Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
A		2115295

Effects of Interspecific Competition on the Decomposition Efficiency of Fungi under Different Conditions

Summary

The decomposition of wood fibers is considered as an important process in carbon cycle. The key role in this is played by wood-rotting fungi. Wood-rotting fungi are commonly distributed in various climatic environments and have an influence on the ecological environment. Therefore, it is significant to study the relationship between different factors and wood fiber decomposition rate to maintain **ecosystem stability**.

The reaction mechanism of decomposition of wood fibers with fungal extracellular enzyme reactions has been elucidated in current works such as *Introduction to Mycology*, *Lignin*, etc. In this article, we mainly focus on the relationship between growth rate and moisture tolerance of various wood decay fungi on decomposition rate. Then we establish a macroscopic model and collect a large amount of data affecting the decomposition rate of fungi. In addition, we use K-means cluster analysis to classified the numerous and miscellaneous fungi into three representative types and develop a general formula for the decomposition rate of single fungal species by using **multivariate nonlinear regression equation**, build a competition model under multi-fungal state by **multivariate differential equation**, and verify the simulation by using meta-cellular automata, so as to predict the change of fungal population.

On this basis, in order to simulate the environmental fluctuations in the real state, we introduced two sinusoidal variation correction terms to the differential equation to represent the effect of temperature and humidity on the population growth amount, and used it as a variation factor of the **cellular automaton** to achieve **the sensitivity analysis** of the model. After performing many simulations of cross combinations of fungal species in different environments, we obtained the variation pattern of population size, obtained the effect of species diversity on the rate of decomposition and gave the conclusion that the combination with the highest decomposition rate in the environment was a single fungal species along with the related parameters and descriptions.

At the same time, we obtained **the same conclusion in the paper of D.S. Maynard** et al.*fungal interactions reduce carbon use efficiency* . This model and its conclusion will have a positive impact on agriculture, ecology and other aspects of research.

Keywords: Fungal traits; Decomposition rate; Regression analysis; Species diversity; Differential equation ;Cellular automata

Contents

1 Introduction

1.1 Background

The carbon cycle describes the process of the exchange of carbon throughout the geochemical cycle of the Earth, and is a vital component for life on the planet. It is a chain of material cycles between the inorganic environment and organic organisms that maintains the CO2 balance in the atmosphere.

One part of the carbon cycle is the decomposition of organic matter into carbon dioxide by microorganisms and its eventual emission into the atmosphere, allowing carbon to be renewed and used in other forms. A significant component is the decomposition of plant material and woody fibers. Some of the key agents in decomposing woody fibers are fungi.

The authors of a recent research article on wood decomposition by fungi identified fungi traits that determine decomposition rates and also noted links between the hyphal extension rate and moisture tolerance. There are also some problems that arise in this process.

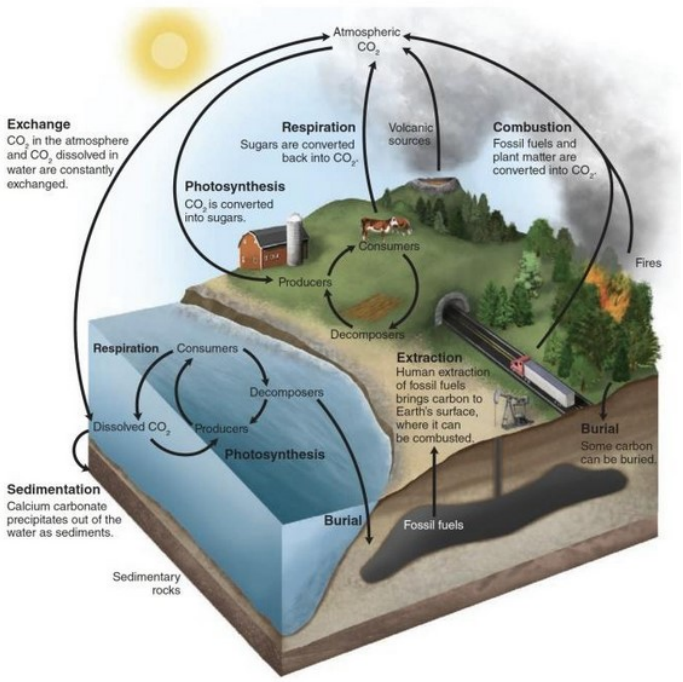


Figure 1: The Process of Carbon Cycle

Our team's mission is to construct mathematical models to assist scientists in solving these problems in order to advance the field of fungal decomposition-related development. Fungi act as decomposers in the environment to break down complex organic matter into substances that can be reused by producers, and fungal vitality and diversity are important for the effective functioning of an ecosystem.

In addition, the application of fungi also plays an important role in the field of ground waste decomposition and makes a great contribution to the environmental protection industry. Therefore, there is a great ecological and economic value behind these problems.

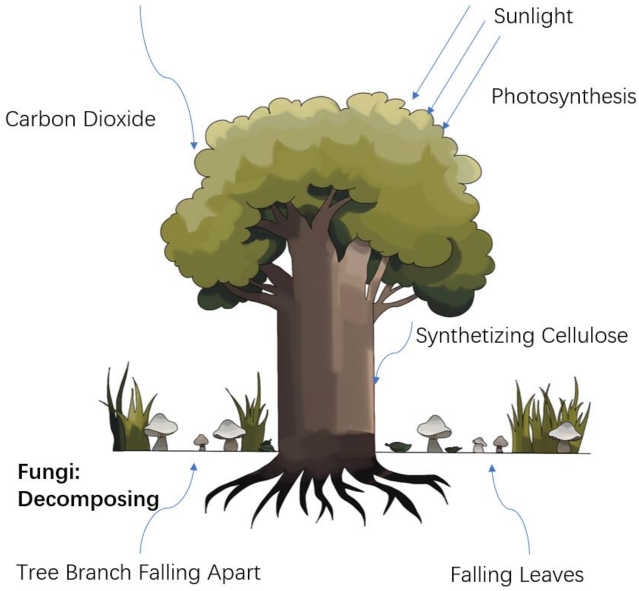


Figure 2: The Process of Decomposing

1.2 Problem Restatement

- Build a mathematical model that describes the breakdown of ground litter and woody fibers through fungal activity in the presence of multiple species of fungi.
- In your model, incorporate the interactions between different species of fungi, which have different growth rates and different moisture tolerances as shown in Figures 1 and 2.
- Provide an analysis of the model and describe the interactions between the different types of fungi. The dynamics of the interactions should be characterized and described including both short- and long-term trends. Your analysis should examine the sensitivity to rapid fluctuations in the environment, and you should determine the overall impact of changing atmospheric trends to assess the impact of variation of local weather patterns.
- Include predictions about the relative advantages and disadvantages for each species and combinations of species likely to persist, and do so for different environments including arid,semi-arid, temperate, arboreal, and tropical rain forests.
- Describe how the diversity of fungal communities of a system impacts the overall efficiency of a system with respect to the breakdown of ground litter. Predict the importance and role of biodiversity in the presence of different degrees of variability in the local environment.

1.3 Our Approach

- Based on the experimental data of decomposition of wood fibers by different species of fungi, a multiple linear regression model on the decomposition rate was developed.

- Different fungal species were clustered according to moisture tolerance and hyphal extension rate, and the experimental data of mixed culture of multiple fungi were used to calculate the multi-fungal competition weights and refine the new index: total hyphal extension rate and total moisture tolerance.
- A population competition differential model was constructed based on the natural growth rate and environmental accommodation of different fungal populations in the experiment, and indicators of climatic conditions were introduced to perform sensitivity analysis and predict the trend of fungal community reproduction.
- Predicting the growth of each species and species combination in different environments and performing a strengths and weaknesses analysis.
- Specify the role that fungal diversity plays in its response to environmental change and material decomposition, and also describe its effect on the overall efficiency of decomposing surface litter.

2 Assumptions and Model Overview

2.1 Assumptions

To simplify the problem, we make the following basic assumptions, each of which is properly justified.

- Assumption 1: For the experiment of decomposition rates of wood fibers, at the level of the fungi itself, the two main factors of moisture tolerance and hyphal extension rate are the main concerns.

  *Justification: The hypothesis focuses on these two factors, which allows a clearer study of the influence and mode of action of these two factors on the survival and decomposition of wood fibers by fungi. Meanwhile, we reviewed the references and found that other factors produced negligible effects.

- Assumption 2: The decomposition rates of wood fibers by different species of fungi is predictable.

  *Justification: Although the decomposition of wood fibers by each fungi of a population does not always follow the normal process and rate ,according to the law of large numbers, the behavior of the group will exclude the existence of unpredictable accidental factors, so we can predict the decomposition rates of wood fibers by different species of fungi by their hyphal extension rate and moisture tolerance.

- Assumption 3: Different species of fungi require essentially the same growth environment, they will compete interspecifically for resources such as nutrients, water, and space.

  *Justification: Only when different fungal populations are associated with each other because of certain factors, the effects of common survival will be manifested:

both or more inhibit each other or promote each other and mutually beneficial symbiosis. Therefore, it can be assumed that interspecific competition exists between different fungal populations.

- Assumption 4: In the forecasting model, we assume that the environment in which the fungi grows will not change dramatically during the study period and the fungi itself will not develop mutations that would have a significant impact.

  *Justification: This is because the model considers the influence of the external climatic environment and its own conditions on the survival of the fungi, and then compares the growth trends of the fungi in different climatic environments. Such a comparison is only meaningful if these conditions are essentially the same.

2.2 Model Overview

First of all, set the decomposition rate model. We used the experimental data to study the relationship between the hyphal extension rate, moisture tolerance and wood fiber decomposition rate to construct a multiple non-linear regression model, which was later converted to a multiple linear regression model using mathematical methods.

Next , we constructed a population competition model. On the one hand, we use K-means cluster analysis to classify the fungi and list the corresponding multivariate differential equations for trend prediction; on the other hand, we use the meta-cellular automata model to simulate the results. And then sensitivity analysis was performed together with decomposition rate model.

Finally, the data were analyzed to derive more accurate predictions of the growth trends of fungal populations in different environments, and thus to discover the role of fungal diversity in maintaining the survival of fungal communities.

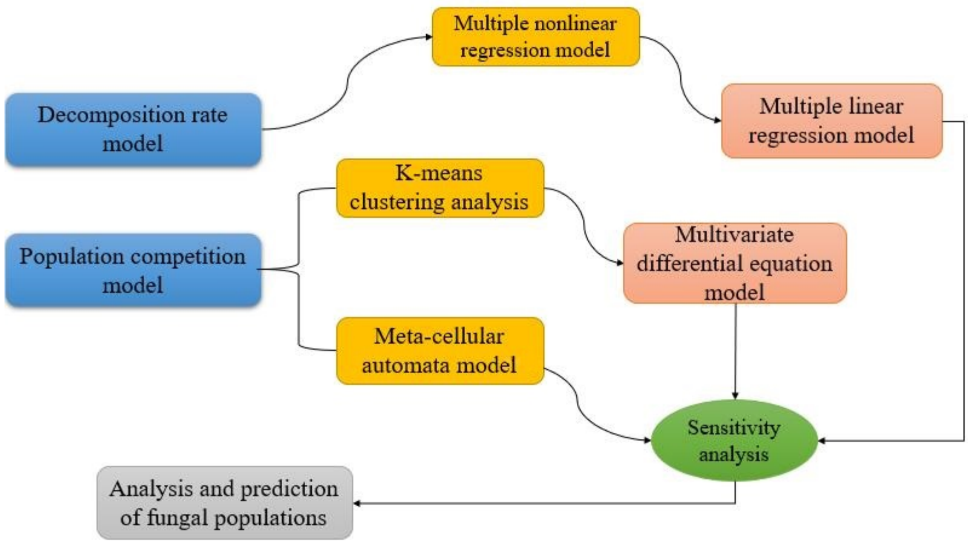


Figure 3: Model Overview

3 List of Notation

Table 1: The List of Notation

Symbol	Meaning
E	Decomposition rate
X	Growth rate
Y	Moisture resistance
$Center_k$	Random Center
y_i	Population size
N_i	Environmental holding capacity
r_i	Population growth rate
P	Annual rainfall
U	Relative Humidity
α_{ij}	Parameters describing the interaction of two given species
m_{ij}	Temperature fluctuation parameter
n_{ij}	Humidity fluctuation parameter
P_0	Stochastic propagation rate
P_{ij}	Competitive factors
f	Frequency of environmental fluctuations
t	Population reproduction time
m	Initial mass
imp	Initial mass proportion
cp	consumption proportion

4 Decomposition Rate Model Development

In order to explore the effect of growth rate and moisture tolerance on the decomposition rate of fungi, we used multiple nonlinear regression to fit the effect of extension rate and moisture tolerance on the decomposition rate of fungi through the analysis of the scatter plot data given in the question. It can be obtained that the two models are respectively power function model and exponential model, so we get the following formula

$$E = D \cdot X^A \cdot e^{B \cdot Y + C} \tag{1}$$

Where E denotes the decomposition rate of the fungi, Y denotes the moisture tolerance of the fungi, X denotes the extension rate of the fungi, and A, B, C, and D are all constants depending on the statistics.

In order to use multiple linear regression models, we take the logarithmic transformation of the above equation, as

$$\ln E = \ln D + A \cdot \ln X + B \cdot Y + C \tag{2}$$

The equation is also in the form of

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + \cdots\cdots + a_n \cdot x_n \tag{3}$$

Thereby, we can solve the parameters by using multiple linear regression models.

And for multi-strain, complex environments, the sum of decomposition rates can be expressed as

$$\sum_{i}^{n} E_i = D \cdot \left(\sum_{i}^{n} p_i \cdot X_i^A \cdot e^{B \cdot Y_i + C} \right) \tag{4}$$

Where p_i is the proportion of each fungus and the competition parameter in order to evaluate the influence of the intensity of competition.

5 Competition Model Development

5.1 Differential Equation Model

We know that the natural resources and space are limited. When the population density increases, the intra-species competition will be intensified, and the environmental tolerance will limit the number of the population, which will lead to a decrease in the birth rate and an increase in the death rate of the population. For fungi, there will also be a process of rapid growth in the early stage and stable growth in the later stage, that is, Logistic growth. The following formula gives the Logistic growth algorithm of single strain.

$$\frac{dy(t)}{dt} = r \cdot y \cdot \left(1 - \frac{y}{N}\right) \tag{5}$$

After the introduction of multiple species to produce competition, the population growth can be expressed by the following differential equation.

$$\begin{cases} \frac{dy_1}{dt} = r_1 \cdot y_1 \cdot \left(1 - \frac{y_1}{N_1} - \alpha_{21} \cdot \frac{y_2}{N_2} - \cdots - \alpha_{n1} \cdot \frac{y_n}{N_n}\right) \\ \frac{dy_2}{dt} = r_2 \cdot y_2 \cdot \left(1 - \frac{y_2}{N_2} - \alpha_{12} \cdot \frac{y_1}{N_1} - \cdots - \alpha_{n2} \cdot \frac{y_n}{N_n}\right) \\ \vdots \qquad\qquad\qquad \vdots \\ \frac{dy_n}{dt} = r_n \cdot y_n \cdot \left(1 - \frac{y_n}{N_n} - \alpha_{1n} \cdot \frac{y_1}{N_1} - \cdots - \alpha_{(n-1)n} \cdot \frac{y_{n-1}}{N_{n-1}}\right) \end{cases} \tag{6}$$

Where $y_1, y_2 \cdots y_n$ indicates the number of n populations, r indicates the population growth rate, which can be expressed by the previously derived fungal growth rate, α_{ij} indicates the multiples of i of resources occupied compared with j , and N indicates the environmental capacity of the population.

For the short-term model, we can approximately consider that the influence of the environment can be ignored, so the α term is a constant. By contrast, for the long-term model, by analyzing the climate histogram of each region and combining the fitting formula of precipitation and relative humidity on the time scale of seasons.

$$P = 3619.1 \times U^{4.2631} \tag{7}$$

We can conclude that in the long term, the α item is affected by the environment, as shown in the following formula

$$\alpha_{ij} = \alpha'_{ij} \cdot (1 - m_{ij} \cdot \sin(f \cdot t)) \cdot (1 - n_{ij} \cdot \sin(f \cdot t)) \tag{8}$$

Where f is the frequency of environmental fluctuations, m and n indicate the resistance to temperature and humidity respectively, and t refers to time.

5.2 Cellular Automata Model

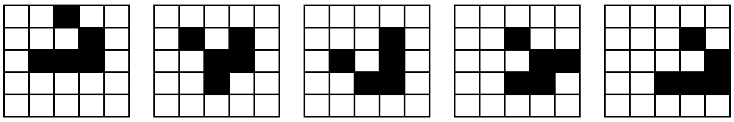


Figure 4: Cellular Automata

We constructed a 200*200 grid to simulate the process of fungal reproduction and competition through metacellular automata, and we specified four states 0, 1, 2, to n to represent

- 0: free areas
- 1: 1 fungi
- 2: 2 fungi
- 3: 3 fungi
- $\cdots\cdots$
- n: n fungi

Each iteration of the refresh changes through Von Neumann method.

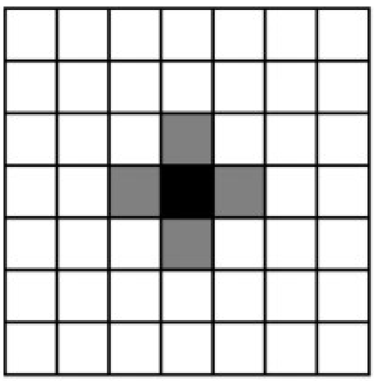


Figure 5: Von Neumann Method

From the above sine environment factor, we define a parameter P_i

$$P_{ij} = (1 - m_{ij}) * (1 - n_{ij}) \in (0, 1) \tag{9}$$

And P_{ij} is only related to the strain and the current environment of rainfall and temperature, each fungus will have P_{ij} probability to occupy the four surrounding spaces with 0 state each time it spreads. And because fungal spores can be dispersed with the wind, it is set that they have P_0 probability to appear randomly at the 0 state of the grid for propagation, and the growth rate is compared by normalized multiplicity and reacted by refreshing the frame number. When two different bacteria touch the same grid, the following happens.

- The probability that $\max(P_{ij}, P_{i'j'})$ becomes the state with the larger value.
- The probability that $\max(P_{ij}, P_{i'j'})$ becomes 0 state.

Given the same initial number of fungi at random, the simulation results are obtained by running for a period of time.

6 Model Application

6.1 Singal Fungus Decomposition Rate Model

We did the statistics on decomposition rate, moisture tolerance, and extension rate of wood rot fungi and record the table2 in the appendix.According to this we can calculate the corresponding logarithmic value, after computer calculation can get the following solution. (Experimental conditions: 22 degrees Celsius , high nitrogen)

$$\begin{cases} \ln D + C = 2.6819 \\ A = 0.1806 \\ B = -0.1420 \end{cases} \tag{10}$$

And we get the following fitted equation as below.

$$E = 2.6819 \cdot X^{0.1806} \cdot e^{-0.1420Y} \tag{11}$$

6.2 Multiple Fungus Decomposition Rate Model

The above gives a general algorithm to solve such problems. However, because the number of strains counted is numerous and jumbled, and it is inconvenient to directly discuss the complex role of such a large number of strains in the system.Hence we will make use of the obtained data results and the limiting conditions of the competition to carry out "K-means" cluster analysis on fungi of different species, so as to simplify the interaction model of multiple species, thus the solution of this model will be greatly simplified.

We take the logarithm of the growth rate of the fungi as the vertical coordinate and the moisture tolerance as the horizontal coordinate and set four iterations and three clusters, i.e., k = 3. From the equation

$$dist\,(\ln X_i, Y_i) = \sqrt{\sum_{d=1}^{D} (\ln X_{i,d} - Y_{i,d})^2} \tag{12}$$

The Euclidean distance between the points is calculated, the initial random center $Center_k$ is set, and the change of center for each iteration is given by the following equation

$$Center_k = \frac{1}{|C_k|} \sum_{\ln X_i \in C_k} \ln X_i \tag{13}$$

The results of the algorithm are as follows.

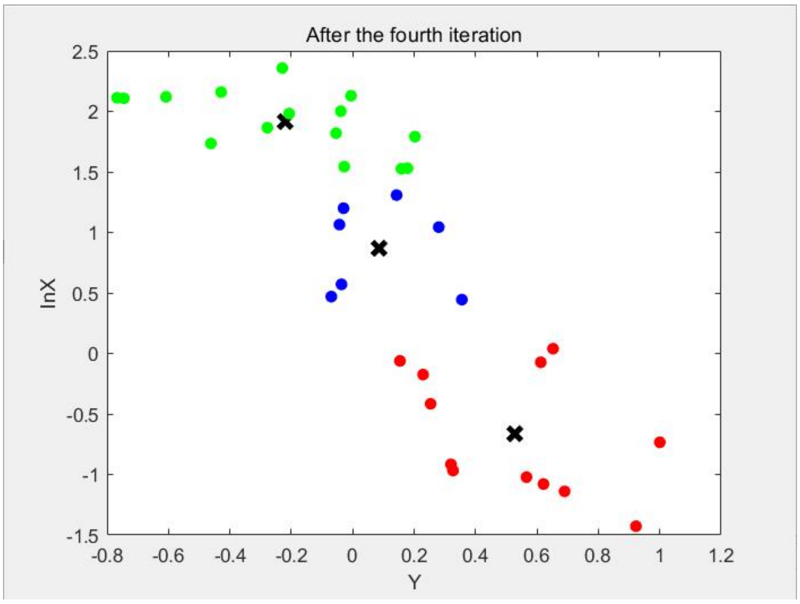


Figure 6: K-means Result

The data of center point coordinates are shown in chart below.

Table 2: The Data of Center Point Coordinates

Type of Fungi	lnX	Y
H	1.919	-0.2208
M	0.8718	0.08559
L	-0.6642	0.529

For the sake of discussion, we named them in order from top left to bottom right: H(high) fungi, M(middle) fungi, L(low) fungi. Three clusters of centroid data were used to represent the three types of fungi.

We estimated the weights using the data in the table 3 shown in the appendix, taking into account the effects of multi-bacterial interactions and competitions.Take H as example.

$$p_H = \frac{m_H}{m_H + m_L + m_M} + \frac{2}{3} \cdot \left(\frac{imp_H}{cp_H} - 1 \right) \tag{14}$$

Where the imp_H refers to the initial mass proportion of a given type of fungi, the cp_H refers to the consumption proportion of a given type of fungi, and m_i refers to the initial mass of a given type of fungi.

Under the circumstances, using the formula (4) , we can calculate the rate of decomposition of wood by various fungi under fungal interaction.

6.3 Short-term and Long-term Fungal Competition Models

Based on the results of cluster analysis, the number of equations of the above population competition differential equations was reduced to 2 or 3 to simulate the competition among species. When delta term is constant, MATLAB software can be used to derive the differential equation (6) and simulate the changes of species number in a short period of time.

After obtaining the final value of the stable presence, the delta is adjusted for the local climate (represented by temperature and humidity) for different climate types to predict changes in the number of species over the long term, that is, at the seasonal scale.

Furthermore, by adjusting the environmental tolerance and other parameters, we simulated the long-term changes of population numbers in arid, semi-arid, temperate and tropical rain forest climates through MATLAB software, and analyzed the advantages and disadvantages of species and the trends in fungal populations at seasonal scales.

7 Results

7.1 Estimation of Multi-fungal Interactions

We use the data in the table below and formula (14) to estimate the weighted parameters.

Table 3: The List of Multi-fungal Interaction Data

Type of Fungi	Initial Mass	Consumption	p_i
H	28.77	18.3	0.6206
M	10.78	5.96	0.1582
L	8.83	5.36	0.1768

Using the data of Table 2 , Table 3 and system of equations (10) , plugging it into the equation (4) , we can calculate the decomposition rates of the three types of fungi as they interact. (Conditions: 22 degrees Celsius , high nitrogen)

$$\sum_{1}^{3} E_i = D \cdot \left(\sum_{1}^{3} p_i \cdot X_i^A \cdot e^{B \cdot Y_i + C} \right) = 15.4902 \tag{15}$$

The calculated results are very close to the real data of the experiment under the combination of Armillaria Gallica, Phlebiopsis Flavidoalba and Phellinus Gilvus, which is about 18.4.

7.2 Short-and-long-term Prediction

According to the hypothesis, by adjusting the corresponding initial value in the differential equation, we obtained the variation of a variety of fungi in a short range through MATLAB software

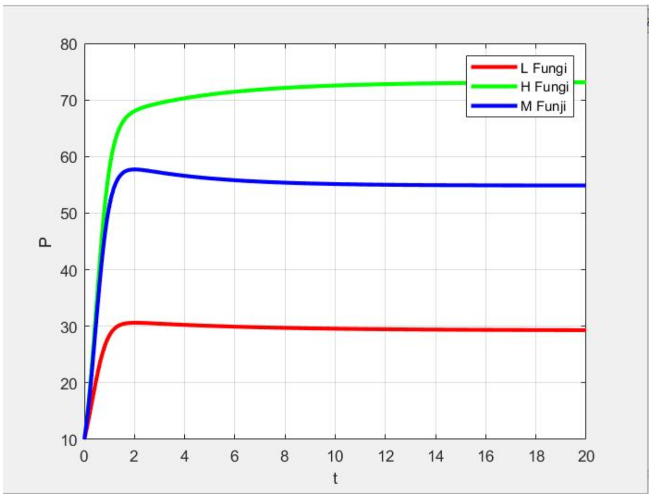
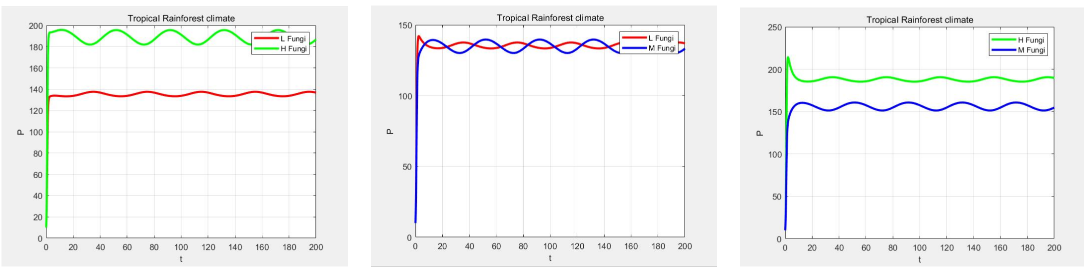


Figure 7: Short-term Variation

Meanwhile, by adjusting the temperature fluctuation parameter and humidity fluctation parameter, we obtain the images of fungal population changes over a long period of time of different environments including arid, semi-arid, temperate, arboreal and tropical rain forests.

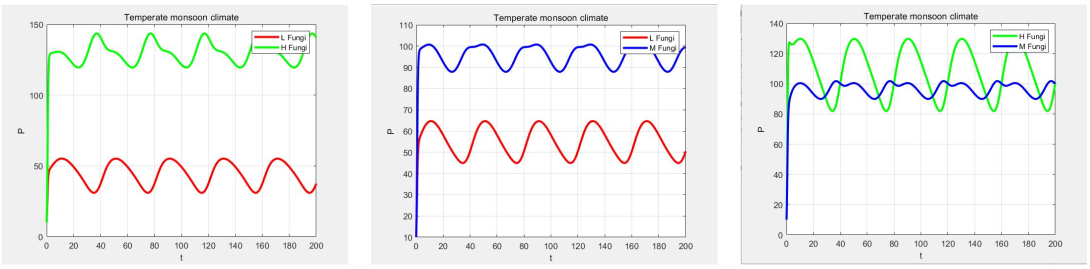
The long-term variation of different assemblages in the tropical rainforest climate is shown in the figure.



(a) No.1 (b) No.2 (c) No.3

Figure 8: Tropical Rain Forests

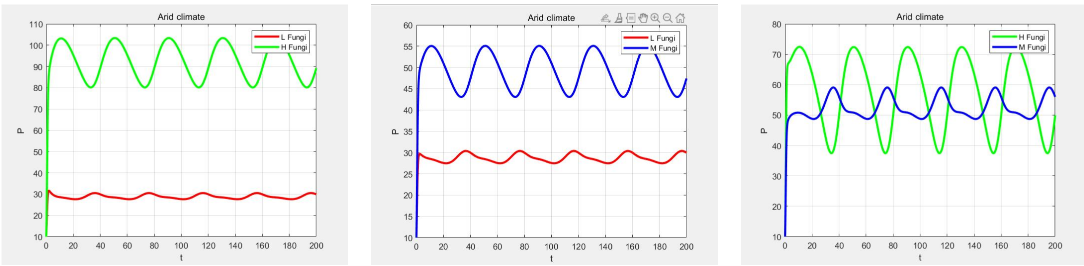
The long-term variation of different assemblages in the temperate mansoon climate is shown in the figure.



(a) No.1 (b) No.2 (c) No.3

Figure 9: Temperate Monsoon Climate

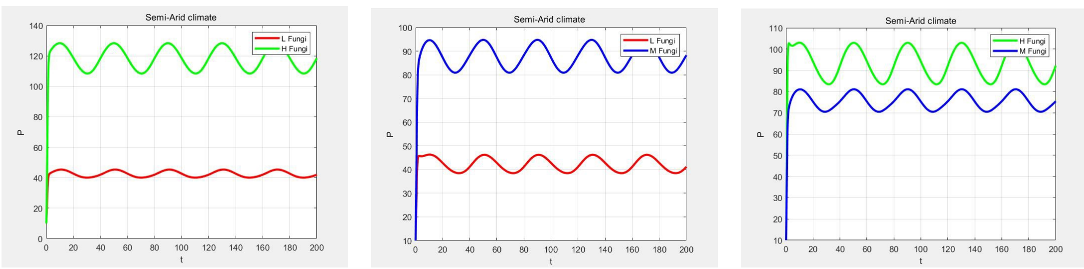
The long-term variation of different assemblages in the arid climate is shown in the figure.



(a) No.1 (b) No.2 (c) No.3

Figure 10: Arid Climate

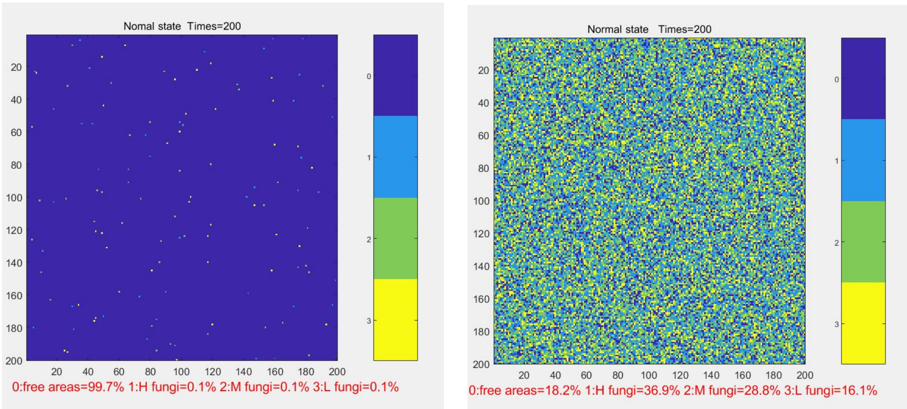
The long-term variation of different assemblages in the semi-arid climate is shown in the figure.



(a) No.1 (b) No.2 (c) No.3

Figure 11: Semi-arid Climate

At the same time, we also use cellular automata to simulate the long-term model, and the results are shown in the figure below.The dark blue areas represent free areas, while the other three represent three different types of fungi. We can clearly see the competition between populations and spot the dominant species.



(a) Normal State (b) Environmental Fluctuations

Figure 12: Differential equation analysis

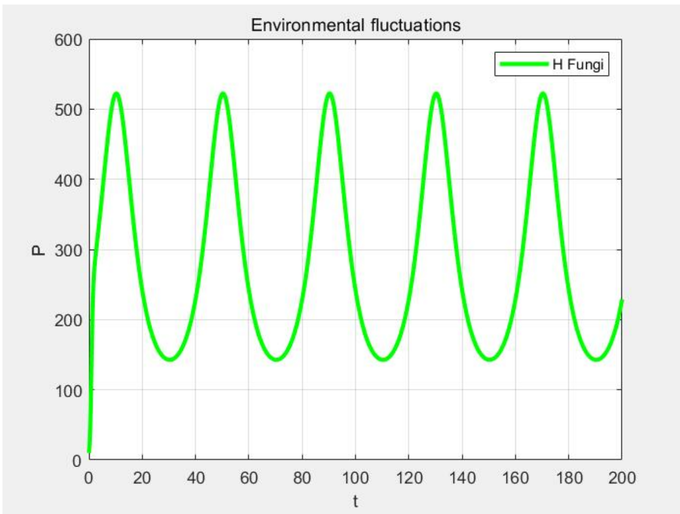


Figure 13: Single Fungal Model over Long-term

Also,we simulated the change of a single fungal model under long-term conditions. It is easy to find that the number of species of a single species fluctuates dramatically when the seasons change.

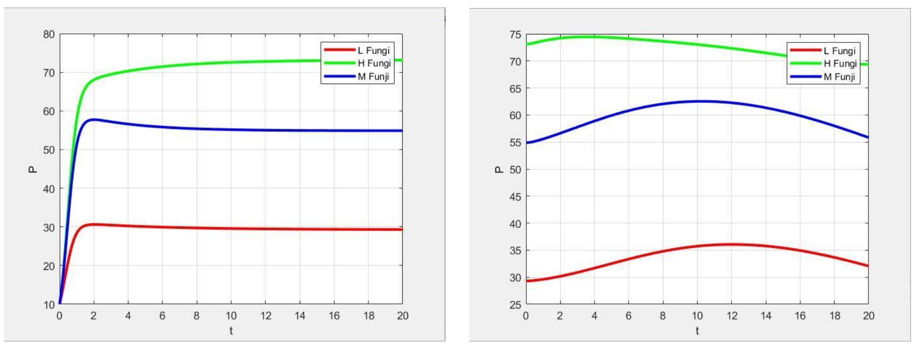
7.3 Overall Conclusion

- In general, when only one species of fungi is present, it makes the most of what the environment can provide, so that a single species can maintain the greatest rate of growth and achieve the greatest rate of decomposition.
- Compared with single fungi, when there are multiple fungi, there will be fierce inter-species competition among these fungi, which is reflected in the resources provided by the competitive environment, resulting in the growth rate and decomposition rate of these fungi are inhibited to a large extent.
- Fungi with high humidity tolerance tend to have a lower growth rate, but because of their high tolerance to humidity, these fungi are able to adapt to a wider range of environmental (temperature and humidity) changes while maintaining small changes in their numbers during short periods of dramatic changes in the atmosphere.

- At the level of species diversity, given that tropical rain forest climate area is relatively close to the equator, the region has unique hydrothermal condition, so the environmental capacity is relatively high. Meanwhile, the annual temperature variation in this area is very small, creating opportunities of the survival of some fungi that can't tolerate rapid climate change.
- In contrast, relatively few fungal species live in arid and semi-arid regions, both because of poor hydrothermal conditions and because of high climatic fluctuations in these regions. Some fungi with poor humidity tolerance cannot tolerate such severe atmospheric fluctuations so they have been eliminated by natural selection or have to keep their fungal population low.
- Although the diversity of species can lead to a decrease in the overall utilization of environmental resources by fungi, species diversity can protect each organism and improve the overall stability of resistance, so that the fungal community can better survive in the face of short-term atmospheric fluctuations and long-term climate change.

8 Stability and Sensitivity Analysis

In the population competition model we developed above, as the growth rate and moisture tolerance of the fungi are affected by temperature and humidity, to explore the general pattern of the short-term competition model for the three fungi, we need to consider the bias caused by environmental fluctuations. We measured the sensitivity of the model in terms of the change in the number of the three populations over a Δt time after taking the previous steady-state solution by bringing the above factors that change with environmental fluctuations into the differential equation.

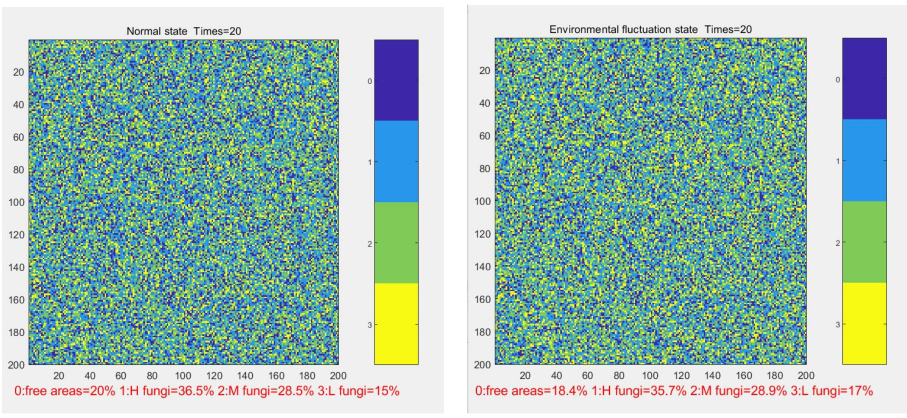


(a) Normal State (b) Environmental Fluctuations

Figure 14: Differential equation analysis

From the above simulation results, it can be seen that after the three fungi reproduction reached the steady state with certain environmental fluctuation disturbances imposed, there was no imbalance in the steady state of the model, but the number of the three fungi fluctuated above and below a certain value and our meta-cellular automata simulation results well support the above view.

All the results show that our model has good stability under short-term environmental fluctuations and is able to detect general patterns in the reproduction of the three fungi



(a) Normal State (b) Environmental Fluctuations

Figure 15: Metacellular automata simulation

9 Strengths and Weaknesses

9.1 Strengths

- The above decomposition rate model has given the residual analysis, and its stability is guaranteed.
- The K-means clustering analysis we take the results after four iterations, and the accuracy is also guaranteed.
- The multivariate differential equation model describing the population competition also provides the sensitivity analysis of the applied environmental fluctuations, and the simulation is carried out by the cellular automata. The results of the two models can be verified mutually, which are more reliable than single predictions.
- The model we developed has good stability and generality, and is able to predict and simulate the decomposition rate of fungi and the number of multi-fungal populations in a generalized way.

9.2 Weaknesses and Extensions

- If we find a sufficient amount of data to support the model's predicted population growth, Cellular Automata simulations can reflect a more real and complex nature.
- The simulation of arid, semi-arid, temperate and tropical rain forest conditions is carried out by introducing two sinusoidal variables into the mathematical formula, which is somewhat different from the real situation.

9.3 Future Work

The decomposition rate model we constructed can help scientists explore the conditions that promote fungal decomposition of wood fibers and accelerate the decomposition rate. If more influencing factors can be considered in the future, it can provide a more comprehensive and realistic response to the mechanism behind fungal decomposition, which can be applied to the decomposition of ground waste to optimize the human living environment and reduce the environmental operational load.

In addition, the population competition model can predict the growth trend of fungal populations and analyze the specific impact of environmental changes on fungal communities, so that humans can target the protection of fungal species that are in the disadvantage of interspecific competition, maintain the diversity of fungal communities, enhance their resistance to environmental changes, ensure the carbon cycle continues to be stable, delay and organize the development of the greenhouse effect, and thus achieve the goal of protecting the ecological environment. Our team believes that our model will have more applications and values in the future as people pay more attention to fungi.

10 References

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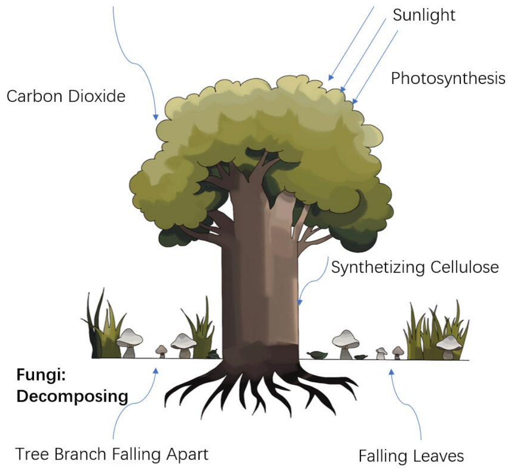
An Article about Recent Advances in the Role of Fungi in Ecosystems

As an essential component of each life on the earth, the carbon cycle has always been the subject of the most intense study. The decomposition of plants and wood fibers into the soil is an important part of the carbon cycle. Recent scientific studies have focused on the key role of fungi in their decomposition, and the results of the decomposition of wood by a large number of different fungi have led to new conclusions that explain some biological phenomena.



(a) Carbon Cycle through Trees

(b) Fungi

Through the analysis of 44 species of fungi, the following fitting formula was obtained.

$$E = D \cdot X^A \cdot e^{B \cdot Y + C}$$

Where E denotes the decomposition rate of the fungi, Y denotes the moisture tolerance of the fungi, X denotes the extension rate of the fungi, and A, B, C, and D are all constants depending on the statistics.

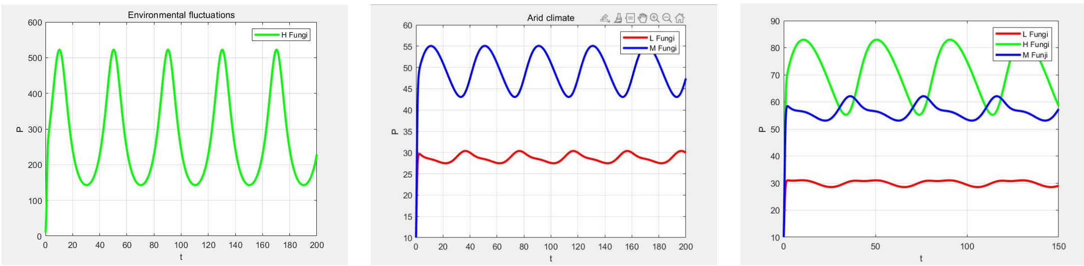
Then through the interaction experiment of multiple fungi, the following decomposition rate model of multiple fungi can be obtained

$$\sum_i^n E_i = D \cdot \left(\sum_i^n p_i \cdot X_i^A \cdot e^{B \cdot Y_i + C} \right)$$

Where p_i is the proportion of each fungus and the competition parameter in order to evaluate the influence of the intensity of competition, which can be computed with the initial data given.

In order to predict the growth trend of various groups of fungal community in reality, a differential model of population competition was established after analyzing various kinds of data, and the growth trend of various fungi was simulated through the application of different climate data.

After simulating the growth trends of different species numbers of fungi, it was found that fungal diversity had a significant effect on the overall decomposition efficiency of fungi and the ability of fungal communities to cope with external environmental changes.



(c) Single (d) Double (e) Triple

In summary, recent studies have been interpreted and drawn conclusions as follows.

- In general, when only one species of fungi is present, it makes the most of what the environment can provide, so that a single species can maintain the greatest rate of growth and achieve the greatest rate of decomposition.

- Compared with single fungi, when there are multiple fungi, there will be fierce inter-species competition among these fungi, which is reflected in the resources provided by the competitive environment, resulting in the growth rate and decomposition rate of these fungi are inhibited to a large extent.

- Fungi with high humidity tolerance tend to have a lower growth rate, but because of their high tolerance to humidity, these fungi are able to adapt to a wider range of environmental (temperature and humidity) changes while maintaining small changes in their numbers during short periods of dramatic changes in the atmosphere.

- At the level of species diversity, given that tropical rain forest climate area is relatively close to the equator, the region has unique hydrothermal condition, so the environmental capacity is relatively high. Meanwhile, the annual temperature variation in this area is very small, creating opportunities of the survival of some fungi that can't tolerate rapid climate change.

- In contrast, relatively few fungal species live in arid and semi-arid regions, both because of poor hydrothermal conditions and because of high climatic fluctuations in these regions. Some fungi with poor humidity tolerance cannot tolerate such severe atmospheric fluctuations so they have been eliminated by natural selection or have to keep their fungal population low.

- Although the diversity of species can lead to a decrease in the overall utilization of environmental resources by fungi, species diversity can protect each organism and improve the overall stability of resistance, so that the fungal community can better survive in the face of short-term atmospheric fluctuations and long-term climate change.

Appendices

First Appendix

Table 4: The Data of Multiple Linear Regression

category	Y	lnE	**X(22 °C)**	**lnE(22 °C)**
Armillaria gallica EL8 A6F	0.327	1.526	0.38	2.74
Armillaria gallica FP102531 C6D	0.621	3.557	0.34	2.84
Armillaria gallica FP102534 A5A	0.690	3.052	0.32	2.40
Armillaria gallica FP102535 A5D	0.922	3.030	0.24	2.51
Armillaria gallica FP102542 A5B	0.320	2.243	0.40	2.22
Armillaria gallica HHB12551 C6C	1.000	2.826	0.48	3.68
Armillaria gallica OC1 A6E	0.566	2.057	0.36	2.23
Armillaria gallica SH1 A4A	0.254	2.878	0.66	2.38
Armillaria sinapina PR9	0.229	2.065	0.84	2.11
Armillaria tabescens FP102622 A3C	0.612	2.413	0.93	2.59
Armillaria tabescens TJV93 261 A1E	0.355	2.678	1.56	2.55
Fomes fomentarius TJV93 7 A3E	0.178	1.630	4.62	3.86
Hyphoderma setigerum FP150263 B2C	-0.028	1.604	4.68	2.93
Hyphoderma setigerum HHB12156 B3H	-0.278	2.230	6.46	2.52
Hyphodontia crustosa HHB13392 B7B	-0.037	0.696	1.77	2.61
Laetiporus conifericola HHB15411 C8B	0.203	1.100	6.00	2.03
Lentinus crinitus PR2058 C1B	-0.054	1.504	6.17	2.77
Merulius tremellosus FP150849 C3F	-0.608	1.630	8.33	3.78
Merulius tremullosus FP102301 C3E	-0.429	0.635	8.67	3.98
Mycoacia meridionalis FP150352 C4E	-0.070	1.500	1.60	2.07
Phellinus gilvus HHB11977 C4H	0.143	2.061	3.70	3.74
Phellinus hartigii DMR94 44 A10E	0.154	2.761	0.94	2.86
Phellinus robiniae AZ15 A10H Banik/Mark	0.280	1.887	2.84	3.27
Phellinus robiniae FP135708 A10G	-0.030	3.070	3.32	2.11
Phlebia acerina DR60 A8A	-0.745	1.935	8.23	4.30
Phlebia acerina MR4280 B9G	-0.767	0.704	8.27	2.78
Phlebiopsis flavidoalba FP102185 B12D	-0.006	1.948	8.41	3.33
Phlebiopsis flavidoalba FP150451 A8G	-0.229	1.217	10.57	3.26
Porodisculus pendulus HHB13576 B12C	-0.043	1.352	2.90	1.47
Pycnoporus sanguineus PR SC 95 A11C	-0.207	1.609	7.26	3.62
Schizophyllum commune PR1117	0.158	1.522	4.60	1.93
Schizophyllum commune TJV93 5 A10A	-0.039	1.939	7.40	2.54
Tyromyces chioneus HHB11933 B10F	-0.462	1.757	5.67	3.37
Xylobolus subpileatus FP102567 A11A	0.652	2.661	1.04	2.15

Second Appendix

The data we use mainly include moisture tolerance and the hyphal extension rate data of different fungi, wood fiber decomposition rate of different fungi, wood fiber decomposition rate under mixed cultures of different fungi, temperature and rainfall data of different climate types. The data sources are summarized in Table 5.

Table 5: Data source collation

Database Names	**Database Websites**	**Data Type**
Fungal Diversity	https://www.fungaldiversity.org/	Biogeography
NCEI	https://www.ncei.noaa.gov/	Geography
PNAS	https://www.pnas.org/	Academic paper
Nature	https://www.nature.com/	Academic paper
Google Scholar	https://scholar.goole.com/	Academic paper
JSTOR	https://www.jstor.org/	Academic paper