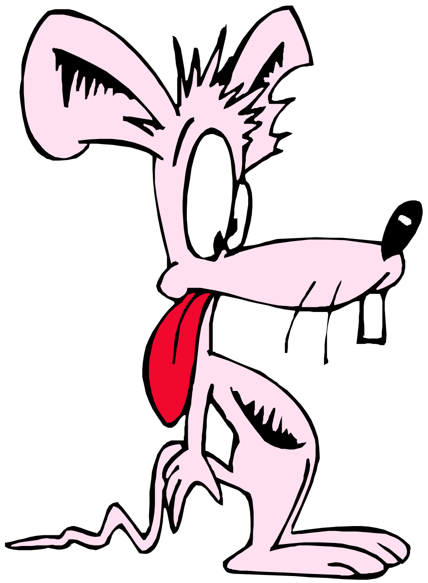
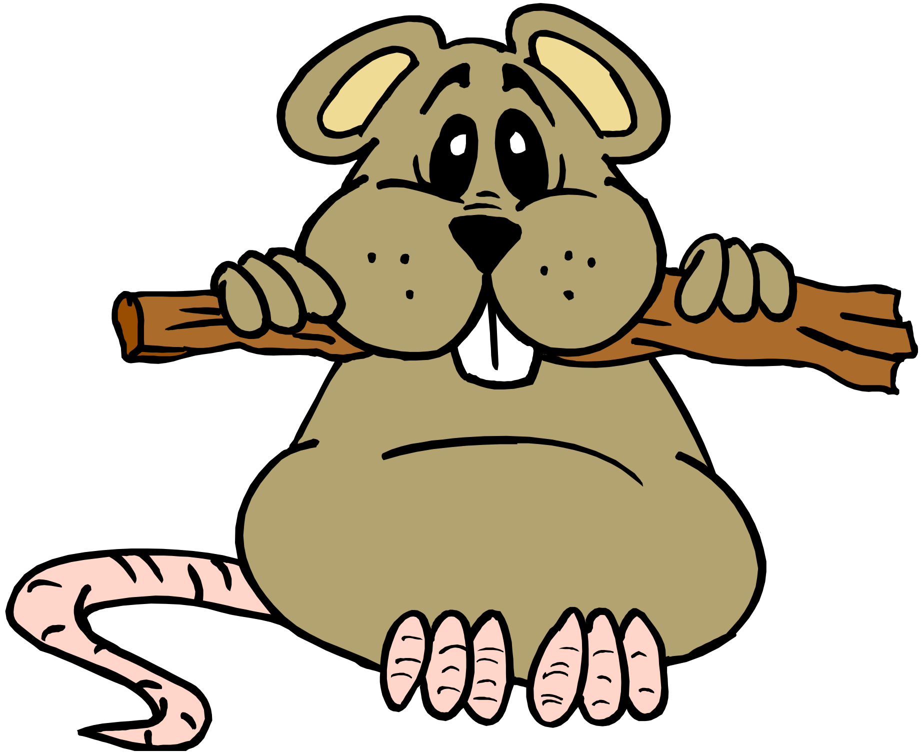
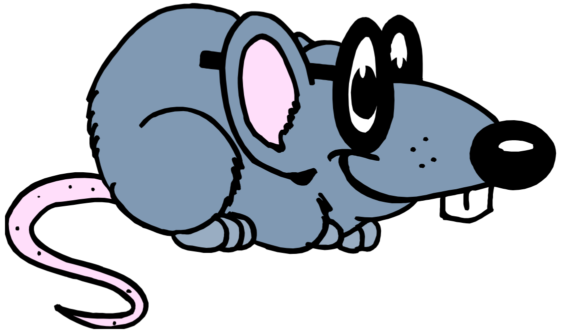
Climate and Plague







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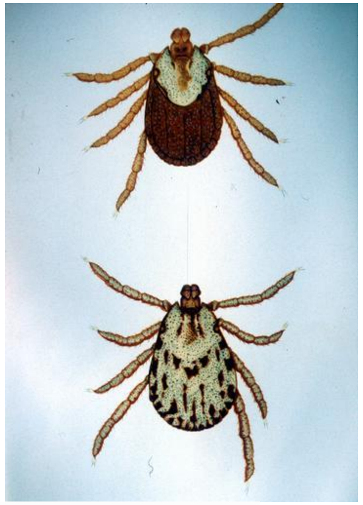
Climatic Impacts on Zoonotic/Vector-Borne Diseases

Four key factors influenced by climatic variables:

- Geographic distributions
- Population densities
- Infection prevalence
- Pathogen load, rate of development and transmissibility



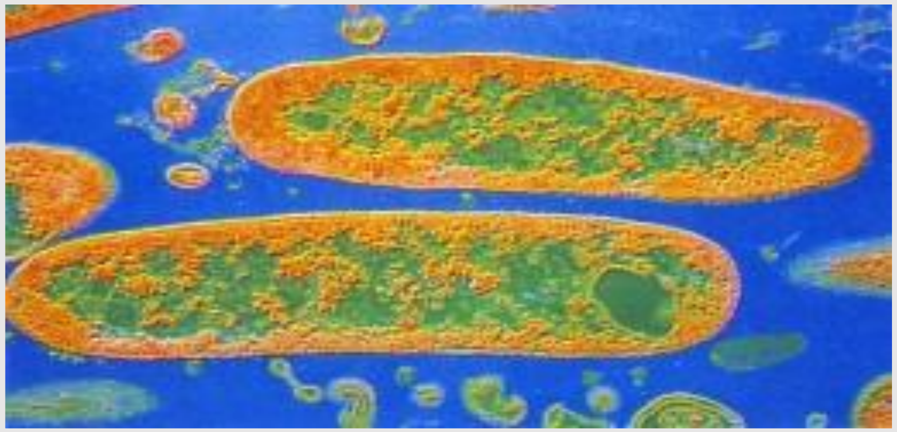
(Gage et al. 2008, Mills, Gage, and Khan 2010)

Climate and Plague Transmission

Major pandemics preceded by significant climatic events:

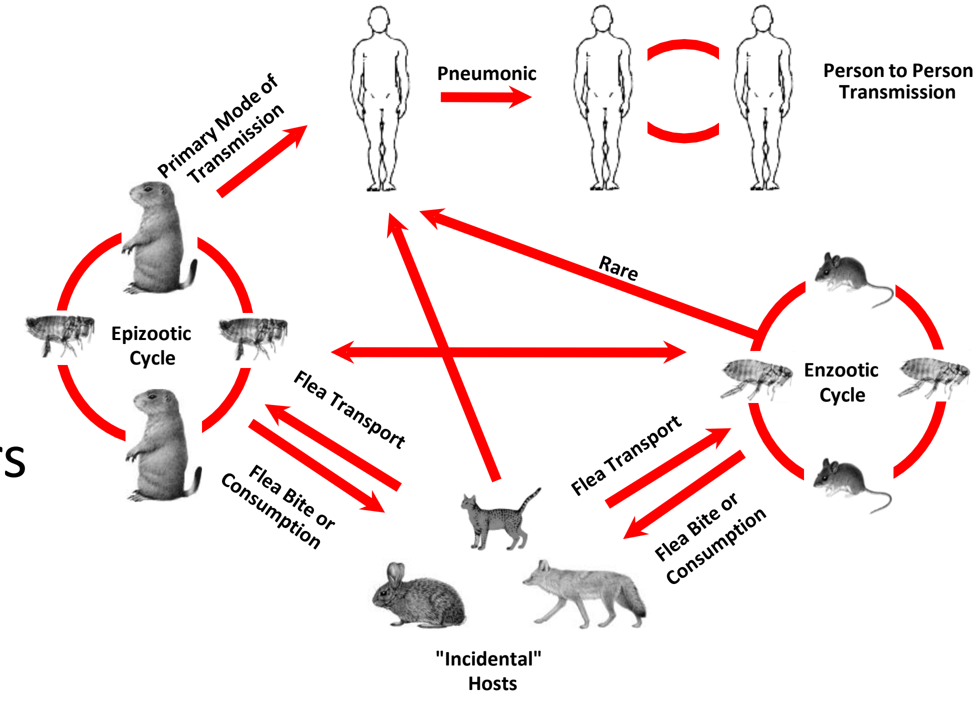
- Justinian's Plague
- Black Death
- Modern Pandemic

(Kausrud et al. 2010, Xu et al. 2011 and others)



Plague as a Model of Climate Effects on VBZDs

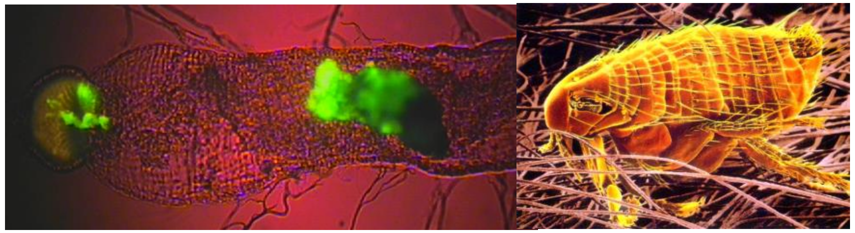
- Rodents respond rapidly to environmental changes
- Vector survival and reproduction affected
- Pathogen development and transmission affected by temperature (inverse relationship?)
- Geographic distribution of foci affected by climatic factors



Effect of Temperature on Blocking of Fleas by *Yersinia pestis* and Mortality among Infected Fleas

Yersinia pestis Strain	Percent of fleas blocked at given temperature			Percent flea mortality at given temperature		
	20°C	25°C	30°C	20°C	25°C	30°C
195-P-wt	32	13	0	42	41	70

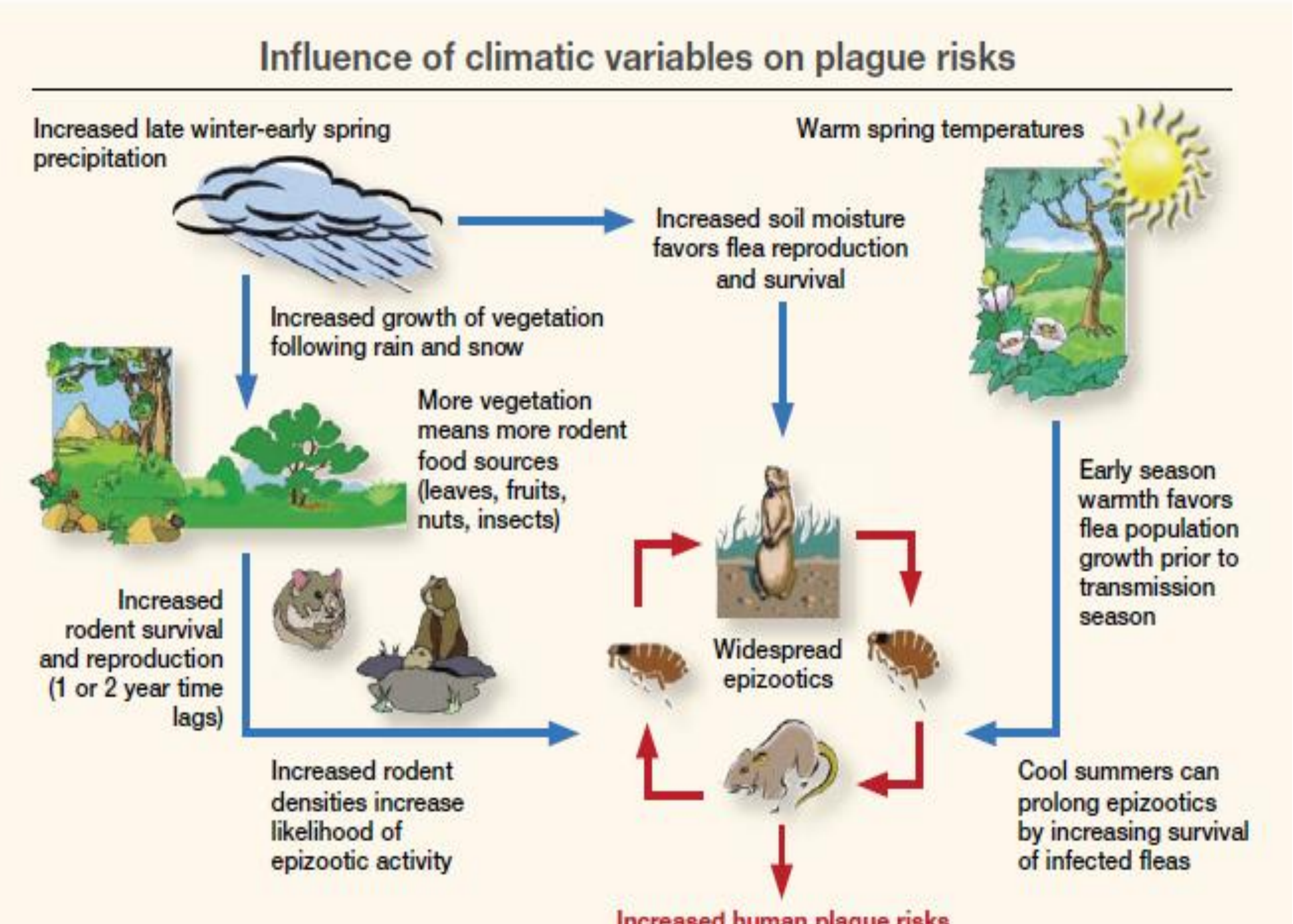
Source: Hinnebusch, Fischer and Schwan 1998



Infected flea photo showing masses of biolfilm and *Yersinia pestis*: Engelthaler et al. 2000

Note: *Most human cases occur when epizootics spillover to local human populations. Occurrence of epizootics often appear related to climatic variability*

- Climate often linked to plague epizootics or epidemics
- Threshold rodent densities appear critical
- Widespread favorable conditions can increase rodent populations and result in large epizootics
- Drought can concentrate rodents in remaining favorable habitats and lead to more focal epizootics
- Effects vary from region to region

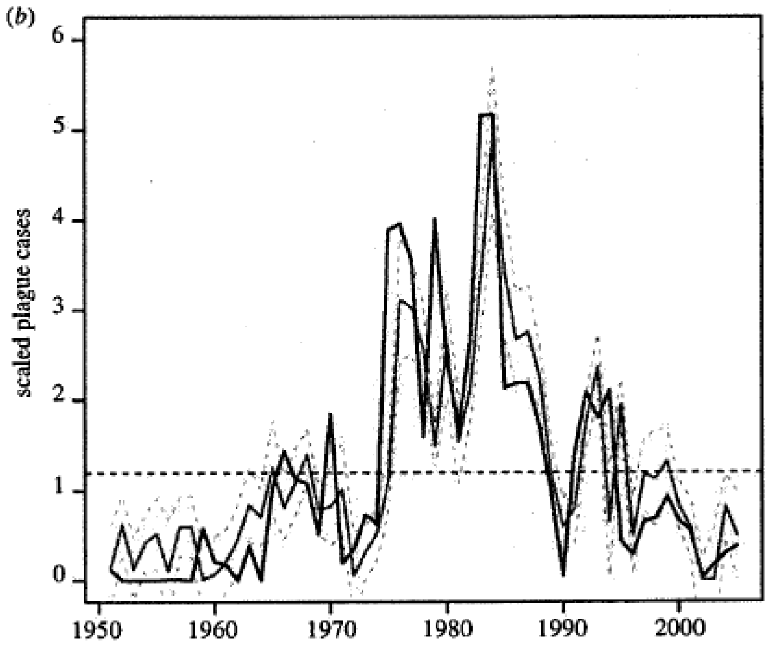


Schotthoefer and Gage (2009)

(Isaacson 1983, Parmenter et al. 1999, Enscore et al. 2002, Kausrud et al. 2007, Ben Ari et al. 2008, Xu et al. 2011 and others)

Regional and Local Climate Influences on Human Plague in the U.S. Ben Ari et al. (2008)

- Analyzed 56 year time series of human cases
- Variability in human plague activity across western U.S. could be explained largely by interactions between
  - Previous plague levels
  - Above normal temperatures
  - Pacific Decadal Oscillation
- Warmer and wetter climate led to increased human cases
- Did not initially see ENSO effect

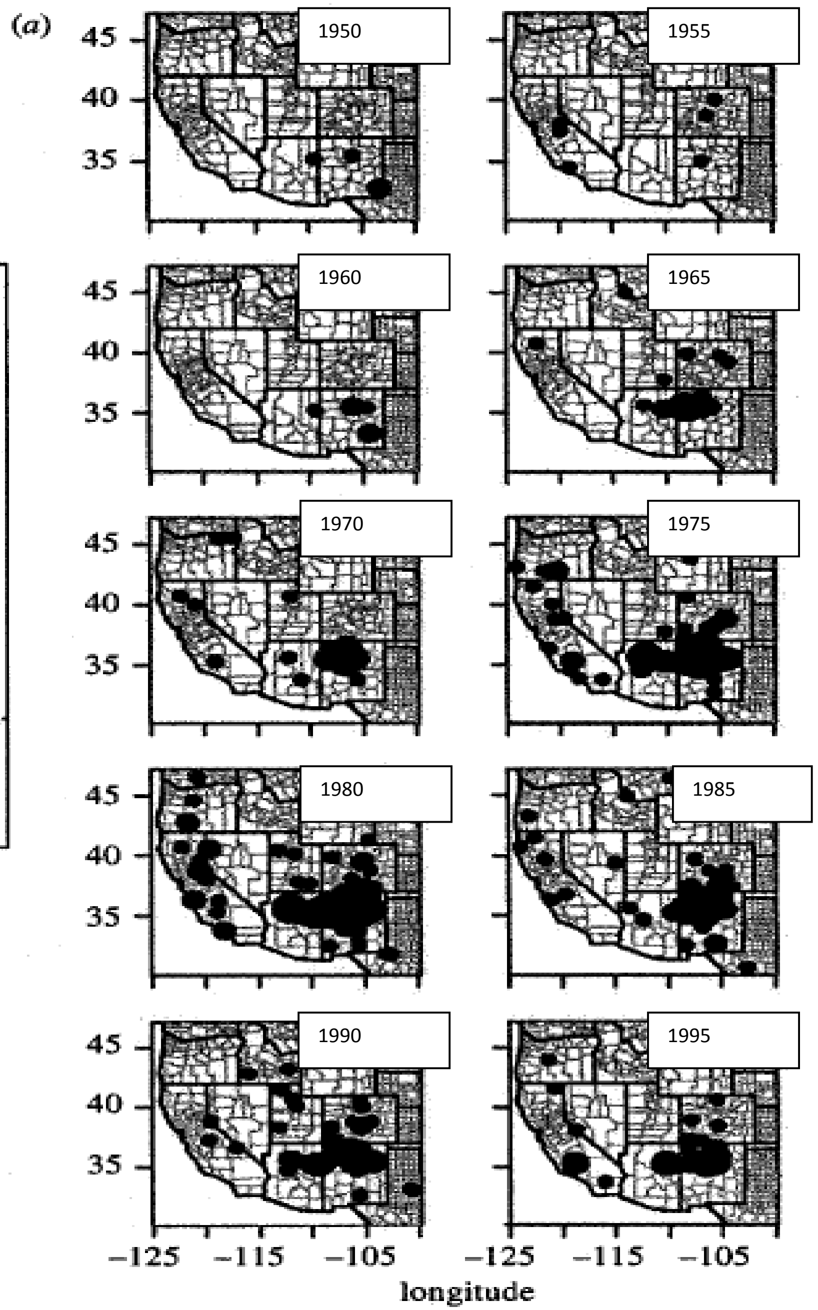


Black solid line – Observed plague

Black dashed line – Mean plague value

Grey solid line – Predicted plague

Grey dashed lines – 95% Confidence intervals

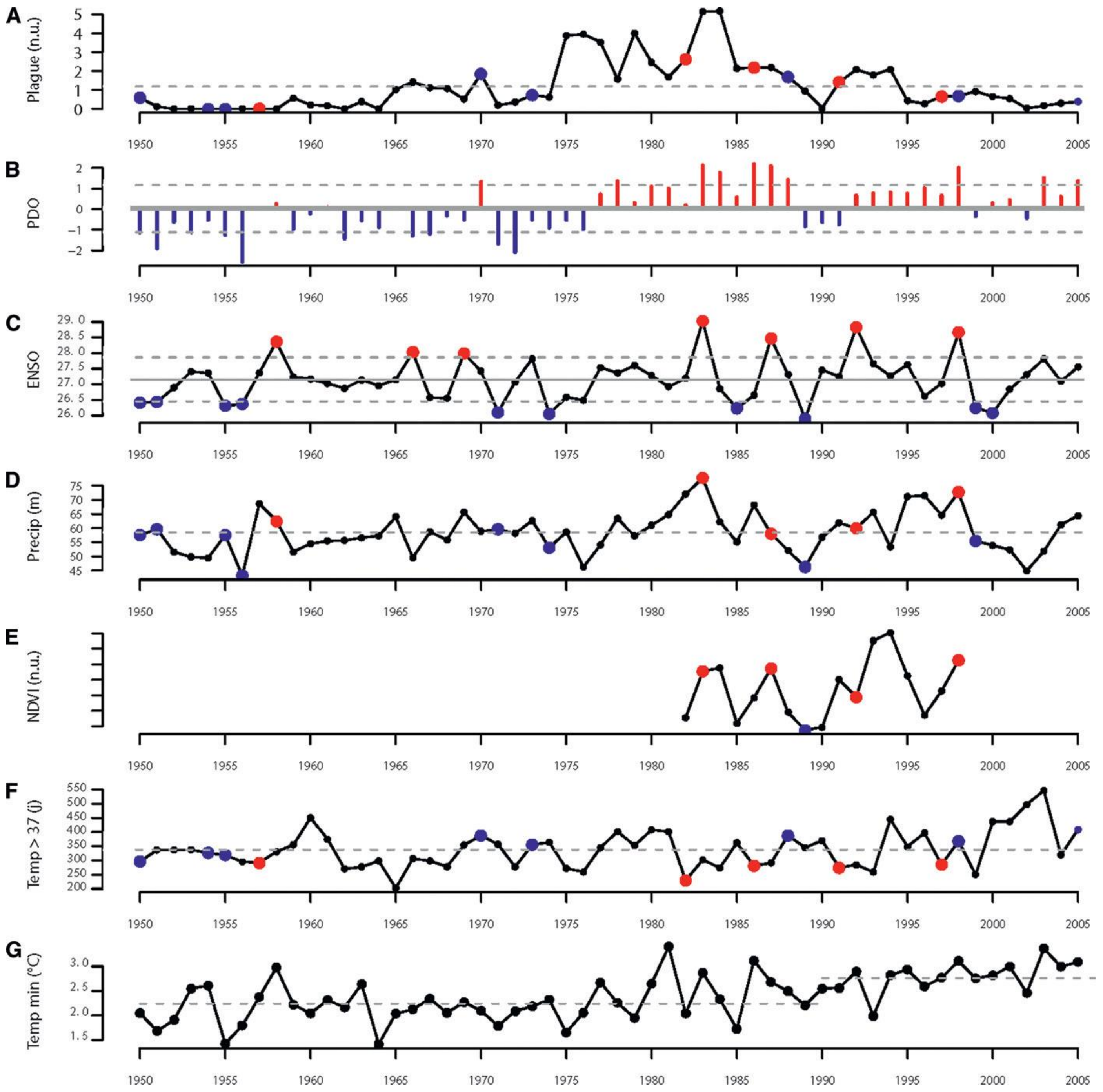


Human Plague Occurrence Influenced by Tropical and North Pacific Ocean Climatic Variability (Ben Ari et al. 2011)

- Used wavelet analysis to examine relationships between human plague occurrence and climate
- Human plague occurrence in western US influenced by interaction of ENSO and PDO

Figure Legend

A. Total density-adjusted human cases
B. PDO Index (March value)
C. ENSO (Sea surface temperatures for Nino 3-4 region)
D. Late winter-spring precipitation
E. Anomaly of yearly maximum NDVI
F. Average number days above 37° C
G. Average minimum temperature



CDC
Centers for Disease Control and Prevention

Influence of PDO/ENSO Anomalies

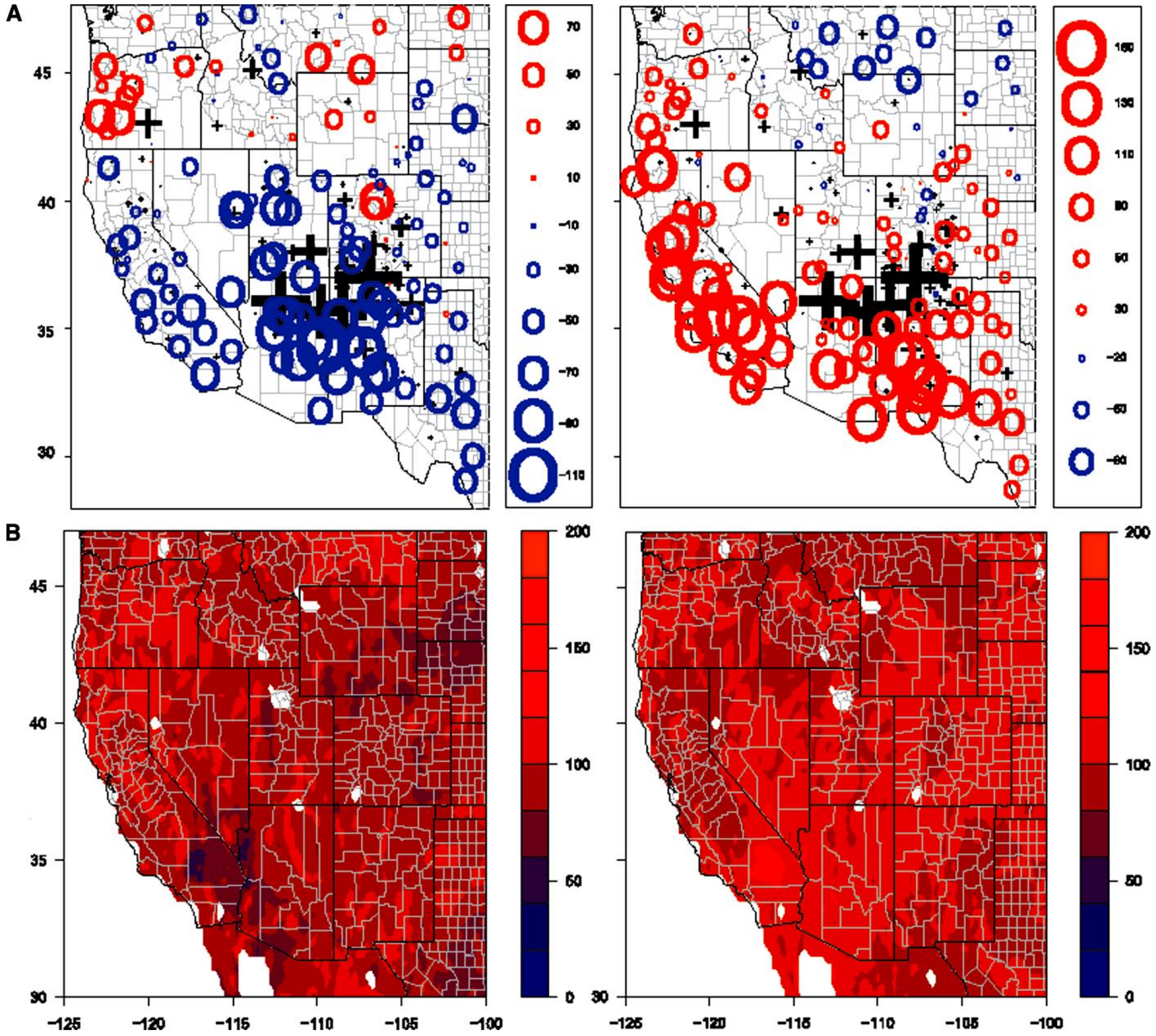
Row A shows composite late-winter spring precipitation anomalies for years with significant:

- Negative PDO and La Nina (left panel) events (very dry) or
- Positive PDO and El Nino events (much wetter than normal)

Row B shows composite NDVI anomalies for years with significant

- Negative PDO and La Nina (left panel) events ("brown down") or
- Positive PDO and El Nino events ("green up")

Negative PDO / La Nina **Positive PDO / El Nino**



Climate and Plague Risk in West Nile Region

Plague risk greatest above 1,300 m and in areas that

- Are wetter
- Are cooler
- Exhibit more bare soil at certain times of the year

(Winters et al. 2009,Eisen et al. 2010, MacMillan et al. 2011, 2012)

Human plague associated with

- Dry season rainfall (negative)
- Rainfall prior to plague season (positive)

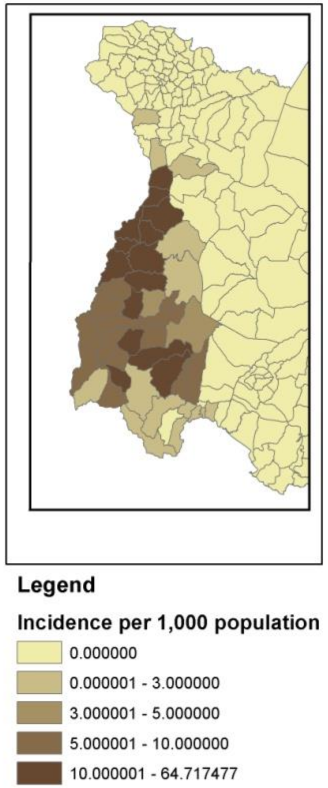
Nile grass rat (*Arvicanthis niloticus*) abundance associated with

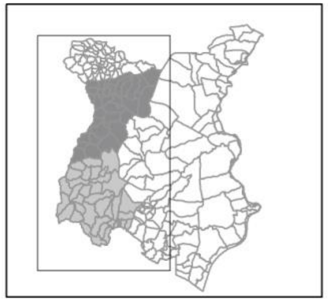
- 6 month-lagged precipitation (negative)
- Current monthly temperatures (positive)

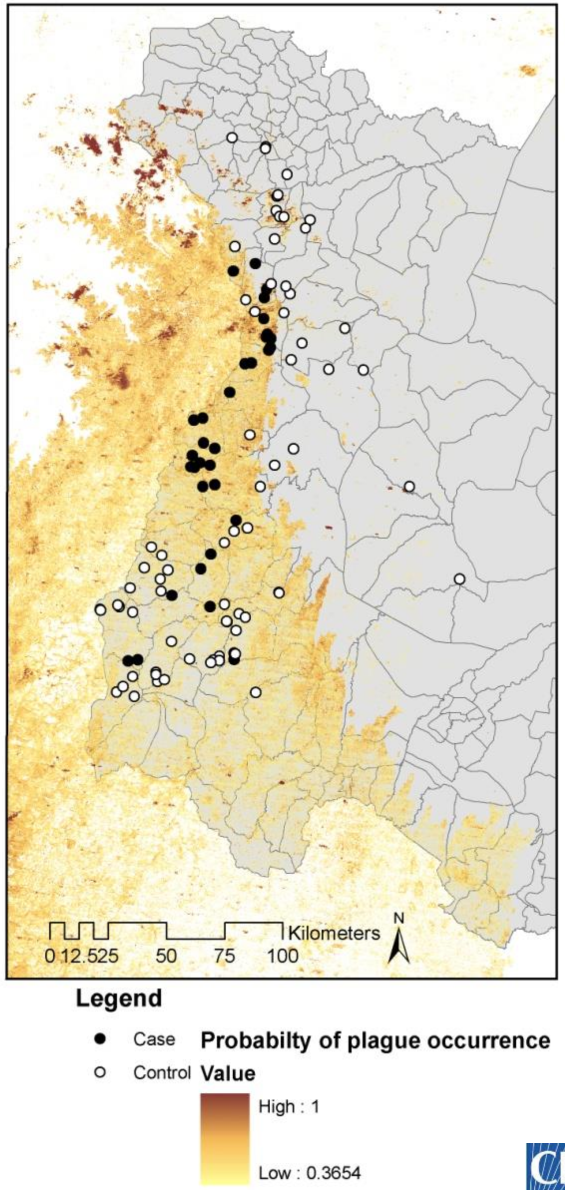
Shrew (*Crocidura sp.*) abundance associated with

- 3 month-lagged precipitation (positive)
- Current temperatures (negative)

Abundance of both species positively correlated with millet and maize harvests (Moore et al. 2012, 2015)



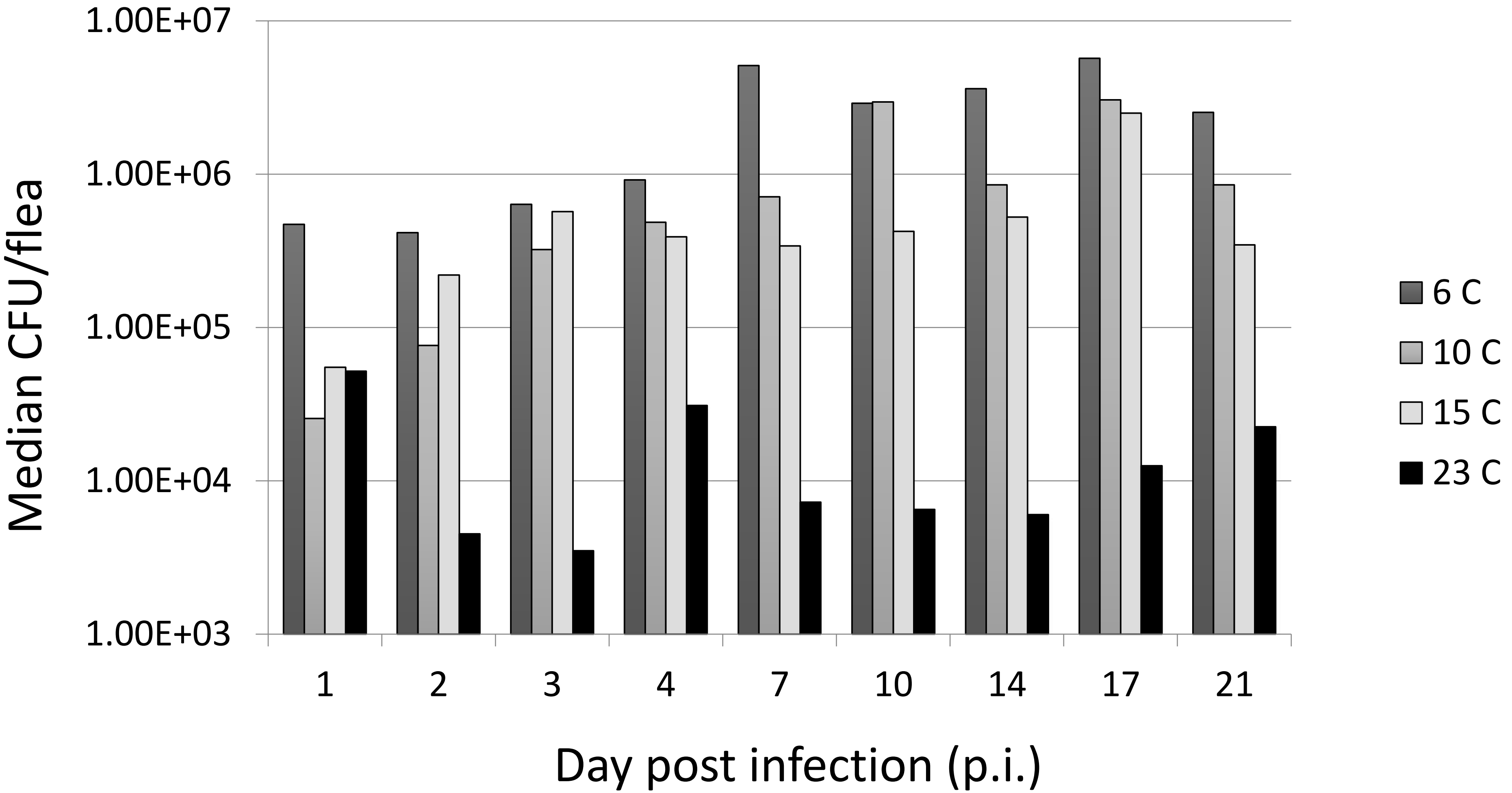




How Does Temperature Affect Transmission of *Y. pestis*?

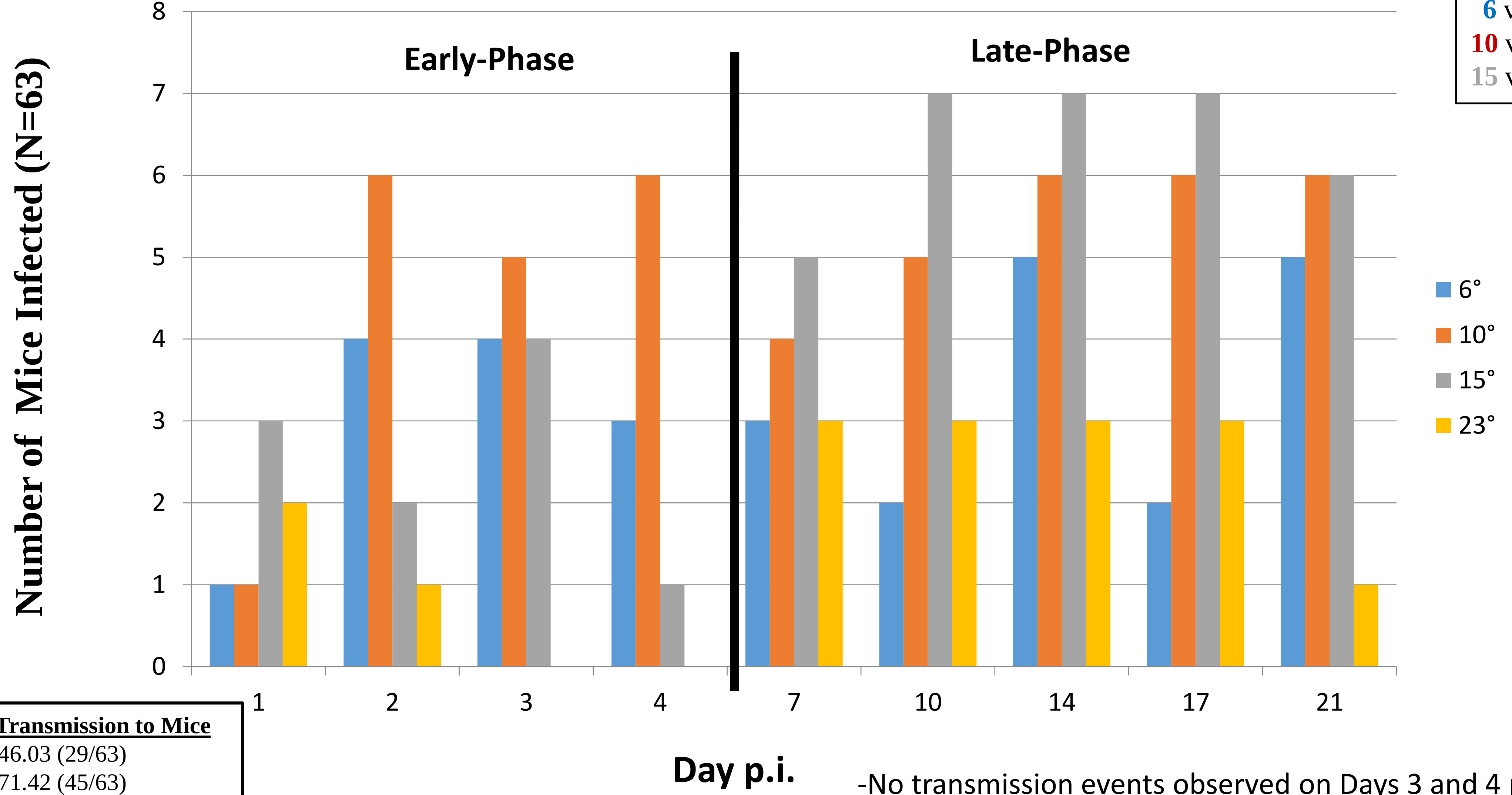
- High temperatures can decrease flea survival
- Affects biofilm formation
  - Biofilm in blockages breaks down above 27.5^{o} C
  - Infection can be lost above this temperature
  - Some evidence spread of plague outbreaks decreases above this temperature (Vietnam - Cavanaugh and Marshall 1972)
- Plague transmission experiments typically done at 21^{o}-23^{o} C
- How do lower temperatures affect transmission?
  - Plague bacteria grow faster at cold temperatures
  - Transmission rates increase at low temperatures for *O. montana* (Williams et al. 2013)
  - Implications for seasonality and focality of plague

Effect of Temperature on Growth of *Y. pestis* in *O. montana* fleas
(Williams et al. 2013)



Flea Transmission to Mice by Incubation Temperature
(Williams et al. 2013)

6 vs.10; p=0.0343*
10 vs.23; p=0.0003*
15 vs.23; p=0.0011*



Percent Transmission to Mice

6º - 46.03 (29/63)
10º - 71.42 (45/63)
15º - 66.67 (42/63)
23º - 25.40 (16/63)

-No transmission events observed on Days 3 and 4 p.i. at 23°C
-100% transmission on Days 10, 14, and 17 p.i. at 15°C

Effects of Temperature on Transmission of *Yersinia pestis* by Fleas
- Summary -

- Low temperatures favors growth of *Y. pestis* in fleas

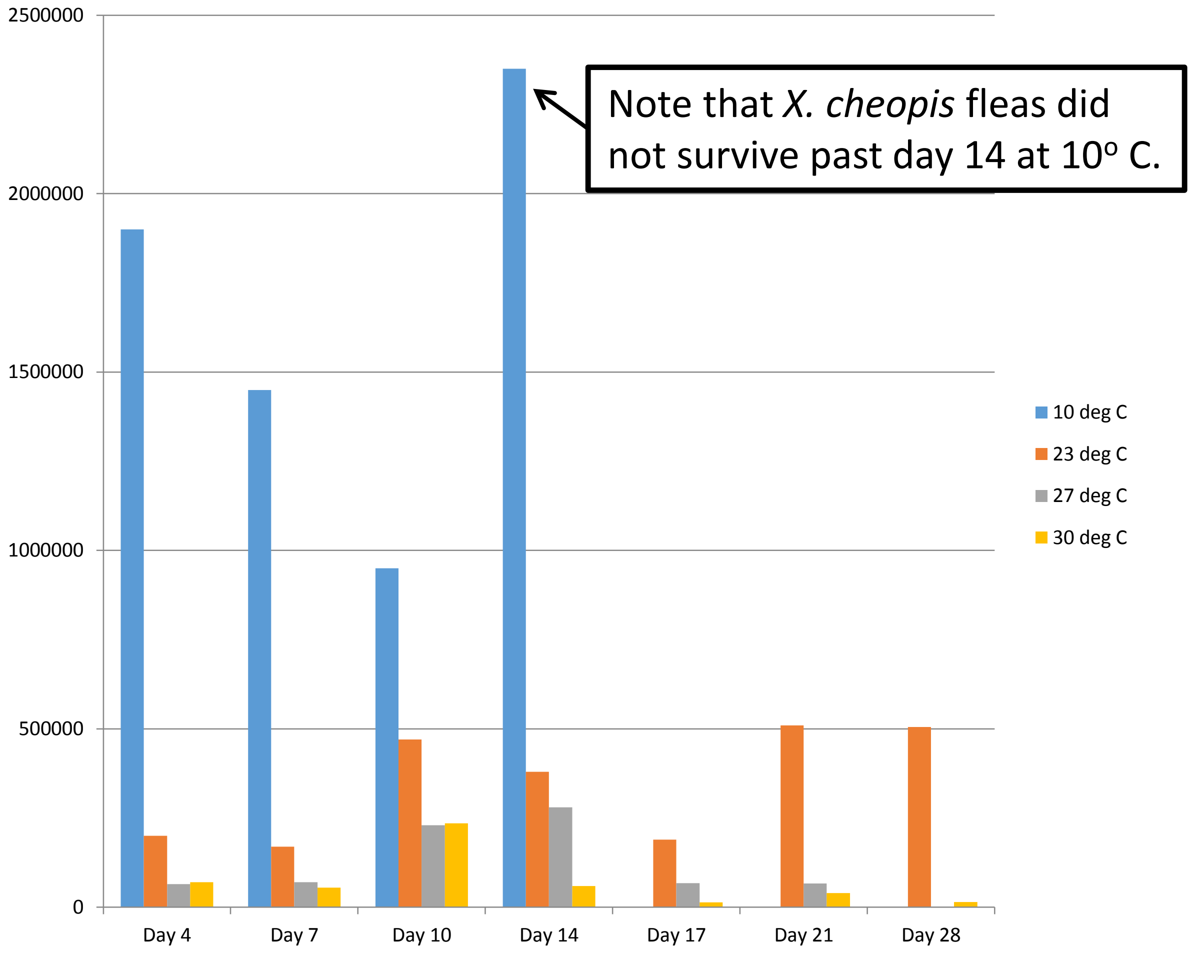
- *X. cheopis* fleas apparently succumb to overwhelming *Y. pestis* infection at low temperatures (10° C)

- *O. montana* (poor blocker) transmits more efficiently at low temperatures

- Can other poorly blocking fleas transmit efficiently at low temperatures?

- *Y. pestis'* closest relative and ancestor (*Y. pseudotuberculosis*) can survive outside hosts at low temperatures in shed fecal material

- Implications for focality in temperate and tropical regions?

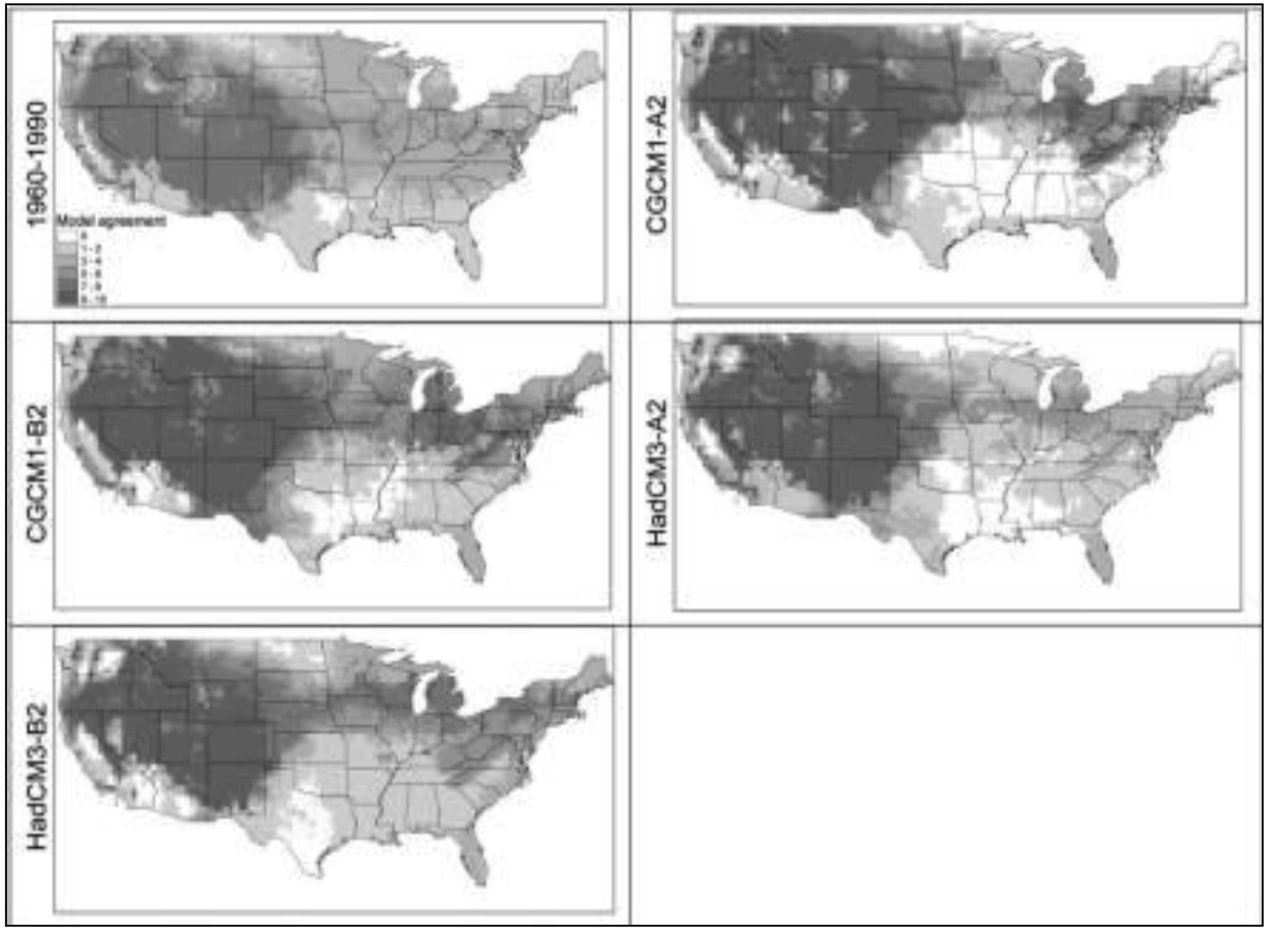


Bacterial Loads in *X. cheopis* held at different temperatures

(Schotthoefer et al. 2011)

Plague and Climate Change

- Nakazawa et al. (VBZD 2008) evaluated spatial patterns of plague transmission using four different general circulation models of project climate change
- Concluded that some shifting of transmission sites would occur but changes will be subtle with general northward movement of areas of high transmission
- Is this realistic and does it apply to other plague foci around the world?



The End