Problem Chosen	2021	Team Control Number
A	MCM/ICM Summary Sheet	2106962

How Does Fungal Diversity Affect Our World

Summary

The main purpose of this paper is to explore the change trend of the decomposition rate of fungi under different temperature, humidity and population composition. In order to solve the above problems, we established a three-layer complex model based on one-variable linear regression, multiple linear regression and a population competition model.

Structure:

In nature, temperature and moderateness are the main parameters that affect fungal activity, so we use these two parameters as the bottom layer of our model. The growth rate of fungi is directly affected by the environment, which in turn affects the population. At the same time, population competition will also affect the number of individuals in the community. Therefore, we use these parameters as the second layer of our model. The decomposition rate of a flora is not only affected by population, but also limited by humidity and temperature. Based on that, we put the decomposition rate in the third layer of the model.

Modeling Procedure:

1. To explore the influence of temperature and humidity on the growth rate, we observed the chart that appears in the problem file and determine to build the model based on linear regression and multiple linear regression models. Then, we collected a large amount of data from literatures to fit and test it. Completed the construction of the first layer.

2. In order to simulate the situation that multiple fungi exist in one environment, we used a population competition model. With the collected data, we simulated and analyzed population competition in different environments. Finally, we found how competitions will affect population. Combined with the results of the previous part, we have the trend of the population number under certain conditions.

3. Through the above two parts, we get the change in population size. Then, we took temperature, humidity, and population changes as independent variables, and decomposition rate as the dependent variable to establish a complex mathematical connection.

A Few Statements:

1. With more different fungal species in an area, the decomposition rate will be more stable.

2. If there are plenty of different fungus living in the same area, and we take all of fungus as a system, when environmental parameter is changing, the system will also take action to keep balence. The decomposition rate of the system will firstly reduce, and then rise again.

Contents

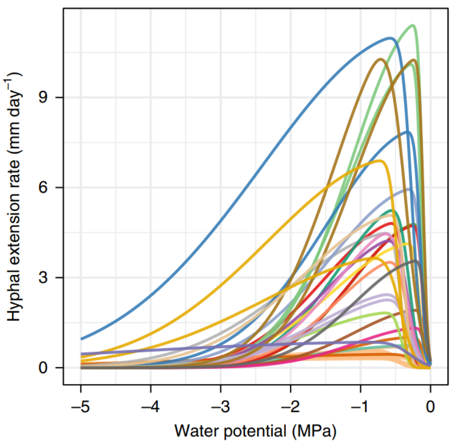
1 Introduction

1.1 Problem Background

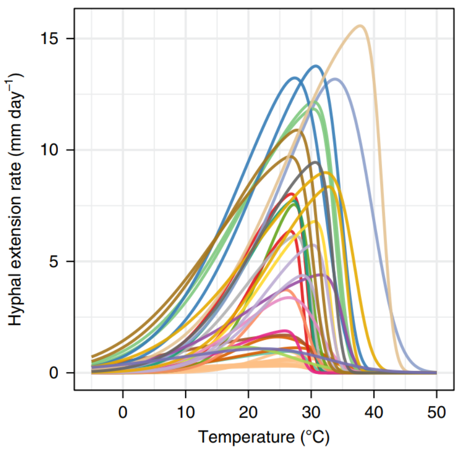
The current severe situation of the global greenhouse effect is mainly due to excessive carbon emissions. Since the first industrial revolution, a large amount of fossil energy has been mined and used. The carbon contained in these fuels has been combined with oxygen to generate carbon dioxide, which is emitted into the air. Before the emergence of this situation, the global greenhouse effect has been in a stable state. The carbon cycle in the biosphere's three primary material cycles has always played an indispensable role in this stability. As part of the chain, fungi bear the responsibility of converting excess organic matter into carbon dioxide. In order to do more in-depth research on the carbon cycle and the greenhouse effect, the decomposition of plant debris by fungi has become a subject that must be studied.

1.2 Our work

In order to study how the growth rate of fungi and their decomposition rate of organic matter (residual branches and fallen leaves and dead wood) in different environments are affected by different environmental humidity and temperature, we established a model to describe it. After the initial modeling, we turn mutual interaction between different species (population competition) into consideration. So far, we have four independent variables, including **fungal growth rate**, **temperature**, **humidity**, and **the impact of population competition**. Additionally, temperature and humidity have a decisive influence on the growth rate. After consulting the literature, we first obtained the influence of humidity and temperature as independent variables on the growth rate (Figure 1 and Figure 2).



(a) The Influence of Water Potential



(b) The Influence of Temperature

Figure 1: The Influence of Environment

1. Establish a model that can describe the decomposition rate of dead plants by fungal activities in an ecological environment where multiple fungi coexist.

2. Based on result of the first question, the model should also reflect the mutual influence of multiple strains and the different growth rates of different strains.

3. Improve the model so that it could describe the interaction between different fungi. The prediction of dynamic trends should be short-term and long-term. Additionally, the model should be tested for its environmental sensitivity. Climate change should also be taken into consideration to evaluate how much change the model will have due to the surroundings change.

4. Predict the superiority and inferiority of different species and different combinations. The model is supposed to work in multiple surrounds, including arid, semi-arid, temperate, arboreal, and tropical rain forests.

5. Describe the relationship between the decomposition efficiency of fungal activities and biodiversity. When there are some variables in the environment, predict the importance of biodiversity.

2 Preparation of the Models

2.1 Assumptions

In this paper, we make the following assumptions to simplify the model:

1. We have collected data on 34 different strains. However, because the data is too miscellaneous, according to the biological classification method, **we merged the data of the fungi from the same genus After the merge, there are 8 categories, respectively Armillaria, Hyphoderma, Merulius, Phlebiopsis, Phellinus, Phlebia, Schizophyllum and Others**. However, since the basis of biological naming is mainly the variation of biological physiological structure, even the properties of different species of the same genus are quite different. But from a macro perspective, this difference can still be approximately ignored.

2. In the real world, different resources per unit of woodland have different benefits for fungus growth. But in order to simplify the model, we do not take this factor into consideration. **Therefore, under these conditions, the growth effect of unit resources on different strains should also be the same.**

3. According to the growth pattern of fungi, the hyphae diverge and extend from the center to the surroundings. We can approximate its shape to a circle, and then we can calculate the size of the flora area(A) to estimate the number of individuals in the population(γ)From this, we can consider that the strain with the highest growth rate has the strongest competitiveness.

$$\gamma \propto A = \pi * r^2$$

4. To measure the growth rate difference between two species, we define the total area as 10 cm^3, and every community start will 10 mm^3

5. **In order to compare the mutual influence and competitiveness of the existing eight species of fungi in the same environment, we used Schizophyllum as a benchmark and compared it with the other seven fungi.** Use the proportional relationship obtained from the comparison to perform weighting calculations to simulate the strength of competitiveness in the same environment.

6. As these floras have no hunting relationship, the competition between them is resources only. **In this case, even if there is contact between different fungi groups, it will not affect their growth rate changes.**

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Definition
t	Time
γ	Population of a fungi community
ξ	Growth rate(extension rate)
η	Decomposition rate
T	Temperature
H	Humidity
N	The maximum value of resourse
S	Consumption to miantain survival for a community
e	Random variable
θ	Random noise

3 The Models

3.1 Model 1

From the given scatter plot, it is not difficult to see that the relationship between the growth rate of the fungus and its decomposition rate can be approximated as a linear relationship. So, for the first question, we perform a linear regression between the growth rate and the decomposition rate, the growth rate is the independent variable, and the decomposition rate is the independent variable. The general formula of a linear relationship is $Y = kX$

3.1.1 Details about Model 1

Table 2: Relationship between Growth Rate and Decomposition Rate

Different Fungi Species	$k = \eta/\xi$		
	10°C	16 °C	22 °C
Armillaria	12.217	10.865	24.475
Hyphoderma	4.522	1.077	2.878
Merulius	5.418	3.901	5.731
Phlebiopsis	3.305	2.093	2.839
Phellinus	4.985	7.727	8.707
Phlebia	2.414	3.088	5.429
Schizophyllum	2.204	2.129	1.63
OTHERS	4.089	6.19	4.645

Based on the table above, we get the relationship between growth rate and decomposition rate fro each fungi species, like figures shown bellow(Figure 2).Then, we used the known data to improve the linear regression of the previous hypothesis. The model was changed to a multiple linear regression with growth rate, temperature, and humidity as independent variables. The general formula of the multiple linear relationship is

$$\eta = a_1\xi + a_2T + a_3H + C_1$$

When transforming the effects of temperature and humidity on decomposition rate into the effects of hyphal extension rate on decomposition rate, we chose to use the known collected discrete data to fit the continuous functions of temperaturehyphal extension rate and humidity-hyphal extension rate. Here, we chose to use the least square method to carry out polynomial fitting.Make a fitting curve $a_0 + a_1x + \cdots + a_nx^n$.The fitting of the given data is transformed into the problem of minimum mean square error:

$$Q(a_0, a_1, \cdots, \cdots, a_n) = \sum_{i=0}^{m-1} (a_0 + a_1x_i + a_nx_i^n - y_i)^2$$

Getting the normal equation:

$$A^TA \begin{pmatrix} a_0 \\ a_1 \\ \cdots \\ a_x \end{pmatrix} = A^T \begin{pmatrix} y_1 \\ y_2 \\ \cdots \\ y_m \end{pmatrix} \qquad A = \begin{pmatrix} 1 & x_1 & \cdots & x_1^n \\ 1 & x_2 & \cdots & x_2^n \\ \vdots & \vdots & \cdots & \vdots \\ 1 & x_m & \cdots & x_m^n \end{pmatrix} \tag{1}$$

Solving the normal equation then we get parameters a_0, a_1... ,a_n.

The basic form of multiple linear regression is as follows.

$$Y_i = \beta_0 + \beta_1X_{i1} + \beta_2X_{i2} + \cdots + \beta_kX_{ik} + \mu_i \qquad i = 1, 2, \cdots, n$$

The population regression is

$$Y_i = E(Y|X_{i1}X_{i2}\cdots, X_{ik}) + \mu_i = \beta_0 + \beta_1X_{i1} + \beta_2X_{i2} + \cdots + \beta_kX_{ik} + \mu_i$$

And the sample regression model is

$$Y_i = \hat{Y}_i + e_i = \hat{\beta}_0 + \hat{\beta}_1X_{i1} + \hat{\beta}_2X_{i2} + \cdots + \hat{\beta}_kX_{ik} + e_i$$

The sample observations were substituted into the population regression model

$$\begin{cases} Y_1 = \beta_0 + \beta_1X_{11} + \beta_2X_{12} + \cdots + \beta_kX_{1k} + \mu_1 \\ Y_2 = \beta_0 + \beta_2X_{21} + \beta_2X_{22} + \cdots + \beta_kX_{2k} + \mu_2 \\ \cdots \\ Y_n = \beta_0 + \beta_nX_{n1} + \beta_2X_{n2} + \cdots + \beta_kX_{nk} + \mu_n \end{cases} \tag{2}$$

Then we get the matrix form of the sample regression model is expressed as

$$Y = X\hat{\beta} + e$$

This model can well describe the relationship between independent variables such as growth rate, temperature, humidity and the dependent variable, decomposition rate. In order to gain the necessary parameters of multiple linear regression, we determine to use the least square method to estimate. The residual sum of squares of the model is

$$Q = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n} (Y_i - (\beta_0 + \beta_nX_{n1} + \beta_2X_{n2} + \cdots + \beta_kX_{nk}))^2$$

Take the partial derivative of the parameter and set it equal to 0 to get the normal equation. Here we use a matrix to represent the normal equation as

$$\begin{cases} \sum(Y_1-(\hat{\beta}_0+\hat{\beta}_1X_{11}+\hat{\beta}_2X_{12}+\cdots+\hat{\beta}_kX_{1k}))=0 \\ \sum X_{i1}(Y_i-(\hat{\beta}_0+\hat{\beta}_2X_{21}+\hat{\beta}_2X_{22}+\cdots+\hat{\beta}_kX_{2k}))=0 \\ \sum X_{i2}(Y_i-(\hat{\beta}_0+\hat{\beta}_3X_{31}+\hat{\beta}_3X_{32}+\cdots+\hat{\beta}_kX_{3k}))=0 \\ \cdots \\ \sum X_{ik}(Y_i-(\hat{\beta}_0+\hat{\beta}_2X_{21}+\hat{\beta}_2X_{22}+\cdots+\hat{\beta}_kX_{2k}))=0 \end{cases} \Rightarrow \begin{cases} \sum e_i=0 \\ \sum X_{i1}e_i=0 \\ \sum X_{i2}e_i=0 \\ \cdots \\ \sum X_{ik}e_i=0 \end{cases} \tag{3}$$

For the sample equation is described in matrix form:

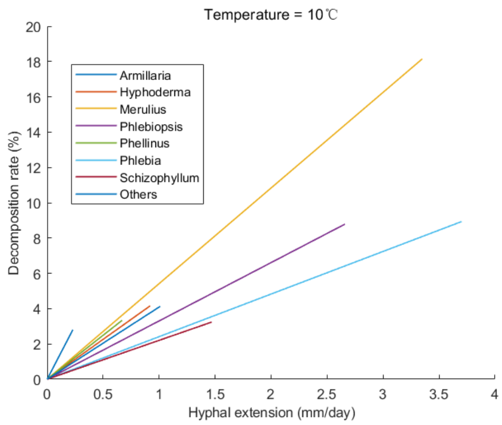
$$X'e=0$$

Multiply both sides of this equation:

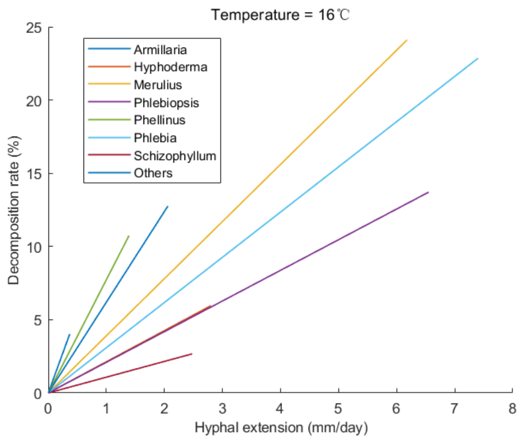
$$Y=X\hat{\beta}+e$$

After fitting with the data obtained before, the following formula was obtained

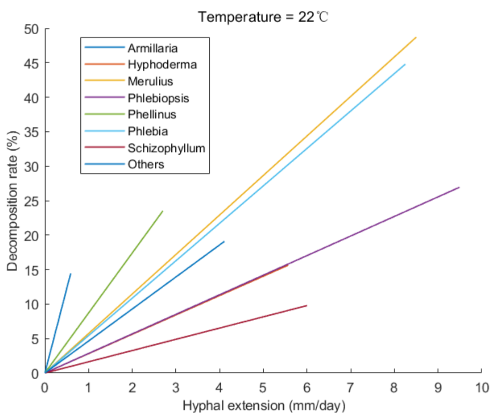
$$\eta=1.9857\xi+1.9991T+8.6785H+1.7800$$



(a) Temperature = 10°C



(b) Temperature = 16°C



(c) Temperature = 22°C

Figure 2: Decomposition Rate and Extension Rate at Different Temperature

3.2 Model 2

In our model, the interaction between different extension rates and different species of fungi is modeled for population competition. Therefore, we established a population competition model based on Schizophyllum fungus.

3.2.1 Details about Model 2

There are two , A and B fungi community, and the number changes of them obey the Logistic rule when they live alone.

$$\frac{d\gamma}{dt} = \xi\gamma(1 - \frac{\gamma}{N})$$

When the two populations lived together, the inhibiting effect of B on the growth of A was proportional to the number of B. A has the same effect on B.

$$\frac{dx}{dt} = \xi_1 x(1 - \frac{x}{N_1} - S_1\frac{y}{N_2})$$

$$\frac{dy}{dt} = \xi_2 x(1 - \frac{y}{N_2} - S_1\frac{x}{N_1})$$

We use x(t) and y(t) to denote the numbers of A and B populations, ξ is the natural growth rates, and N is the maximum capacity for each community. S is the resource consumption required by the flora to maintain survival.

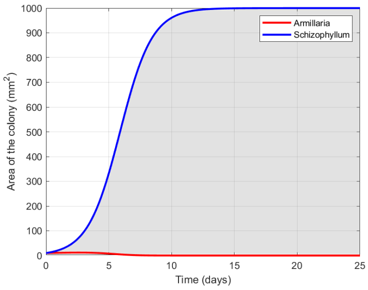
$$\begin{aligned}|S| &= \frac{\eta}{A\xi} = \frac{\eta}{(A_0 + A_\Delta)\xi} \\ &= \frac{\eta}{A_0 + [(\pi/4)(d_0 + d_\Delta)^2 - (\pi/4)d_0^2]\xi} \\ &= \frac{\eta}{A_0 + [\pi/2d_0\xi_\Delta + \pi/4(\xi_\Delta \cdot t)^2]\xi}\end{aligned} \tag{4}$$

$$|S_1| = \frac{\eta_1}{A_0 + [\pi/2d_0\xi_1 + \pi/4(\xi_1 t)^2]} \tag{5}$$

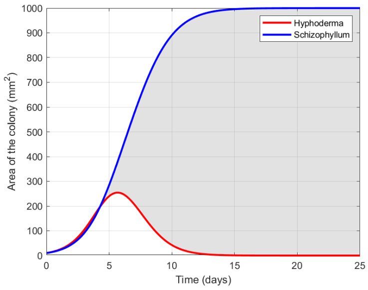
$$|S_2| = \frac{\eta_2}{A_0 + [\pi/2d_0\xi_2 + \pi/4(\xi_2 t)^2]} \tag{6}$$

From the above model, we can get the population competition relationship of two different bacterial groups in the same environment. Based on Assumption 5, we compare different flora with Schizophyllum (Figure 4) and rank the strength of the competitive relationship.

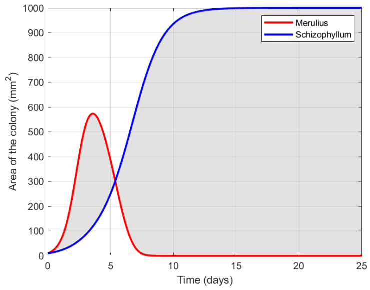
To test the sensitivity of our model that reflects to rapid fluctuations in one environment, we adjusted a series of dependent variables for environment 2, for example, raising the ambient temperature from 16 °C to 22 °C. At the same time, the moisture of the environment was changed so that the water content was higher, made the system moister and wetter. For this reason, the water potential of the fungus increased to -0.5MPa. The results showed that Phlebia, which under normal conditions was an underdog, overcame Schizophyllum after environmental fluctuations and natural changes. Even in the short term, Schizophyllum quickly reaches its limit and cannot grow further. In fact, it is similar to the research conclusions in real life. Phlebia is a fungus that is very sensitive to moisture growth. It is widely distributed in areas with high relative humidity. But Schizophyllum does not seem to tend humid environments so much. Therefore, this proves that our model has good sensitivity to environmental fluctuations.



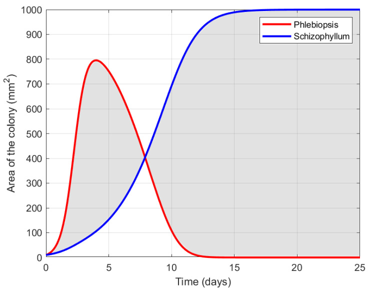
(a) *Armillaria* and *Schizophyllum*



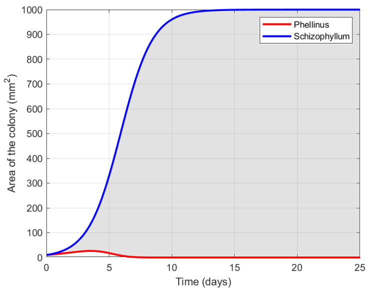
(b) *Hyphoderma* and *Schizophyllum*



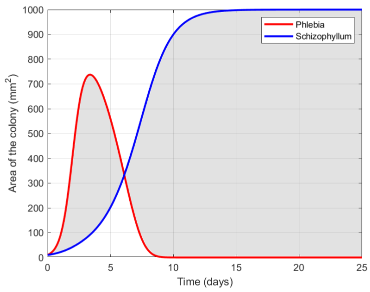
(c) *Merulius* and *Schizophyllum*



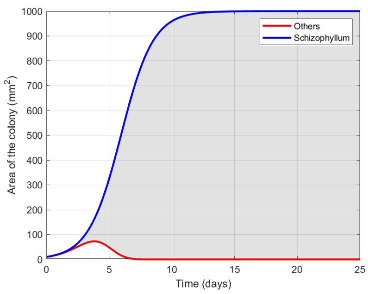
(d) *Phlebiopsis* and *Schizophyllum*



(e) *Phellinus* and *Schizophyllum*

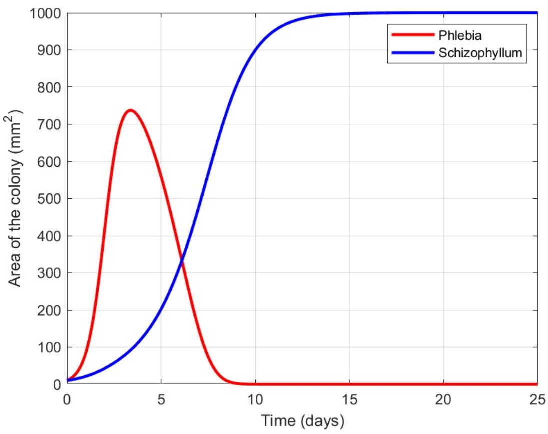


(f) *Phlebia* and *Schizophyllum*

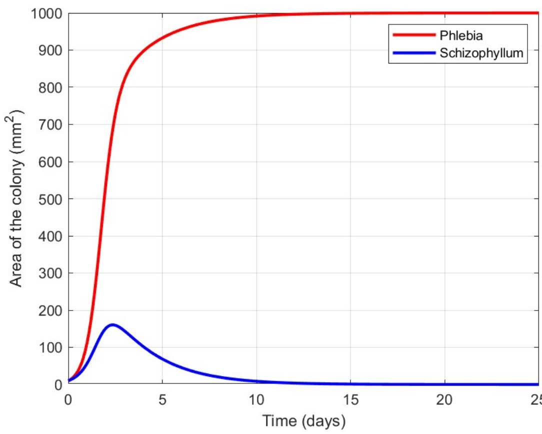


(g) *Others* and *Schizophyllum*

Figure 3: The Results of Population Competition



(a)



(b)

Figure 4: The Results of Sensitivity Check

3.3 Model 3

Similar to the polynomial fitting in the first model, in order to get the relationship between the fungal water potential and the ambient relative humidity, we also used the least square method to carry out exponential fitting.

$$Y = ae^{bx} + ce^{dx}$$

After exponential fitting, we can get: a =-18.72; b =-0.07217; c = -0.716; d =-0.007226.

Finally, the function can be written as follow:

$$Y = -18.72e^{-0.07217x} + -0.716e^{-0.007226x}$$

3.3.1 The Arid Region

According to the relevant research data we have found, most arid areas have a tropical desert climate, so we will use tropical desert climate zone to represent arid regions, like BorderRafha in West Asia, whose average temperature is 26.5, and the relative humidity is 25.15.

Most fungi cannot grow normally in this climate because the humidity and temperature are not suitable, except Phlebiopsis and Schizophyllum. So, we only need to predict the growth of combination of both.

Table 3: Experimental Parameters 1

Name of Variable	*Phlebiopsis*	*Schizophyllum*
Extension rate γ	13.1	10.4
Decomposition rate η	27.93	22.57
r	4.12	3.27
$\lvert S \rvert$	2.13	2.17

In the short term we can see that the numbers of both are going up, but the long-term trend is

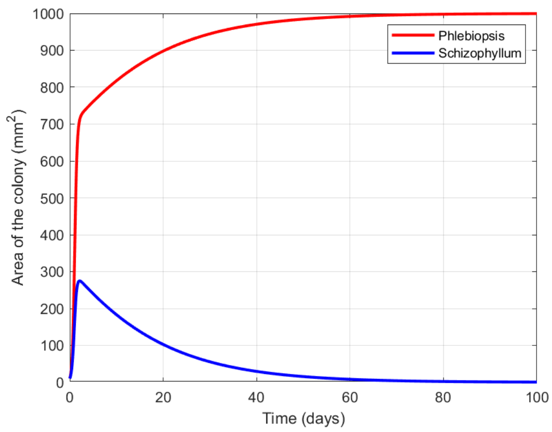


Figure 5: *Phlebiopsis&Schizophyllum* in Arid Region

that Phlebiopsis will eliminate Schizophyllum. But since their |S| values are quite similar, and something we did not consider, they still have a probability of coexisting in nature.

3.3.2 Semiarid Region

Similarly, we use tropical Savanna climate zone to represent semiarid region. Northern Australia for example. The average temperature is 26.66, and the relative humidity is 64.87. Because the dry and wet seasons of the tropical savanna climate separate obviously, the relative humidity is low, only a few fungi grow normally. We only list fungi whose extension rate is significant. (>=10 mm)

Here we can see that in the short term, the dominance of Phlebiopsis is greater than that of

Table 4: Experimental Parameters 2

Name of Variable	*Phlebiopsis*	*Merulius*	*Phlebia*
Extension rate γ	13.3	12.2	10.3
Decomposition rate η	54.7	52.51	48.74
r	4.18	3.83	3.24
$\|S\|$	0.24	0.23	0.21

Merulius, which in turn is greater than that of Phlebia. In the long run, Phlebia is the latter, occupying all the resources.

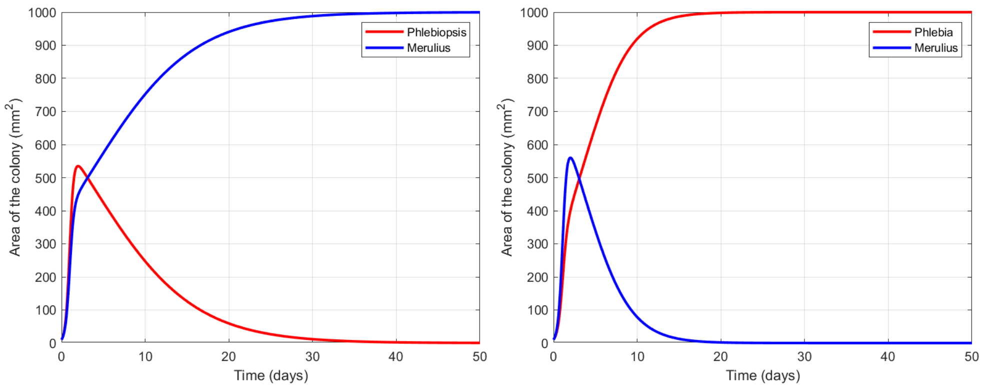


Figure 6: The Influence of Environment

3.3.3 Temperate Region

Temperate zones are widely distributed in the world, among which the temperate continental climate is the most representative. Here we use Minnesota for simulation, with an average temperature of 8.295°C and absolute humidity of 95.46.

In fact, the growth of fungi is more inhibited in cold climate than in dry climate, and the growth rate of fungi will be greatly reduced at this temperature. We use the expansion rate >2.5 mm for simulation. In fact, only Phlebia and Merulius can grow significantly in this climate. Because their |s| values are close to the same, so within the error range, we can think they can

Table 5: Experimental Parameters 3

Name of Variable	*Phlebia*	*Merulius*
Extension rate γ	2.83	2.51
Decomposition rate η	14.06	13.43
r	0.89	0.79
$\|S\|$	0.201	0.198

coexist, even under the premise of limited resources. In the early stage, both of them increased with time, and after reaching the maximum population size, they would maintain a long-term flat trend.

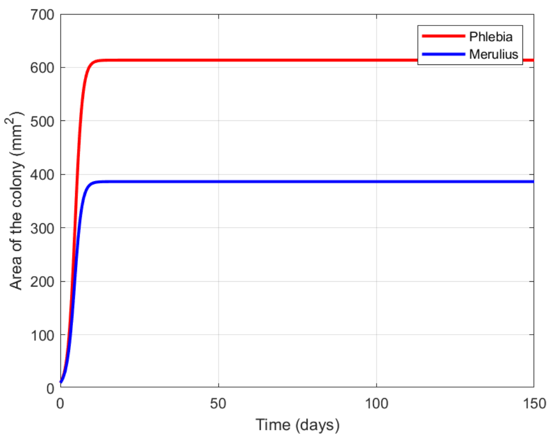


Figure 7: Results of Simulation in Temperate

3.3.4 The Tropical Forest

According to data statistics, the average annual temperature of Amazon forest is 27.86°C, the average relatively humidity is 92.13, and the average annual maximum temperature is 32.85°C. These meteorological data are quite similar to those of semi-arid regions, except higher humidity. There temperatures and humidity are exactly right for most fungi to grow freely. Under the climate conditions of tropical rain forest, abundant water, lush vegetation, and abundant food sources for fungi, we assume that the $|S|$ value of all fungi is 1, that is, we do not consider the situation of limited food.

Table 6: Experimental Parameters 4

Names of Fungus	Extension rate γ
Armillaria	0.7
Hyphoderma	6.7
Merulius	12.3
Phlebiopsis	13.3
Phellinus	3.65
Phlebia	9.7
Schizophyllum	8.1
Others	8.22

In the short term their numbers will rise rapidly, except for the Armillaria. After reaching its maximum population, they will remain stable due to the unlimited availability of food.

Notes:

1. Because the number of Armillaria is ridiculously small (less than 0.01% of the total number in the simulation results), it is ignored in the drawing.
2. The main strains of Others were *Pycnoporus sangunieus* and *Lentinus crini*.

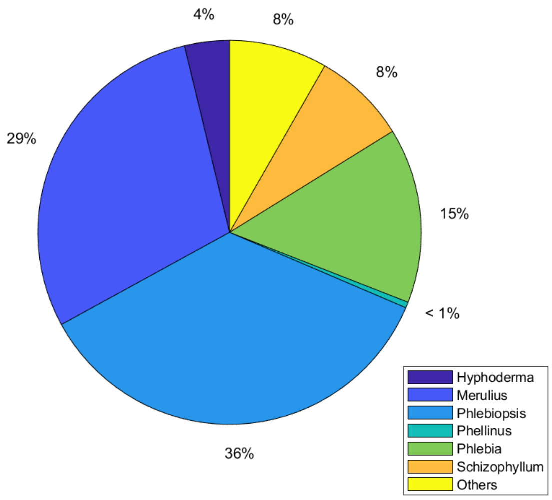


Figure 8: The ideal Distribution of Different Fungus in Tropical Forest

3.3.5 Volcanoes, Ice Sheet and Extreme Areas

In the case of extremely low temperatures, no fungus can perform physiological activities. However, under relatively high temperature (40 to 50), two kinds of fungi can grow, *Psycnoporus sangunieus* and *Laetiporus caribensis*.

However, it is unlikely that there will be food for them in nature under such temperature conditions, which leads to very scarce numbers of them. Therefore, there is no need to discuss the long and short-term natural evolution.

3.4 Model 4

Each kind of fungus has different decomposition ability in different environment. In consideration of the overall efficiency of the system in decomposing ground litter, we will calculate the average decomposition rate of all fungal communities in the system to represent the overall decomposition efficiency of the system.

However, it is a pity that the overall decomposition efficiency of the system is generally only related to the decomposing ability of the most competitive fungus under the current environmental conditions in terms of a single decomposing object (cellulose, lignin).

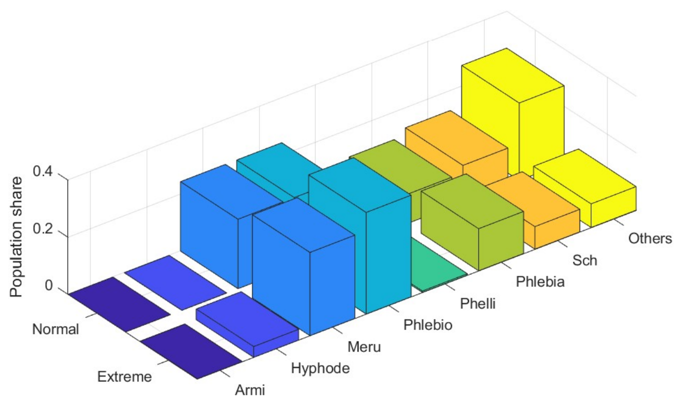


Figure 9: Changes of Fungal Communities Diversity

As mentioned in the previous question, only Phlebia and Merulius can survive in temperate continents with lower average temperatures. Assuming that improving the overall decomposition efficiency of the system in this environment, the number of Phlebia will inevitably increase, while the number of Merulius will be greatly reduced due to increasing population competition. As the decomposition efficiency increases, the entire system will have a trend of decreasing biodiversity.

But when the environment fluctuates, the role of biodiversity is reflected. In the real world, affected by monsoons and cold currents, even in areas with relatively stable temperatures throughout the year, seasonal high and low temperatures will change. If there is only one kind of fungus that can only adapt to high temperatures, then when the temperature drop caused by the cold wave arrives, population reduction or extinction will inevitably occur, and the overall decomposition efficiency of the system will be greatly reduced.

On the contrary, if it is in areas with high biodiversity such as tropical rain forests, even if the decomposition efficiency of the system may not always be in the optimal state, when the temperature, humidity and other conditions change, the system can still maintain a relatively stable decomposition efficiency.

Table 7: Experimental Parameters 5

Names of Fungus	Extension rate γ
Armillaria	0.58
Hyphoderma	0.83
Merulius	12.4
Phlebiopsis	12.5
Phellinus	3.8
Phlebia	7.8
Schizophyllum	8.65
Others	13.55

In the simulation, we changed the temperature (the averange rain forest highest temperature, 32.85°C) and the humidity (relative humidity of drought, 42.5). It can be seen that the overall decomposition efficiency of the system only dropped from 52.7058 to 51.0191 after experiencing fluctuations caused by extreme weather.

The advantage of high biodiversity can be reflected in the relatively stable environmental decomposition efficiency. At the same time, the restoration of the ecosystem can be completed more quickly after the loss caused by environmental impacts.

4 Sensitivity and Stability Tests

Here, we conduct sensitivity and stability tests for multiple linear regression. The residual test result of the regression model we obtained before is R^2=0.8561. The relationship between independent variable and dependent variable is approximately linear, and the simulation effect of the model is robust under specific parameters.

We introduce random noise (θ_1,θ) (representing 20% temperature fluctuation and 15% humidity fluctuation respectively in computer simulation) to influence the signal, so as to test the model.

We've done a number of randomized trials, and the results are roughly the following. R^2 is usually between 0.75 and 0.85, and the statistical average is 0.8012. The model has a considerable range of variation, but it can still explain the relationship between independent variables

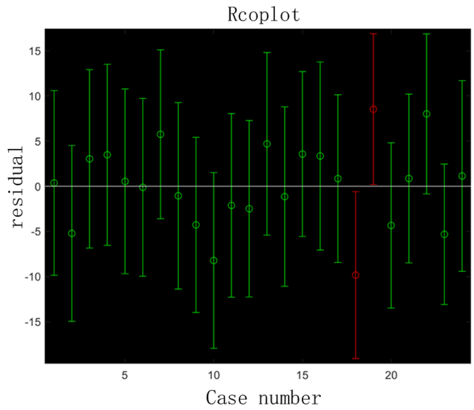


Figure 10: 1st Rcoplot

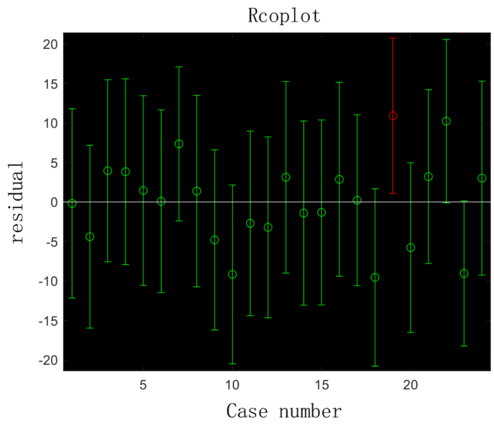


Figure 11: 2nd Rcoplot

and dependent variables at a high level. In terms of comprehensive evaluation, it has good sensitivity, but its robustness is relatively modest.

5 Strengths and Weaknesses

5.1 Strengths

- Because a large amount of data is used for fitting in the modeling process, the model can make more accurate trend analysis and prediction.
- We used different environmental data for testing, and after many tests, we found that the model is very stable.

5.2 Weaknesses

- According to the experimental data obtained later, even if the biological nomenclature of the fungus belongs to the same genus, the singularity between different species is still relatively large. In some cases, this difference is not negligible, so hypothesis 1 is not true in some cases. However, such cases are rare. Overall, it is reasonable to assume one to simplify the model.

6 Conclusion

In general, the decomposition rate of most fungi is related to temperature and humidity, and reaches its peak between 25°C and 30°C, water potential between -0.8 and -0.5MPa. Moreover, the hyphal extension rate is positively correlated with the decomposition rate.

When various fungi are in the same area, they will show different competitiveness based on their adaptability to the environment. The hyphal extension rate determines the short-term population trend of fungi, while the strength of competitiveness determines the long-term population trend.

Finally, biodiversity plays a important role in the stability and resilience of a population. When an ecosystem encounters external influences, the more its biodiversity, the less likely it is to fluctuate, because its ecological structure is complex and diverse.

7 Paper

From the perspective of size, Fungi is never outstanding compare with countless creatures living on the earth. However, it cannot be ignored when we talk about carbon cycle because it is an essential part of the chain. In the other words, we can not live without this little creature. From what we have learned by now, there are more than 120,000 different species in this big family. This family carries the burden of decomposing the organic remaining in natural. So, here is a question. How could fungi groups become more efficient. From our research, the diversity of fungi species in the system is a definitive factor of the answer.

As the three most important basic material cycles in the ecosystem, the carbon cycle, nitrogen cycle and sulfur cycle play an important role in the stability of the ecosystem. Among them, the carbon cycle is especially important as the material basis of all living things. (That is why we are called carbon-based creature) The general process of the carbon cycle is:

1. Producers (mainly plants and some single-celled organisms) use solar energy from the sun to convert atmospheric carbon dioxide and water into carbohydrates through photosynthesis.

2. Then, carbohydrates are obtained by consumers (herbivores and omnivores) and digested. In this process, consumers will eliminate some food residues, which also contain a certain amount of carbon.

3. 3. The energy absorbed by consumers will be transferred to the top step by step through the ecological chain. Finally, after the death the top of the ecological chain, the body remains, together with the previous food residue, are decomposed into carbon dioxide and enter the air again.

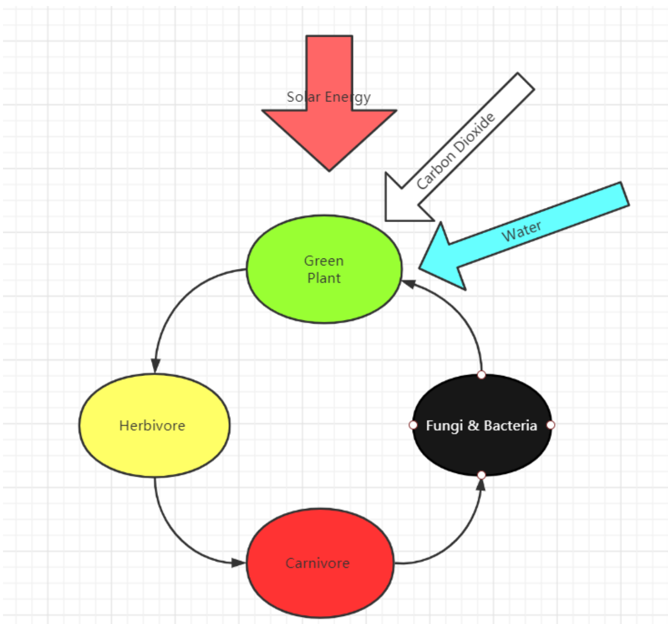


Figure 12: Breif Flow Chart of Carbon cycle

At this point, a complete carbon cycle is completed. In this process, the fungus mainly plays the role of decomposer. Fungi are widely distributed in nature, whether in woodlands, grasslands, wetlands, and lakes. Therefore, today, when the carbon cycle is stable and precarious, the issues related to each link in the chain need to be discussed. In this research, we mainly chose to study the decomposers.

As we can see, different fungi suit different environment, and there are varieties of properties that can affect fungus exist in different surroundings. For example, Schizophyllum will stop decomposing when temperature drop to 5 Celsius degree. Instead, Phlebia rufa can still work efficiently at the same temperature. Since different fungis adaptability to the environment is different, we will study the symbiosis of multiple flora in the same environment. According to our research, considering the volatility of the environment (temperature and moderateness), the increase in fungal species means that the entire population's adaptation range to the environment is expanding. If there is only one kind of fungus in the environment, its adaptability is extremely limited. With the participation of multiple strains, things will become much simpler. For example, the best working range of bacteria A is 10 degrees to 20 degrees, and the best working range of bacteria B is 20 degrees to 30 degrees. Then the working range of the entire population is extended to ten degrees to three degrees. This addition from diversity also applies to humidity.

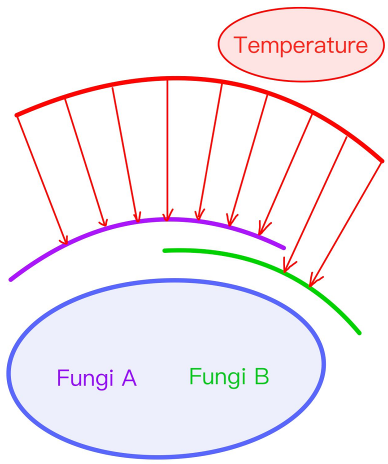


Figure 13: The ideal Distribution of Different Fungus in Tropical Forest

In addition, the population competition between fungi can also improve the work efficiency (decomposition efficiency) of a group to a certain extent. After a long-term change in the environment, temperature and humidity will change. At this time, the competitiveness of the previously dominant strains will decline under current conditions. At the same time, the competitiveness of other strains may increase. Changes in competitive rankings will be mapped to resource allocation and population numbers. Population with higher work efficiency will expand, which also marks the decomposition rate of fungi will increase again after a brief decline. This also promotes that the population ratio of the entire flora is always the optimal solution in this environment. Meanwhile, we can also regard this change as a system that adjusts and repairs itself.

In general, the more fungi species in an environment, the stronger the stability of the environmental flora and the higher the work efficiency. More fungal species will expand the scope of adaptation of the entire community, and the survival rate of the entire community will increase when the environment undergoes major changes. In addition, after a period, the flora will adapt to the environment again by changing from one to the other. The decomposition rate of the entire community will also increase.

8 Appendix : Program Codes

Here are the main program codes we used in our research.

Ternary linear regression.m

```
%x1: extension rate ave
x1=ones(24,1);
for i=1:24
x1(i,1)= Exrateave(i);
end
% 20% Temperature random fluctuation
fl=2*(rand(1,24)-0.5).*0.2;
fl(1:8)=fl(1:8).*10;
fl(9:16)=fl(9:16).*16;
fl(17:24)=fl(17:24).*22;
fl=fl';
%x2: temperature
a=10*ones(8,1)';
b=16*ones(8,1)';
c=22*ones(8,1)';
x2=[a,b,c]';x2=x2+fl;
%x3: moisture or water potential
moi=[-1.756;-1.093;-0.780;-1.592;-1.715;-1.160;-2.774;-1.60];
x3=[moi;moi;moi];
% 15% mositure fluctuation
fl2=2*(rand(1,24)-0.5).*0.15;
fl2=fl2';
fl2(:,1)=fl2(:,1).*x3(:,1);
x3=x3+fl2;
y=[Derateave(:,1);Derateave(:,2);Derateave(:,3);];
x=[ones(24,1),x1,x2,x3];
[b,bint,r,rint,stats]=regress(y,x);
b,bint,stats,figure,rcoplot(r,rint)
set(gcf,'color',[1 1 1])
```

fun.m

```
function dx=fun(t,x,r1,r2,n1,n2,s1,s2)
r1=0.12;
r2=0.78;
n1=1000;
n2=1000;
s1=13.78;
s2=0.072;
dx=[r1*x(1)*(1-x(1)/n1-s1*x(2)/n2);r2*x(2)*(1-s2*x(1)/n1-x(2)/n2)];
```

competition.m

```
clear,clc
h=0.1;
ts=[0:h:25];
x0=[10,10];
```

```
opt=odeset('reltol',1e-6,'abstol',1e-9);
[t,x]=ode45(@fun,ts,x0,opt);
figure
plot(t,x(:,1),'r',t,x(:,2),'b','LineWidth',2),grid;
xlabel('Time (days)')
ylabel('Area of the colony (mm^2)')
legend('Armillaria','Schizophyllum')
set(gcf,'color',[1 1 1])
figure
plot(x(:,1),x(:,2),'LineWidth',2),grid
```

pred.m

```
function y = pred(x1,x2,x3)
y=1.7800+1.9857*x1+1.1991*x2+8.6785*x3;
```

dataprocess.m

```

%% Extreme 2 T=32.85 H=46.8=--1.1495
x2=[0.58,0.83,12.4,12.5,3.8,7.8,8.65,13.55];
x=x2./3.183;
rate1=[0.02,0.03,24,24,1,10.11,12.7,26.78];
s1=sum(rate1);
rate1=rate1./s1;
%% Normal 1 T=27.86 H=92.13=-0.3922
x1=[0.7,6.7,12.3,13.3,3.65,9.7,8.1,8.22];
Armi=[0.016];
Hyphode=[1];
Meru=[7.72];
Phlebio=[9.42];
Phelli=[0.13];
Phlebia=[3.90];
Sch=[2.09];
Others=[2.19];
rate2=[Armi,Hyphode,Meru,Phlebio,Phelli,Phlebia,Sch,Others];
s2=sum(rate2);
rate2=rate2./s2;
%% Plot
finalrate=[rate1;rate2];
bar3(finalrate);
zlabel('Population share')
set(gcf,'color',[1 1 1])
Xname={'Armi','Hyphode','Meru','Phlebio','Phelli','Phlebia','Sch','Others'};
set(gca,'XTickLabel',Xname);
Yname={'Normal','Extreme'};
set(gca,'YTickLabel',Yname);
%% Derate comparation
derate1=pred(x1,27.86,-0.3922);
derate2=pred(x2,32.85,-1.3981);
derate3=rate1.*derate1;
derate4=rate2.*derate2;
derateave1=sum(derate3);derateave2=sum(derate4);
```

References

[1] Wardle, D. A., D. Parkinson, and J. E. Waller. "Interspecific competitive interactions between pairs of fungal species in natural substrates." *Oecologia* 94.2 (1993): 165-172.

[2] J. Huzulák, and F. Matejka . "Relationship between soil moisture and leaf water potential of three forest tree species." *Biologia Plantarum* 25.6(1983):462-467.

[3] Voíková, Jana, and Petr Baldrian. "Fungal community on decomposing leaf litter undergoes rapid successional changes." *The ISME journal* 7.3 (2013): 477-486.

[4] Lustenhouwer, Nicky, et al. "A trait-based understanding of wood decomposition by fungi." *Proceedings of the National Academy of Sciences* 117.21 (2020): 11551-11558.

[5] Maynard, Daniel S., et al. "Consistent trade-offs in fungal trait expression across broad spatial scales." textitNature microbiology 4.5 (2019): 846-853.

[6] Duarte, Sofia, et al. "Temperature alters interspecific relationships among aquatic fungi." *Fungal Ecology* 6.3 (2013): 187-191.

[7] Eberl, Franziska, Christin Uhe, and Sybille B. Unsicker. "Friend or foe? The role of leaf-inhabiting fungal pathogens and endophytes in tree-insect interactions." *Fungal Ecology* 38 (2019): 104-112.

[8] Phillips, Michala L., et al. "Fungal community assembly in soils and roots under plant invasion and nitrogen deposition." *Fungal Ecology* 40 (2019): 107-117.

[9] Crandall, Sharifa G., Norah Saarman, and Gregory S. Gilbert. "Fungal spore diversity, community structure, and traits across a vegetation mosaic." *Fungal Ecology* 45 (2020): 100920.

[10] Gulis, Vladislav, Keller Suberkropp, and Amy D. Rosemond. "Comparison of fungal activities on wood and leaf litter in unaltered and nutrient-enriched headwater streams." *Applied and environmental microbiology* 74.4 (2008): 1094-1101.

[11] Christofides, Sarah R., et al. "Fungal control of early-stage bacterial community development in decomposing wood." *Fungal Ecology* 42 (2019): 100868.

[12] Fukami, Tadashi, et al. "Assembly history dictates ecosystem functioning: evidence from wood decomposer communities." *Ecology letters* 13.6 (2010): 675-684.

[13] Griffin, D. M. "Water potential and wood-decay fungi." *Annual Review of Phytopathology* 15.1 (1977): 319-329.

[14] Hoffman, G. J., and S. L. Rawlins. "Growth and Water Potential of Root Crops as Influenced by Salinity and Relative Humidity 1." *Agronomy Journal* 63.6 (1971): 877-880.