The 4th International Conference on Environmental Geoscience and Earth Ecology
DOI: 10.54254/2753-8818/2026.33786

Response and Prediction of Aedes Albopictus to Climate Change in China

Wu Li

School of Geography and Ocean Science, Nanjing University, Nanjing, China
18951858012@163.com

Abstract. Aedes albopictus is the main transmitter of many mosquito-borne diseases such as dengue fever. It shows a significant global invasion trend, and its distribution has been expanding northward and westward driven by factors such as climate change. Most existing domestic studies focus on distribution prediction, lack density assessment, and often ignore extreme climate and seasonal dynamics of larvae. This study integrates 804 pieces of larval density data, combines historical and CMIP6 future climate scenarios, and constructs a random forest model to predict monthly density and distribution from 2030 to 2090. The results show that longitude and latitude are the main influencing factors, and the extreme minimum temperature of the current month is the most critical meteorological variable. In the middle and late future, the density peak will lag from July to August, suitable habitats will expand to the northwest and northeast, and the peak density will increase by 21.2% under high emission scenarios. This study reveals that spatial patterns and extreme climate jointly drive population dynamics, which can provide a scientific basis for early warning, prevention and control of mosquito-borne disease risks under the background of climate warming.

Keywords: Aedes albopictus, mosquito, climate change

1. Introduction

Aedes albopictus is a vector that transmits many mosquito-borne infectious diseases to humans, such as dengue fever, chikungunya fever and Zika virus disease. It can also carry some new viruses such as Bamako virus, but its medical significance is not yet clear [1]. Besides virus transmission, its distribution range is also expanding. Many countries, especially middle and high latitude regions, have reported the first cases of Aedes albopictus and expressed concerns about the potential threats it may pose [2-5]. As an invasive species, Aedes albopictus has been found beyond its traditional geographical range (Asia and Africa) and is distributed on all continents except Antarctica [6]. Affected by global climate change, land use and socio-economic factors, it can colonize new geographical areas and participate in virus transmission under suitable climatic conditions [7]. Therefore, climate may lead to changes in the density and distribution of Aedes albopictus, which will eventually increase global public health risks.

Many researchers have devoted themselves to exploring the relationship between Aedes albopictus and climate change by the end of the 21st century. Bonnin et al. [8] pointed out that the density of Aedes albopictus may increase by 13%-21%, but will decrease significantly in low-altitude areas in summer. Lamy et al. [9] showed that temperature and precipitation have a combined effect on Aedes albopictus, and the density in low-altitude areas may be lower than that in other areas in Reunion. Gorris et al. [10] showed that the highly suitable habitats of Aedes albopictus increase the most in North and South America. Most studies show that its density and distribution generally show an upward trend worldwide. China provides an ideal research area because of its high density and wide distribution of Aedes albopictus [11]. It is commonly found in subtropical and temperate regions of China, but has recently exceeded its traditional range, extending northward to Northeast China at the China-Russia border and westward to the Qinghai-Tibet Plateau [12, 13]. In addition, niche models predict that the distribution of Aedes albopictus will be wider in the next few decades and pose a greater threat to humans. Suitable habitats within the traditional distribution range may increase, and new habitats may also form in Northwest China [14, 15]. Therefore, the distribution area of Aedes albopictus in China will further expand and tend to migrate to high latitudes, which is consistent with the global pattern.

However, these research findings in China are not comprehensive. First, they only predict the distribution of Aedes albopictus rather than its density. To predict the potential distribution, mosquito data in previous studies are only geographically represented as "presence" or "absence", and combined with environmental factors to identify suitable habitats. However, areas where Aedes albopictus is "present" cannot reflect its abundance, which is not sufficient as a basis for threats to humans. As an invasive species, it may pose a direct and urgent threat to humans if it reaches a high density within a certain range [16]. In addition, previous studies have explored how temperature and precipitation limit the density and distribution of Aedes albopictus. However, new insights have emerged regarding the relationship between Aedes albopictus and climatic conditions. Studies have shown that mosquitoes are significantly affected by average temperature, precipitation, humidity, air pressure and wind speed, and they usually show a non-linear relationship based on current and previous climatic conditions [17-20]. In particular, mosquitoes may tolerate or survive extreme weather conditions such as heatwaves and typhoons [21, 22]. The frequency and intensity of extreme climate events are expected to increase, and it is limited to only focus on average climatic conditions [23]. In addition, most studies focus on annual changes rather than seasonal changes, usually emphasizing adult mosquitoes while ignoring larvae. Therefore, more meteorological parameters should be included to predict the density and distribution of Aedes albopictus.

It is necessary to update the density and distribution of Aedes albopictus in China under future climatic conditions. The data are trained, verified and predicted through a random forest model to obtain the monthly density and distribution of Aedes albopictus in 2030, 2050, 2070 and 2090. This helps to understand the potential density and distribution of Aedes albopictus in China in advance. This study is crucial for the early warning and control of the transmission and invasion of Aedes albopictus under future climatic conditions, thus helping to prevent mosquito-borne diseases. In addition, it also contributes to sustainable development, environmental protection and the promotion of human well-being.

2. Data and methods

2.1. Data preparation

Mosquito density data were obtained from Wang et al. [24]. The selected data were larval data of Aedes albopictus, and the mosquito collection method was the Breteau Index, expressed as a percentage (%). The latest supplementary data of this dataset were up to August 2024. Based on this,

this study referred to the literature search and data collection methods of Wang et al. [24], further supplemented the data to July 2025, and obtained a total of 804 data entries. Historical monthly meteorological data were obtained from the National Oceanic and Atmospheric Administration (NOAA) to establish the relationship between Aedes albopictus and meteorological factors. Future meteorological data were obtained from the BCC-CSM2-MR model based on the latest Coupled Model Intercomparison Project Phase 6 (CMIP6) dataset, enabling modeling under different Shared Socioeconomic Pathway scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5). Temperature, humidity, precipitation, air pressure and wind speed all affect the survival of mosquitoes. Multiple variables were selected to characterize the intensity of these factors and the impact of extreme climate events, as shown in Table 1. Units in the two databases were unified, and a small number of missing variables were obtained by interpolation. Meteorological scenarios were classified by the current month, the previous month and the month before last, which meant that Aedes albopictus density corresponded to 36 meteorological variables. Due to the spatial-temporal heterogeneity of mosquito density and distribution across China [24], monitoring site coordinates were included in the model to obtain more accurate prediction results. The standard map of China (Albers equal-area conic projection) was downloaded from the standard map service website as the base map for analysis.

Table 1. Main variables

Primary variables	Secondary variables	Units
Temperature	Average temperature	℃
	Average maximum temperature	℃
	Average minimum temperature	℃
	Extreme maximum temperature	℃
	Extreme minimum temperature	℃
Humidity	Relative Humidity	%
Precipitation	Cumulative precipitation	mm
	Maximum precipitation	mm
	Number of precipitating days	days
Wind speed	Average wind speed	m/s
	Average maximum sustained wind speed	m/s
	Daily maximum average wind speed	m/s
Coordinates	Longitude	°
	Latitude	°

2.2. Random forest

The random forest model is a non-parametric ensemble classification or regression technique that realizes prediction by averaging the results of multiple regression trees. This method has been widely recognized in forestry applications due to its robustness and modeling flexibility [25, 26]. Seventy percent of each random sample was used for model training and 30% for model testing. Since mosquito density monitoring was mainly concentrated in summer and autumn, it could not fully cover all months of future meteorological data [24], leading to the problem of missing values. This study innovatively utilized the dual functions of random forest. Firstly, its classification ability was used to deal with missing values in the data, that is, to analyze the conditions of presence or absence of mosquito distribution through all influencing factors. Secondly, regression between larval density of Aedes albopictus and influencing variables was established in areas where mosquitoes were distributed, and density prediction was carried out. All model performance indicators reported finally included OOB, MAE, RMSE and R^2.

3. Results

3.1. Model performance

In this study, the average OOB of the random forest model was 0.07, indicating that the classification model had high accuracy. The average MAE was 2.1 and the average RMSE was 3.3. Both values were low, meaning the gap between predicted values and actual values of the regression model was small. The average R^2 was 0.6, showing that the model had a high fitting degree.

As shown in Table 2, among meteorological variables, extreme minimum temperature in the current month ranked first with a factor contribution of 19.6, making it the most important meteorological variable affecting larval mosquito density. Humidity, precipitation and wind speed also had great impacts on the increase and decrease of density. Among important meteorological variables, density was mainly related to meteorological variables of the current month.

Table 2. Ranking of meteorological variable importance

Prioritization	Variables	Month	Factor Contribution
1	Extreme minimum temperature	Current month	19.6
2	Relative Humidity	Current month	17.5
3	Average temperature	Current month	15.8
4	Average minimum temperature	Current month	15.7
5	Cumulative precipitation	Previous month	10.3
6	Average maximum sustained wind speed	Previous month	10.2
7	Extreme maximum temperature	Current month	10.0
8	Average wind speed	Current month	9.7

3.2. Density and distribution

As shown in Figure 1, the maximum monthly average density of Aedes albopictus larvae usually appeared in July or August each year, with the maximum value ranging from 9.16% to 12.04%. The maximum values corresponded to the SSP126 scenario in July 2030 and the SSP370 scenario in August 2090 respectively. In terms of years, the monthly average larval density of Aedes albopictus in 2090 was generally high. The density trends under the four climate change scenarios in 2030 and 2050 were basically consistent, usually peaking in July of the same year. However, the average density peaks appeared in August under SSP126 and SSP370 scenarios in 2070. In 2090, except that the peak of SSP585 appeared in July, the peaks of other scenarios were all in August. The overall trend of density change increased first and then decreased, and mosquito density was usually high in summer and autumn. But in the middle and late 21st century, the density cycle showed an obvious one-month lag.

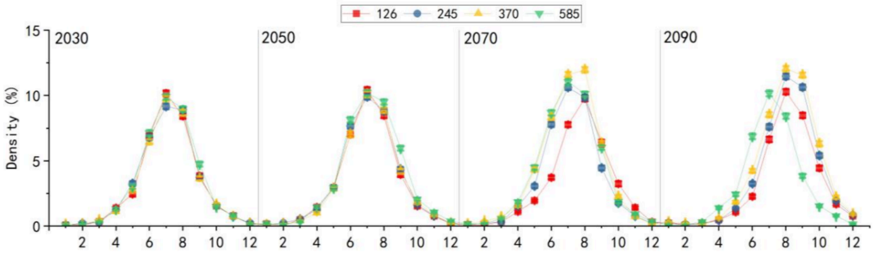

Figure 1. Average larval density of Aedes albopictus in China under four years and climate change scenarios

As shown in Figure 2, Aedes albopictus larvae were widely distributed in most areas of China except the Qinghai-Tibet Plateau. Under the same scenario, compared with 2030 and 2090, the distribution area of Aedes albopictus larvae expanded significantly at the end of the 21st century, especially in the northwest and northeast regions. Under the SSP126 scenario in 2030, the density peaked in July of that year (20.7%), and the density peaked in July under other scenarios. In 2090, the density peaks under all four scenarios were in August, with the maximum value of 21.2% under the SSP585 scenario.

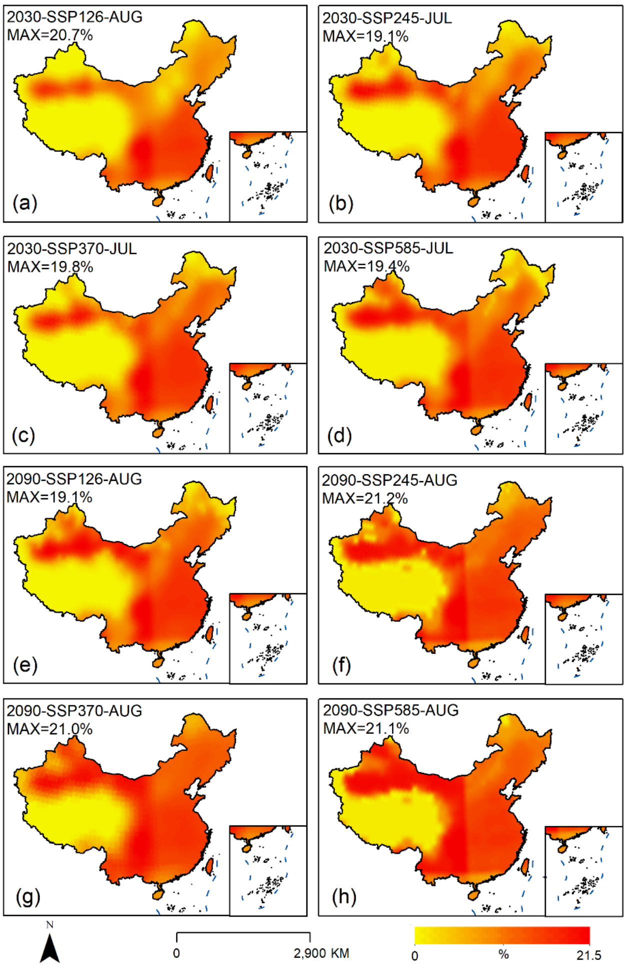

Figure 2. Spatial distribution of maximum larval density of Aedes albopictus under four climate change scenarios in 2030 and 2090

4. Discussion

This study shows that the contribution of geospatial variables to the prediction of Aedes albopictus larval density is significantly higher than that of meteorological variables. Longitude (contribution rate 67.0) is the most core factor, and the spatial distribution of larval density shows a strong longitude dependence. This indicates that the breeding and spread of Aedes albopictus are not only regulated by local climate, but also closely related to spatial background conditions such as hydrothermal background, habitat type and human activity pattern corresponding to longitude zones. When carrying out mosquito-borne disease density early warning and risk zoning, spatial location characteristics should be prioritized as core modeling variables rather than relying only on meteorological factors. Among meteorological factors, extreme minimum temperature in the current month is the dominant factor. Humidity, precipitation and wind speed also have important impacts, and most key effects come from current month conditions, reflecting that larvae are highly sensitive to short-term low-temperature stress and concurrent hydrothermal and wind field environments. Extreme low temperature can directly reduce the survival rate of eggs and larvae, or indirectly regulate the population base by changing the physical and chemical properties of breeding water bodies. Concurrent temperature, humidity and precipitation jointly determine the stability of breeding water bodies and development rate. Short-term mosquito-borne monitoring should focus on extreme low temperature and synchronous meteorological combination in the current month to improve the timeliness and accuracy of density prediction. Jia et al. [27] found based on geographic detectors that both adult and larval density of Aedes albopictus are affected by nonlinear interaction of multiple meteorological factors, but larvae are less sensitive to climate change than adults. More than half of the key meteorological factors for larvae come from the current month, while adults have higher weights of variables from the previous month and the month before last, showing an obvious lag effect, indicating that different growth stages of Aedes albopictus have different responses to the environment.

In terms of temporal dynamics, the peak larval density of Aedes albopictus mostly occurs in July to August, showing a unimodal pattern with high values in summer and autumn and low values in winter and spring, which is consistent with the law that high temperature and humidity in summer in most areas of China are suitable for mosquito development. Under different SSP scenarios, peaks mostly appear in July in 2030 and 2050, are delayed to August in some scenarios in 2070 and most scenarios in 2090. The density cycle shows an approximately one-month seasonal lag in the middle and late 21st century. This lag may be related to prolonged high temperature period, changed accumulated temperature accumulation rhythm and adjusted precipitation pattern caused by climate warming, suggesting that climate warming will change the seasonal occurrence rhythm of Aedes albopictus and prolong the activity period and public health risk period. In terms of spatial distribution, Aedes albopictus larvae are distributed in most areas of China except the Qinghai-Tibet Plateau. The suitable distribution range in 2090 is significantly expanded compared with 2030, especially in the northwest and northeast. Climate warming improves heat conditions in high-latitude and high-altitude areas, gradually making areas originally unsuitable for overwintering and development of Aedes albopictus possess breeding conditions, promoting the distribution to expand northward and westward. Under future high-emission scenarios, the peak density reaches 21.2%, higher than that in early scenarios, indicating that climate change not only expands the distribution range, but also may increase local population density and exacerbate mosquito-borne transmission risks. Although there are few domestic simulation studies on monthly mosquito density and distribution, the conclusions of this study on density fluctuation and distribution change are consistent with existing literature [14, 15, 28].

This study has certain limitations. First, various mosquito density monitoring methods and limited monitoring conditions lead to poor data comparability and limited sample size included. Follow-up studies need to integrate different monitoring indicators and establish conversion standards to improve data support capacity. Second, a variety of models or model combinations can be further compared to optimize the optimal prediction results [29].

5. Conclusion

Spatial pattern dominated by spatial information and meteorological conditions with extreme minimum temperature as the core jointly shape the density and distribution characteristics of Aedes albopictus larvae. Future climate change will further lead to seasonal lag, expanded distribution range and increased population density. The research results can provide a scientific basis for early warning of Aedes albopictus dynamics, regional mosquito-borne disease prevention and control priority setting and public health response strategy formulation under the background of climate change. Follow-up studies can further combine land use, urbanization and prevention and control intervention measures to more finely analyze the synergistic effects of multiple driving factors on the population dynamics of Aedes albopictus.

References

[1] Xia H, Wang Y, Atoni E et al. Mosquito-associated viruses in China [J]. Virologica Sinica, 2018, 33(1): 5-20.
[2] Nazareth T, Seixas G, Lourenço J et al. Aedes albopictus arrives in Lisbon: an emerging public health threat [J]. Frontiers in Public Health, 2023, 11.
[3] Şuleşco T, Buşmachiu G, Lange U et al. The first record of the invasive mosquito species Aedes albopictus in Chisinău, Republic of Moldova, 2020 [J]. Parasites & Vectors, 2021, 14(1): 565.
[4] Lowe A M, Forest-Bérard K, Trudel R et al. Mosquitoes know no borders: surveillance of potential introduction of Aedes species in Southern Quebec, Canada [J]. Pathogens, 2021, 10(8): 998.
[5] Schmidt T L, Chung J, Van Rooyen A R et al. Incursion pathways of the Asian tiger mosquito (Aedes albopictus) into Australia contrast sharply with those of the yellow fever mosquito (Aedes aegypti) [J]. Pest Management Science, 2020, 76(12): 4202-4209.
[6] Garcia-Rejon J E, Navarro J-C, Cigarroa-Toledo N et al. An updated review of the invasive Aedes albopictus in the Americas: Geographical distribution, host feeding patterns, arbovirus infection, and the potential for vertical transmission of Dengue Virus [J], 2021, 12(11): 967.
[7] Franklinos L H V, Jones K E, Redding D W et al. The effect of global change on mosquito-borne disease [J]. The Lancet Infectious Diseases, 2019, 19(9): 302-312.
[8] Bonnin L, Tran A, Herbreteau V et al. Predicting the effects of climate change on Dengue Vector densities in Southeast Asia through process-based modeling [J]. Environmental Health Perspectives, 2022, 130(12): 127002.
[9] Lamy K, Tran A, Portafaix T et al. Impact of regional climate change on the mosquito vector Aedes albopictus in a tropical island environment: La Réunion [J]. Science of the Total Environment, 2023, 875: 162484.
[10] Gorris M E, Bartlow A W, Pitts T et al. Projections of Aedes and Culex mosquitoes across North and South America in response to climate change [J]. The Journal of Climate Change and Health, 2024, 17: 100317.
[11] Atoni E, Zhao L, Hu C et al. A dataset of distribution and diversity of mosquito-associated viruses and their mosquito vectors in China [J]. Scientific Data, 2020, 7(1): 342.
[12] Zheng X, Zhong D, He Y et al. Seasonality modeling of the distribution of Aedes albopictus in China based on climatic and environmental suitability [J]. Infectious Diseases of Poverty, 2019, 8(1): 98.
[13] Li Y, An Q, Sun Z et al. Distribution areas and monthly dynamic distribution changes of three Aedes species in China: Aedes aegypti, Aedes albopictus and Aedes vexans [J]. Parasites & Vectors, 2023, 16(1): 297.
[14] Liu Q, Zhang H-D, Xing D et al. The predicted potential distribution of Aedes albopictus in China under the shared socioeconomic pathway (SSP)1–2.6 [J]. Acta Tropica, 2023, 248: 107001.
[15] Liu B, Gao X, Ma J et al. Modeling the present and future distribution of arbovirus vectors Aedes aegypti and Aedes albopictus under climate change scenarios in Mainland China [J]. Science of the Total Environment, 2019, 664: 203-214.

[16] Fristoe T S, Chytrý M, Dawson W et al. Dimensions of invasiveness: Links between local abundance, geographic range size, and habitat breadth in Europe's alien and native floras [J]. Proceedings of the National Academy of Sciences, 2021, 118(22): e2021173118.
[17] Wang J, Hou J, Zhong J et al. Relationships between traditional larval indices and meteorological factors with the adult density of Aedes albopictus captured by BG-mosquito trap [J]. PLoS One, 2020, 15(6): 16.
[18] Li R, Xu L, Bjørnstad O N et al. Climate-driven variation in mosquito density predicts the spatiotemporal dynamics of dengue [J]. Proceedings of the National Academy of Sciences, 2019, 116(9): 3624-3629.
[19] Ferraccioli F, Riccetti N, Fasano A et al. Effects of climatic and environmental factors on mosquito population inferred from West Nile virus surveillance in Greece [J]. Scientific Reports, 2023, 13(1): 18803.
[20] Camargo C, Alfonso-Parra C, Díaz S et al. Spatial and temporal population dynamics of male and female Aedes albopictus at a local scale in Medellín, Colombia [J]. Parasites & Vectors, 2021, 14(1): 312.
[21] Jia P, Liang L, Tan X et al. Potential effects of heat waves on the population dynamics of the dengue mosquito Aedes albopictus [J]. PLoS Neglected Tropical Diseases, 2019, 13(7): 16.
[22] Kao B, Lin C-H, Wen T-H. Measuring the effects of typhoon trajectories on dengue outbreaks in tropical regions of Taiwan: 1998–2019 [J]. International Journal of Biometeorology, 2023, 67(8): 1311-1322.
[23] Fischer E M, Sippel S, Knutti R. Increasing probability of record-shattering climate extremes [J]. Nature Climate Change, 2021, 11(8): 689-695.
[24] Wang Z, Jia X, Wang Y et al. Spatial variation of population, density, and composition of mosquitoes in mainland China [J]. Scientific Data, 2025, 12(1): 20.
[25] Breiman L. Random Forests [J]. Machine Learning, 2001, 45(1): 5-32.
[26] Biau G. Analysis of a random forests model [J]. The Journal of Machine Learning Research, 2012, 13: 1063-1095.
[27] Jia X, Wang Y, Wang Z et al. New insights into the main meteorological factors affecting mosquito densities: time lags, interaction effects, and species specificity [J]. Environmental and Ecological Statistics, 2025, 32(3): 1091-1113.
[28] Liu H, Huang X, Guo X et al. Climate change and Aedes albopictus risks in China: current impact and future projection [J]. Infectious Diseases of Poverty, 2023, 12(1): 26.
[29] Früh L, Kampen H, Kerkow A et al. Modelling the potential distribution of an invasive mosquito species: comparative evaluation of four machine learning methods and their combinations [J]. Ecological Modelling, 2018, 388: 136-144.