Effects of Irregular Climate Environment on Plant Community Diversity——BP neural network model based on gray prediction optimization

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Abstract. Plant communities play a vital role in the ecological environment. In order to explore the relationship between drought adaptability and the number of species in the plant community, this paper discusses the survival ability of the plant community in a drought environment by constructing a neural network model, and studies and discusses the impact of the interspecific relationship of the plant community on survival. First, we found a positive correlation among the species in community Ⅱ through multiple regression model. Second, we quantify the concept of plant community into time-series data. Under the premise of considering the interaction between species, a BP neural network model based on gray prediction optimization was established to obtain the change law of species diversity index over time under different regular weather conditions. Finally, two concepts of species number and species type are introduced. The stability of the model was tested by changing the size of the species number and exchanging the dominant species among the communities.

Keywords: Plant Diversity, Plant Communities, Gray Forecast, BP Neural Network.

1. Introduction

Growing in a desert environment is a test of the viability of the plant community. Studies have shown that the drought adaptability of plant communities is affected by many factors, such as the number of different species, the frequency and degree of drought, and so on[1]. This requires us to explore the causes and laws of diversity-related phenomena in plant communities. Diversity is an important index to measure the species composition, structural state, functional level and successional dynamics of plant communities. The larger the richness index and evenness index, the higher the diversity index of the community, indicating that the community structure is relatively complex and stable, and the productivity of the entire vegetation ecosystem is high[2]. Therefore, in the study of plant communities, the diversity index is used as an evaluation index to reflect the performance of plant communities in experiments. Quantitative research on plant community diversity is of great significance for determining community types, evaluating habitat quality, judging community development stages and ecosystem stability[3].However, due to the complex relationship between community species in different ecological environments, many studies on the impact of ecological environment changes on plant communities still have many different opinions. [4] So the study of plant communities affected by different environments still needs to be further explored.

Compared with most other deserts in the world, Sonoran Desert has abundant vegetation. Many unique plants grow in the Sonoran Desert. The Sonoran Desert is one of the largest deserts in North America, spanning the border between the United States and Mexico, with a total area of 311,000 square kilometers. With mild winters and hot summers, the amount of precipitation varies from region to region, as is the timing of the rainy season throughout the year. Therefore, this paper takes Sonoran Desert as the object of research[5].

This paper quantifies plant communities as time series. The relationship between species was obtained by multiple regression analysis. Under the premise of considering the interaction between species, a BP neural network model based on gray prediction optimization was established to obtain the change law of species diversity index over time under irregular weather. Introduce the two concepts of species number and species type. The stability of the model was tested by changing the number of species and exchanging the dominant species between communities.

2. Research methods

2.1. Multivariate statistical model

2.1.1 Precondition

Plant communities were quantified in order to predict changes in plant communities over time under irregular weather. Because the *simpson* index is more to describe the evenness of species, and the *Shannon – wiener* index is more to describe the richness of species composition. In order to simplify the quantification process, *Shannon – wiener* index is introduced to comprehensively quantify the community.

$$H' = -\sum_{i-1}^{S} P_i \ln P_i \tag{1}$$

Among them, P_i is the proportion of species i in the total number, and S is the total number of species in the plot. According to this index, the concept of flora can be converted into a numerical value. And based on the survey data, these values are calculated to lay a good foundation for future predictions.

2.1.2 Regional Weather Overview

The variable data mainly comes from the WorldClim and TRY databases and the data information of related webpages. This article uses the weather information of Sonoran Desert in Arizona from January to April 2022 as a weather sample. 101 groups of species in 52 quadrats designed by the three-point sampling method were used as plant samples.

In order to more accurately study the impact of plant communities on the arid environment, by searching for a large amount of climate data on the arid environment, it was finally decided to take part of the Sonoran Desert in Arizona as the research object. Focus on the local flora based on the climate environment of the place. The relevant climate data of Arizona are shown in Figure 2 and Figure 3.

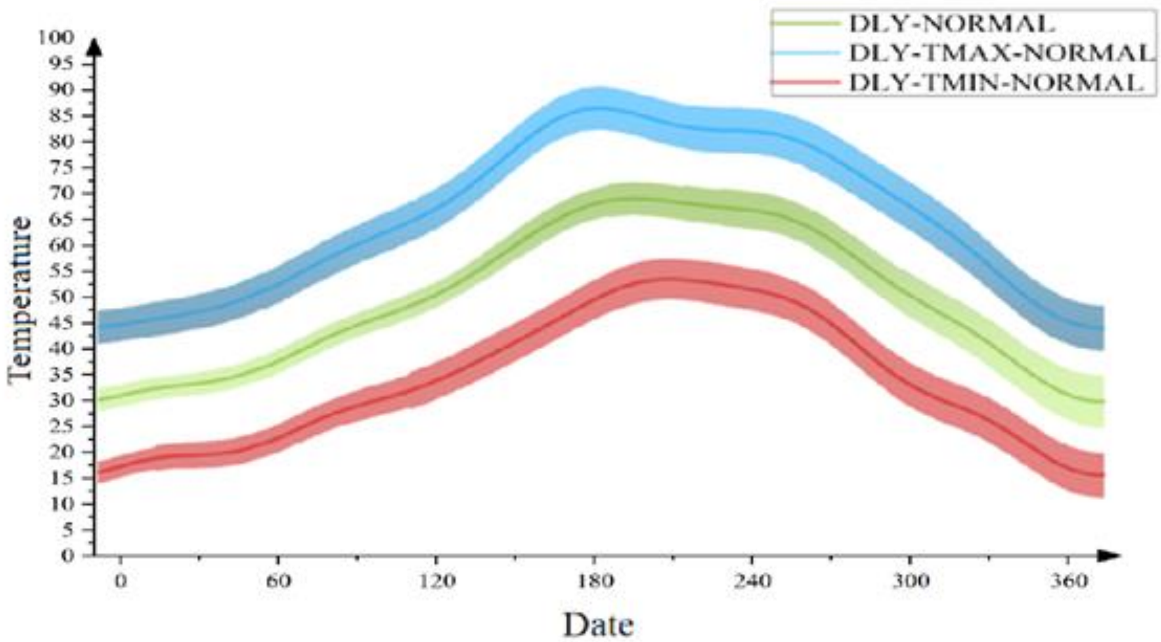

Figure 1. Daily maximum, minimum and average temperatures in the Sonoran Desert

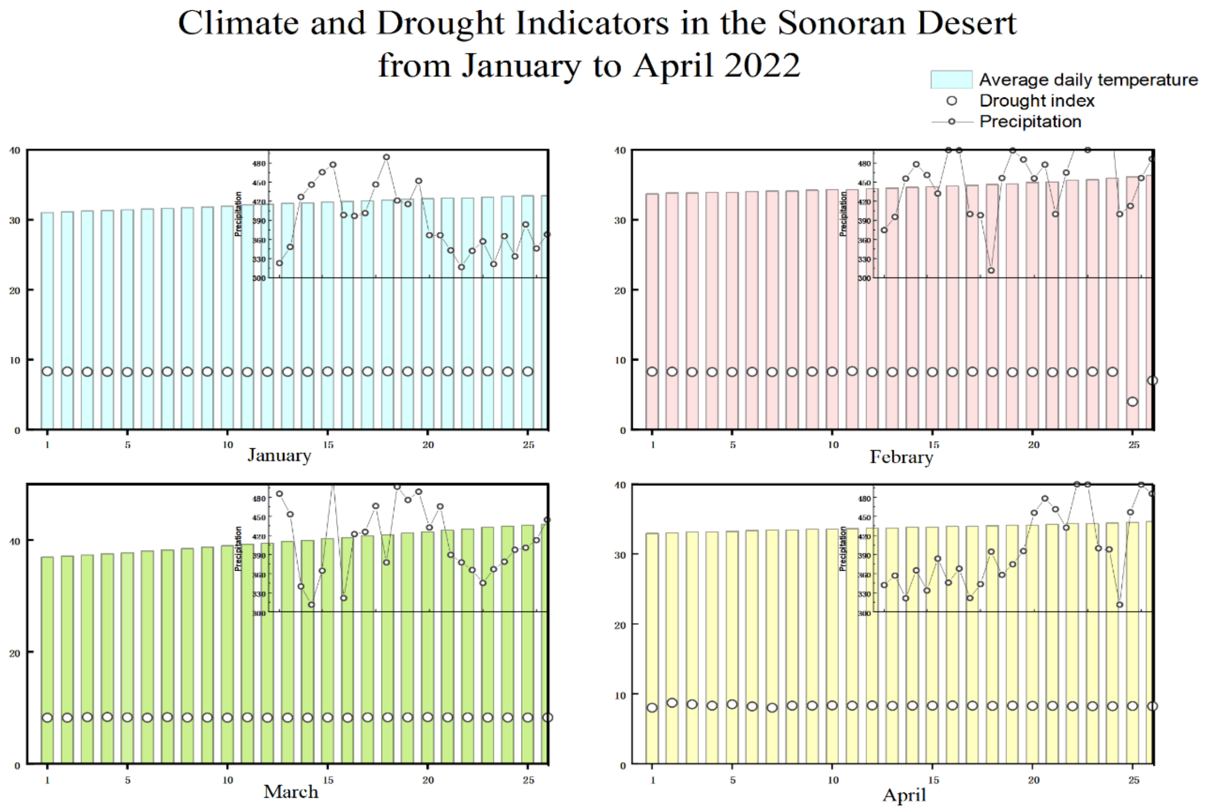

Figure 2. Drought Index, annual evaporation, and mean precipitation in the Sonoran Desert

Figure 1 shows that the daily maximum temperature can reach about 75°C, and the daily average temperature is not lower than 35°C. According to the four pictures in Figure 2, the annual evaporation in the Sonoran Desert is about 5 times that of the precipitation, and the precipitation is less than 500ml. According to this relationship, the drought index R and annual evapotranspiration E_0 are introduced.

$$E_0 = 52.0(P_m - P)(1 + 0.135V_m) \tag{2}$$

$$R = \frac{E_0}{P} = \frac{52.0(P_m - P)(1 + 0.135V_m)}{P} \tag{3}$$

In the above formula, P_m is the saturated vapor pressure calculated according to the surface temperature of the pool, V_m is the daily average wind speed.

Based on the relevant data obtained, Table 1 was calculated.

Table 1. Drought index in the Sonoran Desert

Year	Annual evaporation	Drought index
1	2690.6	8.337775
2	2895.4	8.312949
3	3524.2	8.255329
4	3678.6	8.244285
5	3833.8	8.234107
6	3929.8	8.228224
7	3295.4	8.273663
8	3284.2	8.274628
9	3318.6	8.271685
10	3679.4	8.24423
11	4022.6	8.222813
12	3479.4	8.258723

The data in the Table 1 shows that the annual average drought index is stable at 8.23, so it can be reasonably considered that this area is a typical arid area.

2.1.3 Data analysis of plant communities

A sample plot was set up by selecting flora typical of the Sonoran Desert region of Arizona. Take every 10 10m^3 land as a unit quadrat. Four soil samples were collected at the four corners of the forest quadrat. The diagonal three-point sampling method was used in the shrub quadrat[6]. A total of 52 desert scrub quadrats were surveyed. According to the quadrat, the number and height information of 101 groups of species were obtained.

Because the units of the indicators of the collected sample data are different, in order to eliminate the influence of the dimension, the following formulas are used to normalize the indicators of the sample. That is, the input and output data are mapped to the (0,1) range. After training, it is mapped back to the original data range.

$$x'_{ij} = \frac{x_{ij} - \{x_{ij}\}_{\min}}{\{x_{ij}\}_{\max} - \{x_{ij}\}_{\min}} \tag{4}$$

In the above formula, $\{x_{ij}\}_{\min}$ represents the minimum value of the j th measured index; $\{x_{ij}\}_{\max}$ represents the maximum value of the j th measured index.

Measured by the proportion P_i of the species in the total. Using the Ward clustering method in cluster analysis and according to the classification and naming principles of plant communities[7], the obtained plant species were divided into 5 communities. The approximate distribution is shown in Figure 3.

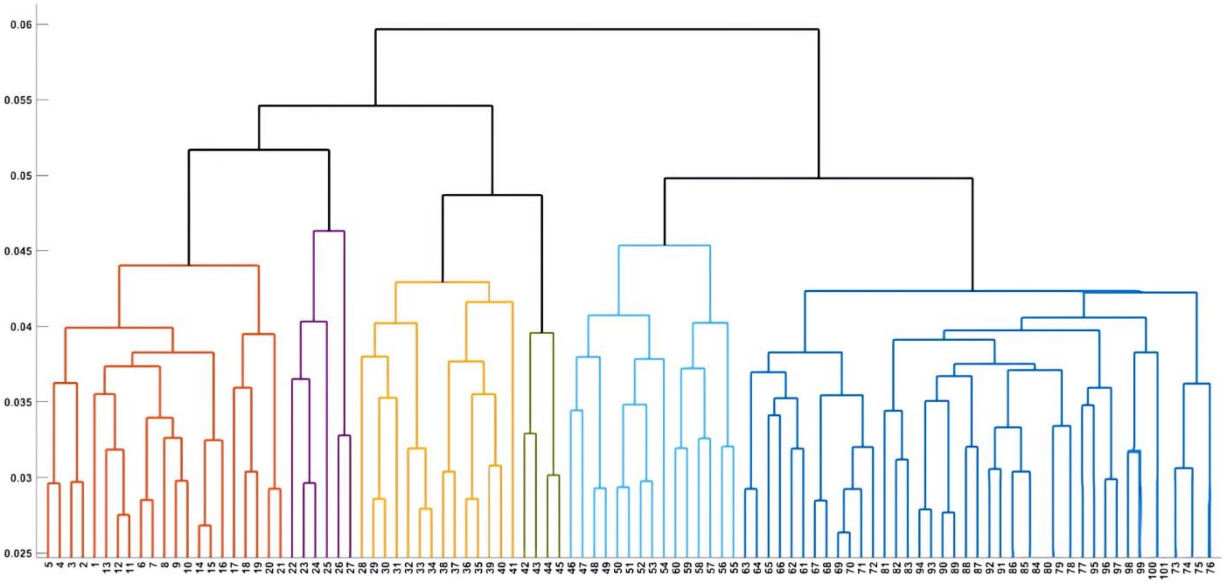

Figure 3. Plant communities after cluster analysis

According to Figure 3, it was found that 101 species were classified into communities by the method of cluster analysis. According to the classification results, the diversity coefficient between each community is calculated, so as to prepare for the next research.

Take community II among the five communities as an example, including Carnegiea gigantea, Abronia villosa, Distichlis spicata, Helianthus niveus, and Pleuraphis rigida. Take the Carnegiea gigantea dominant species as the main body, and carry out the *Pearson* correlation test with other species among the species. Demonstrate the correlation between species and species in the community in arid environment. The following result is shown in Figure 4 and Table 2.

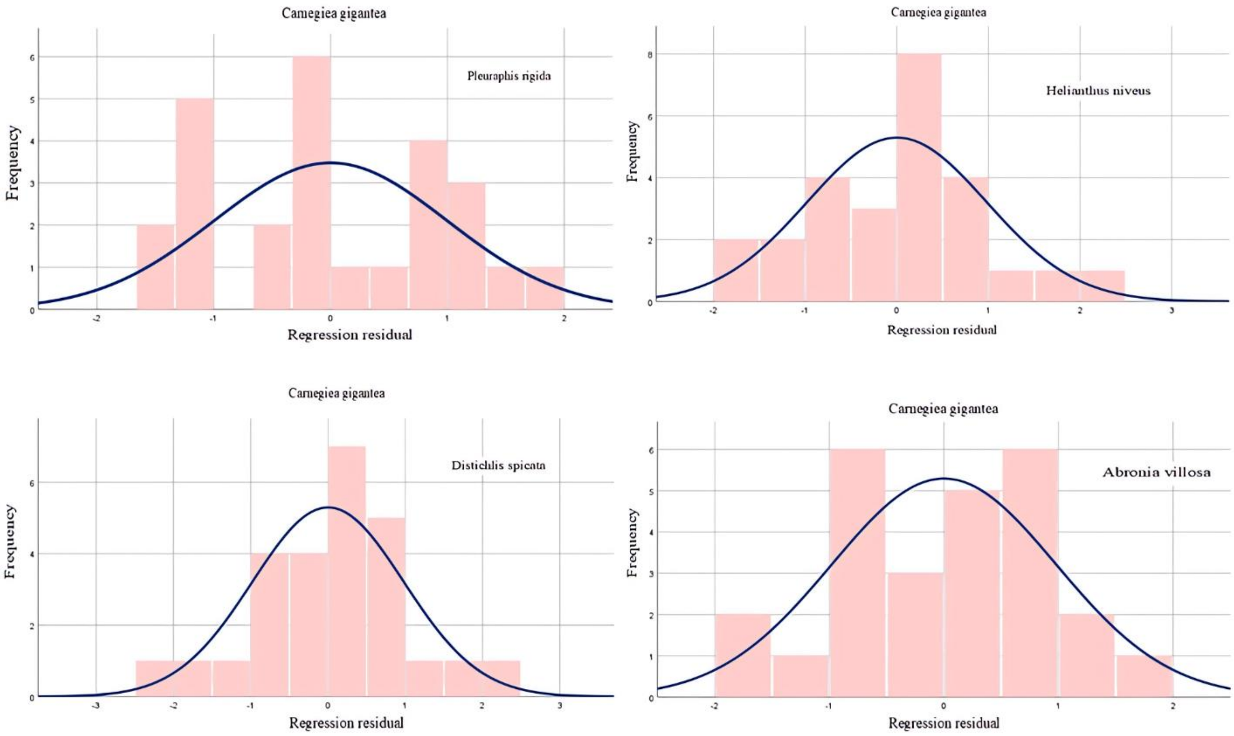

Figure 4. Carnegiea gigantea and other species frequency residual plot

Table 2. Significance level between species

Species	Correlation coefficient	Significant
Pleuraphis rigida	1.247	0.026
Helianthus niveus	4.836	0.000
Abronia villosa	0.718	0.048
Distichlis spicata	0.414	0.048

According to the significance level in the table, it can be seen that Carnegiea gigantea has a higher significance level with other species in the community. According to the correlation coefficient, it can be seen that the correlation coefficients between Carnegiea gigantea and other species are all positive. Of these, Helianthus niveus is particularly closely related. Therefore, it can be considered that there is a positive correlation between species and species in the arid environment.

2.2. Gray Neural Network Model

2.2.1 Model establishment

In the previous prerequisites, plant communities were converted to plant diversity for quantitative expression. Simultaneous selection $Shannon-wiener$ index describe plant diversity. This method converts plant communities into time series data. Through the time-series data of each community under different drought weather, the variation trend of plant diversity index with time under irregular drought weather can be predicted. Four types of dry weather are defined here: dry weather with adequate rainfall, general drought, severe drought and extreme drought. For reasons of space, here are only the $Shannon-wiener$ index of each community in general drought. The following result is shown in Table 3.

Table 3. Significance level between species

Species	Shannon-wiener Correlation coefficient
Pleuraphis rigida	1.247
Helianthus niveus	4.836
Abronia villosa	0.718
Distichlis spicata	0.414

First, the diversity index is subjected to a level ratio test:

$$\lambda(k)=\frac{x}{x^{(0)}(k)}(0)(k-1),\quad \lambda=(\lambda(2),\lambda(3)\ldots\ldots\lambda(7)) \tag{5}$$

Draw the Table 4.

Table 4. Level ratio test results

Index item	Original value	Stepwise ratio	Shift transformed sequence values	Post-level ratio of translation conversion
1	2..2762	0.478	6	0.797
2	1.5238	0.5	7	0.857
3	1.9735	0.667	8	0.875
4	1.8342	0.75	9	0.889
5	4.1059	0.8	10	0.9

From the analysis of the above table, it can be obtained that all the Shift transformed sequence values are within the interval (0.717, 1.396). It shows that the sequence after translation transformation is suitable for constructing gray forecasting model.

Secondly, build a $GM(1,1)$ model. Since the initial condition of the predicted value of the original sequence is:

$$\hat{x}^{(1)}(1)=x^{(1)}(1)=x^{(0)} \tag{6}$$

So the fitting curve must pass the point $(1,x_0)$. In the original definition, the fitting curve does not necessarily pass through this point, which makes it unreasonable to use $\hat{x}^{(1)}(1)=x^{(1)}(1)=x^{(0)}$ as the initial condition. Therefore, it is proposed to use $\varpi x^{(0)}$ [8] instead of $x^{(0)}$ as the new initial value to avoid the problem that the initial value is fixed when solving. The new initial value can be determined only by asking for the value of ϖ, so as to avoid the influence of the accuracy of the prediction model from the initial value. can be written as:

$$\hat{x}^{(1)}(1)=x^{(1)}(1)=\varpi x^{(0)}(1) \tag{7}$$

Define the indicator function as:

$$Q=\sum_{k=1}^{n}\left[\hat{x}^{(1)}(k)-x^{(1)}(k)\right]^2=\sum_{k=1}^{n}\left\{\left[\varpi x^{(0)}(1)-\frac{b}{a}\right]\mathrm{e}^{-a(k-1)}+\frac{b}{a}-x^{(1)}(k)\right\} \tag{8}$$

Integrate the indicator function:

$$\frac{\mathrm{dQ}}{\mathrm{d}\omega}=2\sum_{k=1}^{n}\left\{\left[\varpi x^{(0)}(1)-\frac{b}{a}\right]\mathrm{e}^{-a(k-1)}+\frac{b}{a}-x^{(1)}(k)\right\}x^{(0)}(1)\mathrm{e}^{-a(k-1)} \tag{9}$$

Get the result:

$$\varpi = \frac{\frac{b}{a}(A-B)+C}{Ax^{(0)}(1)} \tag{10}$$

Bring in it can optimize the original formula to:

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)=\left(1-e^{a}\right)\left(\varpi x^{(0)}(1)-\frac{b}{a}\right)\mathrm{e}^{-ak} \tag{11}$$

According to the improved $GM(1,1)$ model, the forecast data for the next five years can be obtained in Table 5

Table 5. Predictive value

Index item	Original value	Predictive value	Residuals	Relative error(%)
1	2..2762	2.6789	0.049	2.134
2	1.5238	2.058	-0.058	2.906
3	1.9735	2.937	0.063	2.109
4	1.8342	3.925	0.075	1.882
5	4.1059	5.036	-0.036	0.713

2.2.2 Results

Finally, the prediction results are imported into the neural network for further processing and analysis to obtain more accurate prediction results. Set the training proportion to 70%, and finally get the following prediction results in Figure 5.

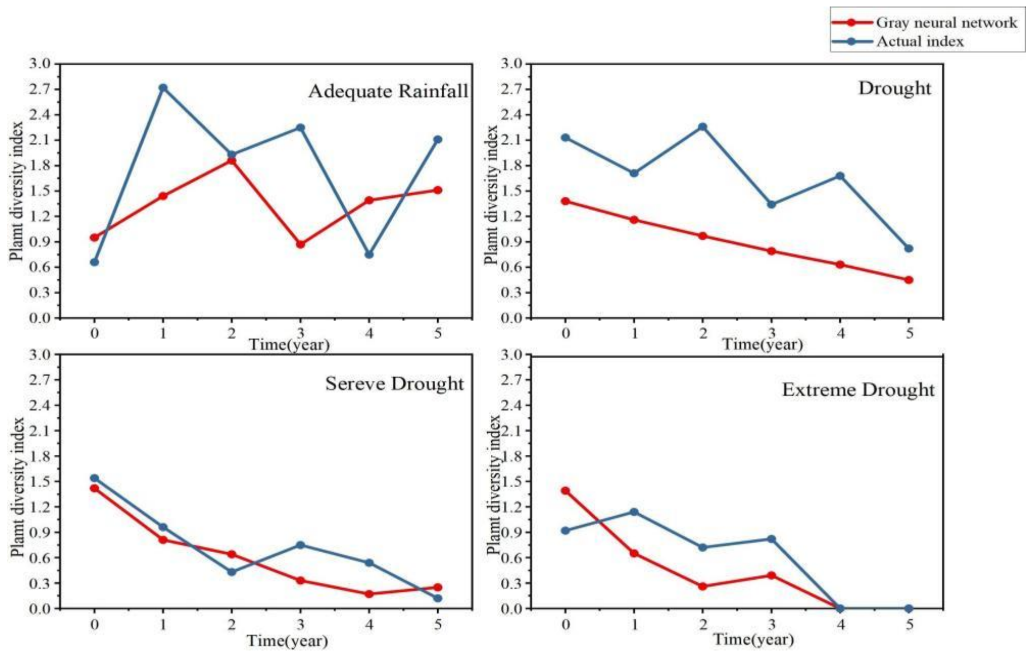

Figure 5. Variation of plant diversity index with time under irregular weather

According to Figure 5, the upper left figure shows that in dry weather with adequate rainfall, the index of plant diversity fluctuates greatly, but generally shows an upward trend. The picture on the upper right shows that under the general drought weather, the plant diversity index maintains a steady downward trend over time. The picture on the lower left shows that under severe drought weather, the plant diversity index has remained very low, and there is a possibility of extinction at any time. The graph on the lower right shows that the plant diversity index reached zero in the fourth year of extreme drought. It means that the studied community has become extinct at this time.

2.3. Model Stability Test

2.3.1 Number of species

In order to verify the stability of the model, the impact on the plant diversity index was analyzed by changing the number of species. The pressure index 1.057[9] is introduced as a reference to discuss and study the degree of benefit of the community to the number of species in Figure 6.

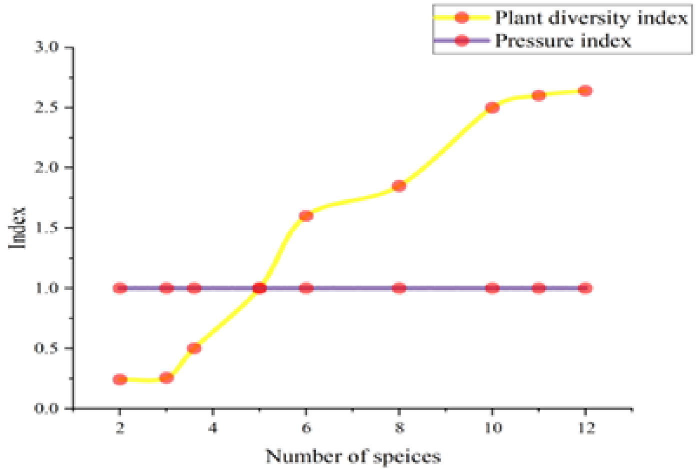

Figure 6. Effects of species number on plant diversity

According to Figure 6, it can be seen that with the continuous increase of the number of species, the plant diversity index is also increasing, and the index gradually stabilizes after reaching 10(with reference to the pressure index of plants). It is concluded that the community begins to benefit stably when the number of species reaches about 5, and as the number of species continues to increase, the diversity will increase slowly and then stabilize.

2.3.2 Species type

The previous prediction model is the prediction result obtained on the basis of community division through the method of cluster analysis. In order to consider the impact of species type on the model, the concepts of dominant species and disadvantaged species are introduced[10]. Because the diversity index of community II was low in several communities, the diversity index in community V was relatively high. Therefore, the inferior species in community II were replaced by the dominant species in community V, and then the numerical prediction under the condition of sufficient precipitation was carried out again. The following result is shown in Figure 7.

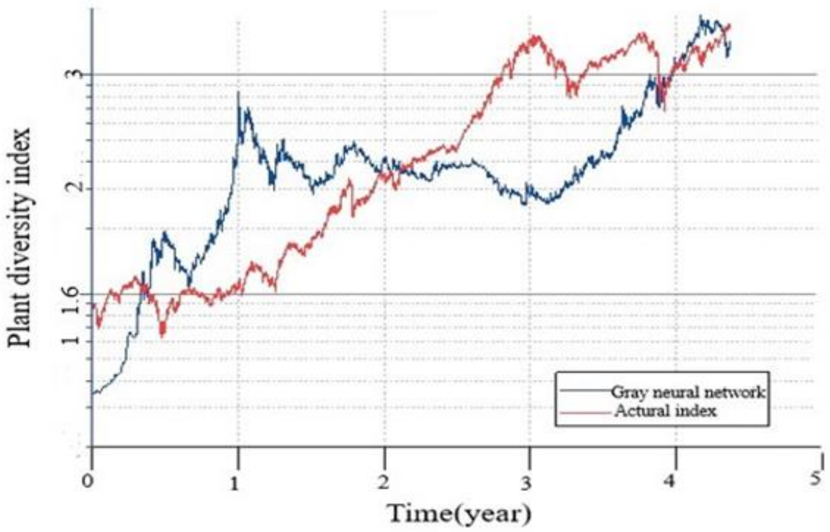

Figure 7. Changes of plant diversity index under adequate rainfall

Comparing the two sets of pictures, it is found that the growth trend of the plant diversity index in Figure 7 is clearer over time. And compared with the previous forecast curve, the up and down range is more stable. Therefore, the following conclusions were drawn: the more dominant species in the community, the more beneficial to the community. In the same way, the more disadvantaged species there are in the community, the smaller the benefit of the community.

3. Conclusions

In order to cope with and resist severe extreme weather conditions, the relationship between species in a plant community always presents a positive correlation. In the case of extreme drought, the diversity index of most communities gradually tended to zero. Under the same drought conditions, with the continuous increase of the number of species, the plant diversity index is also gradually increasing. After increasing to 10, it began to stabilize. It is believed that when the number of species reaches 5, the community can benefit stably. For the discussion of dominant species and disadvantaged species, it was found that the more dominant species in the community, the more beneficial the community. In the same way, the more disadvantaged species there are in the community, the smaller the benefit of the community.

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