

Study on the succession of plant communities under the influence of drought

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Abstract. Drought has a strong impact on the growth of plant populations, and the number of different species in a plant community plays an important role in the drought adaptation of the community's progeny. In this paper, a mathematical model is developed to analyze how the number of different species in a plant community under a long-term irregular drought cycle is adaptive to drought in future generations, and thus how the plant community benefits from it. This paper uses biomass to quantify the growth of plant populations and changes in plant communities, and uses a large amount of visual data for visual analysis. First, a logistic growth model of plant population biomass change is developed based on temperature accumulation, precipitation and interspecific competition as influencing factors. The correlation coefficients were then obtained using the collected plant population biomass to predict the changes in total plant biomass and species richness, and the interspecific competition model was then used to calculate the values of total community biomass after final stabilization based on logistic, and the system of differential equations was solved using the Runge-Kutta Methods was finally concluded that the biomass of the community after final stabilization showed a positive correlation with the number of species and species type, and showed a strong positive correlation with species type and a weak positive correlation with species number.

Keywords: Logistic Model; Runge-Kutta Methods; Interspecific Competition.

1. Introduction

Drought is one of the most serious climatic disasters affecting human society, and it is characterized by high frequency, long duration and wide spread. The frequent occurrence and long-term persistence of drought can cause many adverse ecological and environmental impacts such as water shortage, increased desertification, and frequent dust storms. For plant communities surviving in arid environments, developing drought resistance is a necessary survival rule, especially for drought-sensitive grassland plant communities, which can only be kept from being eliminated if they have drought adaptations in community evolution. Many studies have shown that the number of species plays a prominent role in the adaptability of plant communities during drought cycle turnover. For some monocultures, its later generations are less resilient in drought than monocultures in communities with species numbers of four and above. Spring of 2010, Yu and others chose the meteorological element distance level index to analyze the characteristics of drought; the drought rate and mortality rate to analyze the degree of drought exposure of plant communities and species; the number of drought (dead + wilted) species and their plant numbers, the number of drought tolerant (surviving) species and their plant numbers, and the number of community (drought + surviving) species and their plant numbers to calculate the biological The number of drought-tolerant species and their plant numbers, and the number of drought and survival species and their plant numbers were used to assess the impact of extreme drought on biodiversity^[1]. The study by Hao-Po Shietal. found that the study of the pattern and coexistence of plant populations could help to understand the current ecological adaptations of each species, and could make a rational evaluation of the role of plant populations in community building and biodiversity maintenance in the corresponding environment, introducing the factor of competition between populations ^[2]. Caiqin Zhang, on the other hand, established a model of plant growth under the influence of multiple factors by establishing multiple regression and logistic equations and by computer simulation, which enabled the relationship between plant growth and climatic factors and competition factors to be established ^[3].

2. A model of above-ground biomass dynamics of plant populations under the influence of multiple factors

The paper need to consider the collection of data in the process of building the model. Through the analysis of the problem, the paper need to collect information related to plants, species population and climate in arid areas. For example, temperature, precipitation and population biomass, etc. Some of the data are visualized in this paper. In this paper, the Tianshan Mountains in Xinjiang, China, are selected as the arid region for the problem study, and the data used mainly include the precipitation accumulation in the Tianshan Mountains, the cumulative temperature in the Tianshan Mountains, and the biomass of plant populations in the Tianshan Mountains, Changes in plant population biomass are determined by multiple causes, i.e., environmental factors and interspecific interactions. Therefore, for such a complex kinetic model, the paper used a logistic growth model incorporating interspecific interactions to describe changes in plant population biomass and introduced environmental variables such as precipitation accumulation and cumulative temperature in the process. Here are the paper's solution ideas and methods.

2.1. Growth of above-ground biomass of plant populations

First, in the case of limited natural resources and space, excluding other external factors, Biomass of a plant population w Obey Logistic Growth Model:

The formula is as follows:

$$\frac{dw}{dt} = rw \left(1 - \frac{w}{w_m} \right) \quad (1)$$

Among them, w is the endogenous growth rate of the biomass of the plant population, In addition, r is the paper's survey revealed that the initial biomass of the plant population was :

$$w(0) = w_0 \quad (2)$$

From this, For differential equations (1) (2), The relationship between the biomass of this plant population and time can be obtained by the separation variable method:

$$w(t) = \frac{w_m}{1 + \left(\frac{w_m}{w_0} - 1 \right) e^{-rt}} \quad (3)$$

At this time, the paper's assume that the plant population grows in a certain area, Part of the local flora, Then the biomass of the k^{th} plant population in this plant community Initial Value is :

$$w_k(0) = w_{k0} \quad (4)$$

Then, the relationship between the biomass of the k^{th} plant population and time is given by :

$$w_k(t) = \frac{w_{km}}{1 + \left(\frac{w_{km}}{w_{k0}} - 1 \right) e^{-r_k t}} \quad (5)$$

The mountain grasslands located on the northern slopes of the Tianshan Mountains in China are a typical type of grassland [4], Climate Drought, the criteria required for the paper's model are met, so the paper use this as an example to test and optimize the feasibility of the model.

Collect local daily precipitation R and the annual data of average daily temperature T and accumulate them sequentially to obtain the precipitation accumulation $\sum R$ and cumulative Temperature $\sum T$ of data.

Initial fitting of the data using linear regression with least squares order:

$$\sum T = \lambda t + \mu \tag{6}$$

$$\sum R = \beta_0 t + \beta_1 \tag{7}$$

The fitting results are shown in Fig 1

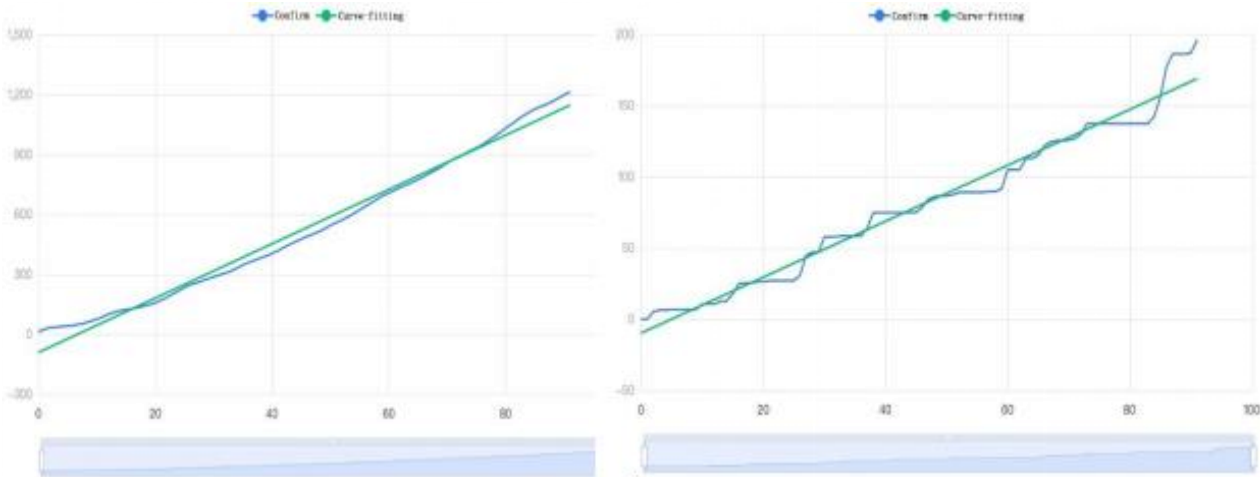


Fig. 1 Linear Regression Fitting

Use least squares to test the fit of the model by testing its correlation coefficient, Analysis of cumulative temperature: F analysis of the results of the test can be obtained with a significant P value of 0.0000 and a coefficient of determination R2=0.987, level presents significance and rejects the original hypothesis that the regression coefficient is 0. Therefore, the model basically satisfies the requirements.

For variable covariance performance, all VIFs are less than 10, so the model has no multicollinearity problem and the model is well constructed.

The equation of the model is as follows:

$$\sum T = -104.557 + 13.599t \tag{8}$$

Analysis of precipitation accumulation: The analysis of the results of the F-test yields a significant P-value of 0.0000 and a coefficient of determination R2=0.974, level presents significance and rejects the original hypothesis that the regression coefficient is 0. Therefore, the model basically meets the requirements.

For the performance of variable co-linearity, VIF is less than 10 in all cases, so the model has no multiple co-linearity problem and the model is well constructed.

The equation of the model is as follows:

$$\sum R = -11.735 + 1.963t \tag{9}$$

2.2. Multi-environmental factors influence

The relational equation for the change in plant population biomass under the influence of multiple environmental factors is:

$$W = \frac{1}{1 + e^{a+UB}} \tag{10}$$

Among them $U = \left(\frac{x_1}{x_{1m}}, \frac{x_2}{x_{2m}}, \dots, \frac{x_n}{x_{nm}} \right)$, Indicates relative impact factor $B = (b_1, b_2, \dots, b_n)^T$ denotes the parameter corresponding to the factor. Accumulate relative precipitation $\frac{\sum R}{\sum R_{km}}$ and relative cumulative temperature $\frac{\sum T}{\sum T_{km}}$ as a relative influence factor, the biomass change functions can be obtained for the corresponding plant populations :

$$w_k = \frac{w_{km}}{1 + e^{a \frac{\sum T}{\sum T_m} + b \frac{\sum R}{\sum R_m} + c}} \quad (11)$$

2.3. Modeling plant population biomass changes under the influence of interspecific competition

Natural resources are limited in arid regions, especially water resources are scarce, so the intensity of interspecific competition is high, which can affect the growth volume changes of plant populations to some extent.

2.3.1 Competitive ranking among plant populations

Since plants have different morphology, growth cycles, and water and heat requirements, the strength of the ability of various plants to compete for water is used as a competitive ranking.

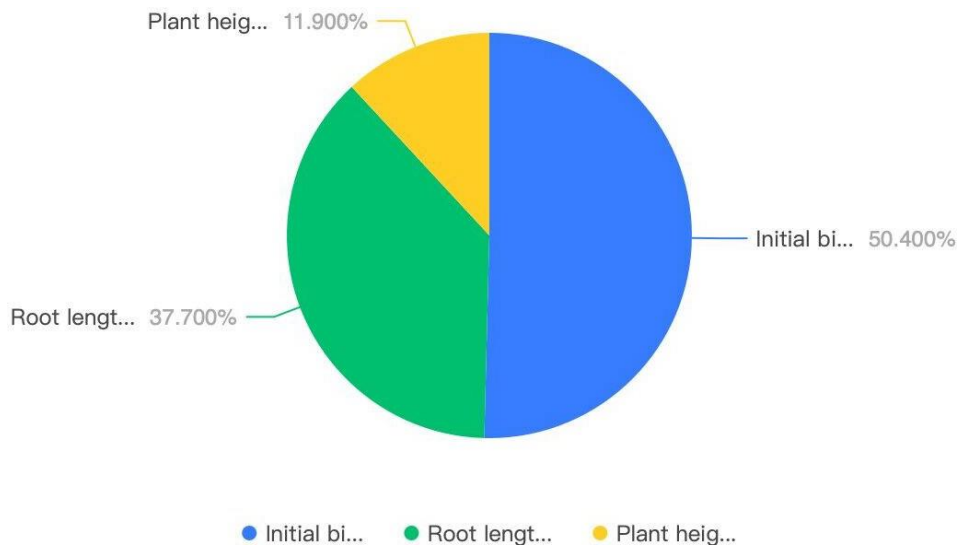


Fig. 2 Competition weight distribution

The paper used plant height, root length, and initial biomass of plants as competitive ranking indicators for evaluating plant populations. Using the information entropy method to give weights to the evaluation indexes and calculate the competitive ranking, the results are as follows Fig 2:

The normalized competition coefficient, which ranges from [0,1], is obtained. In addition, the paper define the relative competitive ranking of the i^{th} plant for the k^{th} plant:

$$\sigma_{i(k)} = \frac{Rank_i}{Rank_k} \quad (12)$$

2.3.2 Description of plant population biomass changes based on competitive ranking indicators

Based on a logistic model to describe the changes in plant population biomass between plant population competition v:

$$\frac{dw_k}{dt} = rw_k \left(1 - \frac{w_k}{w_m} - \sum_{i \neq k}^n \sigma_{i(k)} \frac{w_i}{w_{im}} \right) \quad (13)$$

2.3.3 Integrating multiple factors to describe plant population biomass change models

Taking into account environmental factors and the role of interspecific competition between populations, based on equations (7) and (9), the paper can deduce that:

$$w_k = \frac{w_{km}}{1 + e^{a_k \frac{\sum T}{\sum T_{km}} + b_k \frac{\sum R}{\sum R_m} + c_k E_k}} \quad (14)$$

where Definition $E = \ln \left(\frac{w_{km}}{w_k} + \sum_{i=1}^n \sigma_{i(k)} \frac{w_{im}}{w_i} - 1 \right)$ is the equation describing the relationship between competitive ranking for changes in plant population biomass, and substituting the relative cumulative temperature and relative precipitation accumulation $\frac{\sum R}{\sum R_{km}}$, $\frac{\sum T}{\sum T_{km}}$ as a function of time t into equation (10) yields:

$$w_k = \frac{w_{km}}{1 + e^{a_k \frac{\lambda t + \mu}{\sum T_{km}} + b_k \frac{\beta_0 t + \beta_1}{\sum R_m} + c_k E_k}} \quad (15)$$

In addition, the paper set the precipitation threshold K. The paper consider that the plants will be flooded, i.e., the biomass becomes 0, when the accumulated precipitation in the adjacent seven days is greater than K.

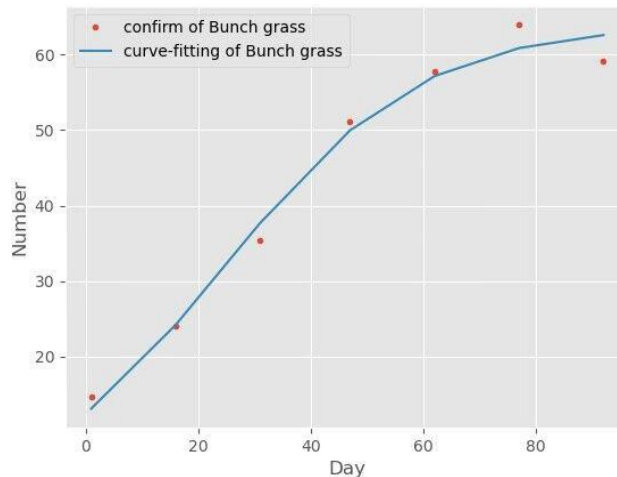


Fig. 3 Fitted model of clumped grass growth

The paper used equation (14) to fit the collected data related to the grasslands on the northern slopes of Tianshan to obtain the value of the correlation coefficient, and the results are shown in Fig 3 below

2.4. A model for calculating community species richness based on population biomass

Equation of species richness is:

$$H = - \sum_{i=1}^n \frac{w_i}{\sum_{i=1}^n w_i} \ln \frac{w_i}{\sum_{i=1}^n w_i} \quad (16)$$

Thus one can obtain the relationship between species richness H with respect to time is shown below Fig 4 and Fig 5:

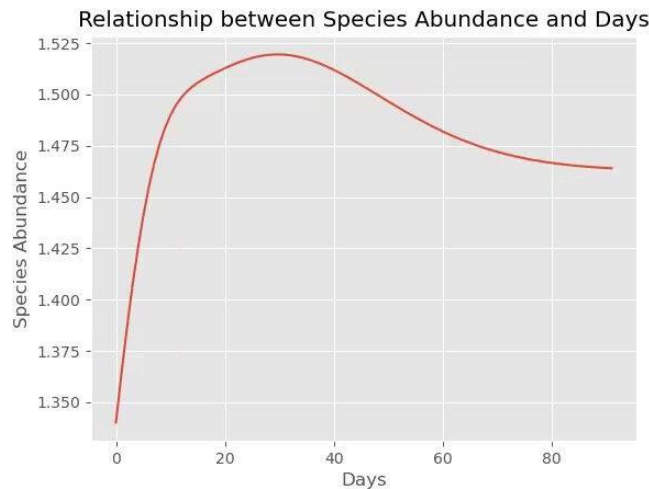


Fig. 4 Relationship Between Species Abundance and Days

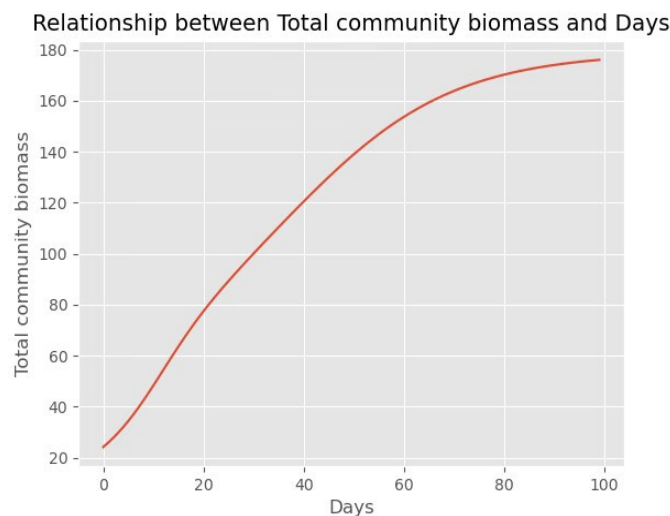


Fig. 5 Relationship Between Total Community Biomass and Days

The species richness index grew faster until day 31 and peaked at day 31 with a peak of 1.51952801; it slowly decreased to 1.46401812 after day 31.

Analysis: This is due to the fact that the growth rate of total community biomass reached a maximum around day 31, which caused the species richness index to reach a maximum, and the species richness index also leveled off after the total biomass remained unchanged.

3. Community competition-related dynamics model

Using the total biomass of the plant community to quantify the final state of the plant community, the paper argue that the plant community eventually stabilizes under the long-term inter- action with the larger environment, so the paper assume that both precipitation accumulation and cumulative temperature eventually meet the requirements for growth, and that eventually the biomass of a given population is related to its competitive ability and the maximum environmental carrying capacity.

3.1. Classification of species in the community

According to the above three evaluation indexes, the clustering effect and confidence rate are in the ideal state, and the clustering dendrogram is shown in Fig 6.

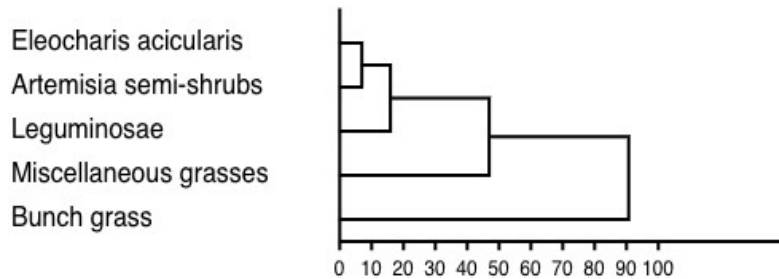


Fig. 6 Clustering dendrogram

From Fig 6 the paper can learn that: according to the biomass and its variation, the plant types are divided into three clusters of population combinations, with tufted grasses as Cluster I, miscellaneous grasses as Cluster II, and small sedge, leguminous grasses and Artemisia semi- shrubs as Cluster III.

3.2. Relationship between total community biomass and species type and number

From equation (9) the paper can learn the growth model of plant populations under the effect of mutual competition, and the paper assume that plant populations of the same class have the same initial biomass and similar competitive ability (using a normal distribution to generate an indicator of the competitive energy of new species). Thus, for n species, the paper can derive n growth models for each population biomass as well as for the total biomass of the community, as shown below Fig 7:

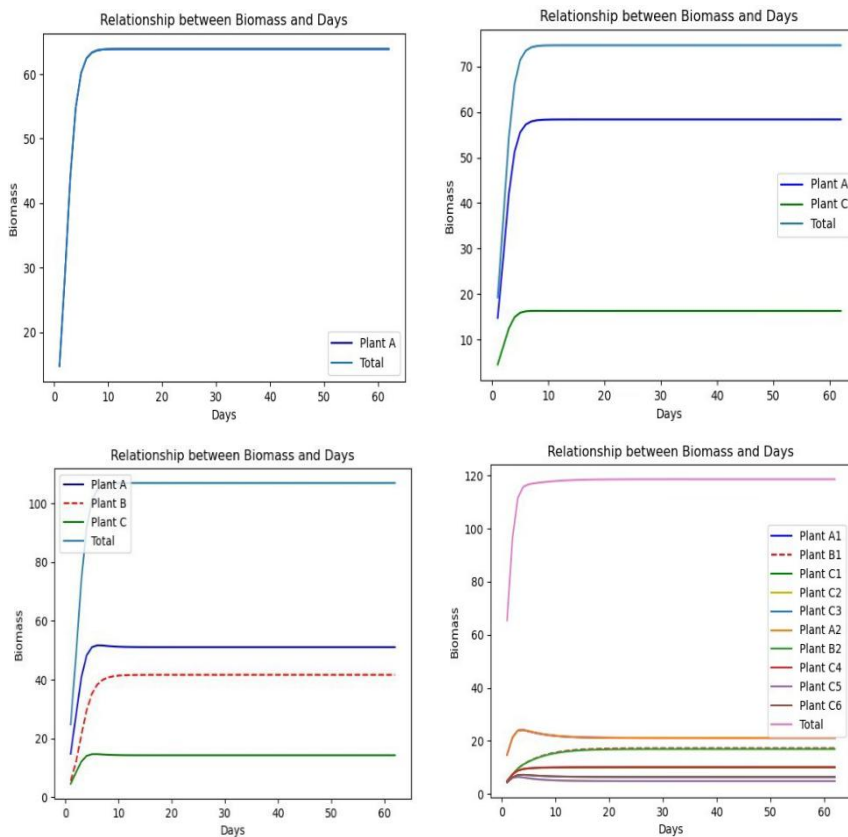


Fig. 7 n Interspecies competition growth model at the time of species (n=1,2,3,10)

Obtaining information from the graph, the paper can know that the total biomass of the community increases faster after stabilization as the type grows, but the total biomass of the community

grows slower when the species type does not change and only the number of species increases. Therefore, the paper use the total community biomass y and the number of community species x to create a function to linearly fit as shown below Fig 8

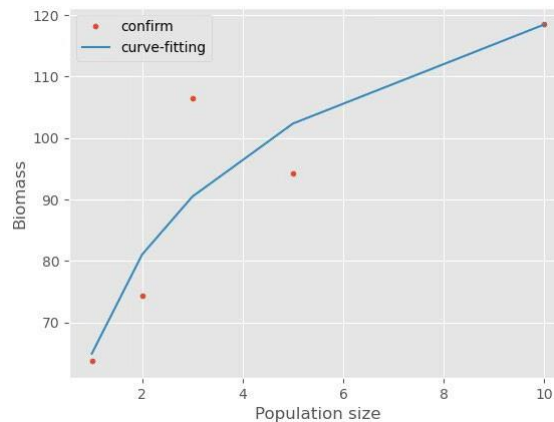


Fig. 8 Relationship between total community biomass and number of species

The paper calculated the coefficient of determination $R^2=0.814$, which is a relatively good fit for the data, so the paper can basically conclude that community biomass shows a positive relationship with the number of species under long-term environmental effects. The total community biomass was more influenced by species type, while when the type was constant and the number of species increased, the total biomass increased less. Therefore, in this community, a greater benefit can be obtained when the number of species is 3 and the number of types is 3. In addition, the paper can extend the conclusion that community benefits are relatively high when the number of types of community species is high.

4. Conclusion

The paper obtained the results of the effects of species type and number on plant communities in arid areas using a population biomass growth model based on a logistic model: the final total biomass of the community increased faster with increasing species type and number of species, while the final total biomass of the plant community increased more slowly when the species type remained the same and the number of species increased, which was basically consistent with the logistic growth model. This indicates that the richness of a population is positively correlated with the competition coefficient of that population, with the maximum value of species richness increasing as the competition coefficient increases and decreasing as the competition coefficient decreases. From the figure, species richness tends to a stable value regardless of the competition coefficient. In the discipline of biology, the environmental holding capacity of a species is constant when the external environment does not change.

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