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2021
MCM/ICM

Summery Sheet

Functioning Fungi: A model based on climate and interaction trait

Summary

Fungi are the decomposers that participate in the last step of carbon cycle in the nature. Their decomposition rate affects the natural ecology of the ecosystem. Therefore, this paper focuses on analyzing the influence of different factors on its decomposition rate.

First, we build a shot-term model and a long-term model based on the life time of the species. Through the analysis, we consider one of the factor, the growth rate, as hyphal extension. Before **short-term analysis**, we introduce the **multi-population model** according to the **Logistics principle** and carry out regression analysis and simulation according to the data to get the growth rate under the interaction of different fungi. **Second**, since we regard the short term as one fortnight, we ignore the influence of temperature and moisture tolerance. Based on the results of growth rate and population density given by the multipopulation model, we get the short-term model about decomposition rate relating to growth rate and population density through nonlinear regression analysis.

Third, we start to analyze the **long-term model**. Since the long-term model needs to take into account the influence of temperature and moisture tolerance, we take **the ratio of moisture tolerance to temperature** as a relevant variable, and different ratios represent different climate types. According to the data analysis, population density and growth rate are still the positive and negative terms with largest influence in the long-term model. Moreover, due to limited resources and lone time, the corresponding population growth rate has changed, so we add a blocking term to adjust the change. Then, according to the ratio, population growth and density, we establish the decomposition rate of the three factors through numerical analysis and fitting equation and then predict fungi's decomposition rate in tropical forest.

Finally, we conduct **sensitivity analysis** to verify the accuracy of the model and the sensitivity of fungi to environmental fluctuations.

Contents

1 Introduction

1.1 Background

Fungi are eukaryotic, sporogenic, chloroplast - free eukaryotes. They are the main decomposers of organic matter. They transform organic carbon into inorganic carbon through decomposition and are the key factor in the global carbon cycle. Additionally, the decomposition of organic matter can be roughly divided into three stages: Firstly, the remains of animals and plants are broken up through physical and biological effects. Secondly, the biological alienation is carried out by the decomposition of related enzymes and humic acids. Finally, the substances return to nature in the leaching stage to form the carbon cycle.

1.2 Problem Restatement

The carbon cycle is an important part of life on Earth, and the key component to this process is the decomposition of plant material and wood fibers. Among them, the key agents to decompose wood fiber are fungi. Different fungi have different ability to decompose lignin fiber. This report simulates the decomposition of lignin fibers in a given land by focusing on fungi's moisture tolerance and their growth rates to address the following problems:

1. 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.
2. Incorporate the interactions between different species of fungi, which have different growth rates and different moisture tolerances as shown in Figures.
3. 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.
4. 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.
5. 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.

2 Assumption and Justifications

2.1 General Assumptions

- It is assumed that other variables are the optimal variables when a single variable is considered.
- Assume that the hyphal extension of the fungus is equivalent to the natural growth rate.
- The interspecific interaction within the fungal community is analyzed only, without considering the influence of other communities on the fungal community.
- Fungi are not subject to devastating effects such as natural disasters during its growth.

2.2 Multipopulation model Assumptions

- Assume that the short term is the initial stage of the community, the growth rate of the single population is constant.

  According to the Logistic rule, at the initial stage of the population, the population quantity in the community shows a linear relationship with time, that is, the growth rate is constant.
- It is assumed that there is only interspecific competition and on other interspecific relationship in the fungal community.

2.3 Short-term model Assumptions

- The short term is considered to be about one fortnight, so the micro changes of temperature and moisture tolerance are ignored. As a compromise, only the influence of interspecific competition and natural growth rate is considered.
- Assume resources are abundant in the short term.

2.4 Long-term model Assumptions

- Assume multiple populations in an ecosystem with relatively limited resources.
- Only competition relationship was considered among the fungal population relationships.

- Assume the natural population growth rate approaches 0.

  According to the Logistic law and the image, when time tends to medium or long term, the growth rate is no longer a constant value, but there should be a blocking term, which makes it approaching to 0.

- The model should consider the influence of temperature and moisture tolerance on the ecological environment.

3 Notations

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

Table 1: Notations

Symbol	Definition
x	Population
r	Population density correlation coefficient
k(a, b, c, m, w, i)	The correlation coefficient
y	The elongation of mycelium
z	The decomposition rate
C	Constant
M	Sb oil moisture content
T	Temperature
ρ	Population density
H	Biodiversity Index
P	The proportion of the total number of individuals in the community of the nth population

4 Multipopulation model

4.1 Analysis

According to the Logistic Law, it can be known that:

$$\frac{dx}{dt} = r * x \tag{1}$$

By transformation, it can be obtained as:

$$\frac{dx}{dt} * \frac{1}{x} = r \tag{2}$$

However, this model only considers the influence of a single population. When considering the influence of interspecific competition among populations, it is assumed to be a linear influence, and the model is modeled as follows.

4.2 Model Establishment

According to the analysis, the influence of other populations is expressed by the linear relationship kx, where k represents influence coefficient of different populations on the dependent variable population, and r is the population growth rate of the dependent variable population. The differential equation model of population growth rate versus population competition is obtained as following.

$$\frac{dx_1}{dt} * \frac{1}{x_1} = r_1 + b_1x_2 + c_1x_3 + d_1x_4 \ldots + n_1x_n$$

$$\frac{dx_2}{dt} * \frac{1}{x_2} = r_2 + b_1x_1 + c_2x_3 + d_2x_4 \ldots + n_2x_n$$

$$\frac{dx_3}{dt} * \frac{1}{x_3} = r_3 + b_1x_1 + c_2x_2 + d_3x_4 \ldots + n_3x_n \tag{3}$$

$$\cdots$$

$$\frac{dx_n}{dt} * \frac{1}{x_n} = r_n + b_1x_1 + c_2x_2 + d_3x_3 \ldots + n_{n-1}x_{n-1}$$

The model refers to the population interaction when the population size is n.

4.3 Model Solving

According to the model, we substitute n equals to 3 to find the population number change within seven days when there are three populations in the community. Besides, the influence coefficient k of other populations can be obtained by numerical estimation. And different r can be obtained when the temperature is 22 ℃ from the referencing article [1].

Table 2 Extension rate

Isolate	Extension rate (mm day^{-1}) ± SD		
	10 °C	16 °C	22 °C
Armillaria gallica FP102531 C6D (south) *	0.30 ± 0.05	0.36 ± 0.05	0.34 ± 0.06
Armillaria gallica EL8 A6F (north) *	0.18 ± 0.06	0.26 ± 0.05	0.38 ± 0.15
Armillaria gallica FP102534 A5A (south) *	0.26 ± 0.05	0.24 ± 0.05	0.32 ± 0.06

The specific model is as follows.

$$\frac{dx_1}{dt} * \frac{1}{x_1} = 0.34 - 0.1 * x_2 - 0.3 * x_3$$

$$\frac{dx_2}{dt} * \frac{1}{x_2} = 0.38 - 0.1 * x_1 - 0.2 * x_3 \tag{4}$$

$$\frac{dx_3}{dt} * \frac{1}{x_3} = 0.32 - 0.3 * x_1 - 0.1 * x_2$$

Since the three populations are in the same surface dish, they can be regarded as approximately the same, and the image is obtained by substituting the data as follows.

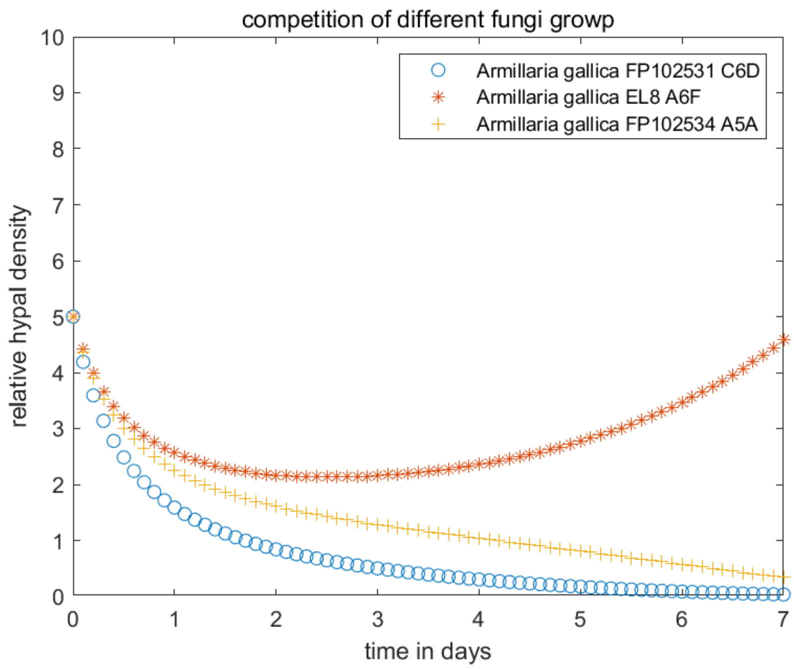


Figure 1 Multi-population model

According to Figure 1, it can be seen that under the condition of multi-population competition, different groups, due to their different adaptability to the environment, have different influence coefficients of other populations in the model, thus forming different images. In the figure, the decomposition rate of Armillaria gallica FP102531 C6D and Armillaria gallica FP102534 A5A are significantly lower than that of Armillaria gallica EL8 A6F in a short period of time, which means Armillaria gallica EL8 A6F is more adapted to survive.

5 Short-term model

5.1 Analysis

According to the hypothesis, when analyzing the short-term model, only the effects of natural population growth rate (i.e., hyphal extension rate) and population number (i.e., mycelium density) on decomposition rate are considered.

Based on that, we assume that the initial density is the same, 5. The density of various populations at different times can be obtained from the solution of multi-population model, and the hyphal extension can be obtained from the topic article [1], the specific values are as follows.

Table 3 Specific values of different species

Species	Extension rate (mm/day)	Decomposition rate (kg/m^3)	Initial density (kg/ m^3)
Armillaria gallica FP102531 C6D	0.34	17.12	5
Fomes fomentarius TJV93 7 A3E	21.87	47.24	5
Hyphodontia crustosa HHB13392 B7B	9.21	13.62	5
Laetiporus conifericola HHB15411 C8B	7.07	7.6	5
Lentinus crinitus PR2058 C1B	8.02	16.01	5
Phlebiopsis flavidoalba FP102185 B12D	17.95	25.93	5
Porodisculus pendulus HHB13576 B12C	3.02	4.36	5
Schizophyllum commune TJV93 5 A10A	4.65	12.69	5

5.2 Model Establishment

By using the data of population density of two variables and dependent variables, nonlinear regression analysis is carried out, and the model is obtained by fitting as follows.

$$z = a + b * \sin\left(m * \pi * \frac{dx}{dt} * y\right) + c * e^{-wy^2} \tag{5}$$

z is the decomposition rate,

y is the elongation rate of mycelium,

$\frac{dx}{dt}$ is the mycelium density.

a, d, w, m are the different coefficients

5.3 Putting the data into the model

After fitting the model according to the data table, the correlation coefficient can be obtained as:

```
General model:
   f(x,y) = a + b*sin(m*pi*x*y) + c*exp(-(w*y)
Coefficients (with 95% confidence bounds):
     a =      0.0676  (-96.8, 96.93)
     b =       0.6841  (-83.05, 84.42)
     c =      0.2934  (-8.76e+04, 8.76e+04)
     m =       0.4181  (-1.051, 1.887)
     w =      0.7742  (-2.881e+04, 2.881e+04)
```

Figure 2 The specific value of different coefficients

Through the model after fitting, we can get the relationship diagram among the three variables to get intuitive analysis.

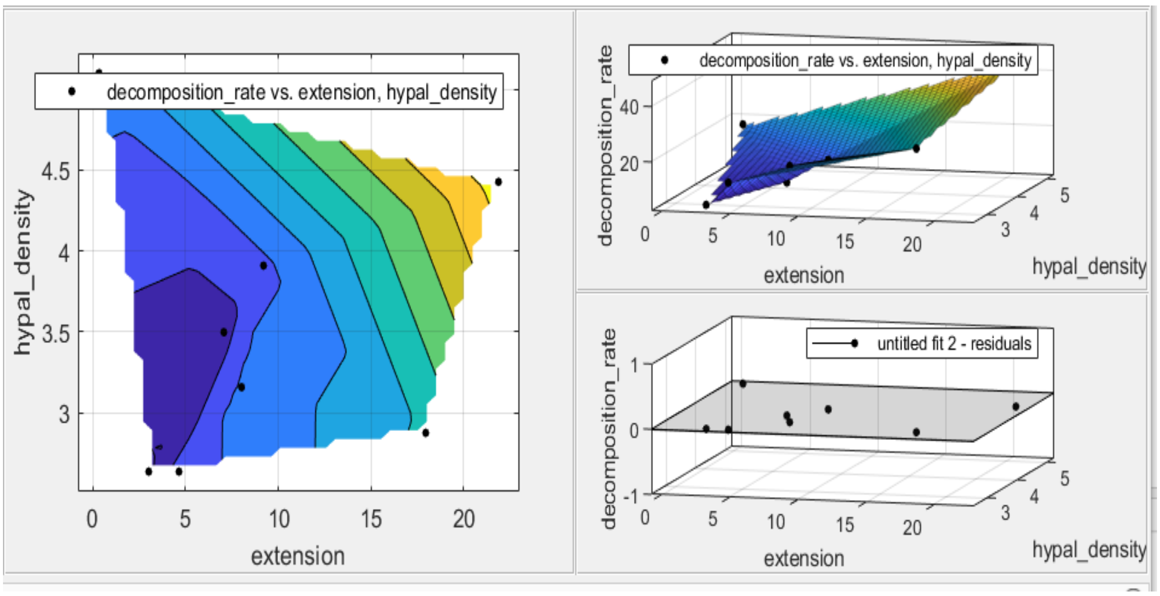


Figure 3 the relationship between three variables

According to the figure 3, in a relatively short period of time, both population density and population growth rate are positively correlated with the fungal decomposition rate, and the two have an enhanced relationship with each other

In order to verify the accuracy of the model, we carry out residual analysis as follows.

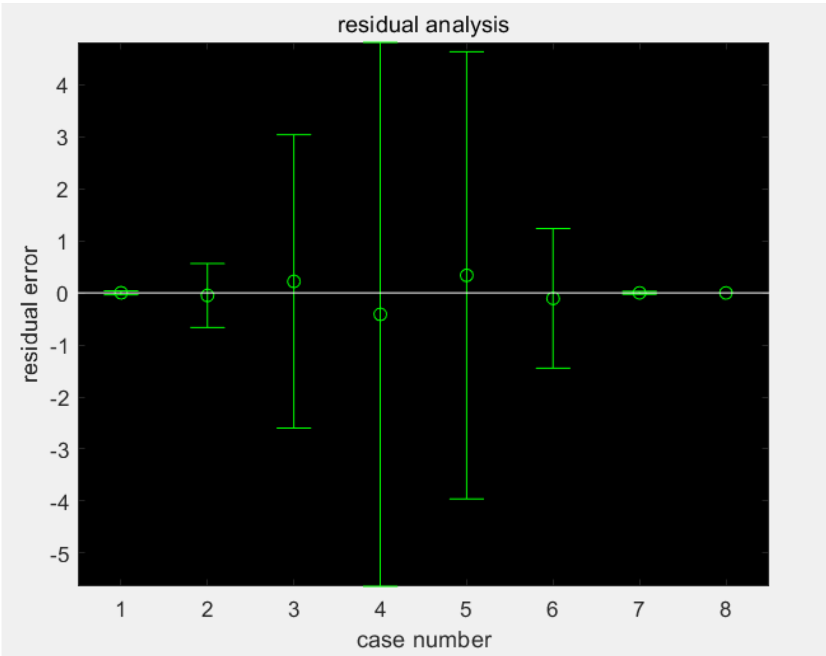


Figure 14 The residual analysis

From the figure 14,we can get that the model can accurately reflect the reality.

6 Long-term model

6.1 Analysis

According to the analysis of the relationship between decomposition rate and biological traits in figure 4 according to Sherman [3] and Mittelbach [4], when the factors affecting decomposition rate are considered, natural growth rate and population density are respectively referred to as positive maximum correlation factors and negative maximum correlation factors. Therefore, when the influence of biological traits on the decomposition rate is considered in the analysis, the natural growth rate and the population density are two indispensable and necessary factors. According to the hypothesis, when the time is medium or long term, the natural growth rate tends to zero, so this model selectively ignores the influence of this factor on the population density.

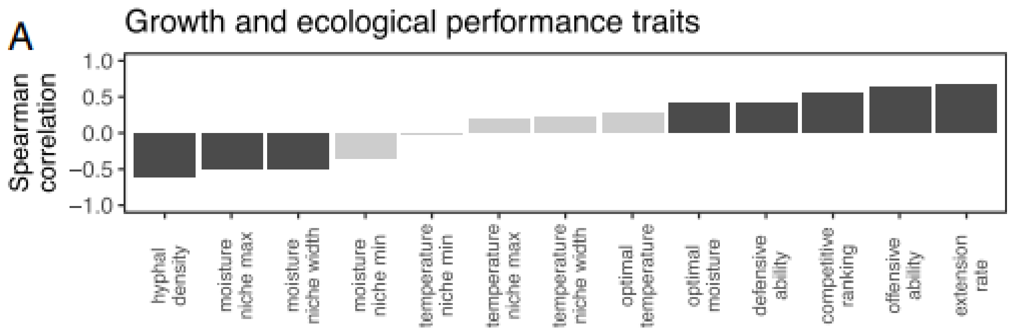


Figure 4 [2] Factors that affects decomposition rate

By analyzing the figure 5 and formula 6 from the data [5][6] it can be seen that the ratio of temperature and moisture tolerance has an obvious influence on the decomposition rate. Admittedly, temperature and moisture tolerance are two important factors affecting the decomposition rate.

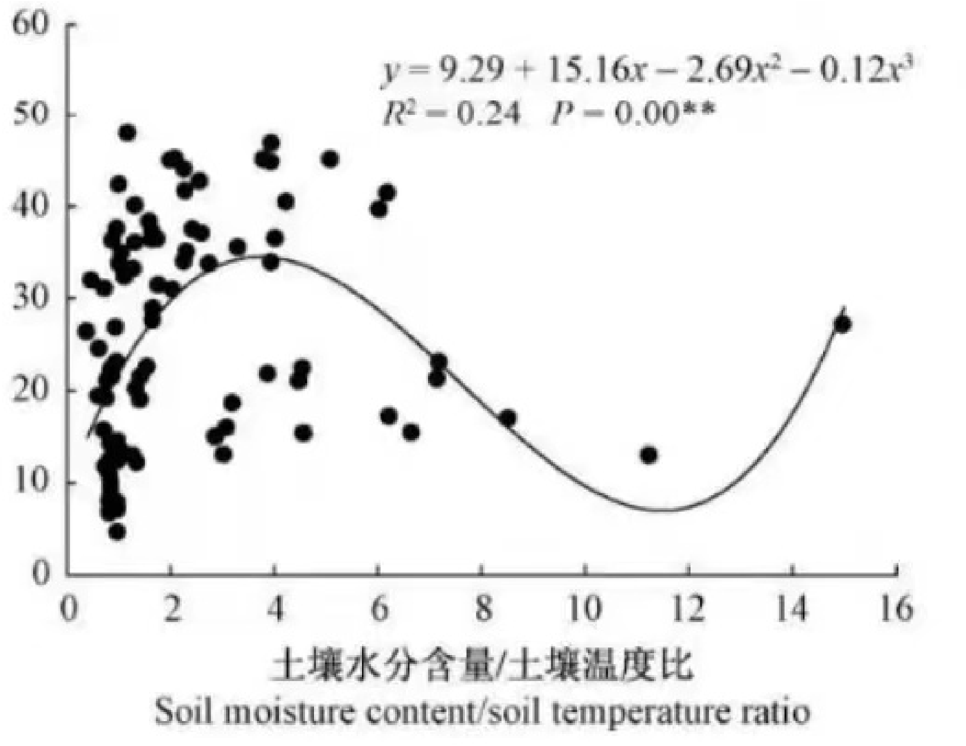


Figure 5 [6] The soil moisture content to temperature ratio of the decomposition rate

From the figure, the relationship model can be also known as:

$$y = 9.29 + 15.16x - 2.69x^2 - 0.12x^3 \tag{6}$$

x is the ratio of soil moisture content to soil temperature

y is the decomposition rate of fungal

Comprehensively considering, when analyzing the factors that affect the decomposition rate, it should not only be related to the community traits of the population density of the fungus body itself, but also the influence of temperature and moisture tolerance in the environment on the community.

As for the analysis of time change, we ignore the influence of time on temperature and moisture tolerance, and only reflect the change of time through the change of population density, while the difference of temperature and moisture tolerance can reflect the difference of climate. Therefore, the model should be established based on these.

6.2 Model Establishment

Through the regression analysis of the moisture tolerance to temperature ratio, population density and the dependent variable, decomposition rate, the correlation model under n populations is obtained as follows:

$$z = C + k * \frac{M}{T} + \sum_1^n i * \rho_i \tag{7}$$

k, i are the corresponding coefficient

z is the decomposition rate

M is the soil moisture content

T is the temperature

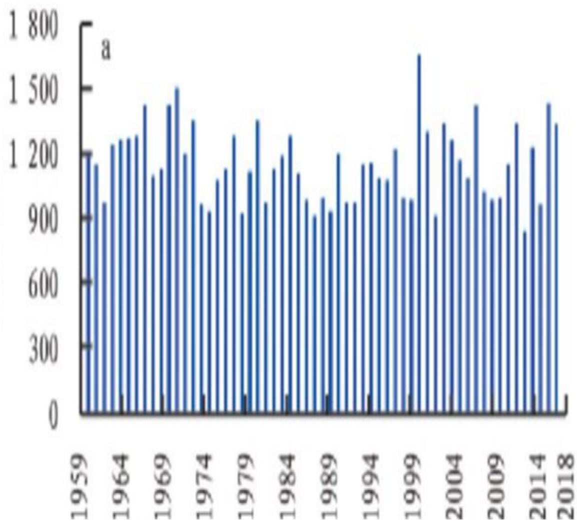
ρ is the population density

For this model, different $\frac{M}{T}$ represents different climatic conditions. Different population densities indirectly reflect the effect of time on population.

6.3 Model Application

6.3.1 Application Conditions

In order to test the rationality of the model, we made model prediction for different fungal models with the same climate characteristics. At the same time, we selected the tropical rainforest climate in Jinghong area of Xishuangbanna as the climatic characteristics of fungal life, among which, the relevant parameters are shown in Figure 6 and 7.



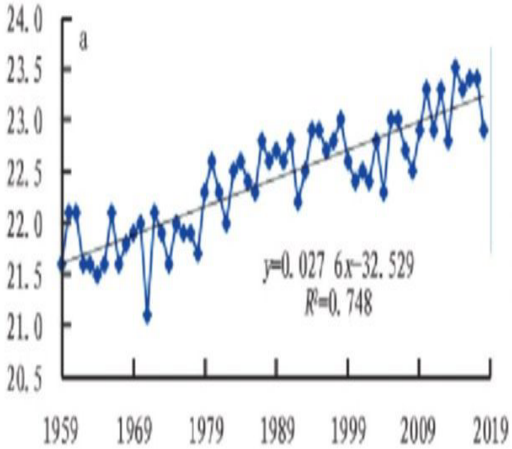


Figure 6 Figure 7

Annual precipitation in Jinghong area Climate characteristic map of Jinghong area[5]

Besides, through the analysis of the above climate factors, we get the temperature and moisture tolerance ratio caused by the relevant climate factors.

$$\frac{M}{T} = 46 \tag{8}$$

6.3.2 Application Solution

Through the study of table 3 and relevant data, we obtain the relevant data and make analysis. The models of five fungal communities in tropical rain climate are obtained as follows.

$$z = -3.14 + 3.1 * \frac{M}{T} + 548.5 * \rho_1 - 1.15 * \rho_2 + 1.21 * \rho_3 - 7.7 * \rho_4 + 8.1 * \rho_5$$

(9)

Based on the above models, through different population density values at different points, we get the images of the decomposition rate relative to time in the long-term time of the five models.

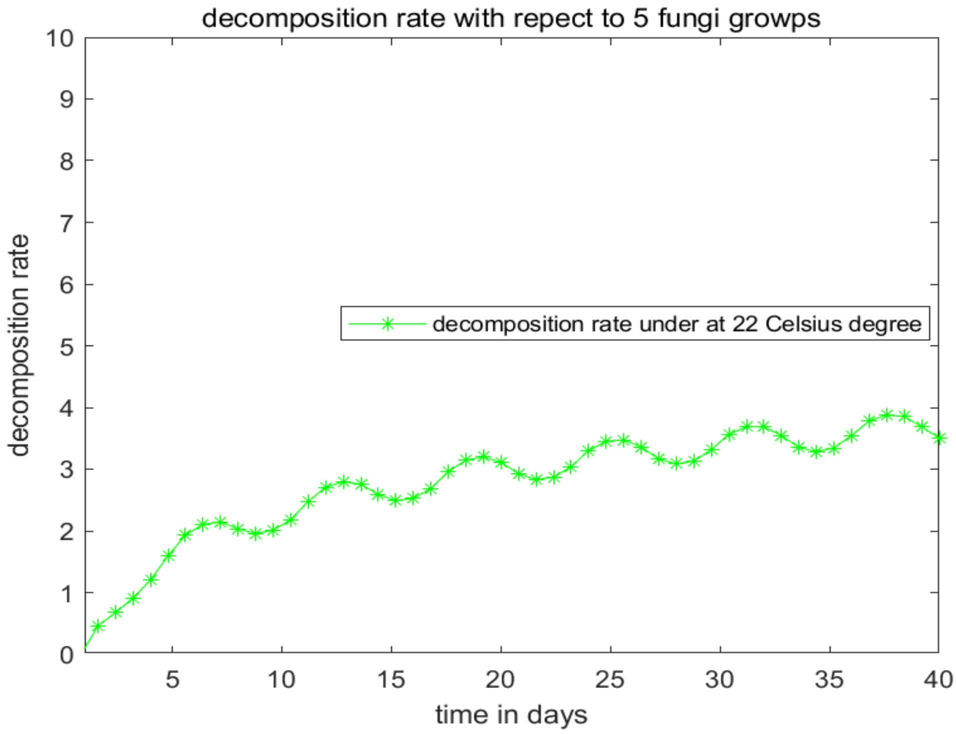


Figure 8 Decomposition rate with respect to 5 fungi groups

Through figure 8 we speculate that when placed five kinds of fungi in the same culture environment, the initial decomposition rate with time linearly related, the same as the above analysis of short-term model, and when the training time exceeds a certain limit, different populations will compete for resources, through the evolution of natural law from rapid growth to slow wave growth eventually to convergence as a fixed value, and this theory actually joint the reason why we set the block item and joint the natural as well.

6.4 Further Research

In order to have a deeper understanding of the relationship between the change of population density of the five different fungal populations on the tropical rainforest climate, we obtained the relationship between the change of population decomposition rate of the five fungal populations over time in different periods through data research and analysis.

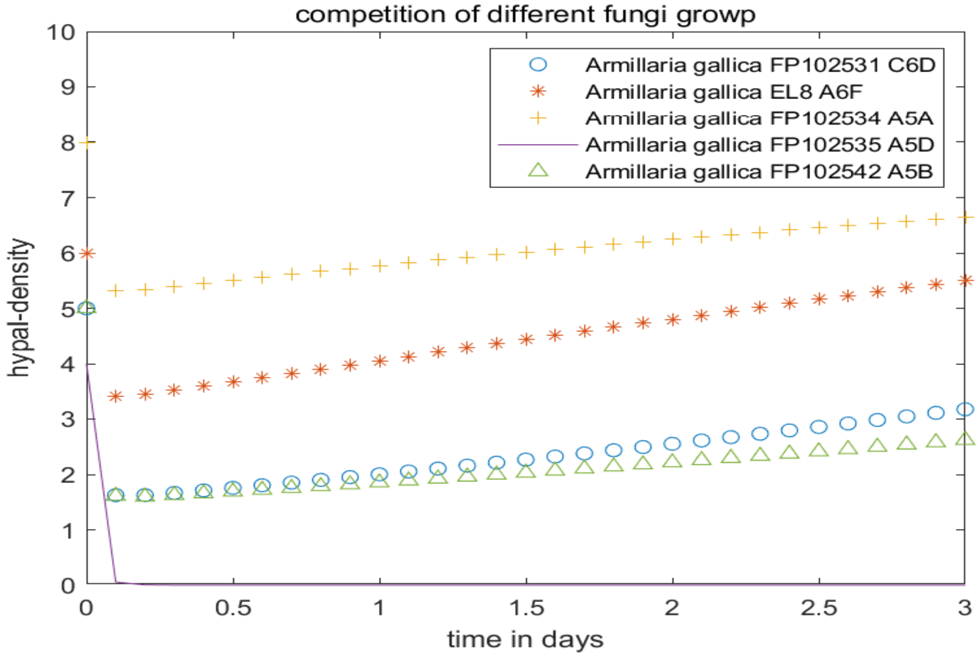


Figure 9

Changes in population density of different fungal species within 3 days

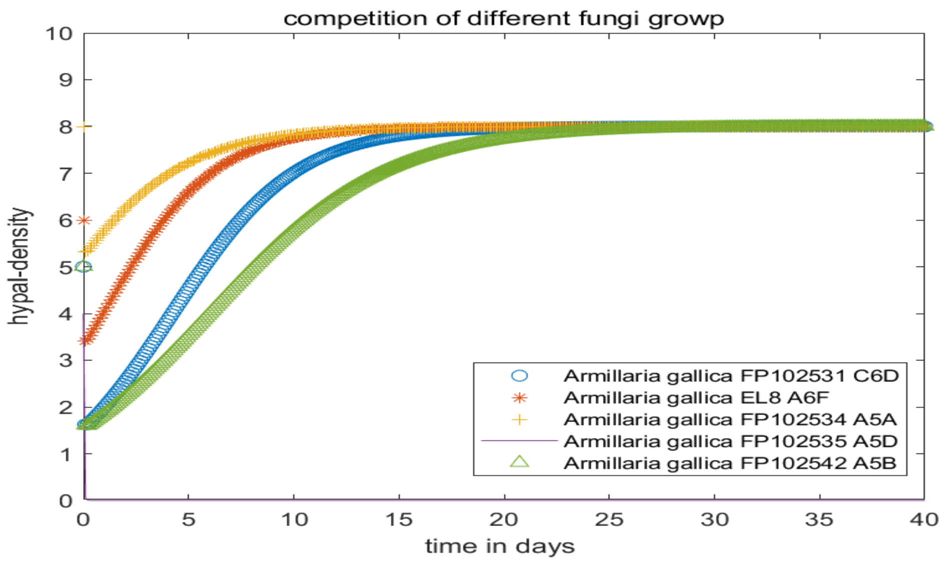


Figure 10

Changes in population density of different fungal species within 40 days

At the beginning (Figure 9), we can know that when the time is relatively short, the relationship is the same as that of the short-term model relationship, so there is no need to add the blocking term. Moreover, it can be found that at the beginning, the species Armillaria gallica FP1102535 A5D was extinct due to non-natural disasters, so in the long-term image after that, the image of this species always tends to 0 in the days after that. However, the growth rule of the other four strains is the same as that of logistics after the introduction of the blocking term in the long-term image, so the accuracy of the analysis can be proved.

7 Sensitively Analysis

7.1 Biodiversity index Analysis

According to the Shannon-Winner, the model for analyzing the biodiversity index is as follows.

$$H = -\sum_1^n P_n \ln{(P_n)} \tag{10}$$

H is the biodiversity index.

P_n denotes the proportion of the total number of individuals in the community of the nth population.

Through data analysis, we obtained the density figures of 5 different fungi under different indices.

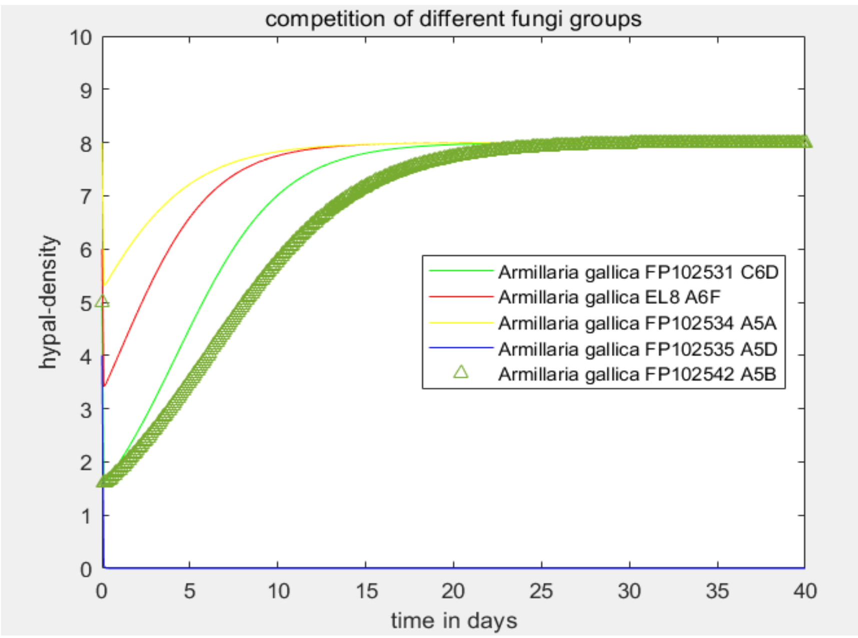


Figure 11 Competition relationship of 5 fungi groups when H=1.06

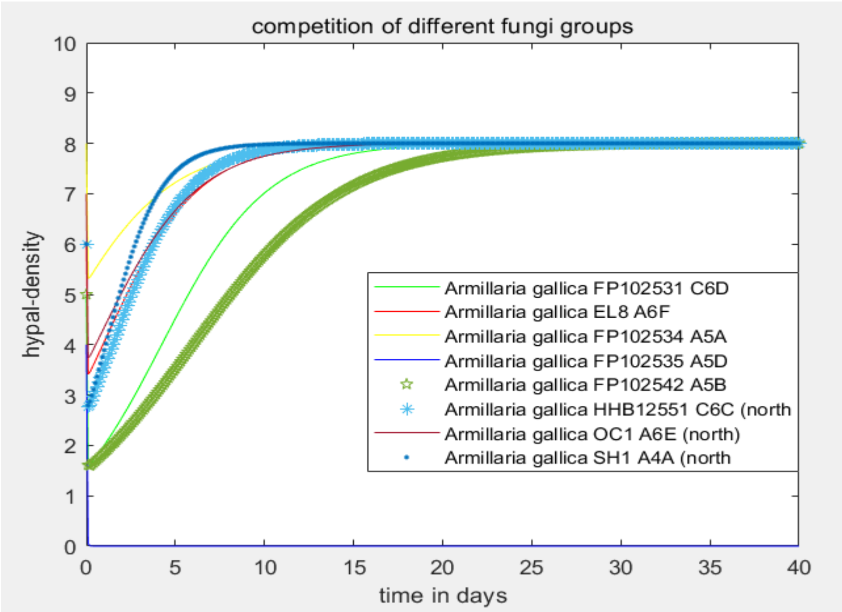


Figure 12 Competition relationship of 8 fungi groups when H=2.04

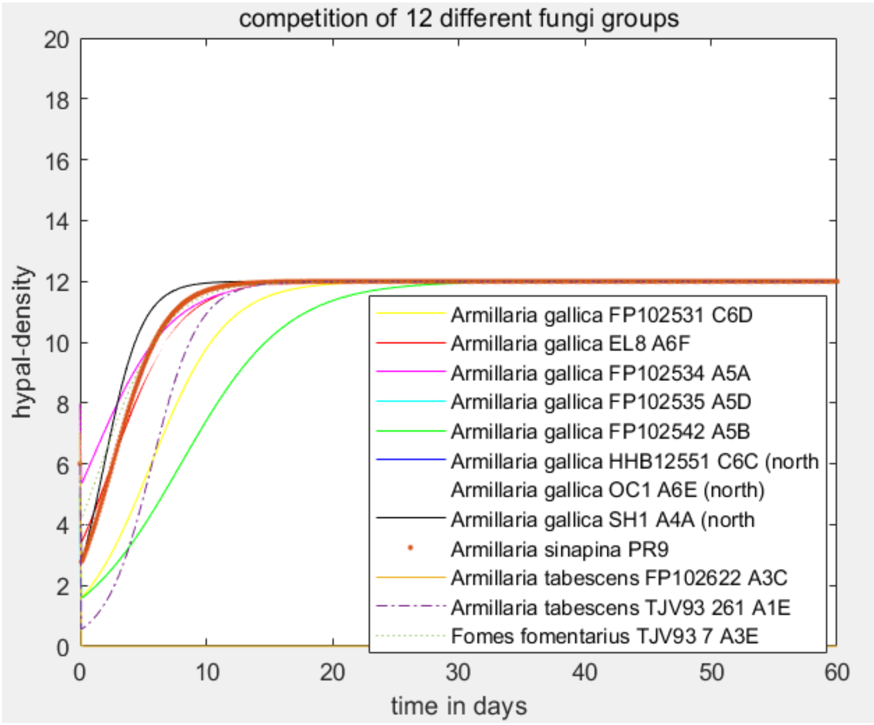


Figure 13 Competition relationship of 8 fungi groups when H=2.48

Through figure analysis, we can know that the larger the index is, the shorter the time for the strain density to reach a certain value. It can be seen that one of the factors that determine the sensitivity of the community of bacteria is the index of biodiversity. The larger the index is, the shorter the time it takes for each population in the community to stabilize, and the higher the sensitivity.

7.2 Climate conditions Analysis

Site	Mean multiannual temperature ℃	Mean multiannual rainfall mm	Total rainfall（mm）	
			2007-2008 study period	2008-2009 study period
Humid-Mediterranean	18.1	780	472.9	647.5
Mediterranean	17	540	322.6	413
Semi-arid	18.4	300	180.8	132.3
Arid	19.1	90	71.1	50.3

Table 4 Different Climate Conditions

Properties measured in four different climate region, where the ratial of moisture toler ance to temperature is different. [3]

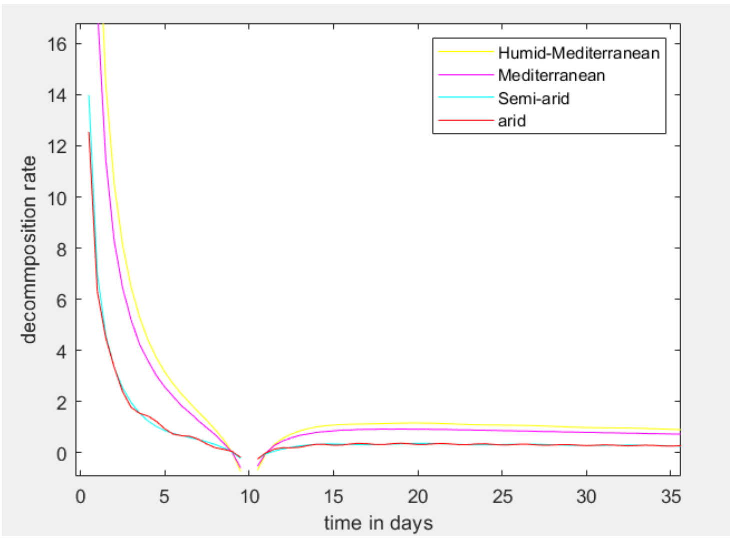


Figure 13

Decomposition rate of different fungi in different climates with respect to time

Through the data from table 4 and figure 13, different temperature and moisture tolerance between different climates can be got, and then the wett-to-temperature ratio under different climatic conditions can be got.

8 Strengths and Weaknesses

8.1 Strengths

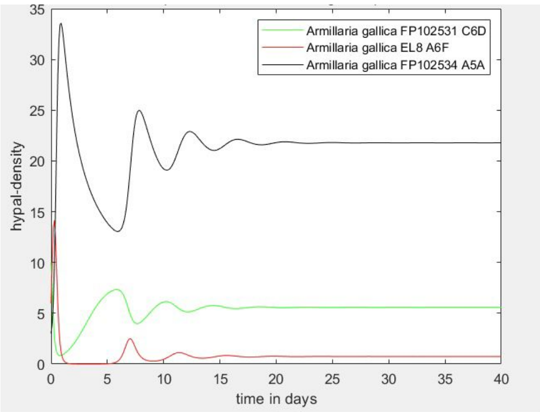
- We have quantified the effects of competing populations.
- We control different variables in different conditions to ensure accuracy.

8.2 Weaknesses

- Predation relationship and competition relationship in population relationship are not considered.

8.3 Model improvement

Since the competition and predation relationship in the population relationship are not considered in the above model, we obtain the following figures through data analysis and independent variable improvement in the original model.



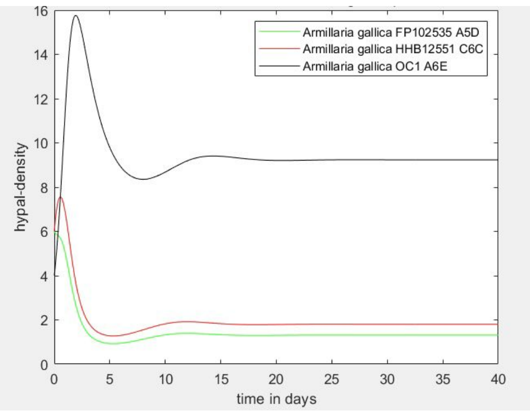


Figure 14

Predation effect on fungi groups

Figure 15

Commensalism effect on fungi groups

By analyzing the figures (more details on [2]), it can be told that Armillaria gallica FP102534 A5AA feeds on Armillaria gallica FP102531 C6D, which feeds on Armillaria gallica EL8 A6F, and Armillaria gallica HHB 12551 C6C and Armillaria gallica FP102535 A5D are symbiotic with each other.

9 The Results Article

There are 2126 Pg of carbon in the global terrestrial ecosystem, of which 46 % is stored in forests. Soil fungi, accounting for 81 % – 95 % of the total underground microorganisms, play an important role in the plant-soil-atmosphere carbon cycle, but have not received due attention. According to Lian Bin [7], fungi can promote photosynthesis by increasing plant uptake of mineral nutrients ; fungi transport large amounts of photosynthetic products underground; Fungi consume organic carbon and release CO2 by respiration. Therefore, understanding the role of fungi in ecosystem carbon cycle is of great significance for further understanding the regulation mechanism of organisms on global carbon cycle and protecting the ecological environment.

This paper mainly describes the performance and interaction of fungi in ecosystem carbon cycle from the following aspects.

1. the increase in the diversity of honey-cycle strains will promote the comprehensive decomposition rate of lignocellulose.

2. In the long term saying, the temperature-moisture ratio will greatly affect the comprehensive decomposition rate of fungal flora on lignocellulose and deciduous leaves.
3. Different interspecific relationships affect the convergence rate of mycelium density.

1 Diversity and decomposition rate

According to Shannon-wiener index, the effect of biodiversity on decomposition rate can be quantitatively analyzed. In this essay, by adjusting this index, we simulated the effect of fungal diversity (H=2.48) on decomposition rate at 22°C as shown in figure 13.

It can be concluded that the time of convergence point can be significantly bring ahead if the Shannon-wiener index is bigger. While in this case, the index H equals to 2.48 (figure 13), which is the highest. Besides, it, is also predicted that the decomposition rate will increase as biodiversity goes up. Shown in equation 9.

2 Climate influence

Apart from biodiversity, another essential factor that was found to determine the decomposition rate is the condition of climate. We simulated the behavior of decomposition rate under 5 different climate condition, where the moisture tolerance and temperature was bound together as one variant. See details in figure 14.

It can be noticed that the decomposition rate is best performance under the condition of Humid-Mediterranean climate, where the figure stays above all other lines. This could be related with enzyme activity under different temperature.

3 Interspecies relationship

Changing the interspecies relationship from competition to predation and commensalism, significant difference can be noticed by figure

Where the first graph on the left side described the predation relationship of 3 groups of fungi, and the right side described the commensalism relationship of 2 groups in 3groups of fungi. What cannot be forgotten is that the decomposition rate is proportion to hyphal density. So it can be concluded that by adding specified relationship, we can estimate the decomposition rate in the long term (40 days). Therefore, the more specification of relationships between fungi, the more accurate the estimation will be.

In conclusion, the 3 factors Diversity, Climate influence and interspecies relationship. These 3 factors interact with each other so when analyzing the specific problem, we need controlled the number of variance. We built the model based on the hypnoses of room temperature, only-competition interspecies relationship and no disaster occurs to fungi groups.

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