

## Relationship Between Climate Change and Marmot Plague of *Marmota himalayana* Plague Focus — the Altun Mountains of the Qinghai-Xizang Plateau, China, 2000–2022

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### ABSTRACT

**Introduction:** Plague is a zoonotic disease that occurs naturally in specific geographic areas. Climate change can influence the populations of the plague host or vector, leading to variations in the occurrence and epidemiology of plague in animals.

**Methods:** In this study, we collected meteorological and plague epidemiological data from the *Marmota himalayana* plague focus in the Altun Mountains of the Qinghai-Xizang Plateau. The data spanned from 2000 to 2022. We describe the climatic factors and plague epidemic conditions and we describe their analysis by Pearson's correlation.

**Results:** During the period from 2000 to 2022, the isolation rates of *Yersinia pestis* (*Y.pestis*) from marmots and fleas were 9.27% (451/4,864) and 7.17% (118/1,646), respectively. Additionally, we observed a positive rate of F1 antibody of 11.25% (443/3,937) in marmots and 18.16% (142/782) in dogs. With regards to climate, there was little variation, and a decreasing trend in blowing-sand days was observed. The temperature in the previous year showed a negative correlation with the *Y. pestis* isolation rate in marmots ( $r=-0.555$ ,  $P=0.011$ ) and the positive rate of F1 antibody in marmots ( $r=-0.552$ ,  $P=0.012$ ) in the current year. The average annual precipitation in the previous two years showed a positive correlation with marmot density ( $r=0.514$ ,  $P=0.024$ ), while blowing-sand days showed a negative correlation with marmot density ( $r=-0.701$ ,  $P=0.001$ ). Furthermore, the average annual precipitation in the previous three years showed a positive correlation with the isolation rate of *Y. pestis* from marmots ( $r=0.666$ ,  $P=0.003$ ), and blowing-sand days showed a negative correlation with marmot density ( $r=-0.597$ ,  $P=0.009$ ).

**Conclusions:** The findings of this study indicate

that there is a hysteresis effect of climate change on the prevalence of plague. Therefore, monitoring climate conditions can offer significant insights for implementing timely preventive and control measures to combat plague epidemics.

### INTRODUCTION

Plague is a zoonotic disease that can persist in natural foci even without human hosts (1). Climate changes in these foci can disrupt plague hosts and vectors, leading to outbreaks in animals and humans. Studies have demonstrated that climate warming can promote the spread of plague (2). The frequency of plague outbreaks significantly increases during dry seasons (3), and the effects of rainfall on plague intensity differ between northern and southern regions of China (4). Therefore, it is important to conduct detailed studies on local climate factors to better prepare for epidemics. The Altun Mountains region, located in the *Marmota himalayana* (*M. himalayana*) plague focus of the Qinghai-Xizang Plateau, has a relatively stable ecological environment with fewer human settlements. This makes it less susceptible to human activities but more vulnerable to ecological changes (5). Consequently, climate change is expected to impact animal plagues in this region.

In this study, we examined meteorological data and plague monitoring data in the Altun Mountains region of the *M. himalayana* plague focus of the Qinghai-Xizang Plateau from 2000 to 2022. Our objective was to understand the plague epidemic and climate conditions in this region. We aimed to analyze the relationship between climate change and marmot plague in the Altun Mountains of the Qinghai-Xizang Plateau from 2000 to 2022, in order to provide a theoretical foundation for developing an early warning system for effective plague prevention and control.

## METHODS

### Data Collection

Meteorological and plague epidemiological data were collected from the *M. himalayana* plague focus in the Altun Mountains of the Qinghai-Xizang Plateau between the years 2000 and 2022. Meteorological data were obtained from the Meteorological Bureau of Aksai Kazakh Autonomous County, Gansu Province, China. Plague surveillance data were obtained from Aksai CDC, with the exception of the years 2003, 2011, and 2016 due to legitimate reasons.

### Analysis Indicators

The meteorological data utilized in this study comprise temperature (°C), relative humidity (% RH), precipitation (mm), occurrences of strong wind days (day), floating-dust days (day), blowing-sand days (day), sandstorm days (day), and sunshine hours (h). Plague surveillance data consist of marmot and vector counts, isolation rates of *Y. pestis* from marmots and fleas, positive rates of F1 antibody in marmots and dogs, as well as the marmot flea index.

### Statistical Analyses

Statistical analyses were conducted using SPSS software (version 26.0, IBM, Armonk, New York, USA). The study described the prevalence of plague in animals and climate change in the Altun

Mountains, which is the natural focus of *M. himalayana* plague, from 2000 to 2022. A Chi-square test was utilized to compare the isolation rates of *Y. pestis* from marmots and fleas in different years. Pearson correlation analysis was performed to examine the correlation between climate change and plague prevalence in the current year, as well as the previous year, previous two years, and previous three years (relative to the current year). The previous 1, 2, and 3 years were considered in relation to the current year as a reference. A *P* value of <0.05 was considered statistically significant.

## RESULTS

### Epidemiological Characteristics of Plague During 2000–2022

Figure 1 depicts the detection of 4,864 marmots, the primary host animal, from 2000 to 2022 (excluding 2003, 2011, and 2016). During this period, 451 strains of *Y. pestis* were isolated, resulting in an isolation rate of 9.27% in marmots. A significant difference was observed in the isolation rate of *Y. pestis* from marmots each year ( $\chi^2=103.00$ ,  $P<0.05$ ). The lowest isolation rate was recorded in 2001 (3.54%, 8/226), while the rate displayed an increasing trend from 2019 (6.47%, 15/232) and reached 22.05% (58/263) in 2022. The isolation rate of *Y. pestis* from fleas was 7.17% (118/1,646). Similarly, the isolation

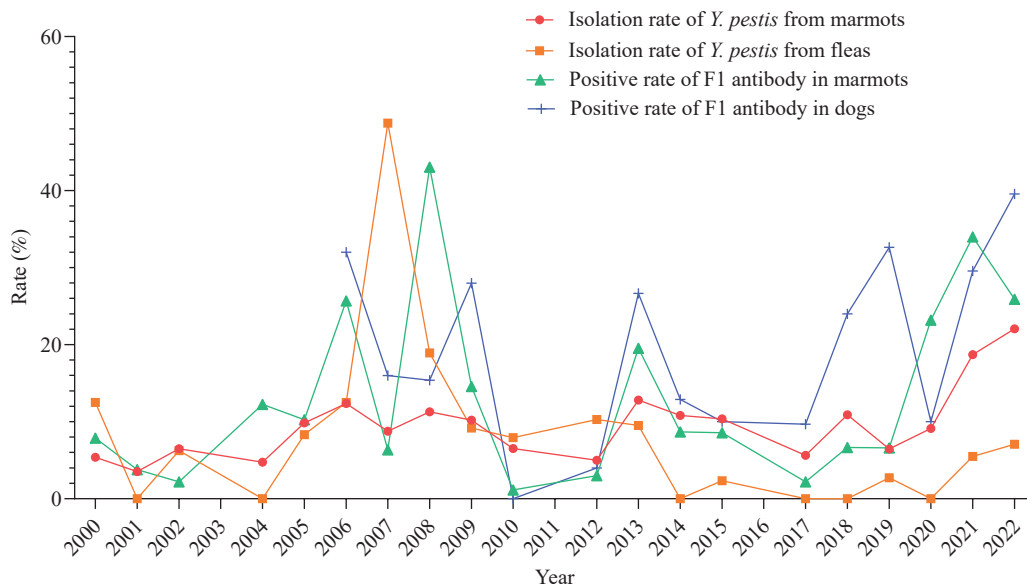


FIGURE 1. Epidemiological characteristics of plague in *M. himalayana* plague foci in the Altun Mountains on the Qinghai-Xizang Plateau, China, 2000–2022.

rate of *Y. pestis* from fleas exhibited a significant difference each year ( $\chi^2=117.17$ ,  $P<0.05$ ). The isolation rate from fleas increased from 2.73% (2/73) in 2019 to 7.09% (28/395) in 2022, mirroring the findings from marmots, except for a high rate in 2007 (48.78%, 20/41) (Figure 1).

The F1 antibody positive rate in marmots was 11.25% (443/3,979). The highest rate was observed in 2008 at 40.06% (59/137). There was a statistically significant difference in the positive rate of F1 antibody in marmots between different years ( $\chi^2=350.36$ ,  $P<0.05$ ). The positive rate of F1 antibody in dogs from 2006 to 2022 was 18.16% (142/782). There was also a statistically significant difference in the positive rate of F1 antibody in dogs between different years ( $\chi^2=59.37$ ,  $P<0.05$ ). Additionally, both the positive rate of F1 antibody in marmots and dogs exhibited zigzag interannual changes.

### Climate Change During 2000–2022

The *M. himalayana* plague foci in the Altun

Mountains on the Qinghai-Xizang Plateau had an average annual temperature ranging from 16.63 °C to 18.51 °C. The RH ranged from 28.10% to 42.86%. The average annual precipitation varied from 18.7 mm to 203.30 mm. Sunshine hours ranged from 1639.30 h to 2063.50 h per year. The number of strong wind days varied from 0 to 7, blowing-sand days ranged from 1 to 20, floating-dust days ranged from 2 to 39, and sandstorm days ranged from 0 to 9 annually. These data exhibited slight variability with minimal fluctuation (Figure 2).

### Correlation Between Climate and Plague

The indicators used for correlation analysis met the criteria of normal distribution ( $P>0.05$ ), and there were significant linear relationships between climate factors and plague epidemic indicators ( $P<0.05$ ) (Supplementary Figure S1, available at <https://weekly.chinacdc.cn/>). In terms of the relationship between current climate change and current plague epidemic, the number of blowing-sand days showed a positive correlation with the isolation rate of *Y. pestis* from fleas ( $r=0.463$ ,  $P=0.04$ ), while temperature was

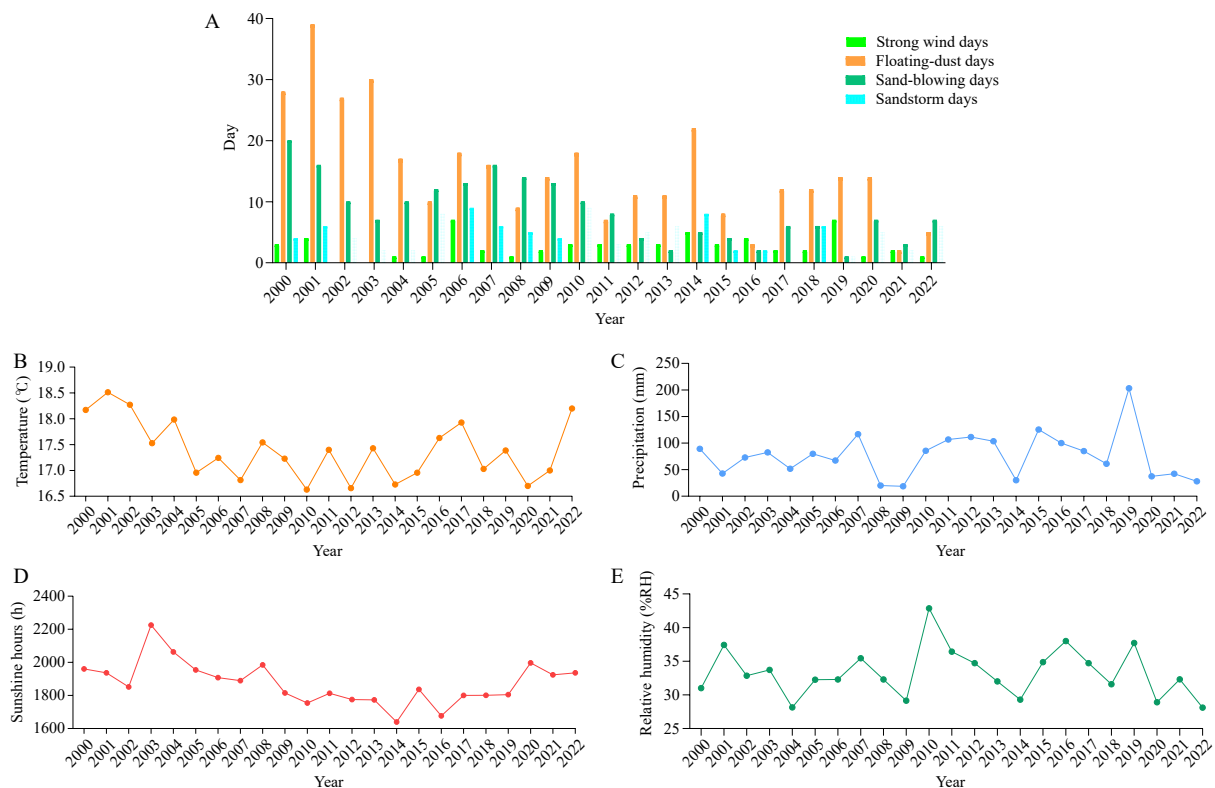


FIGURE 2. Climate change in *M. himalayana* plague foci in the Altun Mountains on the Qinghai-Xizang Plateau, China, 2000–2022. (A) The average annual number of unusual weather days; (B) The average annual temperature; (C) The average annual precipitation; (D) The average annual sunshine hours; (E) The average annual relative humidity.

positively correlated with the positive identification of F1 antibodies in dogs ( $r=0.575$ ,  $P=0.025$ ). Regarding the relationship between climate change in the previous year and plague prevalence in the current year, there was a negative correlation between temperature and the *Y. pestis* isolation rate from marmots ( $r=-0.555$ ,  $P=0.011$ ), as well as the positive F1 antibody rate in dogs in marmots ( $r=-0.552$ ,  $P=0.012$ ). Additionally, there was a positive correlation between average sunshine hours and the positive F1 antibody rate in dogs ( $r=0.550$ ,  $P=0.034$ ) (Table 1).

The correlation between climate change in the previous two years and the plague epidemic in the current year was examined. The results showed a positive correlation between average annual precipitation and marmot density ( $r=0.514$ ,  $P=0.024$ ). On the other hand, there were negative correlations between the number of blowing-sand days ( $r=-0.701$ ,  $P=0.001$ ) and sunshine hours ( $r=-0.593$ ,  $P=0.007$ ) with marmot density. Additionally, a negative correlation was observed between temperature in the previous two years and flea index in the current year ( $r=-0.577$ ,  $P=0.010$ ). Furthermore, the relationship between climate change in the previous three years and plague prevalence in the current year was examined. The findings revealed a positive correlation between average annual precipitation in the previous three years and the number of self-destructed marmots ( $r=0.699$ ,  $P=0.005$ ), as well as the isolation rate of *Y. pestis* in marmots ( $r=0.666$ ,  $P=0.003$ ). Conversely, the number of blowing-sand days showed negative correlations with the number of dead marmots ( $r=-0.676$ ,  $P=0.008$ ), marmot density ( $r=-0.597$ ,  $P=0.009$ ), isolation rate of *Y. pestis* from marmots ( $r=-0.505$ ,  $P=0.032$ ), and positive F1 antibody rate in dogs ( $r=-0.527$ ,  $P=0.043$ ). Moreover, average sunshine hours were negatively correlated with marmot density ( $r=-0.611$ ,  $P=0.007$ ), and positively correlated with the isolation rate of *Y. pestis* from fleas ( $r=0.521$ ,  $P=0.027$ ) (Table 1).

## CONCLUSIONS

The *M. himalayana* plague focus in China is a highly prevalent region for animal and human plague. Animal plague occurs every year (6), with occasional transmission to humans (7–8), highlighting the importance of monitoring animal plague. In recent years, the isolation rate of *Y. pestis* in marmots has continuously risen from 6.46% in 2019 to 22.05% in 2022. Similarly, the isolation rate of fleas carrying *Y.*

*pestis* has also increased. *Y. pestis* was detected in both deceased marmots and the fleas they carried, indicating persistent infection and the widespread presence of plague among animals. The fluctuation in the positive rate of F1 antibody suggests a shift in the active and silent state of the plague foci.

The Altun Mountains in the *M. himalayana* plague focus area have undulating basins formed by the foldings of the Qilian Mountains and the Tianshan Mountains. The main types of terrain in this area are deserts and semi-desert grasslands (9). The climate in this region is characterized by high altitude, cold temperatures, large temperature variations, and dryness. From 2000 to 2022, the climate in this region has remained relatively stable in terms of change.

In analyzing the relationship between climate and plague prevalence in the current year, we observed that an increase in the number of sand-blowing days led to a higher isolation rate of *Y. pestis* from fleas. This is attributed to reduced marmot activities during blowing-sand days, causing them to spend more time in caves. The cave environment provides favorable conditions for flea parasites on marmots and the propagation of *Y. pestis* in fleas (10). Consequently, this increases the risk of plague epidemics. Previous sand-raising events in the two to three years prior have adversely affected marmot foraging, resulting in lower marmot density, decreased number of *Y. pestis* hosts, and reduced isolation rates of *Y. pestis* from marmots.

Regarding the analysis of climate and plague prevalence in the current year, we found that higher temperatures created warmer conditions for marmot hibernation. This leads to earlier hibernation periods and increased activities outside, thereby increasing the likelihood of marmots being preyed upon by dogs. Furthermore, marmots may hibernate with bacterial infections (11), and predation of infected marmots by dogs can elevate the positive rate of F1 antibodies in dogs. Rising temperatures also cause drought, resulting in food scarcity for marmots and decreased resistance, making them more susceptible to *Y. pestis* infection and predation by dogs. Thus, these factors contribute to the outbreak of plague epidemics. Through our study on the relationship between climate and plague prevalence in the previous year, we discovered that increased temperature led to enhanced development and reproductive ability of marmots. As a result, the current year saw a rise in the marmot population, improved healthy survival rates, and decreased isolation rates of *Y. pestis* and F1 antibody positive rates in marmots. These findings align with previous researches

TABLE 1. Correlation analysis of climate factors and plague epidemic indicators in the Altun Mountains on the Qinghai-Xizang Plateau, China, 2000–2022.

Plague epidemic indicators	Current year			Last year			Previous two years			Previous three years		
	Temperature	Number of sand-blowing days	Number of sunshine hours	Temperature	Number of sand-blowing days	Number of sunshine hours	Precipitation	Number of sand-blowing days	Number of sunshine hours	Precipitation	Number of sand-blowing days	Number of sunshine hours
Number of self-dead marmots	r	0.430	0.103	0.030	0.266	0.052	0.070	-0.287	0.135	0.699	-0.676	0.122
	P	0.125	0.725	0.919	0.359	0.860	0.813	0.320	0.645	0.005*	0.008*	0.679
Marmot density	r	-0.017	-0.314	-0.017	-0.273	-0.379	0.514	-0.701	-0.593	0.436	-0.597	-0.611
	P	0.943	0.177	0.944	0.245	0.110	0.024*	0.001*	0.007*	0.071	0.009*	0.007*
Isolation rate of <i>Y. pestis</i> from marmots	r	-0.147	-0.300	-0.555	-0.019	-0.387	0.380	0.001	0.007	0.666	-0.505	-0.009
	P	0.536	0.198	0.011*	0.935	0.101	0.108	-0.433	0.023	0.003*	0.032*	0.973
Isolation rate of <i>Y. pestis</i> from fleas	r	-0.189	0.463	-0.135	0.132	-0.253	-0.175	0.064	0.925	-0.190	0.186	0.521
	P	0.424	0.040*	0.572	0.579	0.297	0.473	0.262	0.271	0.449	0.460	0.027*
Positive rate of F1 antibody in marmots	r	-0.027	-0.015	-0.552	0.195	-0.167	0.208	0.279	0.261	0.214	-0.216	0.181
	P	0.911	0.950	0.012*	0.411	0.494	0.392	-0.182	0.042	0.394	0.388	0.471
Positive rate of F1 antibody in dogs	r	0.575	-0.069	-0.283	0.550	0.278	0.233	0.455	0.864	0.452	-0.527	0.117
	P	0.025*	0.807	0.306	0.034*	0.316	0.404	-0.119	0.220	0.091	0.043*	0.677
Marmot flea index	r	-0.399	0.283	-0.255	0.018	-0.577	-0.187	0.672	0.430	0.051	0.229	0.401
	P	0.082	0.227	0.278	0.940	0.010*	0.444	0.205	0.290	0.841	0.361	0.099

Note: r=pearson correlation coefficient; P=P value.

\* Indicates statistical significance; grey base color indicates correlation.

highlighting the impact of temperature on plague host animals (12–13).

Higher levels of sunshine in the previous year are associated with increased detection of F1 antibodies in dogs, indicating a greater likelihood of dogs being exposed to marmots. The increased sunshine in the previous two and three years also promotes vegetation growth, leading to a higher marmot density in the endemic area. This, in turn, results in greater competition for resources and territory, increasing the risk of plague outbreaks. In contrast, a decrease in marmot density in the current year may be attributed to these factors. Additionally, increased precipitation in the previous two to three years provides favorable conditions for marmot survival and reproduction, leading to higher population density in the current year. However, when marmot density exceeds a certain threshold, the risk of plague transmission and self-dead marmots increases. It is important to note that previous studies have reported an association between increased marmot density and the presence of plague in marmots (14–15).

This study focused solely on examining the correlation between climate change and the occurrence of plague epidemics. However, further analysis is necessary to assess the specific impact of individual climate factors on the prevalence of plague. It is important to note that the prevalence of plague is influenced by multiple factors, and this study only explores the role of climate factors. Future research should consider integrating other relevant factors when analyzing the prevalence of plague.

In this study, we observed variations in the influence of temperature, precipitation, sand-blowing days, and sunshine hours on the prevalence of plague. Specifically, an increase in temperature in the current year increases the risk of plague transmission in the same year. However, temperature increases in the previous one and two years decrease the risk of plague outbreaks in the current year. We also found that an increase in average annual precipitation in the previous two and three years elevates the risk of plague outbreaks in the current year. Moreover, an increase in the number of sand-blowing days in the current year increases the risk of plague outbreaks in the same year, while increases in the previous two and three years reduce the risk in the

current year. Additionally, our findings indicate that an increase in average annual sunshine hours in the previous year raises the risk of plague outbreaks in the current year. Conversely, increases in sunshine hours in the previous two and three years decrease the risk in the current year. Generally, the impact of climate on plague epidemics exhibits a hysteresis effect, in which the effects of climate change in a specific year manifest in subsequent years. Consistent with previous researches on the nature focus of *Rattus flavipectus* plague, we also identified a delayed influence of meteorological factors (15). Long-term climate monitoring can be utilized as a control strategy to provide early warning of future plague epidemics.

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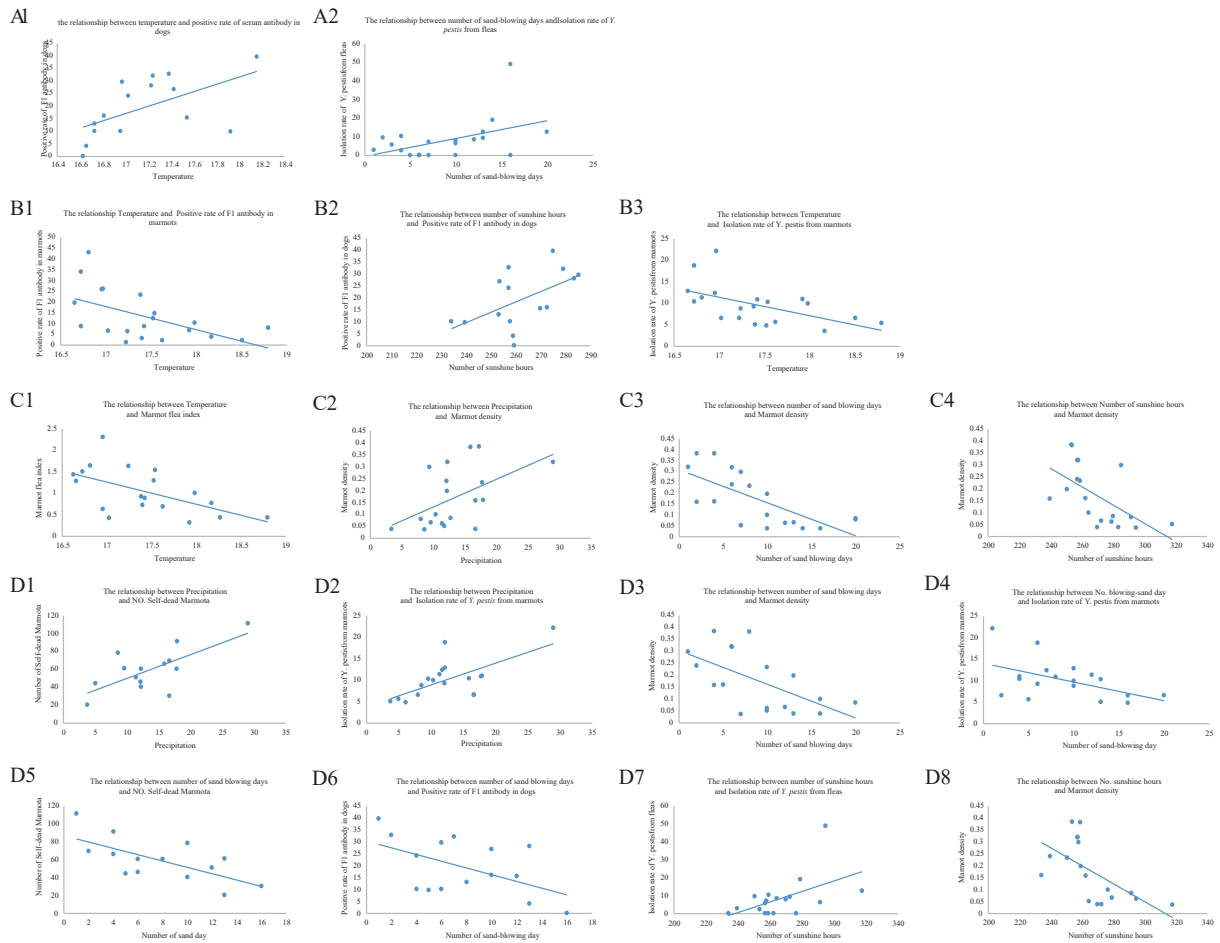
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# SUPPLEMENTAL MATERIAL



SUPPLEMENTARY FIGURE S1. Linear relationships between climate factors and indicators of plague epidemics. (A1–A2) The relationship between climate factors and plague epidemic indicators in the current year; (B1–B3) The relationship between climatic factors in the previous year and plague epidemic indicators in the current year; (C1–C4) The relationship between climatic factors in the previous two years and plague epidemic indicators in the current year; (D1–D8) The relationship between climatic factors in the previous three years and plague epidemic indicators in the current year.