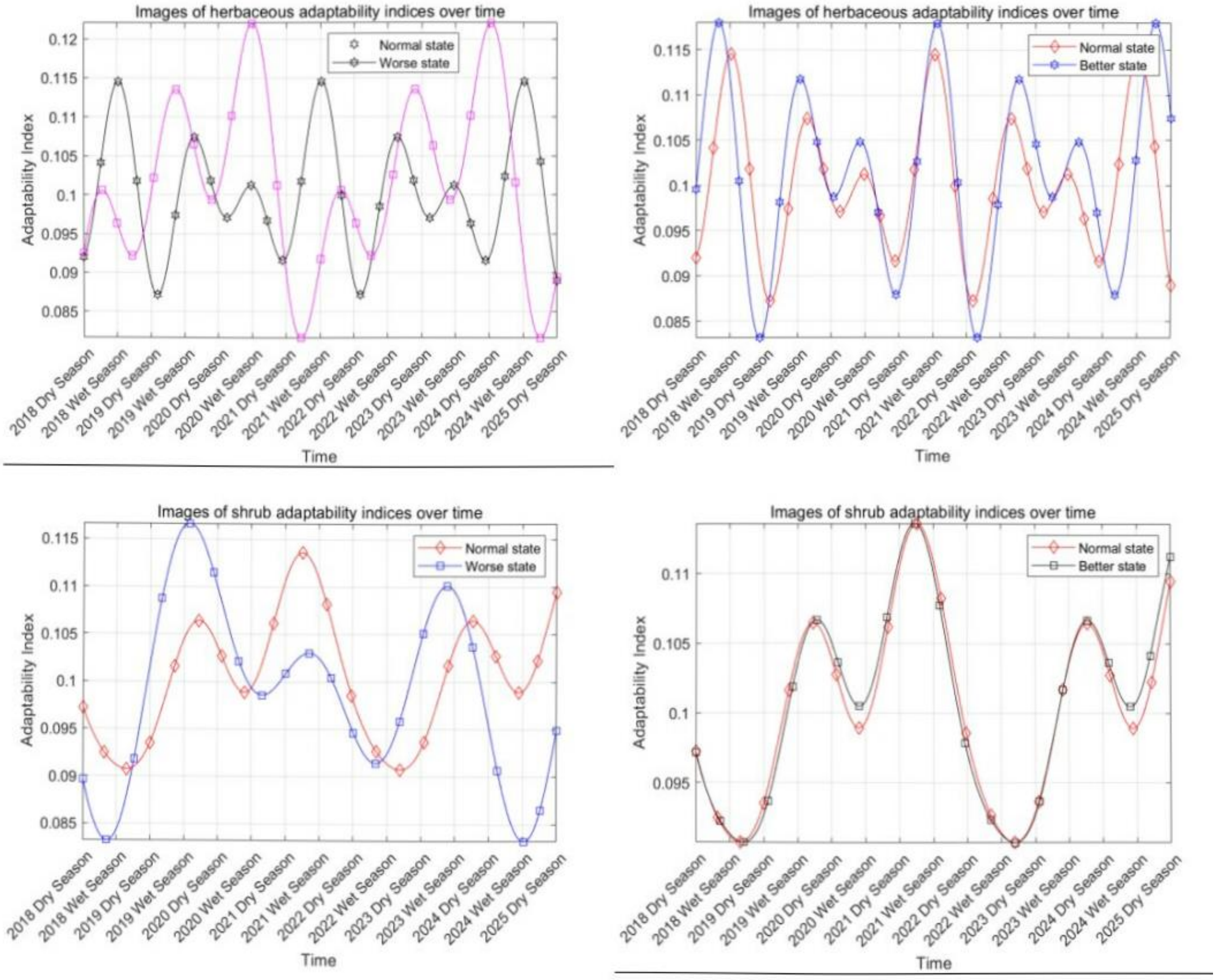

Figure 3 Images of shrub indices over time

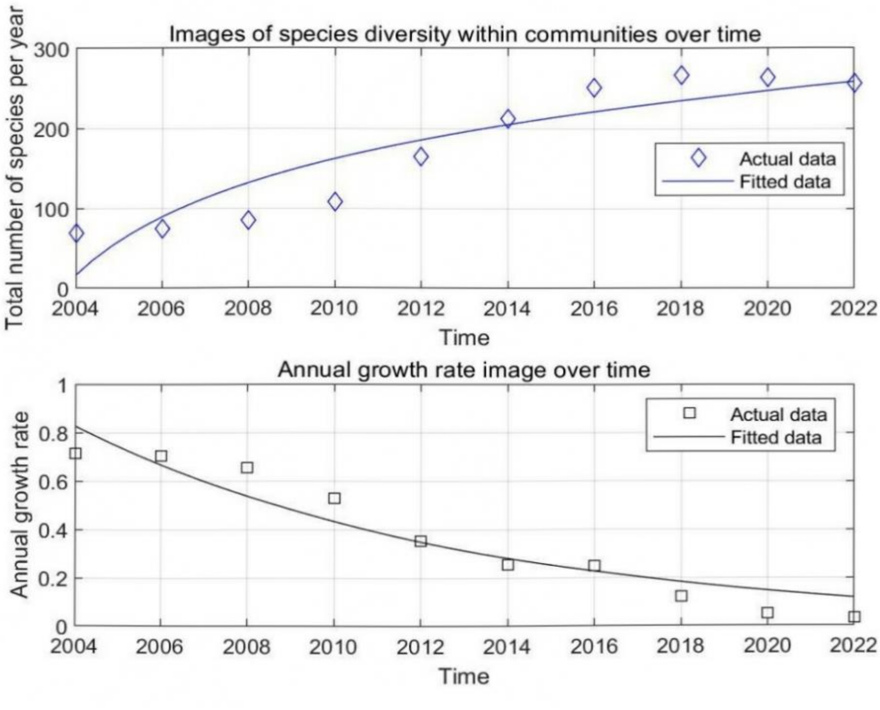

Figure 4 Images of species diversity within communities over time

3.3. The long-term interactions of a community of plants and the larger environment

- The relationship between the number of species and the benefit of the community

Using a plant environmental impact model and ecological niche overlap can infer the optimal number of plant species in a representative area. If the number of plant species is far less than the optimal value, the degree of environmental benefit increases as the number of species increases; if the number of plant species is near the optimal value, the degree of environmental benefit is relatively stable; if the number of plant species is far greater than the optimal value, competition among species in the environment intensifies and the environment will be less able to benefit.

- The optimal plant types for community development

Using an ecological niche model that considers the relative interactions between plant species, the optimal plant types for community development are inferred to be: the proportion of herbaceous plants is the largest, followed by trees, and shrubs are the smallest.

According to the model, the proportion charts are made below.

As shown in Figure 5, we selected the vegetation cover of the Ningxia Hui Autonomous Region as an example. To conclude more intuitively, we assume that the vegetation cover of grassland is 0.2, the vegetation cover of shrubs is 0.6, and the vegetation cover of trees is 1. The weights are derived from the relative density and relative cover of vegetation based on the entropy weight method. The left figure shows the GIS picture of the vegetation cover of Ningxia province in 2020, and the right figure shows the simulation picture drawn based on the constructed model. From the figure, it can be seen that the test results of the scheme are less different from the situation, and the relative error is controlled within 10%, which indicates that the model is more reliable and of better quality.

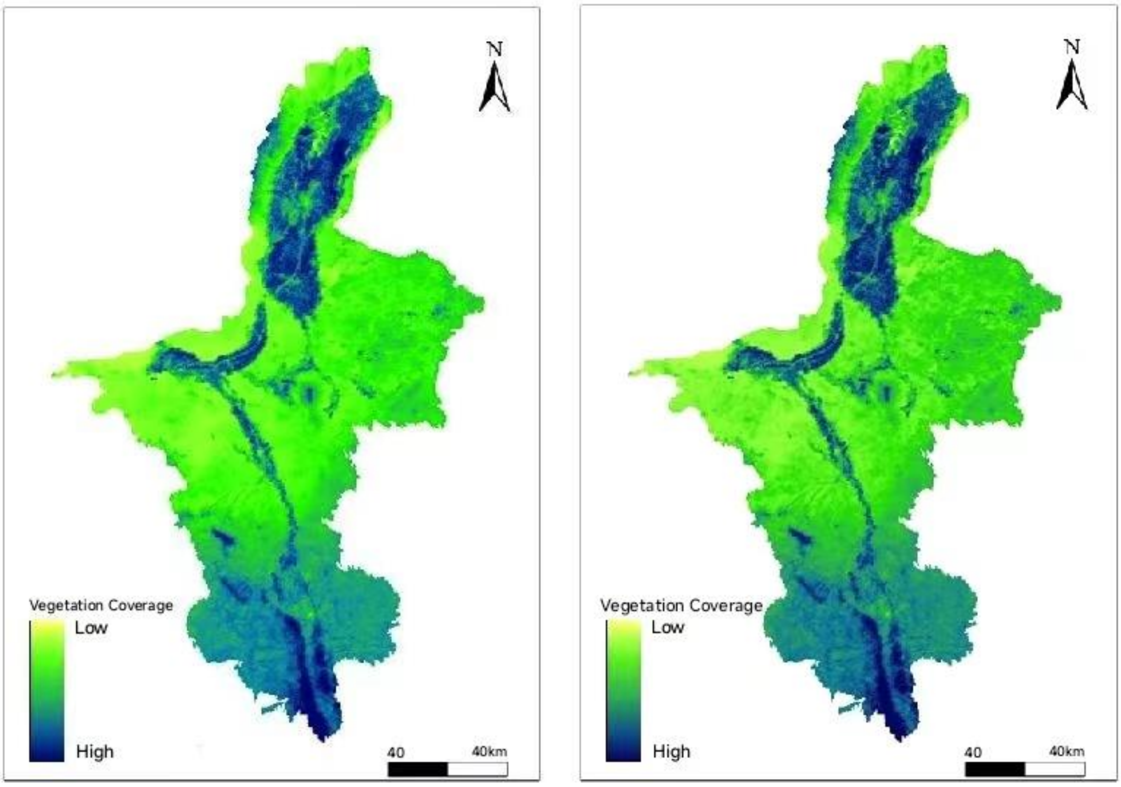

Figure 5 vegetation cover of Ningxia Hui Autonomous Region in 2020& the Prediction of the vegetation cover of Ningxia Hui Autonomous Region in 2020 from Google Picture

3.4. Other factors that affect the community

Using a plant environmental adaptability model and a plant species diversity model, it is inferred that an increase in drought frequency will decrease the PLFAI index of trees, shrubs, and herbaceous plants. Combining the adaptability index and Simpson index in the dry season, it is inferred that in this situation, shrubs have a higher advantage than trees and herbaceous plants, and the growth status of shrubs is the best. When drought frequency decreases, the PLFAI index of plants may increase. Still, according to the logistics curve in the population growth model, it is believed that environmental resistance will not change significantly, so the PLFAI index of plants will not be affected. The influence of the number of species on the overall population will not change. Pollution and habitat reduction will lead to a decrease in the PLFAI index of plants. This means that the adaptability of plants to the environment will weaken, and their growth status will be affected, resulting in a decrease in their growth scale.

4. Conclusions

This paper studied the evolution of grassland plant communities and the interactions among different plants under drought conditions, as well as the impact of human intervention on the ecosystem by establishing a plant ecological environment impact model. The article first established two-cycle models, which are the plant environmental adaptability model and the plant species diversity and ecological niche model. It can be seen that plant environmental adaptations are very sensitive to temporal parameters. It is inferred that over a longer period, herbaceous plants grew better than trees, and trees grew better than shrubs. Based on these models, the impact of human activities was introduced and the impact of human activities on the ecosystem was further analyzed. The adaptability of plants to the environment will weaken, and their growth status will be affected. Finally, by studying the distribution characteristics of plant communities under different seasons and climatic conditions, the plant ecological environment impact model was summarized. The interactions among various species in an ecosystem form a complex ecological network. If the ecosystem is disrupted, it will lead to a reduction in biodiversity, which will further degrade the ecosystem and ultimately threaten human survival. Therefore, protecting the ecological environment is crucial. It is not only for the benefit of human beings but also for maintaining this sustainable and beautiful home.

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