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Study on the Distribution Pattern of Suitable Areas for Rice Blast in China under Different Climate Scenarios

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Abstract: *Rice blast can seriously reduce the yield and quality of rice. Studying the identification of suitable habitats for rice blast can provide scientific advice and theoretical basis for blast control planning, reduce control inputs, and increase control efficiency. This study takes China's rice planting areas as the research area and constructs a model for identifying suitable habitats for rice blast based on SCP. The months of April to October, during which rice is mainly planted and harvested, were selected as the research period. Temperature, humidity, sunshine duration, and landform type, which have the greatest impact on the suitability of rice blast, were used as variables of climate and environmental factors. The distribution patterns of suitable habitats for rice blast in different months in the near and future time periods under the three climate scenarios of ssp119, ssp245, and ssp585 were studied. The results show that: (1) From April to July, the high-suitability areas for rice blast gradually migrated northward from the southeastern Guangxi-Guangdong border region. In May and June, the southern Hunan and Guangxi-Guangdong border areas, most of Jiangxi, and southern Hubei were high-suitability areas for rice blast. In July and August, the high-suitability areas for rice blast reached the Jianghuai Region, and in September and October, the high-suitability areas migrated southwestward, with the Sichuan Basin also becoming a high-suitability area for rice blast. (2) Under the three climate scenarios, the distribution patterns of suitable habitats for rice blast in the near-term time period were similar. Among them, the high-suitability areas for rice blast gradually shifted northward under the ssp245 and ssp585 climate scenarios. Compared with the near-term time period, the high-suitability areas for rice blast gradually migrated northward in the future time period, and under the ssp585 climate scenario in the future time period, the Northeast Plain of Heilongjiang became a high-suitability area for rice blast in July. In summary, the rice blast suitable habitat identification model constructed in this study can not only identify the distribution patterns of suitable habitats for rice blast in different months but also study the distribution patterns of suitable habitats for rice blast in the near and future under different climate scenarios. This can guide the planning and timing of rice blast control efforts under changing climate conditions, reduce human and material inputs, and increase net income from rice production.*

Keywords: *Rice blast, Rice blast control, SCP, Climate scenario, Climatic environmental factors*

1. Introduction

Rice blast is a widely prevalent and highly damaging fungal disease worldwide. The optimal temperature range for mycelial growth of this disease is 25-28°C, while spore formation requires a temperature maintained at 26-28°C and relative humidity above 90%[1]. It is especially severe in areas with less sunlight, prolonged periods of fog and dew, mountainous regions, as well as along rivers and coastal areas with temperate climates[2]. The impact of rice blast on rice production is extremely significant. In severely affected areas, rice production is typically reduced by 10%-20%, and in more severe regions, the reduction can even reach 40%-50%, leading to complete crop failure in some areas. According to statistics from national plant protection surveys, the occurrence area of rice blast in China continues to grow. Over the 15-year period since 2001, the annual average occurrence area of rice blast in China has stabilized at approximately 4.7×10^7 hm², with 2005 being the most severe year, with an occurrence area of 5.82×10^7 hm², resulting in a loss of 6.34×10^5 t of rice[3]. Rice blast not only causes yield reductions in rice, but also negatively affects the quality, appearance, and shelf life of the grain, leading to a decline in quality, deterioration in appearance, and shortened shelf life[4]. Therefore, the

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prevention and control of rice blast is particularly important and urgent.

The prevention and control strategies for early rice blast mainly include scientific fertilization and soil management, regulation of plant density, regular inspection, and proper watering and irrigation management[5]. Among them, scientific fertilization and soil management aim to enhance the resistance of rice to rice blast and promote the overall health of plants. By maintaining soil ventilation, permeability, and good drainage, excessive moisture in rice roots can be prevented, effectively reducing the breeding environment for diseases. At the same time, regulating plant density can optimize ventilation between plants, reduce humidity, and thus slow down the spread of the disease. Additionally, reasonable plant density also helps to improve the lighting conditions of plants and promote their healthy growth. Scientific and reasonable watering management is a key link to ensure healthy growth of rice. By watering at the right time, the spread of pathogens between plants can be slowed down, thereby reducing the probability of rice blast occurrence[2]. With the progress of science and technology, significant achievements have been made in disease-resistant breeding. Many scientific research and production units have successfully bred rice varieties with strong disease resistance, and the application of these varieties has significantly reduced the losses caused by rice blast[6]. However, it should be noted that while the above methods can help create an environment unfavorable for the occurrence of rice blast, they still require a significant amount of manpower and material resources. At the same time, these methods cannot completely eliminate rice blast or reduce its infectivity.

The spraying of chemical agents is an important method for controlling rice blast. In cases of disease outbreak or severity, spraying chemical agents is the most effective means of prevention and control. Selecting effective agents against rice blast and spraying them at the appropriate growth stage can help reduce the occurrence probability of the disease and ensure rice production. However, some grain growers, in order to ensure production, may spray large amounts of pesticides in advance for rice blast prevention. The abuse of chemical agents may have adverse effects on the environment, disrupting the balance of surrounding ecosystems, and the chemicals remaining in agricultural products may pose risks to human health[7].

In recent years, disciplines such as botany, microbiology, geography, and mathematics have increasingly intersected, and microbial ecology has received increasing attention from scholars. Some scholars have been able to identify high-suitability areas for microorganisms by constructing microbial ecological models, providing scientific guidance for microbial control[8]. Therefore, taking China's rice planting areas as the research region and using temperature, humidity, daily sunshine hours, and terrain as variables, we constructed a model for identifying suitable habitats for rice blast based on the Scenario Conservation Planning (SCP) approach[9]. This model identifies the distribution patterns of high-suitability areas for rice planting during different months under three climate scenarios (ssp119, ssp245, and ssp585)[10]. Our aim is to provide scientific guidance for rice blast prevention and control, reduce the consumption of human and material resources, increase prevention and control efficiency, lower the amount of chemical pesticides sprayed, and improve the quality of rice.

2. Materials and Methods

2.1 Materials

2.1.1 Overview of the Study Area

The research area of this study is the rice planting regions in China, which are divided into six major rice-growing areas, namely North China, Northeast China, Northwest China, Central China, South China, and Southwest China, covering 28 provinces (Table 1)[11]. According to the distribution map of rice planting regions (Figure 1), rice planting regions are mainly distributed in Central and South China, followed by Northeast China. From the perspective of the terrain map, most rice planting regions in China are located in hills and mountainous areas, while only some rice planting regions in Jianghuai Region and Northeast China are located in plain areas.

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Table 1: China's six major rice-growing areas and rice production status

Name of rice-growing area	Regional name	Production Status of Rice
North of China	Tianjin, Hebei, Shaanxi, Shanxi, Shandong, and Henan	The cropping system is two crops per year in summer and autumn, with single-season rice as the main crop
Northeast of China	Heilongjiang, Jilin, Liaoning	Harvested once a year, it is dominated by single-season Japonica rice
Northwest of China	Ningxia, Gansu, Xinjiang, and Inner Mongolia	One crop per year, planting single-season Japonica rice
Central of China	Shanghai, Jiangsu, Zhejiang, Anhui, Hubei, Hunan, Jiangxi, Sichuan, Chongqing	Dominated by double-cropping rice
South of China	Fujian, Guangdong, Guangxi, and Hainan	Focusing mainly on double-cropping rice, the crop type is predominantly japonica rice
Southwest of China	Guizhou and Yunnan	It mainly consists of single-cropping indica rice

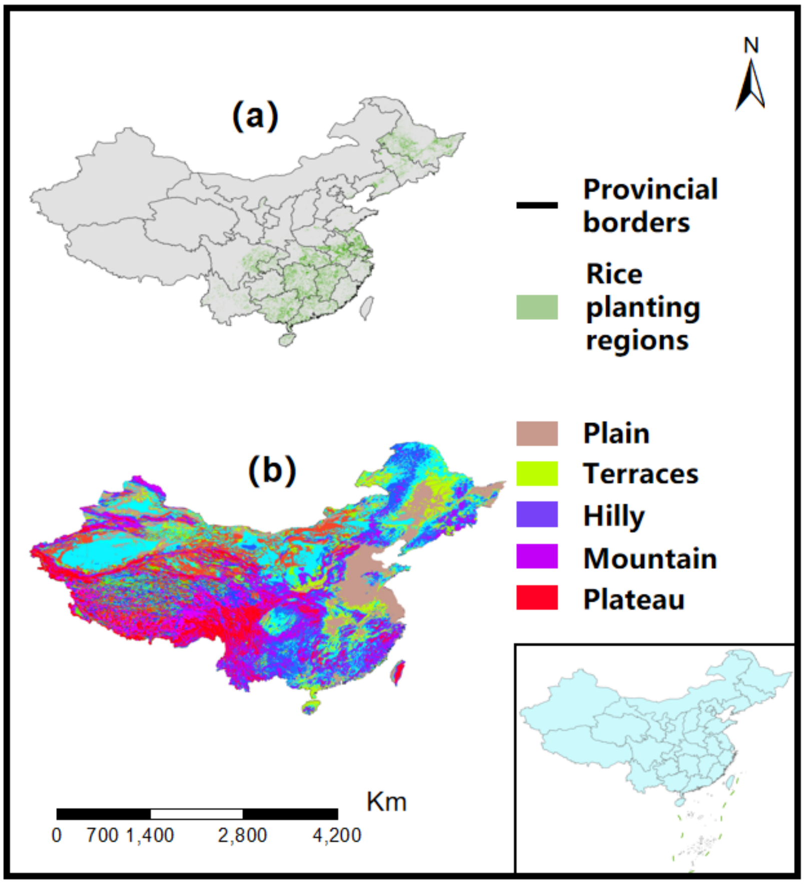

Figure 1: Overview of the study area, including (a) the distribution map of rice planting areas and (b) the geomorphic types map of China's terrestrial regions

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2.1.2 Data Sources

The activity of rice blast is mainly affected by climatic and environmental factors such as temperature, humidity, sunshine duration, and terrain (Table 2). Therefore, this study uses these four influencing factors as input variable data for the model. Among them, temperature data comes from the monthly average temperature dataset with a resolution of 1 km in China from 2021 to 2100 under multiple scenarios and models[12], humidity data comes from site data from the National Meteorological Science Data Center, daily sunshine duration data comes from the site data of the Resource Science Innovation Platform, and geomorphic type data comes from the 1:4 million digital geomorphic dataset of China[13].

Table 2: Definitions and Descriptions of Different Variables

Variable number	Definition of Variables	Instructions
1	Temperature	Mean monthly temperature
2	Humidity	Mean humidity of each month
3	Duration of sunshine	Average daily sunshine duration in each month
4	Landform	The various states of elevation and depression collectively presented by fixed objects distributed above the surface of the earth

2.2 Methods

2.2.1 Climate Scenario Setting

To comprehensively investigate the distribution pattern of suitable habitats for rice blast, this study incorporates considerations of various climate scenarios. Among them, the Scenario Model Intercomparison Project (ScenarioMIP), as a core subproject of the sixth phase of the Coupled Model Intercomparison Project (CMIP6), plays a pivotal role[14]. This subproject designs a series of new scenario prediction experiments targeting anthropogenic emissions and land use changes that may arise from potential energy structure transformations under different shared socio-economic pathways, providing valuable data support for further exploring the mechanisms of future climate change, mitigation, and adaptation strategies.

In this study, we carefully selected three representative climate scenarios, namely ssp119, ssp245, and ssp585, for in-depth analysis. Among them, ssp119 represents a low-forcing scenario, characterized by a stabilization of radiative forcing at 1.9 W/m^2 by 2100. ssp245 is a medium-forcing scenario, with a projected stabilization of radiative forcing at 4.5 W/m^2 by 2100. ssp585, on the other hand, belongs to the high-forcing scenario, with a projected radiative forcing of 8.5 W/m^2 by 2100[15].

By introducing these climate scenarios of different intensities, we can more accurately predict and assess the impact of future climate change on the distribution pattern of rice blast-prone areas, thus providing more scientific and comprehensive basis for decision-making and risk management in related fields.

2.2.2 Data Preprocessing

The data of humidity and hours of light exposure used in this study are presented in a tabular format, documenting the longitude and latitude of each observation site along with the observed data. However, the model employed in this research cannot directly accept tabular data as input. Therefore, we imported the tabular data into ArcGIS and employed the Kriging interpolation method to generate raster data for humidity and hours of light exposure. Compared to other interpolation techniques, the Kriging method exhibits significant advantages during the data gridding process. It places a particular emphasis on describing the spatial correlation properties of the objects, thereby enabling the generation of more scientific and realistic interpolation results. The core formula of the Kriging interpolation method is as follows:

$$\hat{z}_o = \sum_{i=1}^{n} \lambda_i z_i \tag{1}$$

Where $\hat{z}_o$ is the estimated value at point (x_0,y_0), i.e., $z_o=z(x_0,y_0)$. Here, λ_i represents the weight coefficient. It also estimates the value of an unknown point by weighted summation of data from all known points in the space. However, the weight coefficient is not the reciprocal of the distance but a set of optimal coefficients that minimize the difference between the estimated value $\hat{z}_o$ and the true value z_o at (x_0,y_0).

$$\min_{\lambda_i}\mathrm{Var}(\hat{z}_o - z_o) \tag{2}$$

2.2.3 Setting of variable weights

In the model constructed in this study, the weights of variables affect the order of removing cells from the landscape and the proportion of species distribution retained at any location during the process of unit removal. Therefore, when using the model to determine the distribution of suitable habitats for rice blast, we need to set corresponding weight values for each variable. In this study, we used the Analytic Hierarchy Process (AHP)[16] to analyze multiple related articles[17-22], identify the main climatic environmental factors suitable for rice blast, and assign the most reasonable weight values to four different variables. The weights are shown in Table 3.

Table 3: Weight Values of Different Variables

Scale	Significance
1	Indicate that the two elements are equally important
2	Indicate that the element in front is slightly more important than the element behind
5	Indicating that the preceding element is significantly more important than the subsequent element
7	It is extremely important to indicate that the previous element is more important than the subsequent element.
9	Indicating that the previous element is strongly more important than the subsequent element
2,4,6,8	Between the intermediate values of the above adjacent judgments

2.2.4 Model Construction

In this study, we employed the SCP method to construct a model for identifying suitable areas for rice blast disease, aiming to identify regions with high suitability for the disease. SCP generates landscape protection levels driven by complementarity through an iterative process. Initially, the model assumes that the entire landscape is protected, and then gradually identifies and removes units with the smallest marginal loss, reserving areas with the highest protection value until the end, resulting in a theoretical spatial priority protection pattern for multiple species[23]. Therefore, most ecological models constructed based on SCP are primarily applied to biodiversity conservation planning. In contrast to traditional research approaches, this study adopted a reverse thinking by generating a landscape sequence of rice blast suitability through an iterative process to identify high-suitability areas for rice blast, providing scientific guidance for the prevention and control of rice blast. The SCP is described as follows:

$$\delta_i = \max_j \frac{q_{ij} w_j}{c_i} \tag{3}$$

In the formula, w_j represents the weight of variable j, while c_i represents the cost of adding cell i to the reserve network.

The calculation of marginal loss values for cells in SCP depends on the marginal loss rules used. Essentially, loss rules define how variable values are combined into a single cell-specific value that describes the overall loss resulting from the removal of that cell. Among the most commonly used rules are Core Area Zonation (CAZ) and Additive Benefit Function (ABF). In contrast, ABF minimizes cumulative extinction risks and implicitly assigns higher priority to cells with rich species diversity, as they can contribute to multiple species simultaneously, making them more suitable for application in multi-species conservation planning[24]. However, the objective of this study is the prevention and control planning for rice blast disease, therefore, the CAZ loss rule is selected. Specifically, it is expressed as follows:

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$$M_i = \left(\sum_{i=1}^{n} \left|w_j r_{ij}\right|^p\right)^{\frac{1}{p}} \quad (4)$$

In the formula, r_{ij} represents the fractional residual occurrence of variable j in cell i, w_j is the weight of variable j, and p-norm is a generalized mathematical expression for the length of a (multi-dimensional) vector, which has many other applications. In this research model, p-norm is used to calculate the marginal loss of the grid. Different versions of CAZ have different p-norm values. The CAZ version used in this study is CAZ1, where the p-norm value is 1[25].

3. Results and Analysis

3.1 Kriging interpolation results of humidity and sunshine duration

According to the results of the hours of sunshine (Figure 2), it can be seen that the southeast region has relatively shorter hours of sunshine, while the hours of sunshine in the northern region are significantly higher than in the southern region. The hours of sunshine in the Sichuan Basin are lower than those in its surrounding areas. From April to June, the hours of sunshine across the country increase with time, while from July to October, they decrease with time. In terms of humidity, the southeast region has higher humidity than other regions in the country, and the trend of humidity change with time is relatively small. The relative humidity in the northern regions such as North China and Northeast China is lower, but the trend of humidity change is larger, approaching the humidity level of the humid southeast region in August.

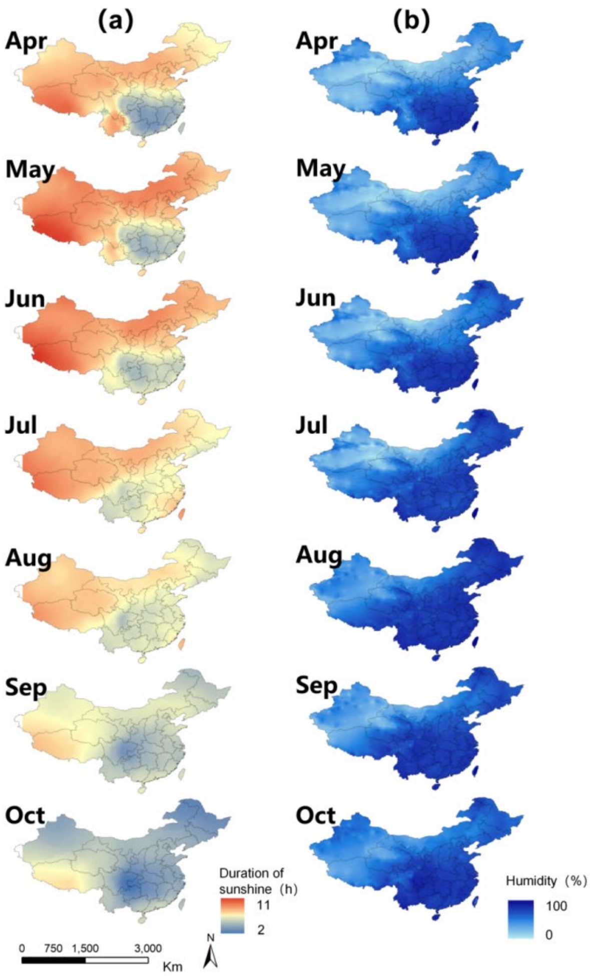

Figure 2: (a) is the Kriging interpolation result of daylight duration table data, and (b) is the Kriging interpolation result of humidity table data

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3.2 Results of Variable Weight Setting

As can be seen from the variable index (Table 4), temperature and humidity are significantly more important than sunshine duration and landforms in the contribution to the environmental suitability of rice blast. According to the results of the AHP hierarchical analysis (Table 5), the weight values of temperature and humidity are relatively large, accounting for 41.699% and 33.203% respectively, while the weight values of sunshine duration and landforms are smaller, accounting for 13.938% and 11.16% respectively. The maximum eigenvalue is 4.143, and the corresponding RI value is 0.882 according to the RI table. Therefore, CR=CI/RI=0.054<0.1, passing the one-time test.

Table 4: Variable Indices

Variables	temperature	Humidity	Duration of sunshine	Landform
Temperature	1	1	4	4
Humidity	1	1	3	2
Duration of sunshine	0.25	0.333	1	2
Landform	0.25	0.5	0.5	1

Table 5: AHP Hierarchical Analysis Results

Item	Feature vector	Weight value (%)	The largest eigenvalue	Consistency Index (CI)
Temperature	1.668	41.699	4.143	0.048
Humidity	1.328	33.203		
Duration of sunshine	0.558	13.938		
Landform	0.446	11.16		

3.3 Distribution Patterns of Suitable Regions for Rice Blast under Different Temporal and Climatic Scenarios

Based on the ssp119 climate scenario (Figure 3), the changes in the suitable habitats for rice blast disease between 2030 and 2050 are relatively minor. Specifically, in April, the high-suitability areas for rice blast disease are concentrated in the southeastern Guangxi and the border regions between Guangdong, followed by the southern Hunan and the border regions with Guangxi and Guangdong, as well as most of Jiangxi. As time passes, the high-suitability areas for rice blast disease gradually migrate northward in May, with northwestern Hunan becoming a suitable habitat, especially during the 2050 time period. The southern Hunan and the border regions with Guangxi and Guangdong, as well as most of Jiangxi, become high-suitability areas for rice blast disease. In June, the high-suitability areas for rice blast disease cover a larger area, including northwestern Hunan, the border region between southern Hubei and Hunan, most of Jiangxi, and the Jiang-Huai region. From July to September, the Jiang-Huai region remains a high-suitability area for rice blast disease, and in October, it migrates southwestward, with the Sichuan Basin also becoming a high-suitability area for the disease.

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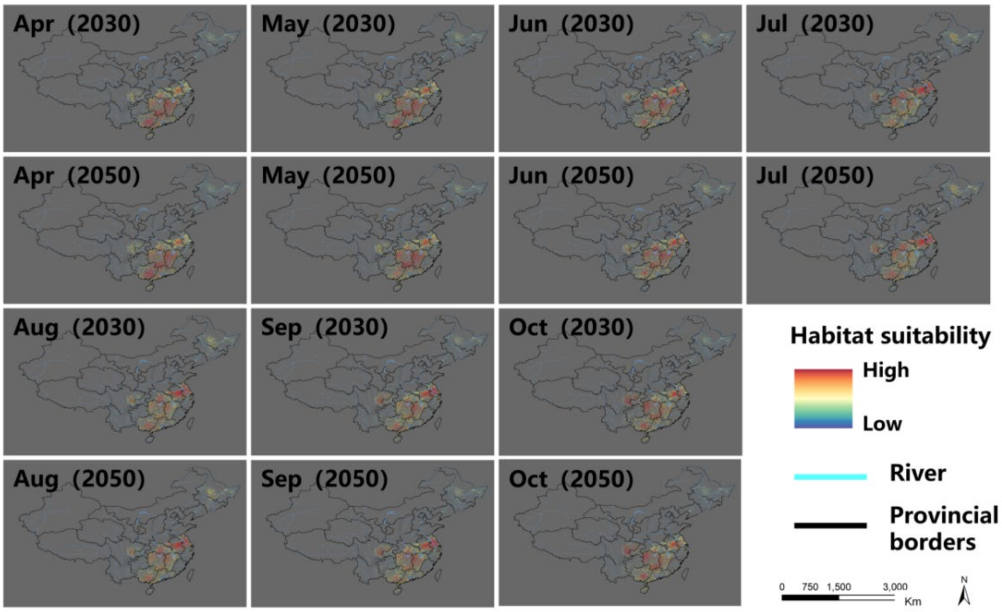

Figure 3: Distribution patterns of suitable habitats for rice blast in each month in the near future and the future under the climate scenario of ssp119

According to the ssp245 climate scenario (Figure 4), there is also not much difference between the suitable areas for rice blast in 2030 and 2050. Relatively speaking, the highly suitable areas for rice blast in 2050 are distributed closer to the north. Compared with the ssp119 climate scenario, there is not much difference in the distribution of highly suitable areas for rice blast from April to July. However, in August 2050, the southeastern part of Guangxi and the border region with Guangdong become highly suitable areas for rice blast, and the northeastern region also turns into a suitable area for rice blast. There is also not much difference between ssp119 and ssp245 in September and October.

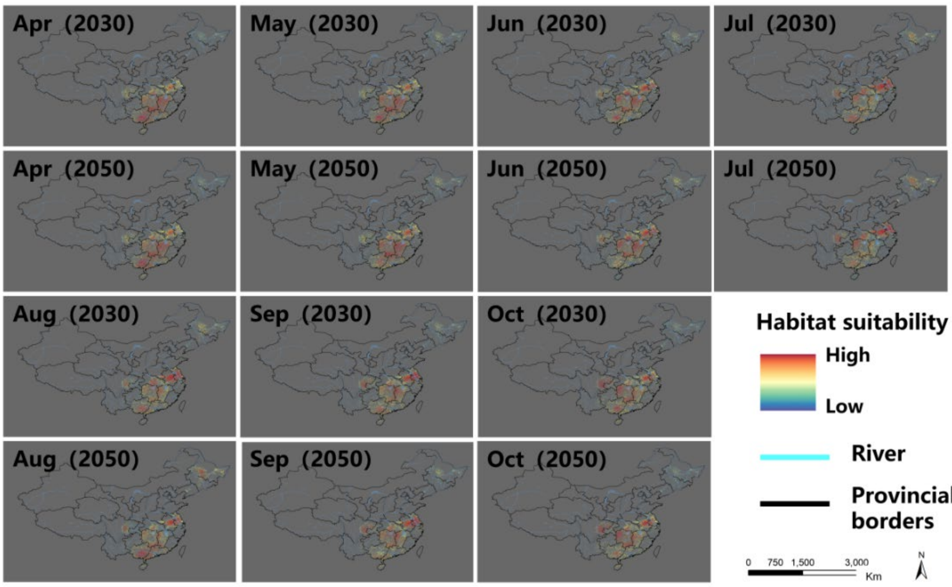

Figure 4: Distribution patterns of suitable habitats for rice blast in each month in the near future and in the future under the ssp245 climate scenario

Under the ssp585 climate scenario (Figure 5), the distribution of high-suitability areas for rice blast disease in the 2050 is closer to the north. Compared with ssp119 and ssp245, the northeastern region and Sichuan Basin also become high-suitability areas for rice blast disease in July of the 2050.

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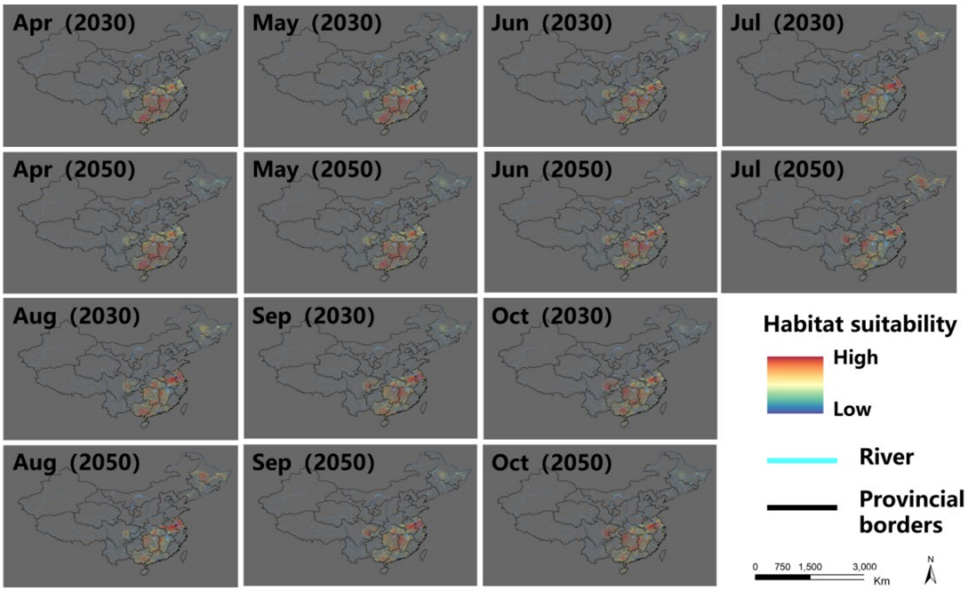

Figure 5: Distribution patterns of suitable habitats for rice blast in recent and future months under the ssp585 climate scenario

4. Discussion and Conclusion

4.1 Discussion

4.1.1 Reasons for changes in the distribution of suitable areas for rice blast disease

As can be seen from the results, the high-suitability areas for rice blast in April were mainly distributed in the southeastern part of Guangxi, bordering Guangdong. Guangxi is generally a mountainous and hilly basin landscape, and at this time, the temperature in Guangxi ranged from 25-28℃, and the humidity was above 90%, which was conducive to the survival of rice blast. Therefore, the high-suitability areas for rice blast in April were mainly distributed in these regions. As time progressed, the temperature gradually increased, and the temperature in the southeastern part of Guangxi, bordering Guangdong, gradually exceeded 28℃, which became unfavorable for the survival of rice blast. In May, the temperature in some areas of Jiangxi, Hunan, and Hubei reached between 25-28℃. Among them, the terrain in the northwest of Hunan was mainly mountainous, while the terrain in the southern part, bordering Guangxi and Guangdong, was mainly hilly and mountainous. The overall terrain of Jiangxi was dominated by hills and mountains. Therefore, these regions were high-suitability areas for rice blast in May. From June to September, the Jianghuai Region also reached the suitable temperature, and at this time, the region received heavy rainfall and had high humidity, which was very suitable for the survival of rice blast. In October, the Sichuan Basin reached the suitable temperature, and the average daily sunshine duration in the Sichuan Basin was relatively short, with high humidity, providing a good living environment for rice blast.

Under the ssp119 climate scenario, the distribution pattern of high-suitability areas for rice blast in 2050 does not differ significantly from that in 2030. This is because under the ssp119 climate scenario, the temperature increase in 2050 is relatively small and the probability of an increase is low, resulting in a minor impact on the suitable environment for rice blast. However, under the ssp245 and ssp585 climate scenarios, the temperature in 2050 is expected to increase significantly with a higher probability. Consequently, the high-suitability areas for rice blast gradually shift northward during this period, especially under the ssp585 climate scenario, where the northeastern region becomes a high-suitability area for rice blast in July 2050.

4.1.2 Suggestions for rice blast prevention and control planning

The planting time of early rice is relatively early, and the maturity time is also early. Generally, it is planted at the end of March and the beginning of April, with a growth period of about 90-120 days, and it is usually harvested in June-July. Medium rice is generally planted from early April to late May, with a growth period of about 120-150 days, and the harvest season is mid-to-late September. Late rice is

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generally planted in mid-to-late June, with a growth period of 150-170 days, and the harvest season is mid-to-early October. The rice cultivation in southern China is mainly double-cropping rice, mainly japonica rice. However, from April to June, the high-suitable areas for rice blast are concentrated in the southeastern Guangxi and Guangdong border areas, the southern Hunan and Guangxi and Guangdong border areas, and most areas of Jiangxi. Therefore, these areas can appropriately advance the planting time to avoid the high-suitable period for rice blast from April to June. Additionally, fertilization, soil management, and irrigation management should be properly carried out during this period to reduce the suitable conditions for rice blast. At the same time, inspection efforts should be increased, and chemical pesticides should be sprayed immediately upon discovering symptoms. In these areas, attention should be paid to water irrigation management during the yellow ripening stage of late rice in October to avoid excessive moisture in the field. In central China, double-cropping rice is also the main crop. The Jianghuai Region of Anhui and Jiangsu provinces is a high-suitable area for rice blast from June to September. The rainfall in the Jianghuai Region is heavy in June and July, so field drainage should be properly done. Similarly, inspection efforts should be increased during this period to prevent the spread of rice blast after infection. In September and October, the suitable areas for rice blast migrate southward, and Sichuan becomes a high-suitable area for rice blast. Therefore, Sichuan should increase the prevention and control efforts against rice blast during the milking and yellow ripening stages of late rice to avoid infection during the harvest stage.

Under the ssp119 climate scenario, the distribution pattern of rice blast suitable areas in 2050 is similar to that in 2030, therefore, the prevention and control planning can refer to the planning in 2030. Under the ssp245 and ssp585 climate scenarios with more significant temperature rises, Sichuan in central China and the northeastern region will become high-risk areas for rice blast in July 2050. It is necessary to strengthen the prevention and control efforts of rice blast to reduce its impact on crop yields.

4.2 Conclusion

The distribution patterns of rice blast-suitable areas vary in different months. In April, the high-suitability areas for rice blast are mainly distributed in the southern regions, where the temperature and humidity are suitable at this time. As time goes on, the national temperature gradually rises, and most areas in the south will have temperatures exceeding 28°C. The temperature in central China reaches a suitable level, and the high-suitability areas for rice blast also shift to central China. Under the SSP585 climate scenario with adverse conditions in the future, Sichuan and the northeast regions will become high-suitability areas for rice blast in July 2050.

The model developed in this study can identify the suitable areas for rice blast under different climate scenarios in 2030 and 2050, facilitating the analysis of changes in suitable areas for rice blast. This provides scientific guidance for the planning of rice blast prevention and control efforts, and is of great significance for reducing the cost of rice blast prevention and control and improving the efficiency of prevention and control work.

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