A study of plant community stability in the lower Tarim River based on MLR and MLP and improved Morneau dynamics model

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Abstract. Taking the lower reaches of Tarim River as the research area, drought adaptability and species number of plant communities were studied. Due to the simple, dry and water-scarce topography, the plant community structure in this region is relatively uncomplicated, so it is a good area for analysis. In this paper, Monod model, a macroscopical internal mechanism of long-term interaction between plant community and environment, is proposed. The Monod model is derived from the growth of microorganisms and therefore needs to be optimized when considering plants: self-inhibition characteristics are introduced to obtain an optimized mechanism model. Based on this model, the conditions to be met when the change rate of plant population density is positive are solved in this paper. Combined with the actual number of species, it is considered that the community needs at least three different plant species to benefit, and the situation caused by the increase of species is discussed. Different types of plants have different NDVI, so they have different effects on the model. In this paper, the analysis is divided into three types of plants, and the effect of changing drought frequency is considered. Since there are only two regions with different drought frequency and easy to be divided, this paper introduced multiple linear regression models in the two regions respectively, extracted the general model from the regression coefficient relationship between the two regions, and analyzed the NDVI regression coefficient of the two regions at the same time, to obtain the general rule of the effect of less drought on the number of species. Due to the lack of pollution data and habitat data in the study area, this paper derived a model of negative environmental factors from the mechanism model, and finally combined with the easily available pm2.5 index. Based on the established model, this paper hopes to help ensure community survival in terms of increasing resource growth rates and preserving diversity.

Keywords: NDVI; Multiple Linear Regression Prediction Model; MLP; Monod Models.

1. Introduction

1.1. The Problem Background

Plants have evolved various mechanisms to cope with environmental stresses such as drought. However, different plant species have different responses to drought stress. Grasslands, in particular, are highly sensitive to drought conditions, and plant communities with only one species often show limited adaptation capacity compared to those with higher species diversity. Interestingly, there is no strong correlation between species diversity and productivity of grassland ecosystems, which is instead more influenced by environmental stress factors such as drought. Surprisingly, disturbances such as drought can have a positive impact on plant functional diversity to some extent, but these effects may be moderated by productivity and other environmental factors. In fact, studies have shown that plant communities with four or more species are better equipped to cope with consecutive drought cycles than those with fewer species. At the same time, plant communities with higher species diversity recover faster, are more stable, and more resistant to environmental stress such as drought compared to those with lower species diversity.

Localized biodiversity can enhance a community's resilience to environmental stresses, but questions remain about the minimum number of species required to achieve this effect and the long-term implications of such biodiversity for ecosystem functioning. The maintenance of biodiversity in plant communities is critical for sustaining ecosystem services, such as carbon sequestration, soil

fertility, and nutrient cycling. Therefore, understanding the relationship between biodiversity and ecosystem resilience to environmental stresses such as drought is essential for effective conservation and management of plant communities.

2. With Respect to the Long-term Interactions of a Community of Pl ants and the Larger Environment

2.1. Optimization Model of the Monod model

To explore long-term interactions between plant communities and the larger environment, we need to develop more macroscopic and intrinsic mathematical models. In natural ecosystems, the competition among plant populations is mainly divided into resource competition (i.e. competition for soil resources such as water and nutrients) and spatial competition, and the spatial competition is mainly mild competition. When the supply of resources is limited, the competition for resources is mainly manifested as the competition within the ecosystem; otherwise, it is mainly manifested as the spatial competition. The traditional resource competition model (Monod model) can not explain this phenomenon well. Therefore, according to the characteristics of plant ecosystems, we need to introduce a new model of resource competition, so that the balance point between different species increases with the change of population density, so as to realize the stable coexistence of multiple species, while the dominant species changes sequentially with the change of resource supply rate.

Monod model:

Monod model is a classic ecological model describing species competition in an ecosystem. The model is based on the assumption that the population size of each species depends on its ability to access environmental resources and population density. This means that as population density increases, so does competition for resources between individuals, leading to a decrease in population size. This model uses a simple mathematical expression in which population size changes over time are described by differential equations. The equation includes parameters such as species growth rate, maximum population density and resource utilization efficiency. By adjusting these parameters, the Monod model can simulate competition and coexistence between different species.

The kinetic equation is as follows.

$$\begin{aligned} \frac{\mathrm{d}N_1}{\mathrm{d}t} &= G_i - M_i = N_i\mu_i(R) - N_i m_i, i = 1, \ldots, n \\ \frac{\mathrm{d}R}{\mathrm{d}t} &= S - LR - \sum_{i=1}^{n} N_i\mu_i(R)h_i, \end{aligned} \tag{1}$$

Where, N_i denotes the population density of species i;

$M_i = N_i \cdot m_i$ denotes the mortality rate of species i;

m_i denotes the relative mortality rate of species i;

R denotes the available resources;

$G_i = N_i \cdot \mu_i(R)$denotes the growth rate of species i;

$\mu_i(R) = \mu_{imax}R/(R + R_{ih})$ is called the Monod function, denotes the relative growth rate of species i;

$\mu_{imax}$is the upper limit (when R tends to infinity)of $\mu_i(R)$;

$R_{ih}$is the size of the relative growth rate $R$when it reaches$0.5\mu_{imax}$;

Sdenotes the resource supply rate;

$h_i$denotes the resources$R$ consumed to reproduce a unit number of species i;

L represents the relative resource self-consumption rate.

The main limitation of the Lotka-Volterra model is its inability to explain the competition and coexistence that are common among plant populations in natural ecosystems. Meanwhile, the

dominant species in Lotka-Volterra model did not change with the change of resource supply rate. Therefore, characteristics of natural ecosystems that change with climate distribution patterns, such as the transition from desert to scrub/grassland to forest as precipitation increases, cannot be replicated. The fundamental reason is that the Lotka-Volterra model is based on plankton and does not take into account the size of individual species, which grow at a rate proportional to their own population density. However, in plant ecosystems, as the number or size of individuals increases, the growth rate of a species gradually approaches saturation, which is called self-inhibition (Reeset al., 2010). For example, the proportion of leaves (producing organs) in a tree's total biomass decreases with increasing volume, leading to a decline in relative growth rates. In addition, with the increase of leaf area index (i.e. total leaf area per unit surface area), plant photosynthetic intensity gradually approached saturation (Dickinson et al., 2008).

So, we change the form of the growth rate as follows.

$$G = \delta(N) \times \mu(R) \propto \frac{\delta_{\max} N}{N + N_h} \times \frac{\mu_{\max} R}{R + R_h} \tag{2}$$

The equation of the Monod model then becomes.

$$\begin{aligned} \frac{\mathrm{d}N_i}{\mathrm{d}t} &= N_i g_i\left(R, N_i\right) - N_i m_i, \quad i = 1, \ldots, n \\ \frac{\mathrm{d}R}{\mathrm{d}t} &= S - LR - \sum_{i=1}^{n} N_i g_i\left(R, N_i\right) h_i, \end{aligned} \tag{3}$$

Relative growth rate:

$$g_i\left(R, N_i\right) = \phi_i \times \left[R/(R + R_{ih})\right] \times \left[N_{ih}/(N_i + N_{ih})\right] \tag{4}$$

ϕ_i is the limiting value of the relative growth rate as R tends to infinity anN_i tends to zero, N_{ih}andR_{ih} is similar in meaning.

Obviously the growth rate will tend to saturate with the increase ofN_i.

Solving this system of equations yields the expressions for population density and available resources.

$$N = \begin{cases} \left(\frac{\phi}{m} \times \frac{R}{R+R_h} - 1\right) N_h & R > R^*, \\ 0 & R \leqslant R^*, \end{cases} \tag{5}$$

Where

$$R^* = R_h/(\phi/m - 1) \tag{6}$$

$$\begin{aligned} R = (&S + N_h mh - LR_h - N_h \phi h + \\ &\sqrt{\left(S + N_h mh - LR_h - N_h \phi h\right)^2 + 4L\left(S + N_h mh\right)}\Big) /2L \end{aligned} \tag{7}$$

A curve of N about R can be made. As shown in Figure 2.1:

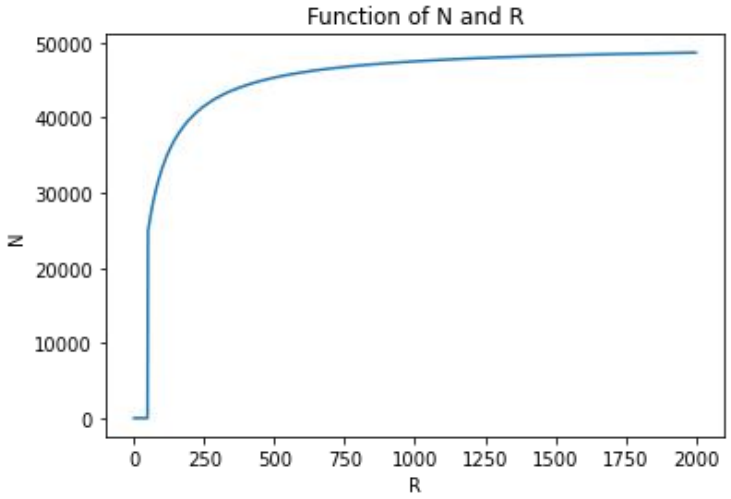


Fig 1. Function of N and R.

From the above results, we know that the population density N at equilibrium depends on the available resources R, and R at equilibrium depends on the resource supply rate S, and both are positively correlated.

2.2. Number of Species that Benefit the Plant Community

Combining the equation of N on R and the equation of R on S, it is obtained that in the case that N is not zero:

$$N = \frac{S}{\phi} + \frac{mh}{\phi} \cdot \left(\frac{S}{R_h} - \frac{S}{R - R_h} \right) + \frac{h}{\phi} \cdot \left(\frac{S}{R - R_h} - \frac{LR_h}{R - R_h} \right) \tag{8}$$

As mentioned above, NDVI can represent the population density of N, while S has a linear relationship with surrounding NDVI, temperature and precipitation on a smaller scale. And R can be regarded as constant in steady state, which means that N is proportional to s. Therefore, the mechanical model based on differential equation is consistent with the previous multiple linear regression model at small geographical scales. To benefit the species in the community, it can be understood that the derivative of the population density of each species with respect to time is greater than 0. It can be obtained from the above differential equation:

$$N_i < \frac{N_{ih} R}{\phi_i \cdot R_{ih} \cdot m_i - N_{ih} R} \tag{9}$$

When the available resources R are held constant, note that ξ is equal to the smallest n
That makes

$$\sum_{i=1}^{n} \frac{N_{ih} R}{\phi_i \cdot R_{ih} \cdot m_i - N_{ih} R} = R \tag{10}$$

Then the entire community is satisfied when the number of species species n is greater than ξ .

Using the multiple linear regression equation above, specific solutions can be calculated that, based on the actual number of species in the four transect zones in the study area, the community needs at least about three different plant species in order to benefit in our study area. As the number of plant species increases, four things may happen: the biodiversity of the plant community will increase; The efficiency of resource utilization is reduced; Increase stability and change in ecosystem function.

However, objective conditions can lead to an upper limit on the number of plant species in a community.

2.3. Effect of Species Type in the Community

In this paper, NDVI was used to characterize the degree of plant diversity, but in detail, the range of NDVI size varied with different plant species, which influenced the conclusion to some extent. Relevant papers show that:

Tree layer: Generally between 0.3 and 0.8, but depending on the tree species and season, NDVI value is usually higher in the growing season.

Shrub layer: Generally between 0.2 and 0.6, but also depends on the type of shrub and growing conditions. Compared with tree layer, shrub layer usually has higher NDVI value in dry season.

Herbaceous layer: Generally 0. 1 and 0.5, but also depends on the type of herb and growing conditions. In the growing season of herbaceous plants, NDVI value is usually higher.

Therefore, it can be concluded that the species type with higher NDVI value is more conducive to the stability of the whole plant community.

2.4. Increased and Decreased Frequency of Droughts

It is important to consider the impact of greater frequency and variability of droughts on future weather cycles. Direct reference can be obtained from different regions of our study area. As you can see, the dividing line between different amounts of precipitation and different temperatures is almost the same. To simplify the model, our study area can be naturally divided into two regions, I and II, as shown in the figure below.

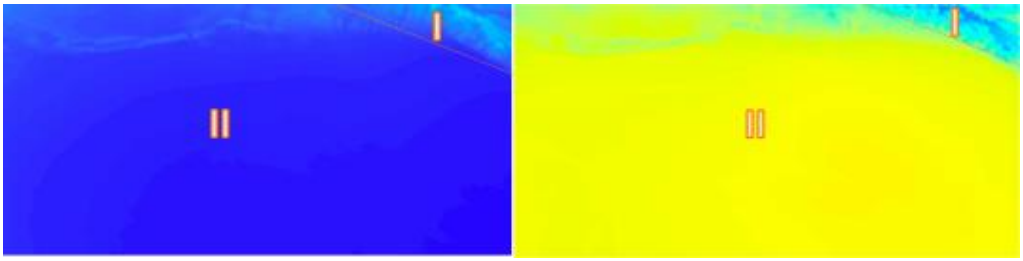


Fig 2. Area I and Area II.

Region, I represent regions with lower temperatures and higher precipitation.

Region II represents regions with higher temperatures and drier precipitation.

The rest of the data belong to region II. Thus we get the data for both parts of the region. In order to keep only the effect of climate change in this paper, we choose to remove the effect of community species richness to achieve the effect of control variables. Using python to construct multiple linear regression models in each of the two regions, we obtained the following results.

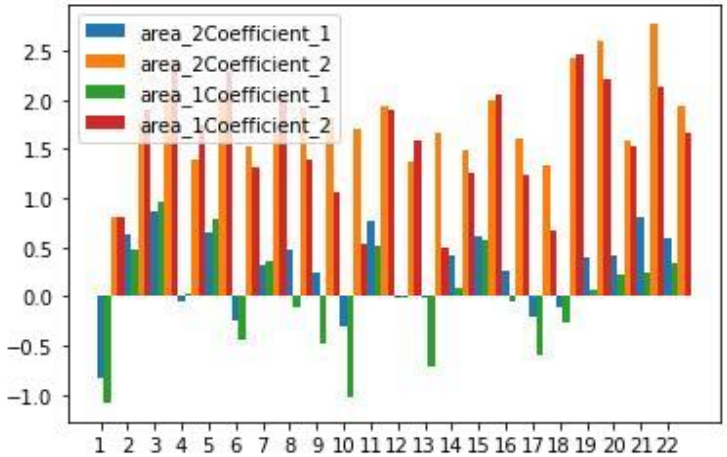


Fig 3. Results.

It is found that there are different regression coefficients of temperature and precipitation index in the two regions. The negative effect of temperature in region 1 is stronger than that in region 2 and the positive effect of precipitation is weaker than that in region 2. In future cycles, higher temperatures and precipitation may improve plant diversity in the already cold and arid lower Tarim River. In order to investigate the effect of species on the whole population when drought frequency decreased, the influence of NDVI index on the central NDVI index was established in each radius of the two regions. python was used to obtain the NDVI regression coefficients of the two regions, as shown in Figure2.4.

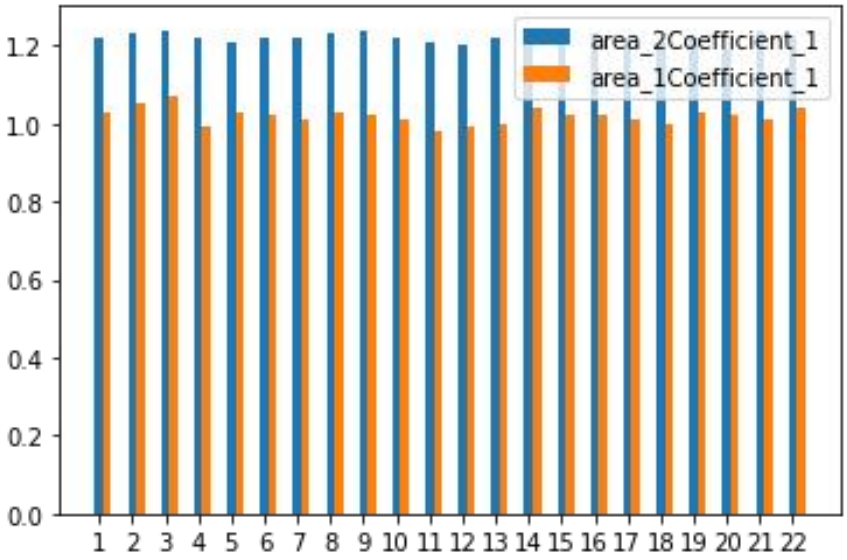


Fig 4. Results.

It can be seen that the beneficial effect of species number on community stability is enhanced when drought frequency increases, that is, the effect of species number decreases when drought is not as frequent.

2.5. Impact of Negative Environment-related Factors

As negative environmental factors such as pollution and habitat reduction arise, the optimized Monod model constructed in the previous section shows that the resource supply rate S decreases, so the population density N decreases, but R also decreases. Rewriting both sides of the above inequality as a function of the relevant S, the following curve is plotted in a biologically reasonable range.

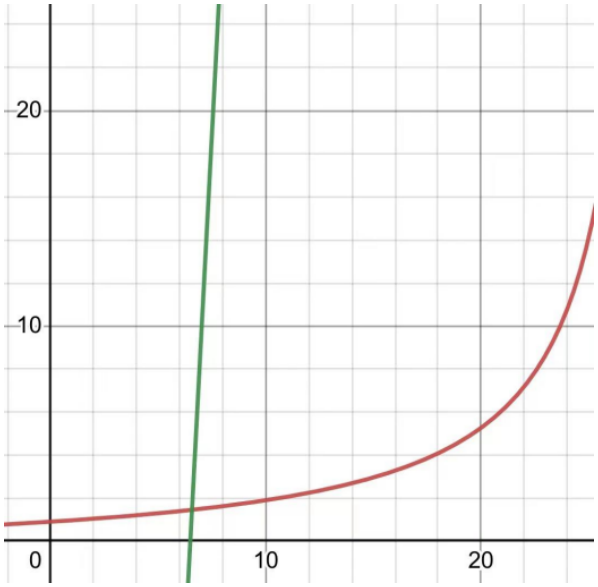


Fig 5. Function Image.

So, in general, the growth rate on the left side of the inequality is higher than the growth rate on the right side of the inequality, and thus for the inequality to continue to hold, a larger number of population species would be required to benefit the entire population.

The data related to pm2.5 from 1999 to 2020 are shown in the figure below. In the overall analysis, the resistance of plant diversity will increase with the increase of pm2.5, and the resistance of plant community stability will also increase.

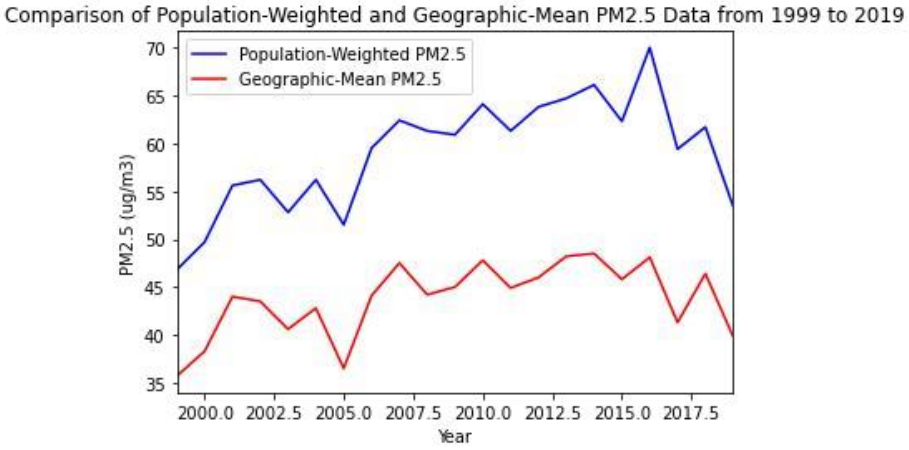


Fig 6. pm2.5.

3. Conclusions

The aim of this study was to investigate the drought adaptability and species number of plant communities in the lower reaches of Tarim River. To this end, we propose a macroscopic and intrinsic mechanism model, Monod model, to explain the long-term interaction between plant community and environment. In the case of plant factors, self-inhibition characteristics were introduced to optimize the model. The study showed that the community needed at least three different plant species to benefit, and explored the impact of increased species. In this paper, the analysis is divided into three types of plants, and the effect of changing drought frequency is considered. In order to analyze the effects of drought on the number of species, a multiple linear regression model was introduced to obtain the general rule of drought on the number of species. On this basis, combined with pm2.5 index, the mechanism model of negative environmental factors was derived. Based on these studies, this paper emphasizes the importance of taking a holistic approach to ensure the long-term survival of plant communities and proposes a range of feasible strategies, such as maintaining soil health, promoting natural regeneration, ensuring water availability, improving environmental quality, reducing harmful air substances, and protecting biodiversity. By adopting these strategies, we can improve the ecological health of plant communities and thus achieve long-term sustainability. Overall, this paper aims to help ensure the survival of plant communities by increasing resource growth rates and preserving diversity. Therefore, the Mono model and other relevant mechanism models are proposed to provide theoretical support for realizing this goal.

Acknowlegements

I am deeply grateful for the support provided by many people throughout the writing process. Thank you to my advisor, classmates, laboratory staff, family, friends, and other individuals who have generously given their time and energy. Your enthusiastic assistance has given me great confidence and motivation in my research. Without you, I would not have been able to complete this paper. I sincerely thank everyone for their support and dedication!

References

[1] Li Junli, Xiao Hao, Shen Zhanfeng, Bai Jie. Vegetation dynamics and its response to ecological water transfer in the lower reaches of Tarim River from 2013 to 2018[J]. Arid Zone Research, 2020, 37(04): 985-992.

[2] Sun Tianyao, Li Xuemei, Xu Min, Zhang Mengsheng. Spatio-temporal pattern of vegetation coverage in the Tarim River Basin from 2000 to 2018[J]. Arid Land Geography, 2020, 43(02): 415-424.

[3] He Rongxiao, Lei Jinrui, Yang Fan. Study on the correlation and spatial distribution characteristics between remote sensing vegetation index and plant diversity: a case study of the central urban area of Haikou City [J]. Guihaia, 2021, 41(03): 351-361.

[4] Gao Qing, Ailixier Kuerban, Xiao Hao. Spatiotemporal changes of vegetation in the lower reaches of Tarim River[J]. Journal of Natural Resources, 2019, 34(03): 624-632.

[5] Yang Qi. SVM prediction and classification of the minimum population reconstruction areas for wild plants on Hainan Island[D]. Hainan University, 2014.

[6] Li Weihong, Zhou Honghua, Yang Xiaoming, Ding Hui. Response of aboveground biomass spatial distribution of grassland plant community to groundwater in arid desert area[J]. Acta Prataculturae Sinica, 2010, 19(05): 186- 195.

[7] Laliberté, E., Norton, D. A., & Scott, D. (2013). Contrasting effects of productivity and disturbance on plant functional diversity at local and metacommunity scales. Journal of Vegetation Science, 24(5), 834-842.

[8] Tilman, D., Reich, P. B., & Knops, J. M. (2006). Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature, 441(7093), 629-632.

[9] Isbell, F., Tilman, D., Polasky, S., Binder, S., & Hawthorne, P. (2013). Low biodiversity state persists two decades after cessation of nutrient enrichment. Nature, 494(7437), 231-234.

[10] Adler, P. B., Seabloom, E. W., Borer, E. T., Hillebrand, H., Hautier, Y., Hector, A., ... & Grace, J. B. (2011). Productivity is a poor predictor of plant species richness. Science, 333(6050), 1750-1753.