Prediction of the growth of fungal communities in different environments: A GomPertz model approach

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Abstract. The growth of fungal community is closely related to the environment. In order to study the effect of environmental change on fungi community, we first assume that global warming is the main trend of atmospheric change and assess the impact of this trend with Winters method and ARIMA model. Next, we improve the GomPertz model by considering temperature and humidity to formulate a fungus-environment model. Finally, we predict the evaluation trend of fungi communities and verify the above model in three different environments: ranging from arid to tropical rain forest. It can be concluded that in long-term, temperature has greater influence on the growth of fungi than humidity, which can somehow compensate for the lack of humidity. Therefore, fungi with better temperature tolerance will have relative advantage in the population.

Keywords: Winters method, ARIMA model, Fungi - environmental model

1. Introduction
The carbon cycle restricts the formation, development and changes of life and the environment, such as element migration, climate regulation, geological changes, human health, etc. It is currently a hot topic in the world and the frontier of earth ecology. Among them, fungi play an irreplaceable role in the decomposition of ground litter and wood fiber, and are an important part of the carbon cycle. Therefore, understanding the growth of fungi and analyzing its influencing factors play an important role in studying the natural material cycle and promoting economic development.

Fig 1. The role of fungi in carbon cycle
According to the research, the growth of fungi is greatly affected by the environment, especially the humidity and temperature. In order to study the effect of environmental change on fungi community, we set up climate prediction model and fungus environment model, and give three kinds of environment: semi-arid, temperate and tropical rain forest. On this basis, we analyze the development of fungus community in different environments.

2. Mathematical model

2.1 Fungi-environment growth model

In the long-term growth of fungal populations, we refer to the experimental conditions set in Analysis of temporal fungal growth dynamics under different environmental conditions to establish a model of fungal growth under specific environmental conditions. In this experiment, only two influence factors of temperature and humidity are set: temperature (15, 20, 25 and 30 °C) and relative humidity (RH) conditions (65, 70, 75 and 80% RH), There are a total of 16 combinations of different environmental conditions.

It can be seen from the experimental results that temperature and humidity have a compound effect on the population of fungi. That is, at the same temperature, different humidity can cause changes in the number of fungal populations; under the same humidity, different temperatures have different effects on the growth of fungi. When they act together on the fungus population, the change in the number of fungi is greatly affected by the dominant factors. Assuming the effects of the long-term population changes of all kinds of fungi under the two factors of temperature and humidity, use a sigmoid-like function that introduces the influence factors corresponding to the two key factors of temperature and humidity to approximate.

The growth function of fungi is:

$$e^{\alpha e^{-\beta t}} + e^{-\gamma t}$$

(1)

Where $x$ is the time, and $\alpha, \beta, \gamma$ are the corresponding parameters. Considering that the commonly used microbial population growth model, the Gompertz formula, is $ae^{-e^{-(\beta t)}}$, combined with the above two formulas, assuming that the growth formula of fungi under the influence of temperature and humidity is:

$$\frac{1}{1+e^{-\alpha e^{-\beta t}} + e^{-\gamma t}}$$

(2)

Where $x$ is time, $\alpha$ is the temperature influence factor, and $\beta$ is the humidity influence factors, which can be obtained separately by substituting the existing experimental data and performing fitting.

2.2 Climate prediction model

In fact, global warming is the most obvious global atmospheric change in recent years. Temperature and humidity changes around the world are deeply affected by it. Therefore, we need to build models to predict the changes of temperature and humidity.

Firstly, we predict the temperature with Winters method. Winters method is a forecasting method that decomposes time series with linear trends, seasonal changes and irregular changes, and combines them with exponential smoothing. The basic components of Winters method are three smoothing equations. Each equation will smooth one of the three time-series-related factors (linear trend, seasonal change, irregular change) to eliminate the noise influence of occasional fluctuations on the results. The recursive function of the three smoothing equations are as follows:

$$a_t = \alpha \left( \frac{Y_t}{F_{t-1}} \right) + (1 - \alpha)(a_{t-1} + b_{t-1})$$

(3)

$$b_t = \beta (a_t - a_{t-1}) + (1 - \beta)b_{t-1}$$

(4)

$$F_t = \gamma \left( \frac{Y_t}{a_t} \right) + (1 - \gamma)F_{t-L}$$

(5)

In which $Y_t$ is the actual value of the $t_{th}$ time series, $L$ is the length of the season, $a_t$ is the
exponential smoothing value of the \( t_{th} \) long-term trend after excluding seasonal changes from the
time series, \( b_t \) is the exponential smoothing of the \( t_{th} \) long-term trend variable, \( F_t \) is the
exponentially smoothed value of the seasonal ratio of the \( t_{th} \) seasonal change period \( L \). \( \alpha, \beta, \gamma \) are
the smoothing coefficient (all in the interval \([0,1]\)). The recursive calculation sequence of the above
three smoothing equations is (1), (2), (3). Before recursive calculation, the initial value must be
determined first. The formula for determining the initial value is:

\[
a_{l+1} = Y_{l+1} \\
h_{L+1} = [(Y_{L+1} - Y_{1}) + (Y_{L+2} - Y_{2}) + (Y_{L+3} - Y_{3})] / 3L \\
\bar{Y} = \left( \sum_{i=1}^{L} Y_{i} \right) / (L+1) \\
F_{i} = Y_{i} / \bar{Y}
\]

The initial value formula calculation sequence is (4), (5), (6), (7). In actual application, the initial
value is calculated first, and then substituted into the recursive formula. According to the recursive
formula, and are initially calculated to provide data for the next prediction.

The formula of prediction model is shown as follows:

\[
Y_{t+k} = (a_t + kb_t)F_{t-L+k}
\]

In which, \( Y_{t+k} \) is the prediction value of \( t + k \) time series, where \( k \geq 1 \), \( t = n \times L \), \( n \) is
number of year.

For the prediction of humidity or precipitation, the ARIMA (Autoregressive Integrated Moving
Average model) model is employed. The usual steps are: (1) Perform zero-mean smoothing on the
time series. (2) Start to gradually increase the order of the model, and fit the ARMA(n, n-1) model.
The model parameters are estimated by the nonlinear least square method, and the specific algorithm
is the steepest descent method. Select the model corresponding to the smallest variance of the residual
sequence as the primary model. (3) Model adaptability test. (4) Seek the optimal model. (5) Deformed
time series forecasting. The known humidity data is successively substituted into the construction
model, and finally the predicted value is obtained.

2.3 Evolution of fungi population in different environments

According to the above climate prediction model, the climate change in different regions was
predicted, and the data was put into the fungus-environment model to analyze the fungi in different
environments. We predict three different climates: semi-arid, temperate and tropical rain forest, and
select a typical city for each area. Only focus on the changes of temperature and humidity. Now given
the average temperature and average precipitation of each area.

![Fig 2. Distribution of arid and semi-arid regions in the world](image-url)
2.3.1 Semi-arid. Semi-arid areas generally refer to climate types where the annual average precipitation is about 350mm~500mm. Its main distribution areas are as shown in Fig 2. This article selects Nur-Sultan in Kazakhstan as typical semi-arid regions. Nur-Sultan has a temperate continental climate, with hot and humid summers, cold and dry winters, and large temperature differences throughout the year; it is located in the semi-desert grassland in north-central Kazakhstan, with low vegetation coverage. The known climate data and predicted climate change data are as follows:

From this, the growth rule of the fungi in the semi-arid area as follows:
\[
\alpha : 1.5592 \\
\beta : 0.671
\]

2.3.2 Temperate. The temperate climate is complex and changeable, mainly including temperate monsoon climate, temperate continental monsoon climate, temperate oceanic climate, subtropical monsoon climate and Mediterranean climate. Due to limited space, this article only discusses the temperate monsoon climate. We choose Beijing as a typical area. Located in this area, it have three distinct seasons throughout the year. The summer is hot and rainy, and the winter is colder and dry; the forest coverage rate is about 44%, mainly deciduous broad-leaved forests and coniferous broad-leaved forests Mixed forest.
From this, the growth rule of the fungi in the temperate zone as follows:

\[
\begin{align*}
\alpha & : 11.9191 \\
\beta & : 0.566
\end{align*}
\]

2.3.3 Tropical rain forest. Tropical rain forest is a forest ecosystem located in tropical areas near the equator. This article selects the Brazilian city of Manaus, the "Heart of the Amazon" as a typical example. In the deep Amazon rainforest hinterland of Manaus, the vegetation coverage rate is very high, where fungi get more nutrients. It is hot, humid and rainy all year round, with an average annual temperature of about 27°C, with small monthly changes in temperature; the total annual precipitation is about 2,300 mm, and it is divided into two seasons, dry and rainy. Rainfall is frequent throughout the year. Although it is near the equator, the sunshine time is short, so the air humidity is the highest. The actual and predicted values of temperature of tropical rain forest are shown below.
Because there is no available humidity data of tropical rain forests, so the humidity prediction is omitted. According to predicted temperature, we set $\alpha$ as 26.8583, as for humidity, we set $\beta$ as 0.95 according to the literature. The corresponding growth rate prediction of fungi in tropical rain forests is shown below.

![Growth prediction of tropical rain forests](image)

**Fig 8.** Growth prediction of tropical rain forests

### 3. Conclusion
To investigate the environmental effect on woody fibers decomposing by fungi, we firstly assess the impact of this trend on climate with Winters method and ARIMA model, then we improve the Gompertz model by considering temperature and humidity to formulate a fungus-environment model. Finally, we evaluate our model in three different environments ranged from arid to tropical rain forest.

The results show that the larger the value of the ordinate, the more suitable the environment is for the growth of fungi. As can be seen from the above figure, the decisive effect of temperature on fungal growth is greater than humidity. When the temperature is not suitable, even higher humidity cannot make up for the disadvantage of growth. However, when the temperature is sufficient, the lack of humidity can be compensated to a certain extent.

Therefore, in the case of different external environments, strains with better temperature tolerance will have an advantage in growth in different geographical environments. The humidity resistance, the influence on the growth of fungi, is after the temperature tolerance. Therefore, in the long-term growth process, fungi with higher temperature tolerance are the relatively dominant species.

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