Problem Chosen	2021	Team Control Number
fungi56decomposition_growth_fungifigure 5	MCM/ICM	
A	Summary Sheet	2112481

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Summary

The carbon cycle is a significant component of life on the earth. Decomposition of plant material and woody fibers, conducted by fungi, is a process of great importance in this cycle. Research has done recently identified fungi traits determining decomposition rates and figured out links between certain traits.

For Model 1, we begin with the mathematical models aimed at describing the decomposition process of a certain type of fungi by figuring out the formula, which relates decomposition rate to extension rate linearly. Finally, the plots of 34 species are put forward.

For Model 2, it is determined that extension rate and moisture tolerance are the only two factors to be analyzed. We first take the extension rate into consideration. Since temperature and moisture are the key factors affecting extension rate-moisture graph are drawn and piecewise linear function are figured out, fitting the curves. Then a multiple linear regression is done to figure out the relation of decomposition rate and the features of different fungi.

For Model 3, we are intended to analyze the interactions of different types of species in both the short and long term. Firstly, we set up an equation set to describe the microcosmic situation concerning single species action. Then we use cellular automaton to simulate the situation of multiple species interaction in the short term.

For Model 4, we are required to compare different species of fungi and reasonable combinations of species and describe their relative advantages and disadvantages in a different environment. So we select multiple niche widths as the index to measure the advantages and disadvantages and use a formula to calculate the niche width.

For Model 5, we are supposed to figure out the relation of diversity and decomposition efficiency. Then a model showing the significance of diversity in different environments that differ in rate of change is required. So we build a model simulating the real world fungi community by plotting digraph. Then we abstract the model and put forward a matrix equation. Finally, based on outcomes in the previous sections, we figure out the formula of the efficiency related to diversity and decomposition factors. It is showed that decomposition efficiency have positive correlation with the diversity. Also, use the variance as an evaluation of stability, it turns out that the stability is positively related to diversity.

Keywords: Carbon Cycle; Fungi; Decomposition; Linear regression; Cellular automata; Differential equation model

Contents

1 Introduction

1.1 Problem Background

The carbon cycle refers to the whole process of the exchange of carbon on the earth, which is a significant component of life around the world. Being part of the process of decomposition of compounds, breakdown of plant material and woody fibers, conducted by fungi, is of great necessity in this cycle. The research did recently identified fungi traits determining decomposition rates and figured out associations between certain traits. It turns out the growth rate of fungi is negatively connected to the resilience to changes. While a great number of traits concerning fungi are examined in the research mentioned above, two traits are laid importance in the extension rate of fungi and the tolerance to moisture.

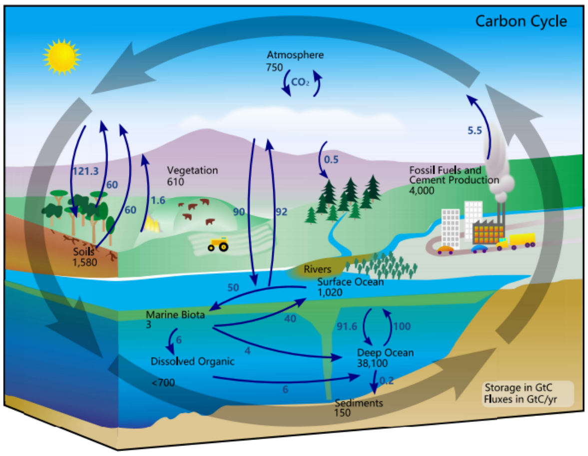

Figure 1: Carbon Cycle

1.2 Restatement of the problem

Build a mathematical model to identify the relation between the decomposition of ground litter and woody fibers caused by fungal activity and the amount of a certain type of fungi. Based on the model above, figure out a comprehensive model that takes the interactions between different types of fungi into consideration. make an analysis of the mutual effect between different types of fungi in both the short-term and long-term. Figure out the sensitivity of fungi to rapid change, and evaluate the comprehensive influence of atmosphere variation on fungi based on the model in the previous section. Compare different species of fungi and reasonable combinations of species and describe their relative advantages and disadvantages in a variety of environments, including arid, semi-arid, temperate, arboreal, and tropical rain forests. Measure the effect of the diversity of certain fungal communities on the decomposition of ground litter and woody fibers. Figure out the significance of biodiversity in different environments with different changeability.

1.3 Our Approach

The topic requires us to figure out the relation between extension rate, moisture tolerance, and decomposition rate of fungi and describe the mutual effect of different species of fungi in a community, also the effect of the diversity of fungi. Our work mainly includes the following: A mathematical model is built to identify the relation between the decomposition of ground litter and woody fibers caused by fungal activity and the amount of a certain type of fungi.

Based on the model above, a comprehensive model is figured out in respect of the interactions between different types of fungi. An analysis of the interaction between different types of fungi in a short and a long period was made. The environmental sensitivity of fungi and the impact of atmosphere variation on fungi are figured out. Different species of fungi and reasonable combinations of species are compared and their relative superiority and inferiority in a variety of environments are measured. The effect of the diversity of certain fungal communities on the decomposition of ground litter and woody fibers is measured. The significance of biodiversity in different environments with different changeability is figured out.

1.4 The Data

Wo got the data from the PNAS and Nature paper in the referrence.

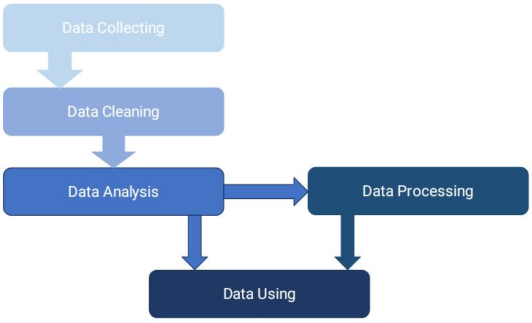

Figure 2: Data FLow

gen.name2	name3	rate.0.5	decomposition_	ranking	slope	temp_slop	temp_b1	temp_slop	temp_b2	mois_slope	mois_b1	mois_slope	mois_slope2
Armillaria_gallica_FP10253	a.gal1.s	0.25	17.12	0.232495277	68.48	0.0131	0.127	-0.064	2.2	0.088496	0.515681	-0.70303	-0.10991
Armillaria_gallica_EL8_A6F	a.gal10.n	0.35	15.42	0.164398987	44.06	0.04	-0.405	-0.2647	8.85	0.069087	0.379133	-1.94118	-0.66029
Armillaria_gallica_FP10253	a.gal2.s	0.21	11	0.232495277	52.38	0.0098	0.12	-0.0641	2.112	0.057371	0.430793	-0.75	-0.18
Armillaria_gallica_FP10253	a.gal3.s	0.25	12.3	0.232495277	49.2	0.0089	0.097	-0.0511	1.729	0.045161	0.366129	-0.6	-0.059
Armillaria_gallica_FP10254	a.gal5.s	0.25	9.2	0.367607311	36.8	0.0176	0.003	-0.0603	1.977	0.144492	0.742195	-1.1069	-0.3491
Armillaria_gallica_HHB125	a.gal6.n	0.49	39.51	0	80.63	0.0282	-0.136	-0.0797	2.751	0.056154	0.422615	-0.675	0.028
Armillaria_gallica_OC1_A6	a.gal8.n	0.25	9.26	0.164398987	37.04	0.0279	-0.169	-0.1843	6.421	0.140385	0.640308	-1.08125	-0.29681
Armillaria_gallica_SH1_A4	a.gal9.n	0.76	10.78	0.402693633	14.18	0.0857	-1.209	-0.2448	7.637	0.189691	0.803361	-3.37333	-0.2828
Armillaria_sinapina_PR9	a.sin.n	0.77	8.28	0.367607311	10.75	0.0444	-0.108	-0.2825	8.815	0.031202	0.227422	-3.78667	-0.23993
Armillaria_tabescens_FP10	a.tab.n	0.5	13.28	0.367607311	26.56	0.0506	-0.181	-0.1646	6.053	0.090614	0.552014	-1.08261	-0.01274
Armillaria_tabescens_TJV9	a.tab.s	1.07	12.75	0	11.92	0.1036	-0.808	-0.1341	5.07	0.512782	1.291865	-5.7	-0.38
Fomes_fomentarius_TJV93	f.fom.n	4.71	47.24	0.284747399	10.03	0.5638	-7.724	-3.2583	100.264	2.680328	6.192623	-30.4	-0.42
Hyphodontia_crustosa_HH	h.crust.n	1.96	13.62	0.569494797	6.95	0.0539	0.507	-0.3353	10.981	1.107843	2.518725	-12.7	-0.385
Hyphoderma_setigerum_I	h.seti.n	4.11	12.45	0.753370804	3.03	0.447	-3.3309	-2.56	76.5	0.808642	3.18284	-26.4615	-7.67231
Hyphoderma_setigerum_I	h.seti.s	4.7	18.82	0.569494797	4	0.448	-3.3308	-2.5	76.4	3.098901	7.398901	-13.9231	-1.80538
Laetiporus_conifericola_HI	l.conif.n	5.16	7.6	0.284747399	1.47	0.4625	-5.38625	-2.3	68.97	3.142857	7.491429	-14.6538	-2.13423
Lentinus_crinitus_PR2058_	l.crin.s	6.38	16.01	0.569494797	2.51	0.409174	-3	-4.09	124.87	2.57037	7.494815	-31.0667	-1.30467
Mycoacia_meridionalis_FP	m.meri.s	1.3	7.96	0.569494797	6.12	0.611679	-6.43285	-1.49231	66.43769	0.857143	1.83	-8	-0.1
Merulius_tremullosus_FP10	m.trem.n	10.62	53.5	0.788429846	5.04	0.103558	-0.55631	-0.82462	24.09	5.660377	13.84264	-58.0625	-1.91375
Merulius_tremellosus_FP15	m.trem.s	9.62	43.91	0.838273644	4.56	0.506087	-1.98635	-4.29375	152.9525	6.837398	15.68154	-59.7692	-4.32692
Phlebiopsis_flavidoalba_FF	p.flav.n	8.04	27.94	0.592748978	3.48	0.452174	-0.74609	-2.8625	102.4025	3.278788	9.647939	-42.3333	-2.97667
Phlebiopsis_flavidoalba_FF	p.flav.s	10.8	25.93	0.986393924	2.4	0.619549	-4.17895	-2.82903	105.171	2.894009	13.56705	-33.7619	-3.93476
Phellinus_gilvus_HHB1197	p.gilv.n	4.04	42.09	0.464990555	10.42	0.639423	-3.06577	-1.88605	67.79721	1.971014	5.658116	-12.3158	-1.96842
Phellinus_hartigii_DMR94_	p.har.n	1.54	17.39	0.493196962	11.29	0.16242	-0.41299	-1.02222	38.17333	0.782609	2.462609	-9.33333	-3.08667
Porodisculus_pendulus_HH	p.pend.n	4.06	4.36	0.464990555	1.07	0.076053	-0.12392	-0.0796	2.829	2.536364	6.392727	-11.6364	-1.83636
Phellinus_robiniae_FP1357	p.robin.n	2.3	8.28	0.519875245	3.6	-0.036	1.196	-0.05799	2.889317	1.133333	3.293333	-7.31579	-1.08632
Phellinus_robiniae_AZ15_A	p.robin.s	2.14	26.29	0.232495277	12.29	0.248148	-2.53037	-1.20909	40.25636	1.060345	3.133103	-5.61111	-0.59444
Phlebia_acerina_MR4280_	p.rufa.acer.n	8.75	16.18	1	1.85	0.440476	-0.16929	-2.5037	83.67037	5.467213	12.68574	-54.3571	-1.16786
Phlebia_acerina_DR60_A8	p.rufa.acer.s	8.51	73.39	0.972597525	8.62	0.381955	0.507293	-2.85	91.84	5.65	14.795	-20.4167	-1.895
Pycnoporus_sanguineus_F	p.sang.s	4.97	37.43	0.697485832	7.53	0.578947	-5.14737	-3.70952	161.051	1.858025	6.473765	-23.3125	-5.9175
Schizophyllum_commune	s.comm.n	4.41	12.69	0.657595949	2.88	0.359504	-1.76331	-1.83333	71.49	2.167421	9.17095	-39.6667	-15.2633
Schizophyllum_commune	s.comm.s	2.57	6.87	0.592748978	2.67	0.392157	-4.09608	-3.80833	139.3417	1.067633	4.745072	-8.68	-1.8508
Tyromyces_chioneus_HHB	t.chion.n	3.88	29.06	0.805387266	7.49	0.448276	-3.47621	-2.47619	87.37619	1.829932	4.168571	-22.7778	-0.24111
Xylobolus_subpileatus_FP	x.sub.s	0.77	8.55	0.493196962	11.1	0.037008	0.385197	-0.06989	2.887856	0.114667	1.11104	-1.39394	0.082727

Figure 3: Data

2 General Assumptions

- The 'S' shape growth curve of fungi under laboratory conditions is of the greatest accuracy in the middle of the curve.
- The relation of the decomposition rate and the features of the species is a multiple linear relation.
- The multiple species situation in the short term can be described by discrete model.
- The multiple species situation in the long term is a resource and space limited situation.
- Temperature and moisture are the two main factors affecting the state of fungi.

3 Model Preparation

sdafsdfadfasd

4 Model 1

It is required that a mathematical model be set to figure out the relation of the breakdown of ground litter and important factors. As stated in the topic, the decomposition rate can be set as an index representing the breakdown situation. Since extension rate is one of the two factors for consideration, a model concerning decomposition rate and extension rate is therefore built to satisfy the needs.

4.1 A linear model of decomposition rate and extension rate

As Some microbiological academic papers stated, there is a law concerning the change of fungi biomass through time under standard laboratory condition, in the middle of fungus growth, which is shown in figure(number3235156161565) below:

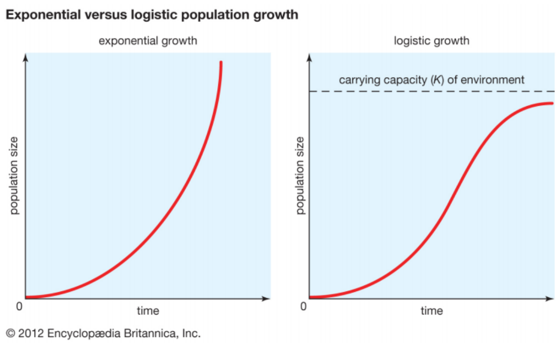

Figure 4: Logistic population growth,John N.Thompson. Eric Post

$$N = kt \tag{1}$$

k: the fungi's growth rate
Also, according to the basic biological knowledge, if the amount of ground litter and woody fiber is sufficient, the decomposition rate V satisfies the formula:

$$V = \lambda N \tag{2}$$

So, it turns out that $V = (\lambda t)k$ is a straight line passing the original point.

4.2 Result

The linear model concerning decomposition rate and extension rate is figured out as: There are 34 types of species altogether, so the graph of each species:

5 Model 2

The interactions between different species of fungi are required to be taken into consideration. Extension rate and moisture tolerance are the only two factors requiring an analysis. So,

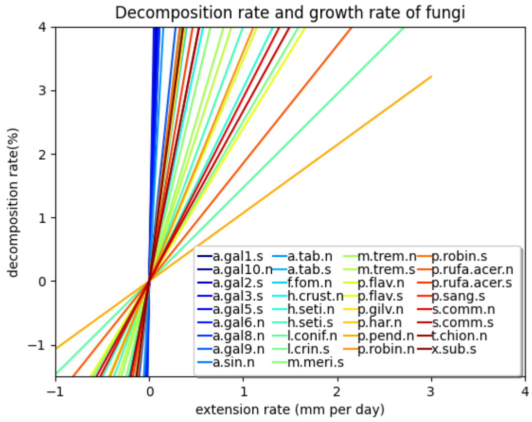

Figure 5: decomposition_growth_fungi

multiple linear regression is conducted to measure the connection between decomposition rate and the features of different species.

5.1 lot fungal growth rate versus humidity and temperature

First, we select two significant factors, temperature, and moisture. Then we plot two scatter diagrams that relate temperature and moisture to extension rate separately and use the smooth curve to fit the data point. The two graphs are as follows.

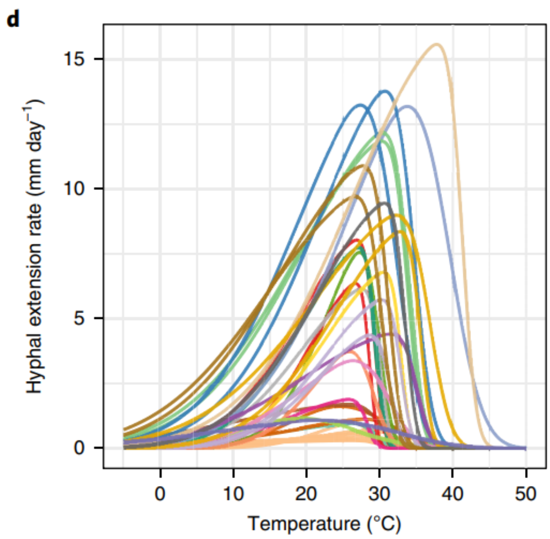

Figure 6: Hyphal extension rate-temperature

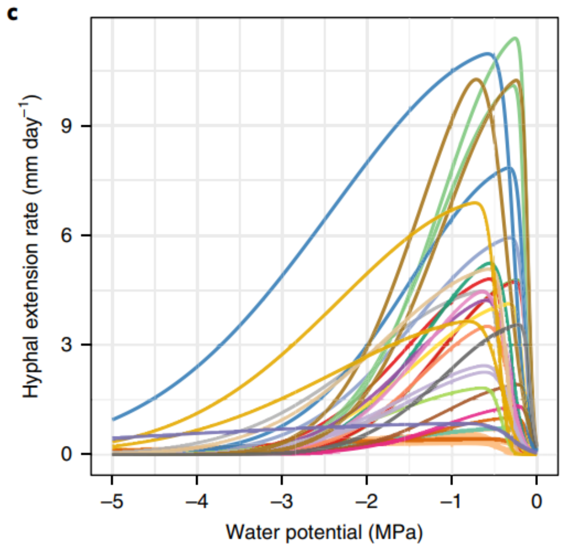

Figure 7: Hyphal extension water

5.2 Linear Fitting

From the graphs, it can be seen that both of the curves are highly identical to the piecewise linear function. In an attempt to figure out the functions, we set two functions with parameters:

$$k = \begin{cases} \alpha_1 T + b_1 \\ \partial_2 T + b_2 \end{cases}$$
$$k = \begin{cases} \beta_1 M + b_3 \\ \beta_3 M + b_4 \end{cases}$$

Then we select some points from the graphs as sample point, and conduct least square method with these sample points to search the best-fitted functions, the outcomes are as follow:

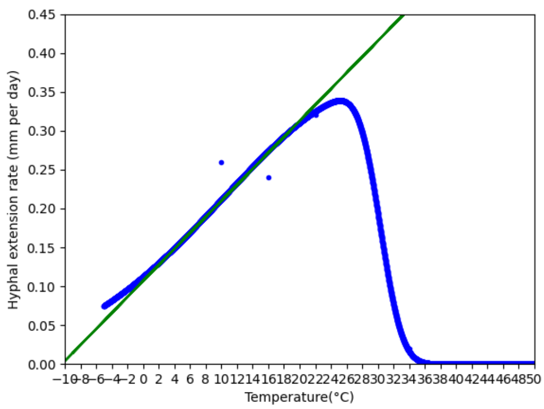

Figure 8: Hyphal extension rate - Temperature

multiple linear regression In order to figure out the connection between decomposition rate and the features of different species, the linear function is put forward. According to competitive ranking, so we take ranking as the estimation of:

$$k_i = [T_i, \quad M_i] \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} + \begin{bmatrix} b_1 & b_2 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \end{bmatrix}$$

6 Model 3

We are required to make an analysis of the interactions between different types of fungi in both the short and long term. So partial differential equation is used first to model the situation of single species at the microcosmic level and the analysis of dynamic multiple species situations of short term is done by a cellular automaton. Then we put forward a partial differential equation set to analyze the interactions of the long term. Then an analysis of model 2 is needed. It is required that we examine the sensitivity to rapid environmental change and the impact of slower environment change.

6.1 Single species model in microcosmic level

Before analyzing the overall situation of the interactions of different species, it is proper to view on a smaller field. To fulfill the basic logic and increase the similarity to real situations, an equation set is put forward:

$$\begin{gathered}
(1)\rho \mathcal{D}_t \vec{v} = \nabla \cdot \sigma + \vec{f} \\
(2)\sigma = \mu\left(\nabla \vec{v} + \nabla vecv^T\right) + (-\varepsilon + \zeta div\vec{v})\mathrm{I} \\
(3)\mathcal{D}_t \rho = \lambda R \rho(1-\rho) - \rho \operatorname{div} \vec{v} \\
(4)\vec{f} = \rho \alpha \nabla \mathrm{R} \\
(5)\frac{\partial R}{\partial t} = -\beta \rho H(R)
\end{gathered}$$

(1) is the dynamic equation, (2) is the constitutive equation, (3) is the proliferation equation, (4) is the motivation equation, (5) is the decomposition equation.

$$\begin{gathered}
\mathcal{D}_t = \tfrac{\partial}{\partial t} + \vec{v} \cdot \nabla \\
\vec{v} =: u\vec{\imath} + v\vec{\jmath} \\
\vec{f} =: f_x\vec{\imath} + f_y\vec{\jmath} \\
H(x) = \begin{cases} 0, x \leq 0 \\ 1, x > 0 \end{cases} \\
\varepsilon \sim T, W
\end{gathered}$$

The above equations can be written in the form of components as follows.

6.2 Cellular Automaton

In the reality, many species of fungi spread, coexisting or competing with each other. To simulate the real fungi interactions, a cellular automaton with special rules is built. A grid group of n*n is set to represent the field of spread and the neighbor mechanism is set as Von Neumann. The rule of the automaton is set as follows: There are some fungi species named $G_1, G_2, ..., G_n$ and their competitive ranking is set as $R_1^\phi, R_2^\phi, ..., R_n^\phi$ which range from 0 to 1. Von Neumann's form of neighbors will react to each other. The original value of the empty cellular is set as -1, and the change of cellular type follows this rule: The original type of cellular is $G_{i,0}$. The frequency of a certain cellular reacting to its neighbor of different types G_k is recorded as n_k. Set$n_j R_j^\phi = max\{n_1 R_1^\phi, n_2 R_2^\phi, ...\}$, and $G_{i,0}$ will transform to G_j.

6.3 The interactions of long term

Different from the situation of the short term, long term situation have to consider the limitation of resources and space, the change of environment condition and the self retardation.

$$
\begin{aligned}
&\frac{dR}{dt} = r_1 e^{-\lambda R} - \beta \rho H(R)\\
&\frac{d\rho}{dt} = \varepsilon r_2 R \rho (1-\rho)\\
&\varepsilon = (1+\xi)\varepsilon_T \varepsilon_W\\
&\varepsilon_T = \left(1 + \exp\left(\frac{\partial ER}{\partial T}\right)\right)^{-1}\\
&\varepsilon_W = \left(1 + \exp\left(\frac{\partial ER}{\partial W}\right)\right)^{-1}
\end{aligned}
$$

$$
\begin{aligned}
&T = T_0 + \Delta T \sin(\omega_1 t + \varphi_1)\\
&W = W_0 + \Delta W \sin(\omega_2 t + \varphi_2)
\end{aligned}
$$

6.4 The analysis of Model 2

In this part, the sensitivity to rapid environment change and the influence of slower atmospheric change is evaluated. Based on the outcome of model 2, we make a linear regression and fitting. The result of fitting is as follows: (formula)<><><><><> (figure)(fugure)

6.5 Result

It can be seen from the model that the interactions of fungi is mainly consists of competition and self-organizing. If the fungi are almost equal in their competitiveness, it is likely that they will lead to the situation of vibration, causing a self-organizing pattern. If they differ in competitiveness, the most competitive one will invade the other, and occupy the whole field in the end.

7 Model 4

It is required that we compare different species of fungi and reasonable combinations of species and describe their relative advantages and disadvantages in a variety of environments. So, we use 'niche width' to save this problem. Niche width is a type of index that represents the adaptability and competitiveness of species in an environment with certain conditions. In regard to the five types of environment mentioned, temperature and moisture are the two most significant factors, for these environment types differ the most in these two aspects. Thus, we use temperature niche width and moisture niche width to evaluate the advantages and disadvantages.

7.1 Multiple niche width

To conduct an evaluation, we use an index named 'multiple niche width'. Nevertheless, considering that the two factors are of the great difference in the five types of environment, it is more reasonable that the two niche widths weigh differently in different environments. Thus, some modification is made to the original formula. The final formula is :

$$B^{\phi} = \sqrt{\mu_T B_T^{\phi^2} + \mu_M B_w^{\phi^2}}$$

The parameters are calculated with the equation set:

$$
\begin{aligned}
&T^{\phi}=\left[1+\exp\left(-0.1\times\frac{T\max+T\min}{2}\right)\right]^{-1}\\
&W^{\phi}=[1+\exp(-0.05\times\text{Rainfall})]^{-1}\\
&\frac{\mu_T}{\mu_M}=\frac{T^{\phi}}{W^{\phi}}\\
&\mu_T+\mu_M=2\\
&B_T^{\phi}=[1+\exp\left(-0.1\times B_T\right)]^{-1}\\
&B_W^{\phi}=[1+\exp\left(-0.35\times B_W\right)]^{-1}
\end{aligned}
$$

7.2 Result

Multiple niche breadth under different climatic conditions

	gen.name2	name3	CAIRO(arid)	XI'AN(semi-arid)	LONDON(temperate)	NY(arboreal)	SING.(trf)
1	Armillaria_gallica_FP102531_C6D	a.gal1.s	1.215839365	1.177087562	1.171245699	1.166003814	1.173565002
2	Armillaria_gallica_EL8_A6F	a.gal10.n	1.060543885	1.0354063	1.0316354	1.028256064	1.033131902
3	Armillaria_gallica_FP102534_A5A	a.gal2.s	1.234095781	1.205118959	1.200772711	1.196877903	1.202497525
4	Armillaria_gallica_FP102535_A5D	a.gal3.s	1.249028948	1.227201358	1.2239391	1.221018334	1.22523336
5	Armillaria_gallica_FP102542_A5B	a.gal5.s	1.143372301	1.111155093	1.10630917	1.101963448	1.10823272
6	Armillaria_gallica_HHB12551_C6C	a.gal6.n	1.167942081	1.162621799	1.16183264	1.161127419	1.162145542
7	Armillaria_gallica_OC1_A6E	a.gal8.n	1.10116713	1.073575407	1.069433002	1.065719969	1.071077046
8	Armillaria_gallica_SH1_A4A	a.gal9.n	0.990665069	0.980709021	0.979227514	0.977902539	0.979815079
9	Armillaria_sinapina_PR9	a.sin.n	1.087652088	1.048231867	1.042273392	1.036923163	1.044639509
10	Armillaria_tabescens_FP102622_A3C	a.tab.n	1.170662967	1.150739877	1.147763062	1.14509804	1.14894405
11	Armillaria_tabescens_TJV93_261_A1E	a.tab.s	1.070139043	1.024264581	1.017302204	1.011043844	1.020067906
12	Fomes_fomentarius_TJV93_7_A3E	f.fom.n	0.957499161	0.932835487	0.929131117	0.925810358	0.930601363
13	Hyphodontia_crustosa_HHB13392_B7B	h.crust.n	1.146234358	1.081678292	1.071797655	1.062895999	1.075725383
14	Hyphoderma_setigerum_HHB12156_B3H	h.seti.n	1.015036401	0.977696999	0.972051169	0.966981231	0.974293196
15	Hyphoderma_setigerum_FP150263_B2C	h.seti.s	0.972471457	0.949450836	0.945997565	0.94290289	0.947368012
16	Laetiporus_caribensis_GDL1_A1A	l.carib.s	1.042650035	1.015858775	1.011835004	1.008227954	1.013432013
17	Laetiporus_conifericola_HHB15411_C8B	l.conif.n	1.009394494	0.97403863	0.968698465	0.963904359	0.970818921
18	Lentinus_crinitus_PR2058_C1B	l.crin.s	1.104034685	1.056552871	1.049345922	1.042867572	1.052208797
19	Laetiporus_gilbertsonii_CA6_C2D	l.gilb.s	1.025364925	0.992859871	0.98796022	0.983563898	0.989905435
20	Laetiporus_huroniensis_HMC1_C2H	l.huron.n	0.973757791	0.94624517	0.942106691	0.938395347	0.943749433
21	Mycoacia_meridionalis_FP150352_C4E	m.meri.s	1.021656483	0.982890463	0.977024762	0.971756401	0.979354239
22	Merulius_tremullosus_FP102301_C3E	m.trem.n	1.089212593	1.036226282	1.028155567	1.020893988	1.031362505
23	Merulius_tremellosus_FP150849_C3F	m.trem.s	1.098189987	1.044543812	1.036371549	1.029018353	1.039618872
24	Phlebiopsis_flavidoalba_FP102185_B12D	p.flav.n	1.084368444	1.041542409	1.035056212	1.029229087	1.037632313
25	Phlebiopsis_flavidoalba_FP150451_A8G	p.flav.s	1.128136112	1.098647315	1.09421722	1.090245656	1.095975535
26	Phellinus_gilvus_HHB11977_C4H	p.gilv.n	1.108312063	1.056368794	1.04846574	1.041357127	1.051605764
27	Phellinus_hartigii_DMR94_44_A10E	p.har.n	1.114113565	1.064986088	1.057524325	1.050815722	1.060488589
28	Porodisculus_pendulus_HHB13576_B12C	p.pend.n	1.055954439	1.011120051	1.004317249	0.998202738	1.007019505
29	Phellinus_robiniae_FP135708_A10G	p.robin.n	1.024264313	0.993521302	0.988891985	0.984739323	0.990729721
30	Phellinus_robiniae_AZ15_A10H Banik/Mark	p.robin.s	1.013956634	0.984227394	0.97975261	0.975739006	0.981528939
31	Phlebia_acerina_MR4280_B9G	p.rufa.acer.n	1.090445623	1.037205156	1.029094825	1.021797385	1.032317535
32	Phlebia_acerina_DR60_A8A	p.rufa.acer.s	1.104226798	1.05028556	1.042068348	1.034674708	1.045333533
33	Pycnoporus_sanguineus_PR_SC_95_A11C	p.sang.s	1.110741843	1.065647426	1.058813025	1.052671976	1.061527574
34	Schizophyllum_commune_TJV93_5_A10A	s.comm.n	1.143187244	1.102583428	1.09644877	1.090940981	1.098884761
35	Schizophyllum_commune_PR1117	s.comm.s	1.079765135	1.056074965	1.052524932	1.04934438	1.053933662
36	Tyromyces_chioneus_HHB11933_B10F	t.chion.n	1.048279047	1.003837507	0.997094579	0.991033948	0.999773043
37	Xylobolus_subpileatus_FP102567_A11A	x.sub.s	1.288808852	1.268183789	1.265103936	1.262347086	1.266325744

Figure 9: Multiple niche width

In the table, within the same type of region, a certain species have advantages over species with a lower niche width than it, and have an disadvantage to species with a higher niche width than it.

8 Model 5

According to the statement of model problem 5, a model describing the relation of fungi community diversity and the decomposition efficiency is to be set. Also, we are asked to figure out the significance of biodiversity in different environments with different changeability. Since temperature and moisture are two significant factors which affect fungi greatly and are possible to witness rapid change or form trends, it is proper to take them into consideration. In order to satisfy the needs, we ought to build a model of a fungi community to describe the mutual effect in a multiple fungi species system. The graphic model is put forward as follows: Based on the graphic model, a mathematical model of matrix is set up:

$$
\begin{bmatrix} T_{n+1} \\ W_{n+1} \\ A_{n+1} \\ B_{n+1} \\ C_{n+1} \end{bmatrix}
=
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
\tau_A & W_A & K(AA) & K(AB) & K(AC) \\
\tau_B & W_B & K(BA) & K(BB) & K(BC) \\
\tau_C & W_C & K(CA) & K(CB) & K(CC)
\end{bmatrix}
\left(
\begin{bmatrix} T_n \\ W_n \\ A_n \\ B_n \\ C_n \end{bmatrix}
+
\begin{bmatrix} \widetilde{T}_n \\ \widetilde{W}_n \\ 0 \\ 0 \\ 0 \end{bmatrix}
\right)
+
\begin{bmatrix} TP_n \\ WP_n \\ AP_n \\ BP_n \\ CP_n \end{bmatrix}
$$

According to the models in the previous section, the mass loss of woody fiber and ground litter is related to the temperature and moisture. The relation can be represented by the formula:

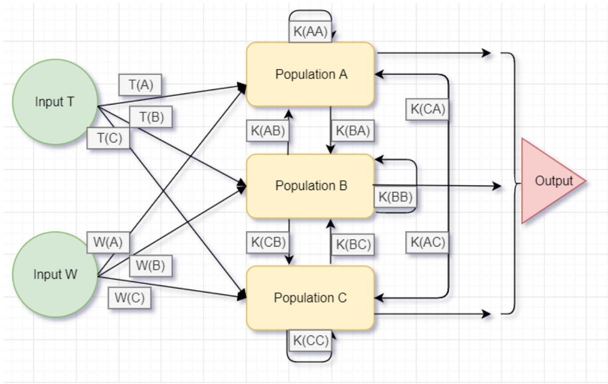

Figure 10: work flow

(ML)

All species of fungi contributes to the decomposition process and their contribution is positively related to their proportion in the community. So the efficiency can be viewed as:

$$\eta = \frac{1}{A_n+B_n+C_n}\left(A_n\Delta ML_n^{(A)} + B_n\Delta M_n^{(B)} + C_n\Delta ML_n^{(C)}\right)$$
$$\Delta ML_n^{(A)} = ML_{n+1}^{(A)} - ML_n^{(A)}$$

It is a common sense in the biology that diversity can improve the stability of the community. So, when mention the significance of diversity, stability is a vital related factor. To measure the stability of the community, we choose the variance of species, and the stability is viewed as weighed sum of all variance. Thus, the formula is put forward as:

(In sdfasdfasd)

We start with single species, then we gradually add more species to the community and calculate the decomposition efficiency and stability to figure out the relation of diversity and efficiency and the importance of diversity.

8.1 Result

As is calculated, the diversity is positively related to the decomposition efficiency. Also, the diversity is of huge importance to the environment, for the diversity is positively related to the stability, a community of diversity is of more stability and resilience.

9 Strengths and Weaknesses

9.1 Strengths

1. Different situation is carefully divided and different model are set to satisfy the needs.

2. Models take most of the rules in real life into consideration. They can simulate real life situation better.

9.2 Weaknesses

1. The temperature curve and moisture curve in model 2 is simplified to piecewise linear function, which have turning point and contradicts with real life situation.

2. Many of the models require a large amount of accurate data and is hard to calculate, which add to the difficulty of data collecting and analysis.

10 The Article: Recent developments in the understanding of the roles fungi play in ecological systems

The carbon cycle, which refers to the circulation of carbon on the Earth, is well known as a vital process for life on the planet. There is a crucial part of the cycle, the decomposition of compounds, in which carbon is absorbed and produced periodically. The decomposition of plant material and woody fibers is a component of the necessity of the whole decomposition part.

Recently, a group of researchers from MCM conducted research to explore the effect of fungi on the environment. First, they focus on the relation between the decomposition rate of fungi and its extension rate. A single species situation is viewed first, then a multiple species situation is figured out based on the single one. It was found that the decomposition rate is positively correlated to the extension rate. The single system relation can be described briefly as: $V = (\lambda t)k$ The multiple systems are fungi break down the ground litter and woody fibers. A higher decomposition rate means fungi can be more efficient in carbon transportation. So the extension of fungi can have a positive effect on the ecological systems.

Researchers then adjust the environment settings of the model to examine the sensitivity of the model to rapid fluctuations and the impact of certain atmospheric trends.

Following the impact evaluation, researchers attempt to figure out the interactions between different types of fungi in the short and long term. An equation set was first put forward as the basis and detail supply of the study, describing the microcosmic situation of single species: ()()()()

Researchers then use cellular automaton to imitate the fungi community in real life. The imitation model contains the spread, competition, and invasion behavior of fungi. According to the result of the simulation,

Besides, an evaluation of the advantages and disadvantages of different species is conducted. Researchers use multiple niche width as the index to compare the competitiveness of different species. As is shown in the table below, environmental conditions can pose great effect on the competition and survival of fungi. It seems that fungi are also affected by the ecological environment. ()()()()

Finally, researchers examine the influence of the diversity of fungal communities on the decomposition aspect in an environment of different degrees of variability. As can be seen from the resulting series calculated by matrix. Diversity is positively related to the overall efficiency of decomposition. ()()()() Also, according to the sensitivity test model, a fungi community of diversity perform better in the stability and resilience facing rapid and long-time change in environment. ()()()() To sum up, it can be seen from the research results that fungi play an important role in ecological systems. The growth and prosperity of fungi can facilitate carbon circulation. In turn, the ecological systems can pose an effect on fungi.

- **Applies widely**
  This system can be used for many types of airplanes, and it also solves the interference during the procedure of the boarding airplane,as described above we can get to the

optimization boarding time.We also know that all the service is automate.

- **Improve the quality of the airport service**
  Balancing the cost of the cost and the benefit, it will bring in more convenient for airport and passengers.It also saves many human resources for the airline.

-

References

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[3] https://www.weather.gov/

Appendices

Appendix A First appendix

some more text **Input Python source:**

```
"""
Cellular Automata are used to simulate the relationships between fungi
"""
import bidict
import numpy as np
import matplotlib.pyplot as plt


class GameOfLife(object):

    def __init__(self, cells_shape, fungi_data):
        """
        Parameters
        ----------
        fungi_data: [[(color1, weight1), [(x11, y11), (x12, y12),...]],
        [(color2, weight2), [(x21, y21), (x22, y22)]], ...]
        ----------
        cells_shape: a tuple
        """

        self.cells = np.zeros(cells_shape)
        self.fungi = dict([fungi[0] for fungi in fungi_data])
        for fungi in fungi_data:
            for coordinate in tuple(fungi[1]):
                xPos = coordinate[0]
```

```
                yPos = coordinate[1]
                self.cells[xPos, yPos] = fungi[0][1]
        self.timer = 0

    def update_state(self):
        """update a state"""
        buf = np.zeros(self.cells.shape)
        cells = self.cells

        for i in range(1, cells.shape[0] - 1):
            for j in range(1, cells.shape[0] - 1):

                if i == 1 and j == 1:
                    if cells[i + 1, j] == cells[i, j + 1]:
                        if cells[i, j] < 2 * cells[i + 1, j]:
                            buf[i, j] = cells[i + 1, j]
                        else:
                            buf[i, j] = cells[i, j]
                    else:
                        buf[i, j] = max(cells[i, j],
                                        cells[i + 1, j], cells[i, j + 1])

                elif i == 1 and j == cells.shape[1] - 2:
                    if cells[i + 1, j] == cells[i, j - 1]:
                        if cells[i, j] < 2 * cells[i + 1, j]:
                            buf[i, j] = cells[i + 1, j]
                        else:
                            buf[i, j] = cells[i, j]
                    else:
                        buf[i, j] = max(cells[i, j],
                                        cells[i + 1, j], cells[i, j - 1])

                elif i == cells.shape[0] - 2 and j == 1:
                    if cells[i - 1, j] == cells[i, j + 1]:
                        if cells[i, j] < 2 * cells[i - 1, j]:
                            buf[i, j] = cells[i - 1, j]
                        else:
                            buf[i, j] = cells[i, j]
                    else:
                        buf[i, j] = max(cells[i, j],
                                        cells[i - 1, j], cells[i, j + 1])

                elif i == cells.shape[0] - 2 and j == cells.shape[1] - 2:
                    if cells[i - 1, j] == cells[i, j - 1]:
                        if cells[i, j] < 2 * cells[i - 1, j]:
                            buf[i, j] = cells[i - 1, j]
                        else:
                            buf[i, j] = cells[i, j]
                    else:
                        buf[i, j] = max(cells[i, j],
                                        cells[i - 1, j], cells[i, j - 1])

                elif i == 1 and 1 < j < cells.shape[1] - 2:
                    dic = {}
                    if cells[i, j - 1] in dic.keys():
                        dic[cells[i, j - 1]] += 1
                    else:
                        dic[cells[i, j - 1]] = 1
```

```
            if cells[i, j + 1] in dic.keys():
                dic[cells[i, j + 1]] += 1
            else:
                dic[cells[i, j + 1]] = 1

            if cells[i + 1, j] in dic.keys():
                dic[cells[i + 1, j]] += 1
            else:
                dic[cells[i + 1, j]] = 1

            if cells[i, j] in dic.keys():
                dic[cells[i, j]] += 1
            else:
                dic[cells[i, j]] = 1

            for key in dic.keys():
                if buf[i, j] < key * dic[key]:
                    buf[i, j] = key

        elif i == cells.shape[0] - 2 and\
                1 < j < cells.shape[1] - 2:
            dic = {}
            if cells[i, j - 1] in dic.keys():
                dic[cells[i, j - 1]] += 1
            else:
                dic[cells[i, j - 1]] = 1

            if cells[i, j + 1] in dic.keys():
                dic[cells[i, j + 1]] += 1
            else:
                dic[cells[i, j + 1]] = 1

            if cells[i - 1, j] in dic.keys():
                dic[cells[i - 1, j]] += 1
            else:
                dic[cells[i - 1, j]] = 1

            if cells[i, j] in dic.keys():
                dic[cells[i, j]] += 1
            else:
                dic[cells[i, j]] = 1

            for key in dic.keys():
                if buf[i, j] < key * dic[key]:
                    buf[i, j] = key

        elif 1 < i < cells.shape[0] - 2 and j == 1:
            dic = {}
            if cells[i - 1, j] in dic.keys():
                dic[cells[i - 1, j]] += 1
            else:
                dic[cells[i - 1, j]] = 1

            if cells[i + 1, j] in dic.keys():
                dic[cells[i + 1, j]] += 1
            else:
                dic[cells[i + 1, j]] = 1
```

```
            if cells[i, j + 1] in dic.keys():
                dic[cells[i, j + 1]] += 1
            else:
                dic[cells[i, j + 1]] = 1

            if cells[i, j] in dic.keys():
                dic[cells[i, j]] += 1
            else:
                dic[cells[i, j]] = 1

            for key in dic.keys():
                if buf[i, j] < key * dic[key]:
                    buf[i, j] = key

        elif 1 < i < cells.shape[0] - 2 and\
                j == cells.shape[1] - 2:
            dic = {}
            if cells[i - 1, j] in dic.keys():
                dic[cells[i - 1, j]] += 1
            else:
                dic[cells[i - 1, j]] = 1

            if cells[i + 1, j] in dic.keys():
                dic[cells[i + 1, j]] += 1
            else:
                dic[cells[i + 1, j]] = 1

            if cells[i, j - 1] in dic.keys():
                dic[cells[i, j - 1]] += 1
            else:
                dic[cells[i, j - 1]] = 1

            if cells[i, j] in dic.keys():
                dic[cells[i, j]] += 1
            else:
                dic[cells[i, j]] = 1

            for key in dic.keys():
                if buf[i, j] < key * dic[key]:
                    buf[i, j] = key

        else:
            dic = {}
            if cells[i - 1, j] in dic.keys():
                dic[cells[i - 1, j]] += 1
            else:
                dic[cells[i - 1, j]] = 1

            if cells[i + 1, j] in dic.keys():
                dic[cells[i + 1, j]] += 1
            else:
                dic[cells[i + 1, j]] = 1

            if cells[i, j - 1] in dic.keys():
                dic[cells[i, j - 1]] += 1
            else:
                dic[cells[i, j - 1]] = 1
```

```
                if cells[i, j + 1] in dic.keys():
                    dic[cells[i, j + 1]] += 1
                else:
                    dic[cells[i, j + 1]] = 1

                if cells[i, j] in dic.keys():
                    dic[cells[i, j]] += 1
                else:
                    dic[cells[i, j]] = 1

                for key in dic.keys():
                    if buf[i, j] < key * dic[key]:
                        buf[i, j] = key

        self.cells = buf
        print(buf)
        self.timer += 1

    def plot_state(self):
        """Draw a graph of the current state"""
        plt.title('Iter :{}'.format(self.timer))
        plt.imshow(self.cells)
        plt.show()

    def update_and_plot(self, n_iter):
        """
        Parameters
        ----------
        n_iter: Number of updated rounds
        """
        plt.ion()
        for _ in range(n_iter):
            plt.title('Iter :{}'.format(self.timer))
            plt.xlim(0, self.cells.shape[0])
            plt.ylim(0, self.cells.shape[1])
            plt.imshow(self.cells)
            self.update_state()
            plt.pause(0.1)
        plt.ioff()


if __name__ == '__main__':
    fungi_data = [[('blue', 0.62), [(2, 3), (2, 4)]],
                  [('green', 0.57), [(27, 27), (25, 27)]]]
    game = GameOfLife(cells_shape=(30, 30), fungi_data=fungi_data)
    game.update_and_plot(200)
```