Could Climate Change Mean More Plague? How Plague and its Vectors are Affected by Climate Factors and What that Could Mean for Plague Spread in Madagascar, the Asian Steppe, and the United States

**Abstract**:

In recent years, much research has been devoted to evaluating the impact of climate change on emerging infectious diseases. Though considered to be a disease of the past, plague, caused by the bacterium *Yersinia pestis*, continues to infect rodents in Central Asia, Southern Africa, and the Western United States, regions in which dramatic increases in temperature could drive these rodents to more densely populated areas and promote potential outbreaks. This paper examines how climate change could affect the primary host species in these regions and

Increasing global temperatures threaten diverse ecosystems, the emergence of infectious diseases, and daily human life. Plague, spread by the bacterium *Yersinia pestis*, may be one such disease threatening to re-emerge in the wake of climate change. There are at least four levels involved in human bubonic plague outbreaks: the bacterium, the flea vector, the rodent reservoir, and the human interaction. Though climate studies chart plague predictions in reference to manifestation of disease, very little research has centered on the unique relationship between climate and each of its species levels. The various species involved in plague spread likely have their own correlations to climate changes and thus it is essential to understand each when attempting to predict future outbreaks. Based on the limited data amassed from ecological climate models on *Xenophylla cheopsis*, *Rattus rattus, Rhombomus opimus,* and *Cynomys ludovicianus,* plague prevalence is expected to decrease in Madagascar and the Western United States but increase in the Asian Steppe region in the next 20-30 years.

Plague is a complex disease with many overlapping features to consider when attempting to understand its epidemiology. There are three major distinct plague infections: bubonic, septicemic, and pneumonic. This paper will focus on bubonic plague, which is spread to humans through contact with infected fleas. The levels involved in bubonic plague spread to humans include the bacterium, the vector, and the reservoir. Each level of infection has its own phenology. Phenology refers to the cyclic phenomena of a plant or animal species in relation to climate change. Perhaps as a result of plague’s many layers, and the understanding that the phenologies of each species involved may be divergent from one another, there is a lot of disagreement in recent historical and scientific studies on how plague outbreaks can best be predicted in relation to climate change.

Three major historical outbreaks of plague are recorded: The Justinianic Plague, The Black Death, and the Third Pandemic. Many studies have been conducted on how climate may have influenced these past plague events, all of which could have vital implications for how plague might spread in future climates. In one such study, Monica Green[[1]](#footnote-1) examined the role of climate in the spread of an assortment of diseases. Of the diseases researched, including malaria, leprosy, and smallpox, plague was designated as the most susceptible to climate change and was generally found to be associated with massive cooling events. These massive cooling events, like volcanic eruptions before the Justinianic plague and the Little Ice Age before The Black Death, coupled with increased precipitation, are thought to have provided an ideal climate for the spread of plague during these two pandemics. A similar study[[2]](#footnote-2) used computer analyses to correlate plague outbreaks in pre-industrial Europe to changing climates and determined wet climates were the best predictors of plague, with a five-year lag period. These historical papers combine to suggest that future warming should either reduce or fail to impact the prevalence of plague in the future, as cooling periods are expected to be less frequent as the planet warms.

Research focused on the most recent pandemic, however, contradicts with these findings. In a highly publicized study[[3]](#footnote-3), plague prevalence in gerbils on the Asian Steppe was found to increase by 59% after a mere 1°C increase in temperature, suggesting that plague is most highly correlated to increasing temperature and humidity. This conclusion is also supported by Ben-Ari[[4]](#footnote-4) on human plague in the United States, which was correlated to above-normal temperatures along with other factors. These papers suggest that modern plague may differ from the historical in relation to climate, and future outbreaks could indeed be on the rise in the future.

Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has published reports summarizing climate change research, including analyses associated with vector-borne diseases, like plague. The most recent IPCC report[[5]](#footnote-5) has emphasized the innate linkage between climate, socioeconomic conditions, vectored diseases, and human health. Others, like the IPCC, focus their research on broad disease expansions in the wake of climate changes. One such study[[6]](#footnote-6) suggests plague outbreaks in the United states may be expected to shift northward in the future due to changing climates. Secondary factors of climate change, including food scarcity and human displacement as a result of natural disaster could also contribute to future plague spread[[7]](#footnote-7).

Though general predictions of plague outbreaks are useful, forecasts may benefit from a multifaceted study of climate effects, focusing on each species involved in its spread. Plague scholars[[8]](#footnote-8) have already recognized the necessity of a segregated study of plague’s complicated components. Each species involved has its own specified mechanism contributing to spread, and it is vital to understand the mode of transmission of each, and how they might be hindered or helped with increased temperatures, when considering the potential for future outbreaks.

The plague bacillus, *Y. pestis*, uses blood-feeding fleas to transmit to larger mammals. *Y. pestis* will either infect via Early Phase or Late Phase Biofilm transmission. Early phase transmission requires many infectious fleas to bite the target of interest because only relatively few bacteria populate the gut at this time. Conversely, during Late Phase Biofilm transmission, *Y. pestis* has been in the gut for long enough to develop a partial or complete biofilm, a cluster of bacteria, which severely limits blood intake of the flea. The formation of biofilm can have a profound impact on the efficiency of the designated vector[[9]](#footnote-9). With increased difficulty obtaining full blood meals, the flea will be forced to increase its biting frequency, thereby expanding the opportunities for *Y. pestis* infection of the target host[[10]](#footnote-10).

Most of the research on the main flea host of plague, *Xenophylla cheopsis*, deals with temperature in relation to biofilm formation. It has been determined that peak plague transmission occurs at 23°C, while peak biofilm formation occurs at 10°C, suggesting the most efficient fleas will be those that are able to produce biofilms at cooler temperatures and transmit in warmer temperatures[[11]](#footnote-11). The primary flea in plague’s urban cycle, *X. cheopsis* has a greater tolerance for higher temperatures than its sylvatic counterpart, *Synopsyllus fonquerniei[[12]](#footnote-12)*. While increased temperature tolerance of *X. cheopsis* may mean the stagnation or expansion of plague in some regions, because *S. fonquerniei* is less adapted to temperature increases, areas like Madagascar might see a decrease in plague cases with global warming. The rodent vector response to increasing temperatures, however, still needs to be considered.

Perhaps one of the most well-known rodent hosts of plague is the black rat, *Rattus rattus*. Considered the major rodent vector for the Black Death and other plague outbreaks, *R. rattus* remains the primary mode of plague transfer in Madagascar, the country with the largest number of plague cases per year[[13]](#footnote-13). The climate of Madagascar is sub-tropical, with a hot and rainy summer and cold and dry winter, all of which could factor into the phenology of *R. rattus.* Though research on the precise dynamics of *R. rattus* in Madagascar is not well-characterized, there have been recent publications observing *R. rattus* and other species in similar climate conditions. One 2007 centered in Italy focused on the response of many small rodents, including *R. rattus*, to temperature increases. Over the course of the study, the rodent populations grew and became more homogenized, implying increased temperatures as a pressure for this alteration[[14]](#footnote-14).

Another paper examined *Apodemus speciosus*, a small Japanese rat that may be undergoing a phenomenon similar to *R. rattus* in Madagascar. Island gigantism is a biological phenomenon in which rodents on islands will become larger than their mainland counterparts. Millien[[15]](#footnote-15) demonstrated that island gigantism may result from the lessened selective pressure on island rodents to retain a small body size, due to the regulated climate. These results, along with those from Kreppel[[16]](#footnote-16) examined earlier, suggest that plague may be expected to decrease in Madagascar in the future with increasing temperatures.

Though *R. rattus* is perhaps the most well-known reservoir of plague, it is certainly not the only one. *Rhombomus opimus* is another plague reservoir, present throughout the arid and varied climate of central Asia. Though it is known to harbor plague*, R. opimus* is also a reservoir for zoonotic cutaneous leishmaniasis (ZCL). Recent studies in Iran seem to suggest the possible expansion of *R. opimus* correlated to climate change, specifically in relation to annual temperature range, mean temperature of the wettest season, precipitation levels in wettest seasons, and mean temperature[[17]](#footnote-17)[[18]](#footnote-18). Though these studies implicate *R. opimus* expansion with increased temperatures, another study suggests that higher temperatures correlate negatively with *R. opimus* habitat saturation[[19]](#footnote-19). This may not indicate decreases of the species, but rather, might suggest expansions of smaller colonies, which could heighten the chance of disease spread[[20]](#footnote-20). Taken together, these results indicate possible expansions for *R. opimus* throughout central Asia due to climate change; however, range shifts are likely to be more accurately predicted on a more specific regional scale.

A final rodent species known to harbor plague is the American prairie dog, or *Cynomys ludovicianus. C. ludovicanus* is known to inhabit the Great Plains of the American West, where the climate is limited in humidity and subject to wide temperature fluctuations. Plague is known to take hold in *C. ludovicanus* and the mortality rate of prairie dogs from plague is close to 100%[[21]](#footnote-21). Plague itself can have important ecological consequences for the species, as outbreaks have been shown to decrease colony size and enlarge distances between colonies, increasing the possible locations for humans to come across the reservoir[[22]](#footnote-22). Based on their habitat, it’s no surprise that prairie dog populations are heavily influenced by draught, but winter temperature severity is also a key climate factor limiting their survival[[23]](#footnote-23). The Northern Great Plains are expected to experience warmer mean temperatures in the future. While these increased temperatures may alleviate the extreme chill of winter for these animals, the draught experienced with summer temperature increases could prove to be a greater limit on *C. ludovicanus* survival and may ultimately imply a decrease in plague transmission to humans.

Though temperature increases may mean an increase in vector efficiency and range expansion of some rodent reservoirs, plague cases in people also depend on human interactions. While it may be argued that plague cases will depend on the urban or rural nature of the vector involved, most plague cases in the past 20 years occurred in rural villages rather than urban environments[[24]](#footnote-24), suggesting little difference between the habitats of these rodent reservoirs. Indeed, *R. rattus*, the most historically urban species examined in this paper, infects largely rural populations in Madagascar[[25]](#footnote-25). Land use changes, like farming and development, in these rural areas could also contribute to the spread of plague in the future.

Plague dynamics are complex and any ecological forecasting used to predict plague’s future spread in response to climate change will need to account for the individual species involved in its transmission. As expected, the various players differ in their climate thresholds, which will affect their movement and population dynamics in the future. Though climate change may lead to a decrease in plague prevalence in Madagascar and the Great Plains, and an increase in human outbreaks in the Asian Steppe, human factors such as land use change and field hunting must also be considered. Noting the limitations of this paper, specifically the limited ecological distribution models for the reservoir species in regions known to harbor plague, it is essential to continue examining these individual dynamics as well as the more macro-model of disease spread. Though plague can be treated, many people around the world continue to perish from outbreaks every year. Early and efficient treatment is necessary to reduce these fatalities, and knowing which locations are at risk can help guide appropriate allocation of necessary medicines. Climate change brings uncertainty to all walks of life and understanding the possible outcomes to temperature increase is the first step in future preparedness.

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