Multidisciplinary Journal of Geology and Earth Sciences
Volume 11 Issue 3, July-September 2023
ISSN: 2995-3669
Impact Factor: 7.76
http://kloverjournals.org/journals/index.php/ges

DYNAMIC ECOSYSTEMS: HARNESSING PCVD TO DECODE THE IMPACT OF DROUGHT ON PLANT COMMUNITIES

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Abstract: Plant communities exhibit varying capacities to withstand drought conditions, a trait intrinsically tied to species diversity. Empirical evidence highlights that communities boasting four or more species demonstrate superior resilience to drought compared to monocultures. This underscores the significance of localized biodiversity in bolstering a community's drought tolerance. Yet, the critical threshold of diversity required for such benefits remains undetermined. Furthermore, the dynamic relationship between species number and this phenomenon remains unclear. These inquiries form pivotal research junctures, holding the potential to guide species conservation efforts and secure the enduring vitality of plant communities. This comprehension of diverse species' responses to environmental stressors serves as an invaluable compass for human-nature interactions.

Keywords: Plant communities, Biodiversity, Drought resilience, Species diversity, Environmental stressors

1. Introduction

Plant communities with different species have different abilities to adapt to drought. Numerous observations have shown that plant communities with four or more species are better adapted to droughts than those with one species.[1] This implies that a certain amount of biodiversity is required for a plant community to benefit from this localized biodiversity.

However, the necessary level of diversity has yet to be determined. Additionally, it is uncertain how this phenomenon changes when the number of species in a community increases [2]. These questions represent important points of research as they could provide insights on how to best conserve species and ensure the long-term sustainability of plant communities. Understanding how different species respond to environmental stresses can act as a valuable tool for how humans interact with the natural world.

2. Systematic model of plant community variation with drought degree

2.1 Module I: Three Types of Plant Community Interaction Model

We applied the established interspecific competition model according to the Logistic rule to the specific plant community [3,4], and divided the plant community into trees, shrubs and herbs for discussion, and studied the competition relationship between them [5]. In the situation of the problem, drought is not the only thing that is unfavorable to the survival of a certain plant on the grassland. Drought also seriously affects the survival of plants, and the shortage of water resources caused by drought will severely compress the living space of plants.

Therefore, we take the parameter Degree of drought into account in the formula, which makes the model more consistent with the actual situation, and established the following differential equation:

$$\frac{dB_b}{dt} = R_b B_b\left(1 - \frac{\beta_t B_t + \beta_b B_b + \beta_h B_h + D}{S_q K_b}\right) \quad (1)$$

$$\frac{dB_t}{dt} = R_t B_t\left(1 - \frac{\beta_t B_t + \beta_b B_b + \beta_h B_h + D}{S_q K_t}\right) \quad (2)$$

$$\frac{dB_h}{dt} = R_h B_h\left(1 - \frac{\beta_t B_t + \beta_b B_b + \beta_h B_h + D}{S_q K_h}\right) \quad (3)$$

2.2 Module II: Community plant species number change model

Next, we will construct a model to track the changes in species population in the plant community. Considering the different growth characteristics of each species, we will devise separate population models for trees, shrubs, and herbs:

$$P_t = V_t * I_t \quad (4)$$

$$P_b = V_b * I_b \quad (5)$$

$$P_h = V_h * I_h \quad (6)$$

Where VV_t, VV_{bb}, VV_h indicate the number of species of tree, shrub and herbaceous populations, and II_{tt}, II_{bb}, II_h indicate the species generation probability of the three populations.

We want to explore the effect of B,S and K on the probability of species formation, which is very small at the numerical level, so we think of amplifying this effect by logit transformation, so that the results will also change greatly with the changes of these factors, so as to solve the sensitivity problem of dependent variables changing with factors .Then we do the logit transformation to the above formula sub:

$$\ln\frac{I_t}{1-I_t} = k\left(\frac{B_t}{S_q * K_t} - 1/2\right) \quad (7)$$

$$\ln\frac{I_b}{1-I_b} = k\left(\frac{B_b}{S_q * K_b} - 1/2\right) \quad (8)$$

$$\ln\frac{I_h}{1-I_h} = k\left(\frac{B_h}{S_q * K_h} - 1/2\right) \quad (9)$$

Where kk is the probability extended constant coefficient. Due to the transformation characteristics of logit, when kk=10, we let:

$$\frac{B}{S * k} - 1/I = 0 \quad (10)$$

Then the result comes to I≈6.6ρ∗ 10^{-3}, which suggests the error is minimal and has a good fitting effect. So the kk takes the value of 10.

Adding up the number of species and biomass of each population, we obtained the total number of species and the total biomass of the plant community:

$$B = B_t + B_b + B_h \quad (11)$$

$$P = P_t + P_b + P_h \quad (12)$$

2.3 Module III: Drought degree and precipitation model

In order to study changes in plant communities under the drought cycle, we need to define the degree of drought. We decided to define the degree of drought by a model of drought index, which involves the water demand of plants and the proportion of rainfall area [6-9].

To define the drought level of a region based on the water requirement of plants and the relative area of precipitation, we take the negative logarithm of it in order to limit the data between 0 and positive infinity, while making the drought level and precipitation amount negative correlation [10].

$$D = -\ln \frac{\int_0^{S_p} A \cdot ds}{S_q(N_t B_t + N_b B_b + N_h B_h)} \quad (13)$$

In the above model, the value of D is zero when the rainfall is excessive, and if D <0 occurs, make D=0 to avoid discussing the effect of excessive rainfall.

The degree of drought as defined by this model allowed us to conduct our next biodiversity-based environmental assessment.

2.4 Environmental assessment model

After obtaining the drought degree index, we comprehensively considered the number of species, the total amount of organisms, and the community area of the plant community to establish an environmental assessment model, which can simate the actual situation of the environment [5, 11].

$$E = \frac{(P_t K_t + P_b K_b + P_h K_h) * S_q}{D + \beta_t B_t + \beta_b B_b + \beta_h B_h} \quad (14)$$

In order to better simulate the reality, we incorporate into the modeling that the value of E increases with the number of species, while decreases with the increase of total biomass. Too much or too little biomass reduces the environmental assessment index.

Within this environmental assessment model, the E index can reflect the adaptation level of the plant community to the environment and further simulate the growth of the plant community in drought cycles.

3. Results

3.1 Change Trend of the Number of Plant Species Error Analysis of Model One

We want to get the result of our model to see the change of the number of plant species. Our model was implemented with MATLAB. We initialized our model and set parameters to common values. Then we ran our program and got the change trend of the number of plant species. As the following figure 1.

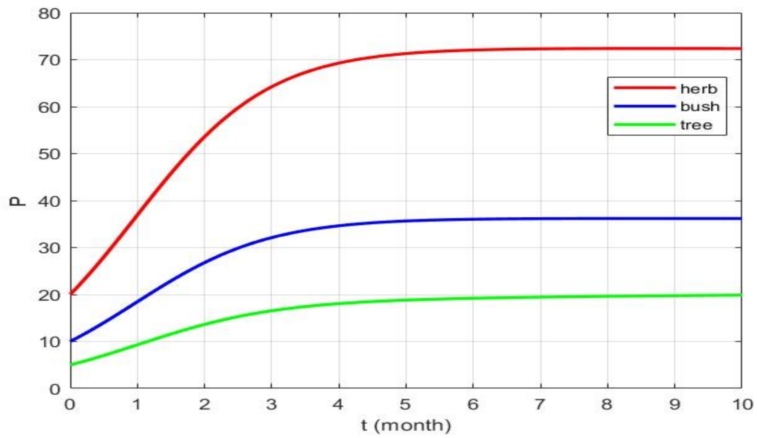

Figure 1: Trends in Species Number

In our model, we use E to represent for environmental assessment indicators, which can assess the larger environment. So we get the change trend of the environental assessment indicators. As the following figure 2.

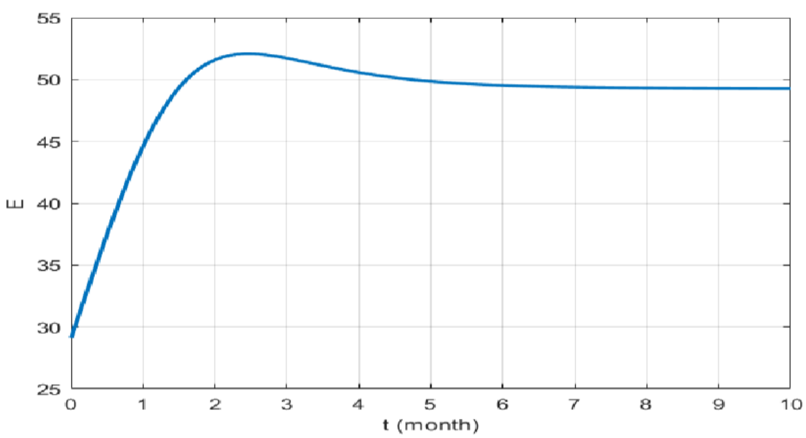

Figure 2: Change Trend of the Environment Assessment Indicators

In this figure 2, we have come to the conclusion that a moderate number of species is most beneficial to the system. Over time, the number of species gradually increased. When the number of species is too large, this may lead to species flooding, excessive consumption of environmental resources, and damage to the entire system. If the number of species is too small, the ecological environment is unstable and easy to be damaged by other invasive factors.

3.2 Impact of Different Plant Communities on the System Error Analysis of Model Three

We're supposed to explore the impact of different plant communities on the system. There are a large amount of plant species in the biosphere so we classified them into three different communities which are tree, bush and herb in our model. In the result, we see that the number of herb in the system is the largest, followed by bush and tree. Then we'd like to show the different impact of these three communities on the system through changing initial value of biomass of different communities and make sensitivity analysis. As the following figure 3.

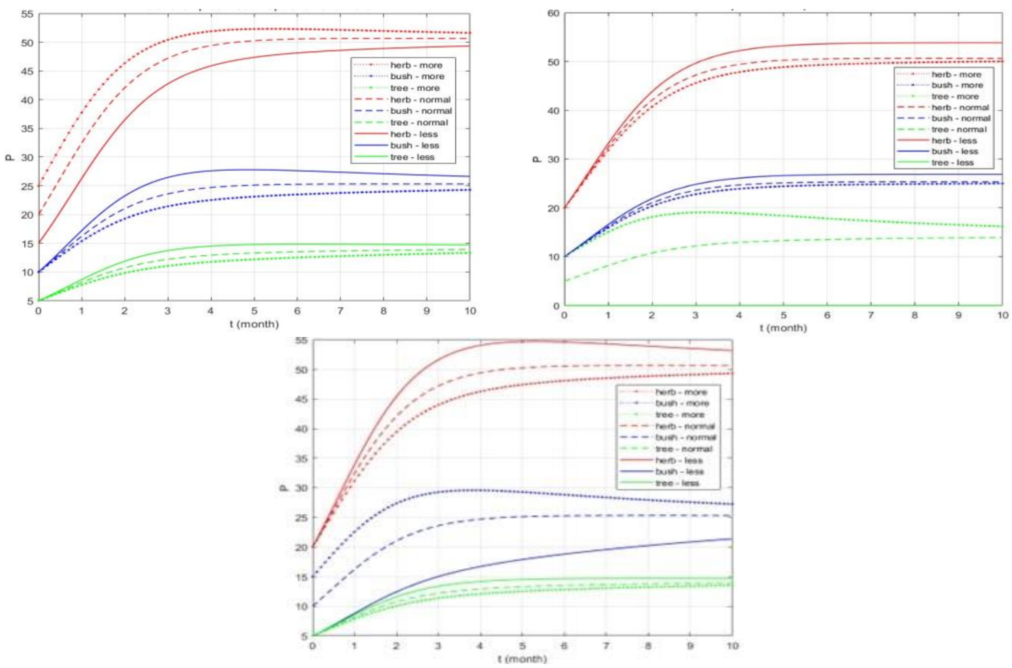

Figure 3: Relationships between Population and Different Plant Communities

In this figure, we can see the different impact of plant communities. Herb has the least impact on environmental assessment indicators, shrubs are in the middle, and trees are the greatest. Obviously can we see that our model has high computational efficiency and precision. As the initial value of biomass of different plant communities fluctuates, the failure probability will gradually approach a stable value.

3.3 System Changes under Various Drought Conditions

We expect to explore the range of drought cycles. In our model, we calculate the degree of drought through precipitation and plant water demand in module III. In order to describe the extent of drought, we use precipitation area SS_{pp} to model wider variation of the occurrence of droughts in future weather cycles. The smaller the precipitation area, the larger the range of drought. Then we changed the precipitation area and got the following figure 4.

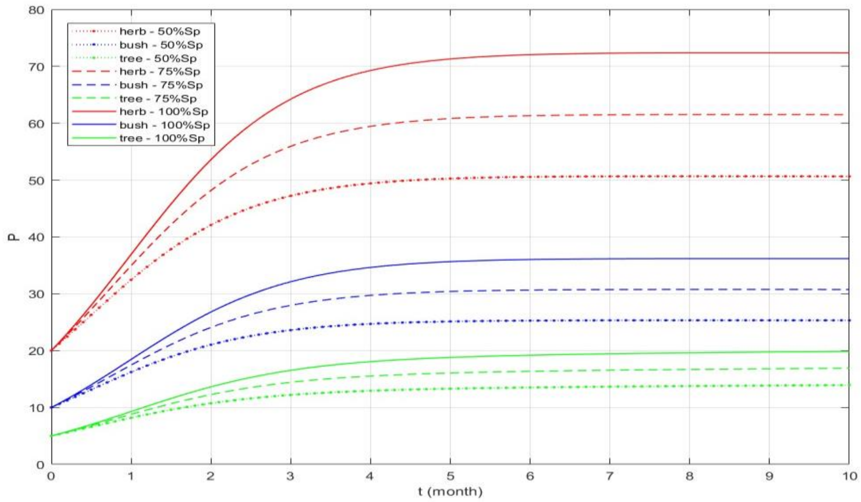

Figure 4: Relationship between population and tree

In this figure 4, we draw a conclusion that with the reduction of precipitation area, the number of plant species decreases.

4. Conclusions

If the number of plant populations keeps increasing or unchanged for a long time, we can think that plant communities have good long-term viability. But this does not mean that the environmental assessment indicators must be better. What we need is a more stable environment, neither species scarcity nor species flooding. So we give the following measures.

1) Plant a variety of plants suitable for the environment in the plant community, so that there are more types of plants in the community;
2) Keep the number of plants in the community moderate through artificial cutting and other methods;
3) Increase the growth rate of plants and reduce the degree of drought through large-scale artificial rainfall in case of insufficient precipitation;
4) Fully treat pollutants and minimize environmental pollution;
5) Reduce the area of human activities and expand the habitat area of plant communities.

Finally, we hope that our models and measures can contribute to drought control and environmental protection. The earth is our common home, and plants are an indispensable and important part of the natural family.

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